SCHOOL OF AGRICULTURE, POLICY, AND DEVELOPMENT
GRADUATE INSTITUTE FOR INTERNATIONAL DEVELOPMENT AND APPLIED ECONOMICS

EFFICIENCY OF SMALL SCALE FARMERS IN PAKISTAN'S PUNJAB AND THE ROLE OF EXTENSION SERVICES IN ITS IMPROVEMENT

AAMIR RIAZ CHEEMA

Ph.D THESES

April 2016

ACKNOWLEDGMENT

First of all, I would like to thank my Lord Allah for being with me in all aspects during my stay at The University of Reading, UK.

I would like to extend my heartfelt thanks to my initial advisors Professor Dr. Tahir-ur-Rehman, and Professor Dr. Chris Garforth for their valuable advice, insight, and guidance starting from proposal development to the completion of the research work. I wish to express my gratitude to my supervisors, Professor Kelvin George Balcombe, and Dr.Alax Arnall for their valuable guidance, constructive comments, and support throughout my research work. Both have worked hard to keep me on the right track and the accomplishment of the study.

I would like also to express my sincere gratitude to The Islamia University of Bahawalpur for funding tuition fee and my research and other study expenses. I would like also to thank Shaji-ur-Rehman for her kindly cooperation and immediate response on financial issues. Though not to exclude others, my special thanks go to Safdar Jam, Muhammad Rizwan, Muhammad Arif Watto, Zia-ur-Rehman and Shahid Shah

I am deeply indebted to my brothers Nayyar and Qamar Riaz Cheema, who have been supporting me during my study from whom I received memorable encouragement and spiritual help. I am also grateful to Professor Dr. Ghazanfar Ali Khan, who helped me to pursue my education at the Post-Graduate level in the University of Reading.

Finally, my tongue is not able to express my appreciation to my mother for her unspeakable support and encouragement during the period of my study. God knows how thankful I am to her.

Aamir Riaz Cheema

DEDICATION

THIS THESIS IS DEDICATED TO MY MOTHER

&

LATE FATHER WHO SACRIFICED MUCH TO BRING ME UP TO THIS LEVEL

I declare that this thesis is the result of my own work and that all sources or materials used in this thesis have been duly acknowledged. This thesis is submitted at the University of Reading in partial fulfillment of the requirements for the Ph.D. degree and to be made available at the University's Library under the rules of the Library. I confidently declare that this thesis has not been submitted to any other institutions anywhere for the award of any academic degree, diploma, or certificate.

AAMIR RIAZ CHEEMA

SCHOOL OF AGRICULTURE POLICY AND DEVELOPMENT,
UNIVERSITY OF READING, UK

Email: ____________________________

ABBREVIATIONS AND SYMBOLS

1.	• **ICARDA**	• International Centre for Agriculture Research in Dry Area
2.	• **A.E**	• Allocative efficiency
3.	• **APO**	• Asian Productivity Organization
4.	• **BCC**	• Banker, Charnes and Cooper model
5.	• **CRS**	• Constant returns to scale
6.	• **CCR**	• Charnes, Cooper, and Rhode model
7.	• **C.E**	• Cost efficiency
8.	• **C.I**	• Confidence interval
9.	• **DMU**	• Decision-making units
10.	• **DEA**	• Data envelopment analysis
11.	• **E.E**	• Economic efficiency
12.	• **FAO**	• Food and agriculture organization
13.	• **GDP**	• Gross domestic product
14.	• **GOP**	• Government of Pakistan
15.	• **Hr**	• Hour (s)
16.	• **Ha**	• Hectares
17.	• **IRS**	• Increasing returns to scale
18.	• **IRRI**	• International Rice Research Institute
19.	• **IFPRI**	• International Food Policy Research Institute
20.	• **IFAD**	• International Fund for Agricultural Development
21.	• **IFA**	• International Fertilizer Association
22.	• **Kg**	• Kilogram
23.	• **Km**	• Kilometers
24.	• **DEAP**	• Data envelopment analysis package
25.	• **MINFAL**	• Ministry of food, agriculture, and livestock
26.	• **IUCN**	• International Union for Conservation of Nature
27.	• **Min**	• Minimum
28.	• **Max**	• Maximum
29.	• **MAF**	• Million Acre Feet
30.	• **NIRS**	• Non Increasing returns to scale
31.	• **NGOs**	• Non-governmental organizations
32.	• **PIDAs**	• Provincial Irrigation and Drainage Authorities
33.	• **SPFA**	• Stochastic production frontier analysis
34.	• **SPSS**	• Statistical package for social sciences
35.	• **SDSN**	• Sustainable Development Solutions Network
36.	• **SCARP**	• Salinity Control and Reclamation Project
37.	• **SE**	• Scale efficiency
38.	• **T.E**	• Technical efficiency
39.	• **TEBC**	• Technical efficiency bias corrected
40.	• **VRS**	• Variable returns to scale
	SYMBOLS	
41.	• **λ**	• Lambda (represent the weight)
42.	• **θ**	• Theta (represent the efficiency value)
43.	• **∑**	• Summation
44.	• **≥**	• Greater or equal to
45.	• **≤**	• Less or equal to
46.	• **Kg**	• Kilogram
47.	• **β**	• Beta
48.	• **$**	• Dollar

ABSTRACT

The existence of "yield gap" highlight that the objective of food security in Pakistan could be achieved by increasing efficiency of the farming systems. The agriculture sector is dominated by small farms, which are often resource constrained and mostly not benefiting from the government's policies. The improvement in efficiency seems to be most feasible alternative. Therefore, the technical, scale, allocative, cost and bias-corrected efficiency of the small farms in the mixed farming system of Pakistan is investigated at crop and farm level to see the possibility of production enhancement within the available resources. In this thesis, Data envelopment analysis (DEA) is preferred because none of the studies in Pakistan have used bootstrapping in estimation, to draw a reliable conclusion within the models explaining efficiency scores, while simultaneously producing standard errors and confidence intervals. For this analysis, the data were collected from two purposively selected Tehsils of the mixed farming system during the year 2012-13. The small farms were found 66, 71, 83, and 58 percent technically efficient for wheat, cotton, maize, and sugarcane crops, implying that the farms have wasted 44, 29, 17, and 42 percent of their resources at crop level for attaining the current level of output, respectively. These farms can still achieve the same output level by substantially reducing their inputs. The impact of scale was found more prominent in per acre analysis than in per farm analysis. The analysis was further extended to estimate the cost and allocative efficiency by using the reliable price information collected during the survey and the findings revealed a considerable room for the wheat, cotton, maize, and sugarcane farmers to reduce their input cost up to 46, 40, 33, and 49 percent, respectively. The mean allocative efficiency was estimated at 81, 86, .81, and .89, suggesting that the wheat, cotton, maize, and sugarcane farmers are 19, 14, 19, and 11 percent inefficient in the allocation of resources, respectively. At an aggregated level, the small farms were found 71, 96, 60, 85 percent technical, scale, cost and allocative efficient, respectively. The results generated by solving bootstrap DEA model for 2000 iterations revealed a significant difference of .17, .19, .08, and .19 points at crop and .13 at farm level between the original and biased corrected efficiency. This difference appears because bootstrap DEA model incorporates noise component in the model and accounts for the inefficiency caused by exogenous factors. This substantial difference further implies that results achieved through the application of standard DEA models can be misleading and must need to be overlooked again. The efficiency scores estimated in the first stage are correlated with the environmental variables used in the second stage, therefore, a double bootstrap truncated regression instead of Tobit and OLS is used to find the possible determinants of technical efficiency. The results of truncated regression analysis revealed that the contact with extension, participation in training, household size, practicing according to extension recommendations, tractor and tubewell ownership, soil quality were the significant determinants, positively influencing the TE at both crop and farm level. A strong inverse relationship between farm size and TE was observed at both levels of estimation. In conclusion, the provision of tractors to the small farms on subsidized rates and installation of tractor driven tubewell could be beneficial for improvement in efficiency. A positive impact of extension also stress that the participation of a large number of small farmers in various extension activities is indispensible in order to operate on efficient frontier. There is need to establish a strong linkage between farmers and extension that ensure the provision of timely and relevant information to the farmers through personal contact and training. More efforts are also required from government to ensure the involvement of different stakeholders in the innovation process.

Keywords: Efficiency, Mixed farming system, Data Envelopment Analysis, Bootstrapping

CHAPTER 1

INTRODUCTION

This chapter is written to provide background to the study presented in this thesis and includes an introduction to Pakistan, the situation of agriculture, the main farming systems, and their features, the important crops and their role in the economy and the objectives of the study.

1.1: AN INTRODUCTION TO PAKISTAN

Pakistan emerged on the globe in 1947 as an independent nation state claiming freedom from British India. Today, Pakistan is one of the most important country in the South Asia with a total area of 796,100 km^2 approximately equal to the combined land areas of France and the United Kingdom. Pakistan is comprised of four provinces and a federally administrated tribal area with a total population of 179.2 million. Pakistan is a lower middle-income country with a total GDP of US $ 231.2 billion in 2012 (World Bank, 2012).

Pakistan has perfect geographical and historical landscape. Pakistan has divided into three major geographic areas: the northern highlands, the Indus River plain and the Baluchistan Plateau[1] (Yaqub *et al.,* 2015). The area is reportedly enriched with a culture that existed since 7000 BC, which makes it as old as Stone Age based on the findings of ancient remains. The geography of Pakistan is an excellent balance of landscapes which includes world's most fertile basins, and deserts of profound vastness (Azam and Muhammad, 2017). It is covered with plateaus starting from coastal areas of the Arabian Sea in the south to the mountains of the Karakoram Range in the north. This colossal altitudinal and latitudinal variation makes unique ecological conditions of the area and supports thousands of species of flora and fauna. In northwestern side, Pakistan hosts a Durand borderline with Afghanistan and continues to enjoy the vicinity of Strait of Hormuz and Gulf of Oman in the Arabian Sea to its south. In the West, Pakistan shares its border with Iran while Northern border is shared with China (Yaqub *et al.,* 2015). Pakistan has the most volatile and lengthy border to its east with India.

1^ "About Pakistan: Geography". *American Institute For Pakistan Studies. Archived from* the original *on 21 July 2011*.Retrieved 24 July 2010.

Pakistan's major Indus River Basin originates in the Himalayas and flows towards the Arabian Sea (Yaqub *et al.,* 2015) and has covered more than 0.6 million Km^2 of the area (Piesse, 2015). Indus River is the biggest and longest of all rivers in Pakistan (Abbasi, 2012) with an overall length of around 3200 KM and total estimated annual flow of 207 billion cubic meters (Yaqub *et al.,* 2015). This system waters more than 16 million hectares of land (Abbasi, 2012). It starts from melting of great glaciers in the northern highlands of Himalaya, Karakoram, and Hindukush mountain ranges. The Indus river system comprises more than 60 small rivers that irrigate the whole country (Yaqub *et al.,* 2015). The climate diverges from tropical to mild, with dry conditions in the seaside south (UNDP, 2015). There is a monsoon season with regular flooding due to substantial precipitation and an arid season with meaningfully less rainfall or none at all. There are four discrete seasons, dry winter followed by a dry spring and a rainy summer season called monsoon and a retreating post monsoon season. The season of rainfall greatly fluctuates from year to year, which results in both flooding and drought.

Figure 1.1: Map of Pakistan

Rabi and Kharif are the two principal cropping seasons prevail in Pakistan (Rehman et al., 2015). Kharif season also called summer season in Pakistan, starts from 16 April and ends on 15 October (Naheed & Ghulam 2010; UNDP, 2015 and Koondhar *et al.,* 2016). Millet, Maize (Corn), sorghum (Bajra), Rice and sugarcane are the dominant crops usually grown the Kharif season. Rabi season is also named the winter season starts from November and lasts on April (Gill, 2015 and UNDP, 2015). The crops grown in this season are harvested in the spring season. Wheat, barley, mustard, and peas are the major crops of this season (Ahmad, 2007 and Naheed & Ghulam 2010).

Pakistan is divided into four provinces, named Sindh, Baluchistan, KPK, and Punjab (UNDP, 2015). Punjab province contributes considerably towards agricultural production and resides roughly 55 percent of the population and most industrial and commercial centers are based in the province (Piesse, 2015). This province contributes about 76% to annual grain production 73% for sugar cane, and 82% for cotton in total national production in the country (Mekonnen et al., 2016). The economy of Punjab is mainly agriculture-based, although industry makes a substantial contribution. Regardless of its dry climate, extensive irrigation makes it a rich agricultural region. The province is playing an important function in agricultural production (Ahmad, 2001). It contributes about 63740.4 thousand tonnes, which is about 59.85 percent towards total agricultural production in the country. Commodity wise Punjab is contributing 74.12 percent cereals, 81.75 percent pulses, 55.45 percent cash crops, 9.39 percent edible oils, 59.95 percent fruits and 77.54 percent vegetables of the total production at the national level (Badar *et al* 2007). In Punjab, there are three major crop production systems, namely, rice-wheat, cotton-wheat and mixed cropping system (Hussain *et al*., 2012; Elahi *et al*., 2015 and Aslam, 2016). The detail of these farming systems is as under:

1.1.1: Rice-Wheat Farming System

In Asia, the rice-wheat system has been practiced by farmers for more than 1000 years (Khan *et al*., 2015). The rice-wheat system is located in the Indo-gigantic plain, covering 13.5 million ha in South Asia: India (10.0), Pakistan (2.1), Bangladesh (0.8) and Nepal (0.5) (Singh et al., 2017). It shows 32% of the total rice area and 42% of the total wheat area in these countries (Cheema *et al*., 2013). In Pakistan, rice-wheat cropping system mainly located in central Punjab with an area of 2.1 million hectares and about three –fifth fall in Punjab and declared to be a more extensive cropping system (Imtiaz *et al*., 2012). Major districts of Pakistan, like Gujranwala, Sheikhupura, Sialkot and Lahore fall in this cropping system. This area is considered the homeland of pure “Basmati Rice” in the world (Imtiaz *et al*., 2012).

1.1.2: Cotton –Wheat Farming System

The cotton-wheat system is of great importance for the economy of Pakistan and this not only ensures food security to a large population but is also a major source of foreign exchange earnings (Javed *et al*., 2009). The total agricultural area under the cotton-wheat farming system of Pakistan is

7.1 million hectares (FAO, 2004).The total agricultural area under the cotton-wheat system in Punjab is 5.5 million ha and constitutes 77 percent of the total area in Pakistan (FAO 2010).

1.1.3: Mixed Farming System

The mixed cropping system prevails in Faisalabad and Sargodha divisions where sugarcane wheat, potatoes, maize along with cotton and fodder crops are grown (Asghar, 2014). A significant amount of agricultural area in these divisions is under orchids. Sugar cane is an annual crop usually grown either in September or in February or March and harvested in November (Rehman et al., 2015). Maize is planted in March-April and harvested in June- July. The potato crop is usually sown twice in a year.

1.2: OVERVIEW OF AGRICULTURE IN PAKISTAN

Agriculture plays a vital and central role in the economic development of Pakistan (Raza et al., 2012 and Azam and Muhammad, 2017). It is the second-largest component of the Pakistan's economy after the services sector and accounts for 19.8 percent of GDP and plays a major contribution to the economic growth of other sectors by providing employment to 42.3% of the labour force (Government of Pakistan, 2016). The overall rate of economic growth in the country is closely linked to the performance of agriculture sector and the historical pattern indicates eras of high/low agricultural growth usually correspond with the epochs of the robust/poor performance of the national economy (Ali, 2000 and Gill, 2015). Pakistan's economy has experienced substantial changes in the past 50 years. The input of agriculture to GDP has degenerated from 39 percent in 1969-70 to 19.8 percent in 20015-16, a gradual and consistent warning of 19.2 percent in forty-six years (Government of Pakistan, 2016). Although agriculture's share in total GDP has declined over time due to economic development, the growth of this sector still has a substantial effect on the overall performance of the economy (Iqbal and Ahmad, 2005).

Pakistan's total area is 79.6 million hectares, of which 22 million hectares are currently used for farming (Ahmad, 2007; Abbasi, 2012; Aslam, 2016 and Azam and Muhammad, 2017). Approximately 19 million hectares are irrigated using a combination of canal and groundwater (UNDP, 2015). The remaining area is rainfed (Barani). Wheat, rice, sugarcane, maize, and cotton are the important crops of Pakistan and the total area under these crops during 2015-16 was 18.31 Mha, constituting 83.22% of the total cropped area (Government of Pakistan, 2016). This includes wheat 9.26 Mha (42.1% of total cropped area); cotton 2.91 Mha (13.23%); rice 2.74 Mha (12.45%); maize 1.14 Mha (5.18%) and sugarcane 1.13 Mha (5.13%) (Government of Pakistan, 2016).

These five major crops account for 4.67 percent of GDP and 23.55 percent of the value added in overall agriculture. The other crops account for 11.36 percent of the value added in overall agriculture and 2.25 percent of GDP. Livestock contributes 58.55 percent to agricultural value addition and 11.61 percent to GDP. Forestry contributes 2.06 percent to agricultural value addition and 0.41 percent to GDP (Government of Pakistan, 2016). Agriculture sector demonstrated a negative growth of 0.19 percent against 2.53 percent growth in 2014-15. The overall crops (major and others crops) have seen a negative growth of 6.5 percent in 2015-16, as compared to previous year's performance, while the other sub-sectors of agriculture posted positive growth. Livestock developed positive indicators of 3.63 percent, Forestry 8.84 percent, and Fishing 3.25 percent (Government of Pakistan, 2016). The growth of sub-sector of crops included important crops, other crops and cotton ginning remained negative as it posted a growth of -7.18 percent, -0.31 percent and -21.26 percent, as a result became the reason of negative growth of agriculture sector (Government of Pakistan, 2016).

1.2.1: Current scenario of major field crops of Pakistan

Wheat, cotton, maize, and sugarcane being the major crops contribute 9.9, 5.5, 2.2, and 3.2 percent to the value added and 2.2, 1, 0.4, and 0.6 percent to GDP, and were cropped on an area of 9260, 2917, 1144, and 1132 thousand hectares during 2015-16, respectively. These figures show a decline of 1.5 and .8 percent for cotton and sugarcane crops when compared to area cropped during 2014-15 (2961 and 1141 thousand hectares), respectively. The decline in sugarcane area is linked with the disposal problem and payment difficulties that shifted sugarcane area to other competitive crops. The decline in cotton area was due to prolonged wheat season. Opposite to cotton and sugarcane, the area under wheat and maize crops show an increase of .6 and .2 percent, when compared to 2014-15, respectively. During 2014-15, wheat and maize were cropped on an area of 9204 and 1142 thousand hectares, respectively (See Table 1.1).

During 2015-16, the production of wheat, cotton, maize, and sugarcane was estimated at 25.48 million tons, 10.07 million bales, 4.92 million tons, and 65.5 million tons against 25.08 million tons, 13.96 million bales, 4.93 million tons and 62.8 million tons during 2014-15, respectively. These results show a very sharp decline of 27.6 percent in cotton production as compared to 2014-15. The decline in crop area was due to prolonged and frequent rains that badly destroyed the standing cotton crop, additional losses came from a severe attack of pink bollworm.

Maize crop production also follows a decreasing trend and shows a decline of .3 percent. However, the production of wheat and sugarcane was increased by 1.6 and .2 percent during 2015-16, as compared to last growing season (See Table 1.1). The wheat production increased as the crop was sown at appropriate time and availability of inputs remained adequate. Despite having a significant share in the economy, GDP, and value added, the production of these major crops is much lower as compared to other countries.

Table 1.1: Area, Production and Percentage Change (Major Crops)

Year	Wheat		Cotton		Maize		Sugarcane	
	Area	**Prod.**	**Area**	**Prod.**	**Area**	**Prod.**	**Area**	**Prod.**
2011-12	8,650 -	23.47 -	2,835 -	13.59 -	1087 -	4.33 -	1,058 -	58.39 -
2012-13	8,660 (0.1%)	24.21 (3.1%)	2,879 (1.6%)	13.03 (-4.1%)	1,060 (-2.5%)	4.22 (-2.7%)	1,129 (6.7%)	63.75 (9.2%)
2013-14	9,199 (6.2%)	25.97 (7.3%)	2,806 (-2.5%)	12.76 (-2.0%)	1,168 (10.2 %)	4.94 (17.2%)	1,173 (3.9%)	67.46 (5.8%)
2014-15	9,204 (.1%)	25.08 (- 3.4%)	2,961 (5.5%)	13.96 (9.3%)	1,142 (-2.2%)	4.93 (-0.1%)	1,141 (-2.7%)	62.82 (-6.9%)
2015-16	9260 (0.6%)	25.48 (1.6%)	2,917 (-1.5%)	10.07 (-27.8%)	1,144 (0.2%)	4.92 (-0.3%)	1,132 (-.08%)	65.47 (4.2%)

Source: (Government of Pakistan, 2016)

The farmers in Pakistan lag behind in achieving maximum potential output of crops. In the case of wheat, Pakistan is achieving 351 kg ha^{-1}, 2311 kg ha^{-1}, and 567 kg ha^{-1} less yield than India, China, and USA, respectively. Being major cash and export crop, rice production is also far below from Egypt, USA, and China, which obtain 6201 kg ha^{-1} , 4152 kg ha^{-1}, and 3620 kg ha^{-1} more yield than Pakistan. The similar situation also exists in the case of sugarcane and yield gap is 69642 kg ha^{-1} as compared to Egypt. Cotton yield is somehow reasonable compared to these countries. A cross-country comparison depicted in (Table 1.2) shows that there is a vast divergence between the productivity of major crops. Such declining and fluctuating trend in production is related to factors like depleting land and water resources (Zia *et al.,* 2004; GOP, 2010; Ahmad and Farooq, 2010; Khan *et al.,* 2012 and Azam & Muhammad, 2017), inefficient use of resources (Naqvi & Ashfaq 2013; Usman et al., 2016; Fatima et al., 2016 and Memon et al., 2016) and a weak extension-research system (Afzal and Shahid 2009 and Saddozoai et al., 2013).

Table 1.2: Yield Comparison of major crops with other countries (Kg per Hectare)

Country	Wheat	Rice	Sugarcane	Cotton
Pakistan	2451	3520	51494	2046
India	2802	2270	68877	1206
China	4762	6556	73114	3906
USA	3018	7672	73765	2250
Egypt	----------	9731	121136	2333
Brazil	----------	4229	79709	3757

Source: Economic Survey of Pakistan (2010-11)

1.2.2: Situation of land and Water Resources

Land and water resources are vital to agriculture and rural development and are essentially connected to global challenges of food insecurity (Food and Agriculture Organization, 2011 & Azam and Muhammad, 2017). Sustainable agriculture largely relies on the stable supply of natural resources (land, water, etc.) (Gadanakis, 2013). However, the land and water of the world are scarce and fall into the category of nonrenewable resources (Niazi 2003; Asian Productivity Organization, 2003; FAO, 2011 and Sustainable Development Solutions Network, 2013). The enormous population growth, industrialization, urbanization, and modernization have seriously affected the land and water resources in many developing countries (APO, 2003; Sikandar, 2015 and Najjuma *et al.,* 2016). Population pressure and modernization along with economic transformation from agriculture to the non-agriculture sector have increased competition on land use and some countries have reached almost to the edge of their agricultural land resources including Pakistan (Khan *et al* 2012). The existence of agriculture for food security has threatened due to rapid use of productive agricultural land for residential and industrial purposes, resulting in unavailability of land for agricultural activities (Sudaryanto *et al.,* 2009; Calzadilla *et al.,* 2009 and Sikandar, 2015). On the other hand, due to fragmentation of landholding, high-quality agricultural-land available for crop-production is also decreasing (Zia *et al.,* 2004). A traditional possession system of inheritance and property rights encourage land fragmentation and access to land for agricultural purposes is becoming difficult (Shuhao, 2005; Bizimana *et al.,* 2004; Sudaryanto *et al.,* 2009; Demetriou, 2014 and Apata *et al.,* 2016). It is estimated that approximately 500 acres of agricultural land goes out daily from agriculture due to urbanization and it is expected that a million hectares of fertile agricultural land will be devoted to non-agricultural activities in future (Siraj, 2011).

Now, the major agriculture production systems in the country have been in a significant transition—from land-abundant to land-constrained. Since independence, huge efforts and investments have been made in bringing more land under cultivation and 23 million hectares have been brought under cultivation so far as compared to the 14.99 million hectares in 1949-50, out of the total available area of 79 million hectares (Iqbal and Munir 2005 and Khan *et al.,* 2012). These figures show an increase in cultivated area by about 56 percent over a period of 58 years at a rate of approximately less than one percent (0.9 %). Most of the best lands have already been brought under cultivation (Iqbal and Munir 2005 and Khan *et al.,* 2012). It is now acknowledged that opportunity for further expansion in land resource for agricultural production is limited and the further increase in cultivated area can only be expected to happen at a much lower rate than that in the past (Ahmad and Farooq, 2010; Fullbrook, 2010 and Khan *et al* 2012). It is questionable that how the future demands for food will be met under this alarming situation of resource depletion. Intensification has been adopted as a measure in many countries to meet the future requirement of food under a condition of land scarcity (Zia *et al.,* 2004; Ewert et al., 2005 and FAO 2011). The policymakers are looking for the ways to intensify production to raise farmers' income from existing land (Lambin and Meyfroidt, 2011). To cope with the challenge of land scarcity and to achieve higher output from the available fertile land, intensification has been adopted in Pakistan and the national average cropping intensity of 162 and 151 percent was reordered on marginal and small farms, respectively (Khan *et al* 2012 and Asghar, 2014). Even a very high cropping intensity, near to 200 percent, was also recorded in the certain irrigated area (Khan *et al* 2012).

It is crucial to calculate recent levels of agricultural land-use intensity before implementing any plan that aims at further long-term yield growth and future land-use developments (Dietrich *et al.,* 2012). Iqbal and Ahmad, (2005) highlighted that the future possibilities for further increase in cropping intensity are limited and improvements are more complicated to attain in cropping systems working at the forefront of intensity levels than for systems at lower intensity levels. Although, crop intensification has lead to a spectacular increase in food production without putting more land under cultivation, but this often comes at a price, such as land degradation through soil erosion, inappropriate irrigation and land management practices (Khan *et al* 2012 and Sustainable Development Solutions Network, 2013). The productive capacity of numerous land and water systems now face the risk of progressive breakdown, under unsustainable agricultural practices and extreme demographic pressure. The external drivers, including climate change, competition with other sectors, technological, institutional and socioeconomic changes further exacerbated the physical limits of land and water availability within these systems (Sikandar, 2015). These cropping systems are at risk and need prior attention for remedial action simply because there are no alternatives (FAO, 2011).

About 6.8 million hectares of productive lands across the country has been degraded (UNDP, 2015) and such damage is mainly attributed to unsustainable land management practices, water erosion, wind erosion, depletion of soil fertility, deforestation, unsustainable livestock grazing and water logging practices (little recharge and overexploitation) (Khan *et al.,* 2012). Around 6 million hectares are prone to wind erosion whereas 11.2 million hectares are affected by water erosion (UNDP, 2015). Pakistan has a highly complex and diversified agro-ecological and socio-economic structure that makes it difficult to control such types of land degradation and this problem is further aggravated by water scarcity, frequent droughts and mismanagement of land resources (Khan *et al.,* 2012). Similarly, Sheikh *et al* (2005) mentioned that per capita availability of land has declined sharply from 0.25 hectare to 0.15 hectare from 1971 to 2003 and will shrink further to 0.06 hectares in 2050. The economy of Pakistan is highly reliant on agriculture and under conditions of continuously declining resources; it is challenging to feed the ever-growing population.

In addition to degradation and declining land resources, Pakistan is also dealing with a challenge of immense water shortage, which is supposed to be worst in near future (GOP, 2014 and Shams, 2016). Pakistan has already reached close to the water scarcity threshold of 1000 cubic meters per person per year (Sheikh, 2016 and Shams, 2016) and declared as “water stress”, and likely to face serious economic and social consequences below this limit (Ahmad, 2007; Iqbal, 2010 and Spross, 2013). IMF (2015) reported that per capita annual water availability has dropped by 81 percent, from 5,600 cubic meters at independence to 1,017 cubic meters. This decline is linked to population growth and is projected to decline further under the current infrastructural and institutional conditions. The 1000 cubic meter per capita per year is the minimum water threshold level below that the country can be declared as “water scarce” (Bhatti and Muhammad, 2014 and Shams, 2016). It is also reported that per capita water availability will further decline to 800 cubic meters, with an expected population increase of about 230 million by 2025 (Latif *et al.,* 2016 and Shaikh, 2016). It is expected that this condition will be further worsened by 2030 when water availability fall below 500 cubic meters per capita per year (Piesse, 2015). Pakistan is drastically heading towards severe water shortage condition and in transition from being water stressed to water scarce and can have a substantial impact upon the irrigated cropping systems, economy and society (Spross, 2013). The projected demand for water will likely to approach 274 million acre-feet (MAF) in 2025, while supply will remain unchanged at 191 MAF (Mustafa *et al*. 2013; IMF, 2015 and Piesse, 2015 and Sukhera, 2016). Unless demand and wastage are curtailed, the water crisis will grow in severity (Piesse, 2015). It is obvious from the discussion that the land and water resources of Pakistan are constantly under severe pressure and the probability of bringing more area under crop production and construction of new dams is very bleak due to the social, financial, environmental and geopolitical situation. The storage capacity of existing reservoirs is lost due to sedimentation and unable to handle if any additional water is added to the system (Government of Pakistan, 2017). The groundwater that has supplemented the canal water supplies during the last many decades is also reaching its safe potential yield and the efficient use of available land and water resources is inevitable.

1.3: PRESENTATION OF PROBLEM

Food security is a principal objective in most of the agricultural policies in Pakistan (Kugelman & Hathaway, 2010 and Government of Pakistan, 2017). Pakistan vision 2025 recognizes that adequate, reliable, clean and cost-effective availability of energy, water, and food – is indispensable in ensuring sustainable economic growth and development (Government of Pakistan, 2016). However, the agriculture sector has partial success in addressing the food-related issues and striving hard to secure the objective of food security over past two decades (Piesse, 2015). Population in Pakistan is growing at an annual growth rate of 2.05 % as compared to an agricultural growth rate that has declined from 5.1 percent in 1960 (GOP, 2013) to 2.9 percent in 2015 (GOP, 2015). Pakistan's population is expected to reach 363 million, ranking it world's sixth populous country in 2050 (Hilal, 2014). It is challenging how the objective of self-sufficiency in food will be achieved under this immense population pressure and declining agriculture growth rate. A rapid growth in output was seen during the early development stages when “Green Revolution” in the 1970s was implemented as a strategic measure for productivity enhancement (Samie *et al.,* 2010 and Sami, 2016). The inclusion of new high-yielding varieties, chemical fertilizers, development of irrigation infrastructure, increased cultivated area and enhanced land use intensity, led to a spectacular rise in production and agriculture in Pakistan transformed radically (Bhutto & Aqeel, 2007; Khan *et al.,* 2012 and Sami, 2016). The increase in productivity stemmed from green revolution was sustained for some time due to intensive use of land, fertilizers, and chemicals but the growth rate sharply declined afterward due to depleted soil fertility, political instability and failures in implementing agricultural policies (MINFAL, 2004 and Sami, 2016). It is now agreed that the potential of these factors has already been exhausted and now would only make a marginal contribution towards agricultural growth in future (Khan *et al.,* 2012).

According to the estimates of Agricultural Census 2010, there are 8.26 million farms in the country, Out of which 5.35 million are small having land less than 5 acres, constituting 64 percent of the total private farms. The small farms have a central role in sustainable development through ensuring the biodiversity, rural population stability, and rural employment (Wolfenson, 2013 and Burja & Vasile, 2016). In the past, small farms thought to be inefficient, unproductive and a major obstacle to economic growth due to a follower of traditional and obsolete methods of cultivation (Rosset, 2000, Sudaryanto *et al.,* 2009 and Odetola & Chinonso, 2013). However, these farms found highly flexible, prolific and efficient, engaged in alleviating poverty (Adleke *et al*., 2010; United Nations, 2014 and Dev, 2014) and contributing much towards food security in the world (Rosset 2000; Hazell and Dorward 2007; Dev, 2014 and United Nations, 2014;). Small-scale farmers need greater attention than large farms because they are a diverse group, involved in providing food for the growing population (Ahmad and Farooq, 2010; United Nations, 2014 and Ahmed et al., 2016). Empirical evidence shows that the small farmers are desirable not only because they provide employment opportunities to rural peoples but also provide more equitable distribution of income (Binam *et al*., 2005; Hazell et al., 2007 and Thabethe, 2013)

After a series of debates, inverse relationship between farm size and productivity has become a "stylized fact" and a hypothesis of "poor but efficient" has been supported by various authors in different parts of the world (Matchaya, 2007; Gul *et al.,* 2009; Tsimpo, 2010; Okon *et al.,* 2010; Taraka *et al.,* 2010; Sial *et al* 2012; Bhatt & Shaukat, 2014; Mahmood *et al.,* 2014; Kitila, G. & Alemu 2014; Hameed *et al.,* 2014; Ali & Khan, 2014; Danso-Abbeam *et al.,* 2015; Ladvenicová & Silvia, 2015; Sarker & Alam 2016 and Anang *et al.,* 2016). Rosset (1999) mentioned small farm higher production as "small farm wisdom" and described their domination over larger farms in the following manner;

- Small farms intensively cultivate their land and grow two to three crops annually, while large farm rely on single crop,
- Small farmers use full potential of their land and do not leave it fallow while large farmers underutilize land.
- Larger farmers hire labor from the market that shows less commitment and determination while small farms employ family labor.

The agricultural policies particularly inclined towards productivity enhancement on small-scale farmers are indispensable for agricultural growth and food security in Pakistan. However, the small farms face challenges and suffer from widespread poverty, rising unemployment, growing income inequalities and disproportionally low health and education opportunities (Kugelman & Hathaway, 2010; Ahmad and Farooq, 2010 and Khan et al., 2011). Most of these problems arise mainly, if not solely, from the skewed distribution of land ownership, leading to correspondingly highly unequal distribution of income and social power (Khan, 1997; Hameed, 2008; Ahmad and Farooq, 2010; and Kugelman & Hathaway, 2010). The accessibility to inputs is asymmetric and large farmers due to better social status mostly get benefit from government policies (Asim, 2010; Ahmad and Farooq, 2010 and Dethier and Alexandra, 2012). The small farms under-utilize about 30 to 50 percent of various inputs than large farms —resulting in low productivity, greater poverty and food insecurity

(Ahmad and Farooq, 2010). The productivity of small-scale farmers could be accelerated by providing conventional inputs (Ali *et al* 2009; Aung, 2012; Feel & Basheer, 2012; Gill, 2015 and Sami, 2016), introducing agricultural technologies (Javed, *et al*., 2008; Otchia, 2014; Ali and Khan, 2014 and Sami, 2016), upgrading infrastructure (Ahmed et al., 2016), increasing area under crop production (Aung, 2012 and Najjuma *et al*., 2016) and strengthen some institutions (extension services) involved in transferring agricultural knowledge (Abedullah, 2007; Javed *et al* 2010; Feel & Basheer, 2012; Aung, 2012; Mokgalabone, 2015 and Sami, 2016).

There is increasing evidence that the prospects for further expansion in the cropped area are limited since most arable land is already in use (Rockström and Karlberg, 2009; Ahmad and Farooq, 2010; and Lambin & Meyfroidt, 2011). Similarly, the scope for production enhancement through the intensified use of land is also bleak as the average national cropping intensity has reached even near to 200 percent in many farming systems of Pakistan (Ahmad and Farooq, 2010; Khan *et al* 2012 and Asghar, 2014). The implementation of new technologies at farm level and increased use of inputs are highly influential for better crop production but many of them are left behind, unlike large farms, they have poor access to markets (Ahmad et al., 2016 and Suvedi & Kaplowitz 2016). Further, an increase in productivity based on increased use of inputs and material resources is feasible at some instant but not sustainable (Ali *et al* 2009 and Ahmad and Farooq, 2010). Technological change has been considered another major source of productivity growth (OECD, 2012). However, negligible savings due to low-income hinder small farms to shift toward modern, technology-based agriculture (Ahmad, 2003; Barrett *et al*., 2010; Hussain *et al*., 2011 and Kusz, 2014). The benefits from new technology may not be realized unless the potential of existing technology is fully exploited (Ayaz, 2010). The production can be increased remarkably by providing them credit (Khan & Farman., 2013; Rajendran, 2014; Mokgalabone, 2015; Usman *et al*., 2016 and Yang *et al*., 2016) improving the system of research and extension (Abedullah, 2007; Asogwa *et al*., 2012, Bakhsh *et al*., 2014; Kitila & Alemu, 2014 and Mokgalabone, 2015) and upgrading the infrastructure (Abedullah, 2007; Adeleke *et al*., 2010; Feel & Basheer, 2012 and Mokgalabone, 2015). However, the introduction of revolutionary change in the overall agriculture sector is a time-consuming process and requires investment (Javed, 2009).

A large number of studies have noticed the prevalence of “yield gap” between the farmers with similar resource endowment and agro-climatic environment, in different production systems within the country (Hussain *et al*., 2000, Aslam, 2000; Bakhsh *et al*., 2005; Luqman *et al*., 2005; Hussain *et al*., 2014; Noonari *et al* 2015; Gill, 2015; Aslam, 2016; Koondhar *et al*., 2016; Abro *et al*., 2016; Mekonnen *et al*., 2016 and Dogar *et al*., 2016). The “yield gap” signifies variation in productivity on “best practice” and other farms under the same technologies possibilities (Abedullah *et al*., 2007; and Dogar *et al*., 2016). The national average yield of various crops is far below their potential yield as realized at the progressive farms and that demonstrated at research stations (Iqbal and Ahmad, 2005 and Aslam 2016). Luqman *et al* (2005) mentioned that average yield per hectare of wheat, rice, sugarcane, and cotton, was 2384, 2012, 47927 and 621 kg, as compared with the yield potential of these crops being 5302.69, 6125, 107500 and 5261 kg ha^{-1}, respectively. Hussain *et al* (2014) declared this gap in the mixed, cotton-wheat and rice-wheat zone, and found that the wheat yield is 33.0%, 43.0% and 50.6% less than the potential yield, respectively. Aslam (2016) revealed that wheat, cotton, rice, maize and sugarcane farmers are obtaining a yield of 2.26, 1.87, 2.88, 1.77 and 48.06 tons per hectare, against potential yield of 6.80, 4.30, 5.20, 9.20 and 300 tons per hectare, respectively. This reflects a yield gap of 67, 57, 45, 81 and 84 % between the average and potential yield of wheat, cotton, rice, maize, and sugarcane, respectively (Aslam, 2016).

Such colossal productivity differential among farmers highlights that the maximum potential output from available technology has not been realized yet (Bakhsh *et al* 2007 and Najjuma *et al*., 2016) and with existing technology and resources, the agriculture output could possibly be raised by improving the techniques of input application as employed by the ‘best practice’ farms (Abedullah et.al 2007). This sharp difference in actual and potential yield may rise due to the ineffective application of inputs and available technologies (Nin-Pratt et al., 2011 and Henderson et al., 2016). The cropping systems with a large difference between actual and potential yield have great potential for further yield increases (Neumann *et al*., 2010). Conceptually, inter-farm yield variability might be either due to differential use of physical inputs or difference in technical efficiency level (Abatania, 2013). Therefore, in a situation where farmers have meager resources and inputs constraints are quite apparent, basic emphasis must be on to bridge this gap by identifying the factors causing yield variability and inefficiency rather putting more attention towards technology generation (Giroh and Adebayo 2009 and Aung, 2012). This approach can be seen as a short-term analysis of agricultural potential since it focuses on agricultural inputs and management, which can be changed and optimized within years (Dietrich *et al* 2012). Most countries can achieve self-sufficiency in food if potential crop production levels are achieved (Pardhan, 2015). The improvement in productivity by narrowing the yield gap through improvement in the technical efficiency is the most suitable solution without using any additional inputs (Aung, 2012 and Abatania, 2013).

It is often cited in the literature that a major source of yield gap among farmers in developing countries is due to the difference in their management practices that then present as technical inefficiency (Gill, 2015). Efficiency is a relative concept defined as the ability of a producer to drive maximum output from a minimum quantity of inputs (Sarkar, 2012 and Elahi *et al*., 2015) and is used to determine the optimal level of inputs needed to produce the desired output. An improvement in production efficiency can have huge potential benefits not merely in terms of higher output and productivity but also resource conservation (Sarkar, 2012 and Melkaw, 2014). Similarly, the economic efficiency or cost efficiency provides information that how much input cost can potentially be reduced to get the maximum benefit. The economic efficiency is achieved when the firm appears fully technically and allocatively efficient (Melkaw, 2014). The profit maximization occurs when a firm is able to equate the marginal revenue to the marginal cost and it has been used as a criterion to evaluate the cost minimization behavior of the farmers (Mendola 2007). The profit can be maximized by reducing the cost of production or by increasing the revenue.

The first main objectives of the present study are, therefore, to quantify the farm level technical allocative economic, scale and biased corrected efficiency and to highlight factors hindering some producers, possibly a majority of them, to achieve maximum economic returns. By measuring the extent of farm-specific efficiency and identifying causative factors, it would be possible to decide whether there is the need for radical changes in the overall agriculture system or farmers can improve their productivity by using physical inputs up to the level that is optimal. If farmers appear using their resources optimally after quantifying their efficiency level, then the emphasis of policies must be on technology generation otherwise improving efficiency will be the most cost-effective. The assessment of technical efficiency levels provides an understanding of what makes an efficient system and how to improve efficiency and hence productivity. In addition, the efficient resource utilization has a potential to increase food production without necessarily increasing resource use like production area. This drives the need to augment agricultural productivity through increased efficiency of available technologies and resources.

The impact of agricultural extension on farm production has received considerable attention in the farm efficiency literature. The agricultural extension represents a mechanism by which information on new technologies, better farming practices, and better management can be transmitted to farmers (Ahmed, *et al*., 2016 and Suvedi & Kaplowitz, 2016). Although the other factors like access to market and credit are also equally important in determining the efficiency level of the farmers, but the effect of extension is greater as it has evolved over time and has undergone a process of diversification (Suvedi & Kaplowitz, 2016) and now engaged in providing various support services to the farmers. The extension was initially regarded as a service to transfer research-based knowledge to the farmers in order to improve their productivity but now It has become more decentralized, demand-driven, participatory and pluralistic and in transition (Suvedi & Kaplowitz, 2016). Extension thus included components of technology transfer, broader rural development goals, management skills, and non-formal education. Traditionally extension was viewed in developing countries, focusing on increasing production, improving yields, training farmers, and transferring technology. Today's understanding of extension goes beyond technology transfer to facilitation, beyond training to learning, and includes helping farmers form groups, deal with marketing issues, and partner with a broad range of service providers and other agencies. The agricultural extension now includes the entire set of organizations that support people engaged in agricultural production and facilitate their efforts to solve problems; linking them to markets and other players in the agricultural value chain; and obtain information, skills, and technologies to improve their livelihoods (Davis, 2009).

A number of studies (Rahman , 2003; Croppenstedt, 2005; Solıs *et al*., 2009; Byma & Tauer 2010; Olarinde ,2011; Asogwa *et al*., 2012; Naqvi and Ashfaq 2013; Khan & Farman., 2013; Battese *et al*., 2014; Bakhsh *et al*., 2014; Kitila & Alemu 2014; Usman *et al*., 2016 and Yang *et al*., 2016) have reported a positive and significant impact of extension services on the efficiency, in different regions of the world. The improper and limited interaction with extension services is more conspicuous among all other factors pushing farmers away from the efficient frontier (Chirwa, 2007; Oladeebo *et al*., 2007; Kiani, 2008; Jema, 2008; Obare *et al*. 2010; Mekonnen, 2013 and Saddozai *et al*., 2013). This is because, the farmers who have no contact with the extension agents, do not apply state approved recommended agricultural practices, innovations and suboptimal input usage cause inefficiency. A suboptimal input usage and improper management practices lead to yield gap among the farmers that can be bridged by deploying more efforts in agricultural extension and educating the farmers about the recommended practices related to crop production (Mondal, 2011).

Like other developing countries, most of the extension work in Pakistan is carried out through public sector extension services, funded by the government. The prime objective of extension services is to increase the productivity and efficiency of the farmers by disseminating relevant technologies and information in non-formal educational settings (Baloch & Thapa, 2016 and Suvedi & Kaplowitz, 2016). To accomplish this goal several approaches and models were tried to develop institutional arrangements that would facilitate delivery of agricultural extension services to smallholder farmers efficiently and effectively; but all programmes met with partial success (Davidson, 2001) and about the effectiveness of public extension, serious reservations are expressed in different studies. The studies of (Siraj, 2011; Mari *et al*., 2011 and Baloch and Thapa, 2016) criticized extension service due to poor access of small farmers to advisory services, dissemination of irrelevant information, lack of updated knowledge and preferential treatment to large farmers. The small-scale farmers face problem in getting information from this public funded department and remain outside the ambit of the extension activities (Bajwa, 2004). A number of past and recent studies (Murgai *et al*., 2001; Naqvi and Ashfaq 2013; Croppenstedt, 2005; Battese *et al*., 2014; Bakhsh *et al*., 2014; Usman *et al*., 2016, Yang *et al*., 2016; Khan and Farman., 2013 and Kitila & Alemu 2014) have concluded that the effective and efficient use of the current technology transfer institutes like extension service can play its role to enhance the capacity and productivity of the small farmers.

Therefore, the second main objective of this study is to determine the farmers' access to and participation in the extension activities in the study area. Secondly, to identify the factors influencing the participation of the farmers in extension activities and then the effectiveness of the various extension methods will be analyzed by measuring their effect on the level of technical allocative and economic efficiency of the farmers. The best practice knowledge (The production practices used by the technically efficient farmers) will be identified and future strategy for extension will be explored that how the service delivery can be improved to educate the farmers in the study area. The extension service can use the identified best practice as a benchmark to educate inefficient farmers through a learning process that what adjustments are required to the input resources to behave like efficient farmers. Based on the above, the second part of this study will seek to determine perceptions about extension services in order to provide foundational data that can be translated into practical recommendations for extension service providers, policymakers and farmers regarding the delivery of extension education programs in the future.

1.4: CONTRIBUTION TO KNOWLEDGE

A comprehensive review of literature highlighted that numerous studies have been conducted to estimate the TE in different farming systems of Pakistan and majority of them preferred parametric approach (SFA) (Hussain,1995; Parikh *et al*., 1995; Burki and Shah, 1998; Ahmad, 2002; Ahmad, 2003; Hassan & Ahmad, 2005; Bashir and Dilwar, 2005; Abedullah *et al*., 2006; Mari and Heman 2007; Abedullah *et al*., 2007; Saheen *et al*., 2011; Dilshad and Afzal 2012; Hussain *et al*., 2012; ; Khan and Ghafar, 2013; Buriro *et al*., 2013; Khan and Farman., 2013; Naqvi and Ashfaq 2013; SaddozI *et al*., 2013; Ali *et al*., 2013; Rauf *et al*., 2014; Battese *et al*., 2014; Ali and Khan, 2014; Miraj and Ali , 2014; Bakhsh *et al*., 2014; Saddozai *et al*., 2015; Elahi *et al*., 2015; Gill, 2015; 2016 and Fatima *et al*., 2016). Only few studies have exercised the technique of Data Envelopment Analysis for the quantification of technical efficiency in Pakistan (Shafiq and Rahman, 2000; Ayaz *et al*., 2010; Bhatt and Shaukat, 2014; Hameed *et al*., 2014; Fatima, 2015; Hashmi *et al*., 2015 and Usman *et al*., 2016). According to Simar and Wilson (1998, 2007), the use of standard DEA procedure suffer from methodological problem because the efficiency scores computed in the first stage, and then regressed on environmental variables in the second stage, failed to describe a coherent data-generating process. Due to the complicated nature of serial correlations among the estimated DEA efficiencies, the standard DEA model may produce invalid results (Melkaw, 2014). This study adds to the existing literature of TE in Pakistan's agriculture by estimating for the first time bias-corrected TE by incorporating the stochastic components into DEA estimates through bootstrapping technique. This not only permits correction of the bias from the raw DEA scores but it also helps to construct confidence intervals for DEA scores. Therefore, It is also assumed that standard DEA model produces bias efficiency results and bootstrap DEA method enable statistical inference to correct the efficiency from biases. Instead of Tobit model, it is decided to use a double bootstrap truncated regression model in second step contextual analysis to account for the impact of environmental variables.

From the review of the literature, a number of issues are identified that have never been addressed in past. A large number of efficiency studies conducted in Pakistan, emphasized on evaluating the efficiency of a single or two crops (Battese et el 1993; Hussain *et al*., 1999; Shafiq and Tahir, 2000; Hussain *et al*., 2000; Ahmad *et al*., 2002; Hassan and Ahmad 2001; Hassan and Ahmad 2005; Hassan *et al*., 2005; Ahmed *et al*, 2002; Bashir and Dilwar, 2005; Hussain *et al*., 2012; Dilshad and Afzal 2012; Saddozai *et al*., 2013; Hussain, 2014; Buriro *et al*., 2013; Battese *et al*., 2014; Ali & Khan, 2014; Hameed *et al*., 2014; Elahi *et al*., 2015; Gill, 2015, Mirza *et al*., 2015; Hashmi *et al*., 2015; Hashmi *et al*., 2016; Usman *et al*., 2016; Memon *et al*., 2016 and Ali & Abbas 2017). No consideration has been given to evaluate the efficiency of the farming systems at crop and farm level. Secondly, these studies have either used per acre or per farm data, both kinds of data is not considered by any study. Therefore, this research adds to the existing literature of efficiency in the agricultural sector in a number of different ways. First, this study relies on four major crops (wheat, cotton, maize, and sugarcane) rather emphasizing on single or two crops and analysis is made by using per acre and per farm data, as ignored in above mentioned efficiency studies. To comprehensively understand the change in efficiency patterns, first the efficiency analysis is carried out separately for each crop and then at aggregated level. In addition, the higher level of input use has an adverse effect on the environment and soil fertility status. This research also contributes to the environmental literature by providing information about the possible reduction in inputs, without any alteration in the output that can improve environmental performance. In addition, slack-based DEA models are also employed to see the further possibility of input reduction and output augmentation.

In previous studies, the extension has been measured only as an independent variable in the analysis. None of the above studies has assessed the role which extension can play in improving the efficiency of the farmers. This research will assist by producing recommendations for a diverse set of stakeholders. It would help policymakers to decide whether there is a need for technological intervention or improvement in efficiency can lead to productivity enhancement. It would help in formulating and revising agricultural extension strategies in the region as well as in other areas with similar socio-economic conditions. It will provide information to extension agent how effectively they can disseminate new research findings to farmers, aligned to farmers' needs. The results of this research can also be used by extension service to identify the “best practice” regarding the production of cotton, wheat, sugarcane and maize to decide which farm production practices need to be disseminated to farmers for output expansion. Peer farms are identified for the inefficient farmers and the production practices used by these peer farms are highlighted in this study and extension service can use this information for efficiency enhancement of inefficient farmers.

1.5: OBJECTIVES AND RESEARCH QUESTIONS

Based upon the above discussion, the specific objectives and research questions that will be pursued in this research are:

Objective 1

The main objective of this study is to estimate the technical, scale, cost, allocative and bias-corrected TE at crop and farm level and Identification of the determinants of Technical efficiency in the mixed farming system.

This objective is very comprehensive and a wide range of research question can be answered under this single objective. The research questions that are addressed and answered under this objective are:

- How efficiently the small farmers are using the available resources at crop and farm level and what is the extent of cost and allocative efficiency?
- How effectively can the Bootstrapping procedure be applied to correct the efficiency from bias and to find the determinants of technical efficiency in a second step contextual analysis?
- How can DEA be used in benchmarking process to distinguish non-physical factors between the peer farms and inefficient farms to reduce inputs level?
- IS there any difference in TE, SE, CE, AE and BCTE when per acre and per farm data is employed?

Objective 2

Analysing the role of extension services for efficiency enhancement by monitoring the extension activities, farmer's interaction with extension staff and examining the factors influencing farmers' participation in the study area.

The questions addressed are:

- What is the farmers' level of access to information and participation in extension activities and what factors influence farmer's participation in extension activities?
- What is the difference in technical, allocative and economic efficiency between contact and non-contact farmers and what is the farmers' perception about the various aspects of service delivery of the extension?
- How can the existing extension system improve their service delivery for effective dissemination of findings to the farmers?

Objective 3

Draw conclusions and extract recommendation from the above research to policymaking and extension departments for the improvement in efficiency in the study area.

1.6: SUMMARY

In this chapter, the geography of Pakistan and the current agricultural condition has been discussed along with explaining the importance of cotton, wheat, and sugarcane and maize crops in Pakistan's economy. Although these crops have a considerable contribution to the economy, but there is a huge gap in actual yields and potential yield and this difference in productivities among farmers providing an indication that there might be some factors for this variation. Under the light of various studies, it is also discussed in this chapter that extension might be the cause of low efficiency among farmers and by studying the role of extension services in the study area might lead to the productivity enhancement. This stresses that to study the factors influencing the efficiency of farmers and to define the future role of extension services for efficiency improvement.

1.7: ORGANIZATION OF THESIS

In addition to the introduction Chapter, This thesis is further comprised of 8 chapters. Chapter 2 is related to a review of relevant literature and divided into various sections. The first section discusses information about the small farms (definitions, status, threats, and challenges to small farms and farm size and productivity theories etc.). In the next section, the concept of efficiency and productivity, output and input efficiency, approaches used for the calculation of TE are discussed briefly. In the next section, the agricultural efficiency in the world and Pakistan are reviewed. In the last section, technical efficiency studies are reviewed to discuss and understand the role of extension services for efficiency improvement. Chapter 3 is devoted to describing the technique of Data Envelopment Analysis and it starts with discussing some important basic methodological concepts and definitions related to DEA. The concept and definitions are further elaborated by giving example through original data used in this research. Next, the DEA models and advancement made over time are described. An illustrative example related to DEA modeling is formulated and solved to familiarize the new researchers about DEA. The merits and demerits related to DEA are discussed at the end of this chapter. Chapter 4 provides information about the study site, sampling framework, data collection tools, ethical consideration and the steps that were followed to conduct the informal and formal survey. At the end, the problems that were encountered and strategies adopted to overcome these difficulties are discussed in detail. Chapter 5 begins with describing the farm and farmer's specific characteristics in the mixed farming system and the production technologies that are used by the respondents to grow wheat, cotton, maize, and sugarcane is discussed in detail. A mechanism that is used to calculate input and output variables to be used in DEA models is also discussed comprehensively.

Chapter Six initially provides descriptive statistics of input and output variables used in DEA models. Afterwards, the results from DEA input oriented analysis is presented followed by the analysis of scale efficiency, cost, and allocative efficiency. The bias-corrected technical efficiency results are then presented along with confidence interval. The efficiency analysis is carried out using data on per acre and per farm for each crop, separately. The factors affecting technical efficiency are then estimated and discussed. Chapter 7 at the start details out the procedure used to aggregate the input and output data for four crops under study. To evaluate the performance of the farmers in the mixed farming system as a whole, multiple inputs and single aggregated output are used in the model and results related to this are presented in this chapter. Chapter 8 deals with the extension activities carried out in the study area and level of farmers’ interaction with the extension services and the effect on a technical efficiency level. The efficiency level of the farmers is compared across participants and no participants. The purpose of this chapter is to define the future role that extension can play for efficiency enhancement. Finally, Chapter 9 summarizes the key aspects and findings of this research, discusses the possibilities of future research and the potential policy implications.

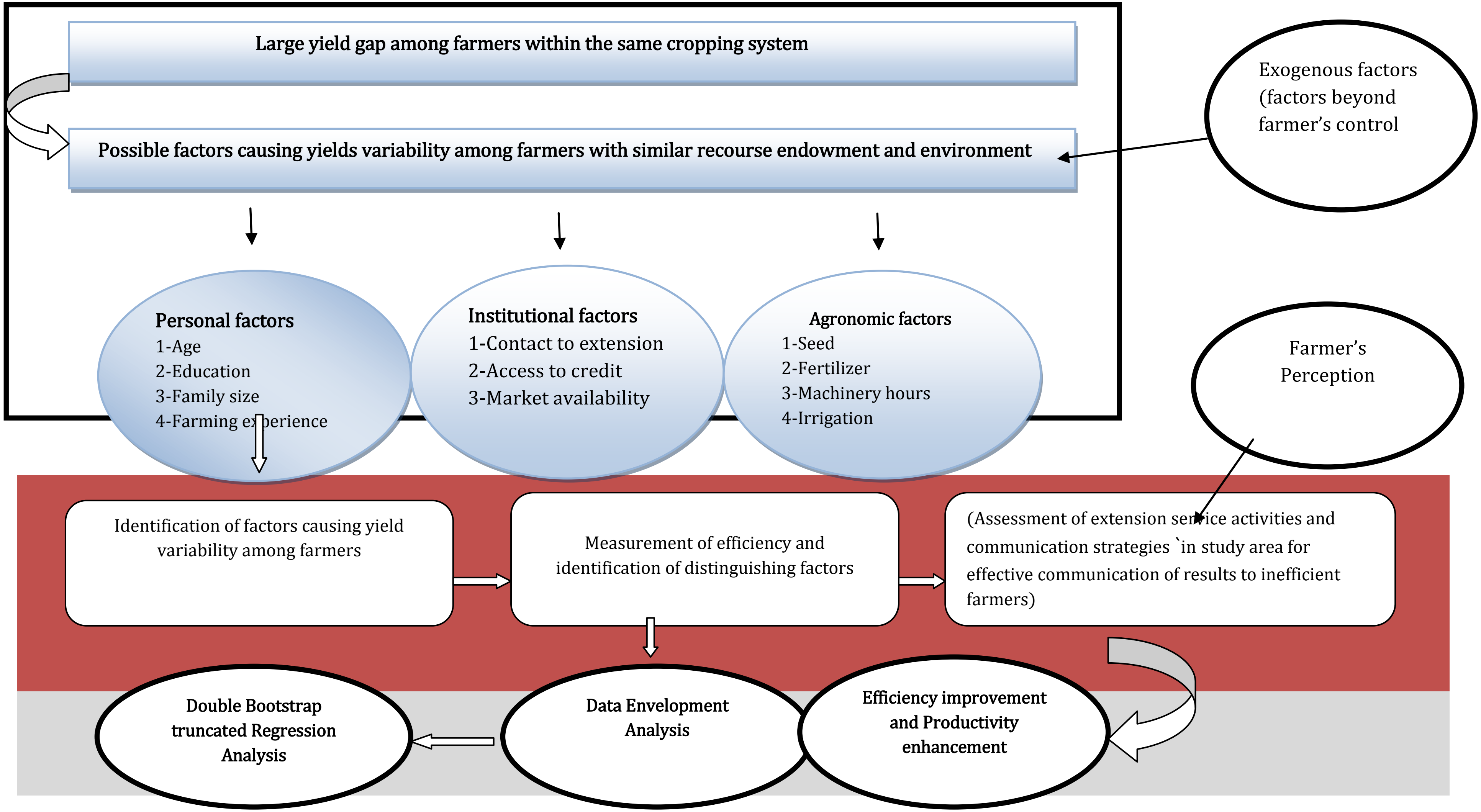


Figure 1.2: Conceptual framework for this study

CHAPTER 2

LITERATURE REVIEW

This chapter is devoted to a literature review and comprised of five sections. This first section describes the definitions of the small farms prevailing in the world, recent trends in farm size, factors affecting the farm size, small farm productivity theories and challenges to the small farms in a globalized world. In the next section, the current situation of small farms in Pakistan and possible ways to enhance their productivity are discussed in light of various studies. The next section has been written to explain, the concept of productivity, efficiency, and approaches that have been developed over time to estimate the productive efficiency of the decision-making units (DMUs). The major aim of this chapter is to comprehensively review the past literature related to the efficiency of the farming system in order to find the research gap. In the fourth section, the efficiency studies conducted in different parts of the world are reviewed considering various dimensions like sources of data, type of enterprises and efficiencies and methods applied. First, all the studies were reviewed without making any demarcation in the approach used (either parametric or non-parametric) to evaluate the efficiency of the farming system.

Further, the literature that specifically deals with the evaluation of efficiency through the application DEA is reviewed. The studies are reviewed in order to get updated information about the DEA models and to identify the basis of variations among researchers in the use of these models. Further, the DEA studies that have performed the second stage contextual analysis are reviewed in order to find the appropriate method that can be used at the second stage to find the determinants of efficiency. In addition, the methodological advancements made in DEA technique to serve some specific purpose while evaluating the performance of the agricultural sector are also acknowledged. At the end of this section, the agriculture policies related to various institutions are evaluated to find the possible causes of failure. The overall summary of the chapter is presented in the last section.

2.1: BACKGROUND

Small-scale farming is the prominent mode of agricultural production throughout the developing countries, especially in Africa and Asia (Thapa, 2009; FAO, 2012 and Gollin, 2014). About, 80 percent of the farms in sub-Saharan Africa and Asia are operated by smallholders and supply up to 80 percent of the food in both continents (FAO, 2012). However, there is no sole consensus exists among scholars on the meaning and definition of small farms, although various stakeholders have established definitions either for purely analytical purposes or for the implementation of government programs (FAO, 2010 and Lowder *et al.,* 2016). The terms small and family farm are often used interchangeably or in combination without clear definitions but these two terms are different and must not be used interchangeably (Lowder *et al.,* 2016). All small farms are family farms, but not all family farms are small farms (Gollin, 2014 and Plaas, 2014).The small farms have been defined in the literature using different criterion and methodologies. Lipton (2005) defined small farm as "The farms on which most of the farm activities are carried out by the family members themselves". Mostly small farms are defined based on farm size (Thapa, 2009) or net annual income, incurred from farm activities. World Bank (2003), FAO (2010) and Lowder *et al* (2016) described, "Small farms are those having less than 2 hectares of land". However, contrast to small farms, family farms can have land less than or greater than 2 hectares (Lowder *et al.,* 2016). In Pakistan, the farmers with land less than 5.06 hectares (12.5 acres) in the irrigated area are considered small (Government of Pakistan, 2010). In the context of African agriculture, Tshuma (2014) defined that the farmers operating a farm area equal to one hectares or less are small. The farmers that sell less than $250,000 in agricultural products annually are declared small in USA (USDA, 2007 and Hoppe *et al.,* 2010). Smallholding sizes vary across countries (0.5 to 10 ha) and even 500 ha is considered a smallholding in Australia (Wolfenson, 2013).

A number of other dimensions have been ignored while defining smallholder on the basis of farm size and the farmers with low capital and education level, produce low quantities and yields, lack the skills to participate in markets, produce food primarily for self-consumption and rely heavily on family labour can also be defined as smallholders (FAO, 2010). Various agro-ecological and demographic conditions, economic and technological factors determine the size of farms across countries (FAO, 2010). Therefore, the concept of the small farm is relative and highly context-specific; with national definitions of small farms differ widely across countries and fluctuation in approaches exists in measuring the number of smallholders (Wolfenson, 2013; Grain, 2014 and Lowder *et al.,* 2016).

2.1.1: Small Farm in the World and Recent Trends

According to (Lowder *et al.,* 2014), various estimates have been used in agricultural economics literature to provide accurate information about the number of small farms in the world. Most of the studies (Hazell et al., 2007 and IFAD, 2011) maintain the information of (Nagayets, 2005) that there are about 500 million small farms (Lowder *et al.,* 2014). However, (Lowder *et al* (2014) & Lowder *et al* (2016) attempted to provide a more accurate, updated and reliable information and it is estimated that there are about 570 million farms in the world, of which more than 475 million are small farms, being less than 2 hectares in size and constituting 83 percent of the total farms. The overwhelming majority of these farms are located in Asia (87 percent), while Africa is home to another 8 percent and Europe approximately 4 percent (Figure 2.1). In Asia, China alone accounts for almost half the world's small farms (193 million), followed by India with 23 percent, other countries in the region with a large proportion of small farm include Indonesia (17 million), Bangladesh (17 million), and Vietnam (10 million) (Thapa, 2009; Thapa & Raghav, 2011).

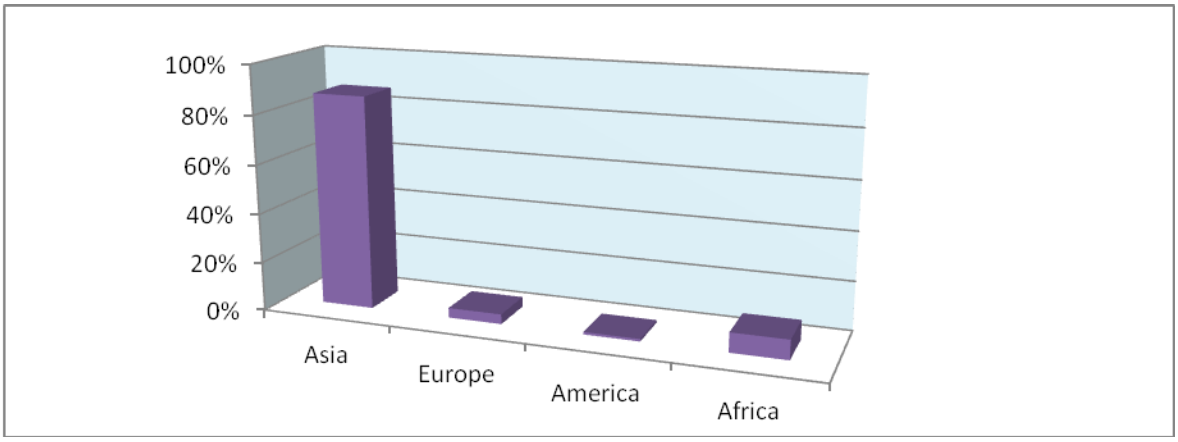


Figure 2.1: Distribution of Small Farms in World (Nagyets, 2005)

The average farm size is generally thought to have increased in countries with higher per capita GDP, while it has decreased in low-income countries (Eastwood *et al.,* 2010; Chand *et al.,* 2011; Grain, 2014; Robinson, 2014 and Lowder *et al.,* 2016). The average farm size in many poor countries is estimated at 1.6 hectares (Ha), with a 34-fold difference from rich countries where average farm size is 54.1 Ha (Adamopoulos & Restuccia, 2011). During the last three decades, the size of land holding in USA and Canada has increased enormously and the government subsidies, price supports and highly subsidized crop insurance program are the major reasons for agricultural consolidation in developed countries (Government of USA, 2014).

The size of land holding has a continuous declining trend in Asian countries (Grain, 2014) and in Japan, China and Korea farm size remain in the range of 1.2 hectares (Chand *et al*., 2011). The Asian countries are more vulnerable to the division of farms (Grain, 2014). Elepaño, (2009) highlighted that the average size has declined sharply from 3.6 to 2 hectares in Philippians. According to Chand *et al* (2011) the size of Indian farms has declined from 1.84 ha to 1.32 ha. The farm size has declined from 5.3 hectares to 3.1 hectares in Pakistan (Agriculture Census Organization, 2000). The average size of operational holdings (actual area cultivated) is only 0.5 hectares in Bangladesh, 0.8 hectares in Nepal and Sri Lanka, 1.4 hectares in India and 3.0 hectares in Pakistan (Thapa, 2009). In China and Nepal 95 and Nepal 93 percent of operational holdings are operated by small farmers with land less than 2 hectares (Thapa & Raghav, 2011). Population explosion (Grain, 2014) and laws of inheritance are the leading driving forces for this reduction and due to government policies and agrarian reforms land is usually distributed among heirs after the demise of the original landowner (Bizimana *et al.,* 2004; Shuhao, 2005; Chand *et al*., 2011; Sudaryanto *et al.,* 2009 and Demetriou, 2014). To maintain the size up to economical standard, cooperative agriculture is also introduced in some countries to overcome this problem (Yercan *et al.,* 2002 and Demetriou, 2014). It is not ordinary process and requires some special requirement for its smooth operation. In cooperative farming, the farmers share their resources to run farm activities.

In the context of food security, the involvement of small farms has been gaining immense attention, particularly in the developed countries. However, their role is often compared to large-scale commercial farmers in feeding future populations (Hazell *et al*., 2007). It is, therefore, imperative to have better knowledge of the contribution of family farms and small food businesses to food security, and their resistant to shocks in an environment of increasingly changing international agricultural policies, mostly favoring large commercial farms (Hazell, *et al*., 2007). In conventional wisdom, the prospect role of the small farms in agriculture and economic development was questioned whether they can contribute to food security in the same proportion as the large farms. In the past, the small farms were thought to be inefficient, unproductive and a major hurdle to the economic growth due to the use of conventional and outdated methods of cultivation (Rosset 2000). Being resource constrained, the small farms have contributed much, toward the betterment of the society and economic development, all over the world (Grain, 2014 and Ahmed et al., 2016). There are different arguments present in the literature that supports small farms. A series of studies were conducted, to find a relationship between farm size and productivity with the aim to provide a guideline to the policymakers to reform land policies. In different countries, researchers have found a very strong inverse relationship between farm size and productivity. Although, the results are inconclusive, but in most studies, small farms found technically more efficient in allocating the scarce resources. Masterson (2007) conducted a study using farm-level data from Paraguay agriculture and augmented the theory of “Schultz” that small-scale farmers in traditional agriculture are more efficient in comparison to large-scale farmers. Rehman et al (2012) quantified the level of efficiency of rice farmers in Bangladesh and suggested that national policies in favor of small farms must be promoted as small and medium farmers are more technically efficient. The inverse relationship between farm size and efficiency in various cropping system of Pakistan was observed by (Burki 1998 and Parikh Ali and Shah 1995; Sial et al., 2012; Hameed et al., 2014 and Mahmood et al., 2014). Similarly, Enete *et al* (2010), Mkhabela (2005) and Enwerem and Ohajianya (2013) supported the inverse relationship in Nigeria. A similar set of other studies also found inverse relationship between farm size and efficiency (Matchaya, 2007; Gul *et al*., 2009; Tsimpo, 2010; Okon *et al*., 2010; Taraka *et al*., 2010; Sial *et al* 2012; Bhatt & Shaukat, 2014; Mahmood *et al*., 2014; Kitila, G. & Alemu 2014; Hameed *et al*., 2014; Ali & Khan, 2014; Danso-Abbeam *et al*., 2015; Ladvenicová & Silvia, 2015; Sarker & Alam 2016 and Anang *et al*., 2016). This inverse relationship is attributed to many factors such as land quality (Eastwood *et al*., 2010), use of family labour and intensified cropping (Kiani 2008 and Dethier and Alexandra, 2012). However, in the presence of market imperfections and failures, large farms may have an advantage compared to small farms, because they are more able to obtain loans and hence face lower capital costs (Dethier and Alexandra, 2012). The review of above farm efficiency and productivity studies highlight that the role of small farmers in poverty alleviation, food security, and economic development cannot be neglected as it is evident that these farms are more efficient and productive. Small-scale farming is very efficient in terms of production per hectare, and they have great potential for growth. Experience reveals that supporting smallholder farmers can contribute to a country's economic growth and food security (International Fertilizer Association, 2014). For example, Vietnam has become a major food exporter country from a food - deficit country, and it is now the second largest rice exporter in the world and this target is achieved largely through the development of its smallholder farming sector (IFAD, 2012)

2.1.2: Threats to Small Farmers in World

The role of smallholders in agriculture have often been ignored in a discussion and neglected in policy making at various levels (Wiggins, 2011). Despite having a significant position in the agriculture, small farmers face numerous exceptional, intersecting challenges, often emerging at World levels; increasing competition for land and water (Kerssen, 2014), changing markets (Druilhe & Barreiro, 2012 and Dev, 2014), rising fuel and fertilizer prices (Khan *et al*., 2011) and climate change (De Haan *et al*., 2001; Kerssen, 2014 and Dev. 2014). This shifting circumstance poses complicated challenges to smallholders, who are directly reliant on ecosystem services and have little resources and capacity to cope with this changing environment as compared with large farmers, more resource-enriched capitalistic farmers (Dethier and Alexandra, 2012). Moreover, two decades of under-investment in agriculture, tied with growing competition for land and water, soaring input prices and climate change, put small farmers more vulnerable to risk (IFAD, 2013).

In some countries, the agriculture sector is no more assumed valuable for economic growth and the creation of employment due to more emphasis on other emerging and growing business and it becomes relatively minor and neglected sector (Hazel *et al*., 2007). The small farms have no desirable future in these countries as labor is attracted towards other highly paid professions. Globalization and the international trade policies reduced the price of the agricultural commodities, the introduction of new market chains in the developing world also increased the competition, and timely and high-quality food is demanded (Dethier and Alexandra, 2012). The large farmers can easily cope with this condition and have a comparative advantage over small farms (Reardon *et al*., 2009) as they have the resources to turn inputs into the output as demanded (Hazel et.al 2007; Dethier and Alexandra, 2012). Therefore, in these conditions, the small farmers are not worthwhile to supply timely supply of enterprise as their farm size restricts them to do so (Dethier and Alexandra, 2012). Globalization also has a positive impact on the agriculture sector, but the small farmers are unable to be benefitted as their purchasing power do not let them to use multimedia equipment, the source of modern agricultural information (Anne 2007).

The small farms in general terms are more vulnerable to the risk as compared to large farms in terms of availability of inputs, agricultural information, machinery, etc (IFA, 2014). The operational holding of the small farms determines their access to the critical inputs and they usually operate at a low level of equilibrium. Secondly, they entirely have a different set of problems, both in input and output market (Ahmed et al., 2016). To empower them there must be a need to upgrade their status by identifying their problems. The land is becoming constrained and the large farmer engulfing the small farms as there is no option for the small farmers except to follow exit pattern. The size of the farm is becoming uneconomical to operate.

Transactions cost of managing and supervising labor is less on the small farms, but in terms of other inputs, the large farmers are at a competitive advantage (Ahmad 2003, Poulton *et al*., 2010; UN, 2014 and Dirro & Abdoul, 2015). For the survival of the poor and small landholders, their access to farm inputs, machinery, and must be ensured. Land usually determines their access to inputs and the poor farmer operates at a lower level of production due to inadequate access to the valuable inputs in Pakistan (Ahmad, 2003). Unregistered cultivators, tenants, and tribal cultivators all face difficulties in accessing institutional credit and other facilities available to farmers with land titles (Dev, 2014).The small farmers operate below the production function due to under-utilization of inputs. Non-farm income is also considered indirect determinant of productivity as it enhanced the purchasing power of the farmers, in a condition, where institutional credit is not accessible or have a high-interest rate (Dirro & Abdoul, 2015).

2.1.3: Status and Current Situation of Small Farms in Pakistan

In Pakistan, the mainstream of the farmer's population has small or marginal farms with land less than 12 acres. According to recent Agricultural Census of 2010, there are a total number of 8.26 million farms covering an operating area of 52.91 million acres. The distribution of this farm area is highly skewed among small and large farms (Ahmad and Farooq, 2010; Khan *et al*., 2011 and Naseer *et al*., 2016). The farms of 5 acres or less constituted 64 percent (5.35 million) of the total private farms, but they operated only 19 percent (10.18 million acres) of the total farm area. Whereas, the farms of 25 acres and more, constituted only 4 percent (0.30 million) of the total farms and operated 35 percent (18.12 million acres) of the total farm area. Now in the country, the average farm size is 6.4 acres and cultivated area per farm is 5.2 acres (see table 2.1). The number of marginal and small farms increased to 5.36 million in 2010 as compared to the Figure of 3.81 million as mentioned in the census of 2000 (GOP, 2010).

Table 2.1: Number of Farms and Farm Area – By Province

Province	No. Of Farms (Million)		Farm Area (Million)		Aver. Size (Acres)	
	No	Percent	Total	Percent	Farm	Cul.Area
Punjab	5.25	64	29.33	55	5.6	5.1
Sindh	1.11	13	9.87	19	8.8	6.9
Baluchistan	.36	4	8.14	15	22.7	9.7
KPK	1.54	19	5.57	11	3.6	2.9
Pakistan	**8.26**	**100**	**52.91**	**100**	**6.4**	**5.2**

(Agricultural Census 2010)

Small farmers in Pakistan generally have the same characteristics, as these farmers have in other developing countries. These are characterized by a high percentage of land devoted to food and cereal crops, a low proportion of marketable output, diversification in farming (Rosset, 1999), greater aversion to risk (Thapa and Rajhv, 2011 and Dev, 2014), limited access to inputs (Druilhe & Barreiro, 2012) and scarcity of cash and capital resources (Khan *et al*., 2011), lack of storage facilities at farm level, large family size, illiteracy and abundance of family labour available (Khan, 1990 and Dirro and Abdoul, 2015). In spite of these characteristics, their contribution to farm output and the national economy are admirable. The small farmers exercise 30% higher land use and cropping intensities and higher irrigation intensities, grow 28% more acreage of wheat, 11.8% more acreage of rice, 48.9 % more acreage of maize, 54% more acreage of cotton, 21.2% more acreage of sugarcane, 66% more acreage of fodder, in comparison to large farmers (Chaudhry, 2001). Therefore, small farmers performing well under economic stress, social disparities, and uncertain environment.

Pakistan's rural sector faces severe challenges in social, economic, and technological dimensions that are major hurdles for development (Sami, 2016). The skewed distribution of land ownership is a major social problem that makes the society both rigid and iniquitous (Sami, 2016). The skewed distribution of land leads to unequal distribution of income and social power among the farmers (Hameed, 2008 and Khan *et al*., 2011). Similarly, uneven distribution of land leads to technological problems like traditional methods of cultivation, small landholding, and tenancy farming, all of which restrict incentives for technological progress (Khan, *et al*., 2011 and Sami, 2016). The economic problems emerge from the agriculture sector's inability to provide jobs to a growing population and the failure of agricultural markets resulting in lower returns on agriculture (Khan, *et al*., 2011).

The availability of small areas for cultivation is a hindrance to the welfare of entire families, especially when livelihood depends greatly on agriculture. The small-farming community faces challenges like hostilities of market forces (resulting in continuous increases in agricultural input prices) and the vagaries of weather e.g. droughts, floods, and erratic rains etc (Druilhe & Barreiro, 2012 and Kerssen, 2014). In the last few years, the prices of inputs like fertilizers, pesticides, seed and diesel have increased at a very fast rate (Khan *et al*., 2011). The price of DAP and Urea increased from Rs. 1900 to 3400 and Rs. 1100 to Rs. 2000, in the last 5 years, respectively. The fertilizers are the most vital and expensive input (Druilhe & Barreiro, 2012) and balanced fertilization can increase yield from 30 to 50 %, in different crop production areas. It is estimated that one kg of fertilizer nutrient produces about 8 kg of cereals (wheat, maize, and rice), 2.5 kg of cotton and 114 kg of sugarcane (GOP, 2013). The decisions of farmers on how much fertilizer to apply for a specific crop is nexus with the prices of fertilizer and apply low quantities of fertilizers in a situation of high fertilizer price and low crop price (Druilhe & Barreiro, 2012).

The farmers and government started to see problems after getting tremendous crop production at the advent of "Green Revolution". However, the advancements in agricultural techniques led to a sudden change in agriculture sector creating economic imbalance and large interregional agricultural disparities (Virat, 2016). In order to survive in the competitive agricultural market, it has been brought to the attention of many farmers to adopt new technology in order to increase crop productivity and yet not all farmers can afford this new technology (Virat, 2016). The increasing prices of inputs and technology, particularly the fertilizers have made it increasingly difficult for the small poor farmers to purchase these costly inputs, as their level of income is very low (Aziz, 2011).

The seriousness of the dilemma should be viewed in the context that the government is giving a massive amount of subsidies on fertilizers, but fertilizers are going beyond the reach of small farmers (International Fertilizer Association, 2014). There is clear indication that if such condition persists and prices go on increasing at the same pace, then small and poor farmers will not have any choice except to sell off their lands and to adopt other business. Farming is their major source of livelihood; hence, their livelihood is at high risk in this situation.

Modernization in agriculture means "the transformation from traditional labour-based agriculture to technology-based agriculture and declared as leading force for agricultural growth (Wu, 2011 and Kusz 2014). The creation and implementation of modern technologies on farms ensure increase farm-level production and improve livelihoods of farmers in less developed countries (Dirro & Abdoul, 2015). In low-income countries, farmers still use primitive technologies that are linked to low income of farms (Barrett *et al*., 2010; Kusz, 2014). Similarly, in Pakistan, farmers spend a major portion of the income on basic inputs and are unable to purchase modern agricultural technologies due to low-income (Ayaz, 2010). The mechanization is not an ordinary process in Pakistan as the available farm machines are designed to facilitate large farm holdings (Khan *et al*., 2011). The adoption of modern agricultural technologies is higher on the large farms as compared to small due to their high purchasing power (Odhiambo, *et al*., 2004 & Ghosh 2010). The adherence to the traditional mode of cultivation among small farms is a detrimental factor for low productivity (Druilhe & Barreiro, 2012). Mostly, the small farms belong to the poor segment of the society and not get benefits from the government policies, on the other hand, the more influential large farmers have better access to inputs and other facilities (Ahmad, 2003; Asim, 2010; Riaz, 2010 and Baloch & Thapa, 2017). Due to underutilization of various inputs, the small farms are unable to secure the maximum output from their piece of land (Ahmad 2003). In the face of tremendous challenges like land and water issues; old cultivation techniques; lack of information on marketing; poverty; degradation of natural resources and environmental issues; population growth; inadequate support services; framework and institutional constraints; and lack of agricultural and rural development policies, it is very much difficult to upgrade the overall agricultural system in a short run. The upgradation of agriculture system requires proper planning, huge investment, and timely evaluation. Because of population increase and competing demands for land, for other sectors of the economy, the increase in food production will have to take place by increasing the productivity per unit of land rather than increasing the area under agriculture. In this situation, the production can be increased by properly utilizing the available resources and increasing the efficiency of farmers.

2.1.4: Existence Of Yield Gap In Pakistan's Agriculture And Efficiency

Most countries have the opportunity to attain food self-sufficiency levels by securing potential crop production levels (Pradhan *et al*., 2015). A yield gap refers to the difference between two levels of yield (FAO, 2015) and of two types. Yield gap I is the variation between experiment/research station yield and the potential farm yield and this gap is not exploitable. Yield gap II is the difference between the potential farm yield and the actual average farm yield (Alam, 2006). This gap is manageable as it appears due to suboptimal doses of inputs and cultural practices and and can be bridged by deploying research and extension approaches and government interventions, especially institutional issues (Iqbal & Ahmad, 2005 and Aslam, 2016). Numerous factors (physical, biological, socioeconomic and institutional) are responsible for exploitable yield gaps (Sharazar *et al*., 2012; Pradhan *et al*., 2015 and Usman *et al*., 2011), which can be improved successfully through participatory and holistic approaches and government intervention. Majority of the small farmers in Pakistan are unable in combining the inputs in a rational way (Manzoor *et al*., 2003 and Sharazar *et al*., 2012) and poor resource management, particularly in terms of input use is more prominent factor for this yield gap (FAO, 2015; Pradhan *et al*., 2015 and Usman *et al*., 2016). Various authors mentioned the existence of these yield gaps in Pakistan and argued that the potential of the existing technology has not been realized fully (Luqman *et al* 2005; Aslam, 2000, Hussain *et al*., 2014 and Aslam, 2016). In this perspective, Hussain, (2014) observed yield gaps of 71%, 58%, 48% and 41% for cotton, rice, sugarcane and maize crops, respectively. A large increase in production (45% to 70% for most crops) is possible by closing yield gaps to 100% of attainable yields. Similarly, the farmers are still lagged behind in realizing the large potential yield that the well-irrigated and fertile soil of the Indus Irrigation System could produce. This situation providing a clue that with current technology and resources, the productivity of small farmers could possibly be increased by improving the techniques of input application as employ by the best practice farms. In countries where small farmers have meager resources and inputs constraints are quite apparent, basic attention must be on to narrow this gap by identifying the factors causing yield variability and inefficiency rather putting more attention towards technology generation (Yusuf and Malomo , 2007 and Giroh and Adebayo 2009). The concept of efficiency is relative and represents the ability of a farmer to drive maximum output from limited resources without using any additional inputs or to produce a given level of output by using the minimum quantity of inputs.

2.2: THE CONCEPT OF PRODUCTIVITY AND EFFICIENCY

The notions of productivity and efficiency are normally used to measure the performance and competitiveness of firms, but these concepts have been employed interchangeably in the literature (Wu, 2008; Latruffe, 2010) and are two different concepts. The productivity is an absolute concept in its simplest form is "the outputs divided by inputs" (Latruffe, 2010). Coelli (2005) defines productivity of a firm as a ratio of output (s) that it produces to the input (s) that it uses to produce output. Productivity can be divided into two-component i.e. partial and total factor productivity (Latruffe, 2010). When a single factor of production is used to produce single output then it is called partial factor productivity like labour productivity etc. (Felipe 1999 and Latruffe, 2010).

productivity can be measured by two indicators, partial and total factor productivity (Ali et al., 2009; Aslam, 2016). The partial factor productivity is the measurement of productivity when a single input is used to produce output and it shows the output divided by a single factor of production (Aslam, 2016). While, total factor productivity is the portion of production not explained by the level of inputs used (Ali *et al*., 2009 and Latruffe, 2010). In contrast to productivity, efficiency is estimated by comparing the actual ratio of output to inputs with an optimal ratio of output to inputs and is a relative concept. The difference between productivity and efficiency is explained in the diagram below.

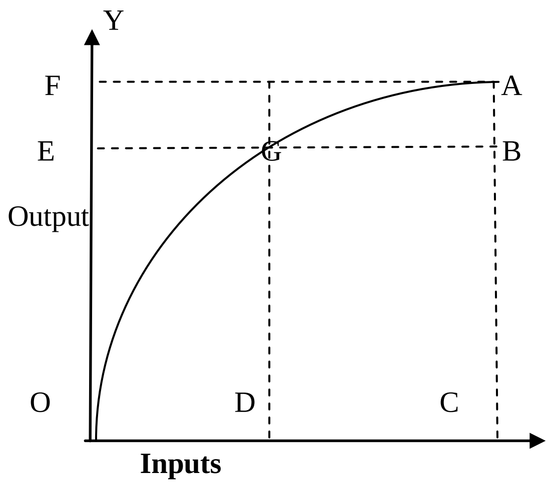


Figure 2.2.: Concept of productivity and efficiency

In this Figure, curved line OA presents the maximum output that is achievable by utilizing the inputs. The inputs and outputs being applied and produced are along the X and Y-axis, respectively. As productivity is the ratio of output to input, the productivity of producer B is OE/OC, currently producing an OE level of output by using OC levels of inputs. The firm B here in this Figure is not optimally combining its inputs and still has the possibility to produce the same level of output by further reducing inputs from OC to OD, which is called its input efficiency, revealing a potential reduction in input without any reduction in the existing level of output. Hence, input efficiency of the producer B, in this case, is OD/OC. Likewise, taking into account output efficiency, it could possibly increase its output further from OE to OF by using same input level OC. Therefore, output efficiency is OE/OF.

2.2.1: Production and Production Function

Production is a process of transforming inputs into output (Debertin, 1986). The production technology can be described by applying production function, cost function and revenue function. In contrast to production, "Production function highlights the technical relationship that transforms inputs into output" (Debertin 1986).

In the simplest way, production function can be expressed in mathematical form

$$y = \mathrm{f}(\mathrm{x}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

(Debertin 1986)

Where y represents the output and x is an input, whereas f specifies the functional form.In any production process inputs used can be separated into two groups: variable and fixed inputs (Debertin, 1986). The quantity of the variable inputs can be altered during the specified period of the production process (Debertin, 1986). However, fixed variables cannot be changed during the production process. All inputs used are assumed variable inputs, in a long run production process. Whereas in the short run, at least, one input is recognized as fixed and all other are assumed variable.

Mathematically, it can be expressed as;

$$y = \mathrm{f}\ (x_1\ /x_2) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.2)$$

(Debertin 1986)

Where y represents the output, x_1 and x_2 are representing the variable and fixed inputs, respectively.

2.2.2: Explanation Of Technical, Allocative And Economic Efficiency

The concept of efficiency dates back to 1950's when Debreu (1951) Farrell (1957) laid the theoretical foundation and gives a new direction to the study of production efficiency. Koopmans (1951) proposed the formal definition of efficiency, as a producer is technically efficient if none of its inputs or outputs can be improved without worsening some of its other inputs or outputs. Onwards an important theoretical advancement was put forward by Farrell and Debreu and proposed that efficiency comprised two individual components allocative and technical. Technical efficiency is recognized as the ability of a firm or decision-making unit (DMU) to produce the maximum level of output by utilizing a minimum amount of inputs under available technology (Banker *et al*., 1984). For a firm to be efficient, it is essential for that firm to produce the given level of output on the production frontier. A downward deviation from this efficient frontier leads to inefficiency in terms of achieving maximum output from inputs (Farrell, 1957).

Allocative efficiency also known as price efficiency differs from technical efficiency and it is the ability of a producer to produce a given level of output by selecting that set of inputs which minimize the cost of production (Coelli, 2005). Allocative efficiency also represents the ability of a producer to utilize the inputs in optimal proportions, given their respective prices (Coelli, 1996, Latruffe, 2010). According to Bojnec and Latruffe (2009), allocative inefficiency reveals divergence of the firm from frontier under given the market price of end product and inputs. They further argued that allocative efficiency determines how output can be maximized by combining and utilizing the factors of production at given market price of inputs and output. On multiplication, technical and allocative efficiency is conceptualized as overall economic or cost efficiency (Coelli 1996; Ajibefun 2008). Economic efficiency deals with profit maximization and is achieved when a firm appears efficient both technically and allocatively (Asogwa, 2011).

Farrell's idea regarding technical and allocative efficiency from input and output side also illustrated by Coelli (1996) can be explained by a simple diagram. The efficiency of a production unit could possibly be improved either by reducing inputs and keeping output level same relative to the efficient unit or by maximizing the output by absorbing the same level of input (Soteriades, *et al*., 2015). The former is input-oriented measure and later is known as output-oriented measure of technical efficiency

2.2.3: Efficiency Measurement from Input Side

To understand the phenomenon of efficiency measurement from the input side, Let us consider a producer, firm or decision making unit using two inputs x_1 and x_2 for the production of a single output (q). Assuming constant returns to scale, the curved line SS' is representing the efficient frontier in Figure 2.2.1 below. Any firm that lays on this frontier SS' is efficient, depicting that the firm is achieving maximum output than other units in a group by combining inputs x_1 and x_2.The firm Q in this Figure is on the frontier and is efficient in utilizing the resources with respect to other firms. While firm P lies away from this SS' and its technical inefficiency can be represented by line QP. The QP is the amount by which firm P could proportionally reduce its input level without any change in the level of output.

.

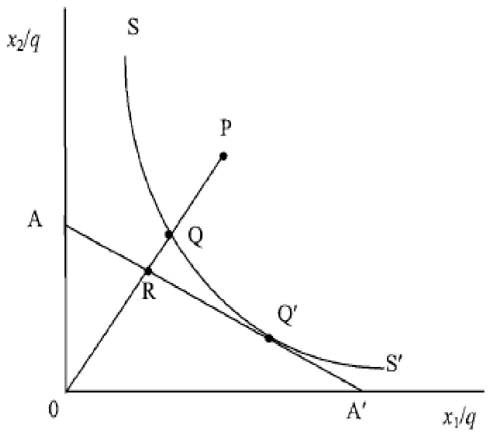


Figure 2.3.: Efficiency from input side (Coelli 2005; Ajibefun 2008)

In the form of a ratio, the technical efficiency can be expressed as:

Technical Efficiency (TE) = OQ/OP ………………….. (2.3)

(Coelli 2005; Ajibefun 2008)

Allocative efficiency can easily be estimated if the unit price of inputs is available. In this Figure, allocative efficiency can be calculated by introducing iso-cost line AA'. The allocative efficiency is expressed by the following formula.

Allocative Efficiency (AE) = OR/OQ ……………….. (2.4)

(Coelli 2005; Ajibefun 2008)

The firm R is allocatively efficient as it is on the line AA' and the firm Q is technically efficient but allocatively inefficient as it lies away from iso-cost line AA'. Thus, the firm Q can reduce its cost of production by an amount of RQ that would be possible at point Q'. After measuring both technical and Allocative efficiency, overall economic efficiency is the product of both TE and AE.

Economic Efficiency (EE) = Technical Efficiency * Allocative Efficiency ………… (2.5)

(Coelli 2005; Ajibefun 2008)

2.2.4: Efficiency Measurement from Output Side

The output-oriented measure of technical efficiency differs from the input measure and tells how much output could possibly be achieved with the inputs available (Olasup and Carolyn, 2013; Soteriades, *et al.*, 2015). The phenomenon of output measurement is explained below.

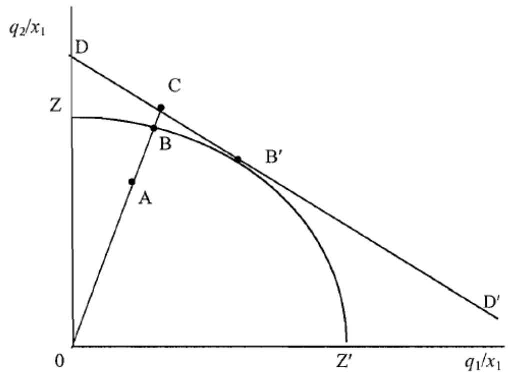


Figure 2.4: Efficiency from output side (Coelli 2005; Ajibefun 2008)

This Figure is highlighting a firm producing two outputs q_1 and $q_2$utilizing one inputx_1. The curved line ZZ' is signifying the production possibility. Any firm that lies on this line is considered to be efficient and the firm A which is below the curved line ZZ' is inefficient. The line AB is clearly showing the inefficiency of firm A and AB is the amount by which output could possibly be increased with the current level of inputs. The technical efficiency, in this case, can be written as.

TE = OA/OB ……………………… (2.6)

(Coelli 2005; Ajibefun 2008)

Again the iso-cost line DD' can be drawn in the Figure if price information is available for the estimation of the allocative efficiency and can be written as

AE = OB/OC ………………………. (2.7)

(Coelli 2005; Ajibefun 2008)

2.3: DIFFERENT APPROACHES TO MEASURE EFFICIENCY

The two major methods have been applied to evaluate the efficiency in the agriculture sector are data envelopment analysis (DEA) and stochastic frontier analysis (SFA). The SFA is statistical in nature and assumes prior functional form instead of Data Envelopment Analysis which is based on fractional linear programming (Demircan *et al* 2010).

2.3.1: Stochastic Production Frontier

The parametric approach or Stochastic production function was independently proposed by Aigner et.al (1977) and Meeusen and van den Broeck (1977) and onward a series of research conducted for the extension and application of these basic frontier models. This approach assumed that the deviation from the frontier is not completely under the control of the firm being under evaluation, random shocks (weather, etc.) may also be accountable of this deviation and inefficiency. Uri (2001) argued that expect random shocks, the error or imperfection while specifying the parametric model could be responsible an increase in the degree of inefficiency. The original production frontier designed to take into account cross-sectional data had an error term that can split into two components: one to absorb the random shocks and other is to estimate technical inefficiencies.

This basic stochastic model can be summarized as;

$$y_i = \boldsymbol{x_i}\beta + (v_i - u_i) \qquad ,\mathbf{i=1,...,N}, \ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(2.8)}$$

y_i = is the production (or the logarithm of the production) of the i-th firm;

$\boldsymbol{x_i}$ = is a k×1 vector of (transformations of the) input quantities of the i-th firm

β= is a vector of unknown parameters;

u_i = is random variables

v_i = which are non-negative random variables which are assumed to account for technical inefficiency in production

2.3.2: Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a computationally simple method for measuring the relative efficiency of the DMUs. All observations in the data set are used to establish the efficient frontier. It is a powerful nonparametric methodology which involves piecewise linear programming and is preferred over statistical approaches because it can be used without knowing the algebraic form of the relationship between outputs and inputs i.e., we can estimate the frontier without knowing whether output is a linear, quadratic, exponential or some other function of inputs (Hanh, 2009). Secondly, DEA ability to handle multiple inputs and outputs with any unit of measurement, makes it advantageous over other approaches (Coelli 1996). To date, data envelopment analysis has been used for a wide range of applications to performance evaluation and choice of particular approach depends on the type of data (cross-sectional or panel) and type of variables (quantities alone or quantities with their prices) used (Cooper *et al* 2004). Technical efficiency alone can be measured from the data set when only the physical quantities of the inputs and outputs are available (Lu, 2012). Economic efficiency can be estimated when the reliable price data available about inputs and outputs (Shafiq 1998).

2.4: REVIEW OF AGRICULTURAL EFFICIENCY STUDIES

The section provides the review of previous efficiency studies in agricultural sectors, conducted in several countries located in Europe, America, Asia, Africa and Australia. In Europe, the majority of studies were conducted in countries such as Bulgaria, Czech Republic, Estonia, Germany, Hungary, Poland, Russia, Slovakia and Slovenia, located in Central and Eastern Europe. In Asia, the most studies were conducted in Bangladesh, India, Pakistan, Iran, Uzbekistan, and Nepal. A large number of agricultural efficiency studies in Africa are conducted in Nigeria. A review is provided by taking into consideration various general dimensions considered in previous efficiency studies such as area of interest, countries of applications, type of efficiencies measured and data sources. Efficiency is measured and interpreted taking different subjects into account through the application of several methodological variations of DEA models depending on the context of the study. In general, DEA models focus on the relative efficiency aspects of the evaluated units. Moreover, formulation and implementation of the models or further analyses on the results can provide insight for different types of implications. Efficiency can be evaluated from a certain point of view or results of the DEA models can be interpreted to provide an emphasis on different subjects. In agricultural sectors, these subjects can include agriculture-related topics such as environment, irrigation, subsidies etc.,

2.4.1: Data Used

Many efficiency studies vary in terms of data used in evaluating the efficiency. The data used in farm efficiency studies are collected and gathered from different means of sources. Many researchers in previous studies relied on organizations like ministries of agriculture, agricultural boards, agriculture-related foundations, statistical institutions to obtain secondary data. Jaime & César (2011) measured the efficiency of wheat farmers in chili and data used is obtained from VII Agricultural and Forestry Survey. Slovak Research Institute of Agricultural and Food Economics was the major data source in a study conducted by Fandel (2003) to estimate the technical efficiency of 1147 corporate farms. Pakistan Institute of Development Economics (PIDE) is a major source secondary data in many efficiency studies in Pakistan (Burki & Shah, 1998 and Ahmad *et al*., 2002). Farmer Accountancy Data Network (FADN) databases are used as a data source in a number of studies conducted in Europe (Iraizoz *et al*., 2003; Fogarasi, 2006; Latruffe *et al*., 2008 and Bojnec and Latruffe, 2009). In addition, many studies collect the required data through the ministries of agriculture and their related institutions in the country of application (Martinez & Tadeo, 2004; Bhushan, 2005; Candemir and Ertugrul, 2007; Hossain *et al*., 2012).

To collect cross-sectional data, surveys are the most common methodology that is adopted by the researchers in the intended region of study. Rahman and Brodrick (2015) collected the cross-sectional data from three geopolitical zones of the Delta state of Nigeria: North, Central and South Delta. Javed *et al* (2008) and Javed *et al* (2011) used survey methodology to collect primary data from the different farming system of Pakistan. In the context of Indian agriculture, Murthy *et al* (2009) and Umanath & David (2013) collected cross-sectional data by administering questionnaire during the survey. Similarly, Houshyar *et al* (2010) and Hasanov & Ahmed (2011) adopted a similar approach of survey research for the collection of primary data in Iran and Uzbekistan, respectively. Numerous studies in different parts of the world also focused on cross sectional data collected through a survey (Binam *et al*., 2005; Ogundari & Ojo, 2007; Javed *et al*., 2008; Koc *et al*., 2011; Hussain et.al 2012, Mohapatra, 2013 and Mwajombe & Malongo, 2015). However, in a number of efficiency studies panel or time series data is used in contrast to cross-sectional data to evaluate the change in efficiency over time (Bhushan, 2005; Fogarasi, 2006; Candemir and Ertugrul, 2007 and Hossain *et al*., 2012). Malmquist Productivity Index (MPI) introduced by Malmquist (1953) and Caves *et al* (1982) and improved further by Färe *et al* (1992) is mostly applied to see the difference in efficiency in different years.

2.4.2: Type of Farming Systems and Enterprises Studied

A farming system is an economic and agricultural concept holistically describing (as a whole, based on a set of many variables and indicators) a farm household in terms of agricultural land use, i.e., the systems of crop and livestock production, non-agricultural economic activities of farm household members (on-farm and off-farm activities), the income generated and the structure and in terms of the natural, social, economic, infrastructural and institutional resources and environments that determine these all of economic activities" (Madry *et al*., 2016). Depending on the agricultural and economic importance of crop and livestock production associated with the income structure from the agricultural production of a farm, three main types of farming systems are distinguished: crop farming systems, livestock farming systems, and mixed crop-livestock farming systems.

The livestock farming systems can be categorized into more specialized types of systems such as dairy cattle, beef cattle, dairy-goat, pig or sheep systems in addition to fisheries. A large number of different systems can be recognized within crop systems, such as cash-crop system (e.g., tobacco, coffee, sugar cane, sugar beet, oilseed rape or horticultural crop production), cereal systems (sorghum-wheat, maize-wheat, wheat-rice and soybean system), and mixed crop systems. A mixed cropping system is specialized in raising three to four crops supplemented with activities related to livestock and agro-forestry (Madry *et al*., 2016). The majority of agricultural efficiency studies employing DEA have considered agriculture farms as decision-making units (Boundeth *et al*., 2012; Nurwahidah *et al*., 2015; Ngenoh *et al*., 2015 Binuyo *et al*., 2016 and Lema *et al*., 2017). Farming systems are diverse and involved in producing different types of agricultural products. Some studies deal with crops either single or multiple crops, whereas some focus on livestock farms only. Moreover, numerous studies jointly deal with both types (crops and livestock) and in few studies, specific types of farms are studied (dairy, fishery, Poultry, horticultural and organic products).

A huge volume of studies dealing with farms producing single crops such as wheat (Ali and Munir, 2014; Gill, 2015; Chebil *et al*., 2016; Usman *et al*., 2016;), citrus (Lambarraa *et al*., 2011; Clemente *et al*., 2015 and Madau, 2015), coffee (Rios and Shively, 2005; Furi & Getachew, 2016), corn (Boundeth *et al*., 2012; Nurwahidah *et al*., 2015; Ngenoh *et al*., 2015), cotton (Gul *et al*., 2009; Adzawla *et al*., 2013; Watto & Mugera, 2014;Fatima *et al*., 2016), olive (Lambarraa *et al*., 2006; Kashiwagi *et al*., 2012; Kashiwagi *et al*., 2013), rice (Umanath & David, 2013;Kea at al, 2016; Binuyo *et al*., 2016; Lema *et al*., 2017), sugarcane (Ali *et al*., 2013; Thabethe *et al*., 2014). The efficiency of farms raising multiple types of crops is studied by (Binam *et al*., 2005; Hasanov and Ahmed, 2011; Ali *et al*., 2012; and Dao, 2013). Livestock producing farms can be noted as another type evaluated in several studies. Examples include Uzmay *et al* (2009) in beef cattle production, Galanopoulos *et al* (2006), Laure and latruffe (2008) and Petrovska *et al*., (2013) in pig farming and Gul *et al*., (2016) in goat farming, Galanopoulos *et al* (2011) in sheep and goat farming. In addition to above specifications, it can be noted that a number of studies are conducted in other specific types of agricultural production such as dairy (Solis and Corral, 2009; Spicka & Lubos, 2014 and Kelly *et al*., 2012), Poultry (Yusuf and Malomo , 2007 and Heidari *et al*., 2011), organic farming (Lansink *et al*., 2002; Guesmi *et al*. 2014; Poudel *et al*., 2015; Flubacher. 2015 and Lanker and Gunner, 2017), fisheries (Andersen and Bogetoft, 2007) and horticulture (Belen, *et al*., 2003 and Iráizoz *et al*., 2003).

It can be observed from the agricultural DEA studies that in order to evaluate farms relative to their analogs, different classifications of samples are undertaken depending on product type and organizational form. As mentioned, various studies can be found assessing the efficiency in both crop farms and livestock farms. In these type of studies, crop and livestock production are mostly treated separately depending on the farm specialization (Spicka & Lubos, 2014; Thirtle *et al*., 2003, Latruffe *et al*., 2004; Grazhdaninova and Lerman, 2005; Cherchye and Van Puyenbroeck, 2007 and Latruffe *et al*., 2008).

2.4.2.1: Studies Related to Crop under Study

A large number of studies have been found in the literature that has evaluated the efficiency of wheat, cotton, maize, and sugarcane production in Pakistan as well as in different part of the world. In Pakistan, the efficiency of wheat production has been investigated by (Battese et el 1993; Hussain *et al*., 2000; Ahmad *et al*., 2002; Hassan and Ahmad 2001; Hassan and Ahmad 2005; Hassan *et al*., 2005; Ahmed *et al*, 2002; Bashir and Dilwar, 2005; Hussain *et al*., 2012; Hussain, 2014; Buriro *et al*., 2013; Battese *et al*., 2014; Ali & Khan, 2014; Elahi *et al*., 2015; Gill, 2015, Mirza *et al*., 2015; and Usman *et al*., 2016). The efficiency of cotton production in different farming systems of Pakistan is explored by the studies of (Hussain *et al*., 1999; Shafiq and Tahir, 2000; Saddozai *et al*., 2013; Dilshad and Afzal 2012; Hameed *et al*., 2014; Hashmi *et al*., 2015; Hashmi *et al*., 2016 Fatima *et al*., 2016; and Fatima *et al*., 2017). The studies of Naqvi & Ashfaq (2013) Memon *et al* (2016) and Ali *et al* (2013) Ali & Abbas (2017) were found evaluating the efficiency of maize and sugarcane crops, respectively.

From the review of these studies, it is evaluated that the SFA or Standard DEA models were commonly applied to estimate the technical, allocative, or cost efficiency of the farms. These studies mostly relied on either per acre or per farm data to evaluate the technical efficiency of the wheat, cotton, maize and sugarcane farms. None of these studies had tried to use both per acre and per farm data in their study to find differences in the results. It is also found that none of these studies have investigated the efficiency of any farming system by considering all the four crops and then overall efficiency of the farming system by aggregating the data of all these four crops. The studies in different parts of the world were also conducted to estimate the efficiency of the crops under study and enlisted in Table 2.2:

Table 2.2: Studies In World Related To Crops Under Study

Crops	Studies
wheat	Jha *et al*., 2000; Wilson *et al*., 2001; Bakhshoodeh & Thomson, 2001; Goyal & Suhag, 2003; Croppenstedt, 2005; Bakh and Serajul, 2005; Alemdar & Oren, 2006; Dağistan, 2010; Houshyar *et al*., 2010; Jaime & César, 2011; Ali *et al*., 2012; Feel and Basher, 2012; Ali *et al*., 2012; Sarker, 2012; Mburu *et al*., 2014; Tiruneh and Endrias, 2015; Dinarvand & Sabbaghi, 2015; Chebil *et al*., 2016; Kelemu & Negatu , 2016; Tavva *et al*., 2017
Cotton	Gul *et al* ., 2009; Tsimpo, 2010; Cobanoglu 2013; Solakoglu, 2013; Adzawla *et al*., 2013; Rodríguez & Elasraag 2014; Singh *et al*., 2015; Sarker and Alam 2016
Maize	Seyoum *et al*, 1998; Binam *et al*., 2005; Chirwa, 2007; Olarinde ,2011; Koc *et al*., 2011, Viengpasith *et al*., 2012'Boundeth *et al*., 2012; Degefa, 2012; Olapade *et al*., 2013; Chiona *et al*., 2014 ; Karimov *et al*., 2014; Kitila & Alemu 2014; Ahmed at al., 2015, Tesso *et al*., 2015; Mokgalabone, 2015; Martey *et al*., 2015; Ndjodhi, M. 2016; Ahmed *et al*., 2017
Sugarcane	Dlamini *et al*., 2010; Supaporn, 2015; Nyanjong & Lagat, 2012; Padilla-Fernandez & peter, 2012; Thabethe *et al*., 2014

2.4.3: Types of Efficiency and Subject of Interest

Through the application of SPFA and DEA models under various returns to scale assumptions, it is possible to investigate the various types of efficiencies (technical, allocative, economic, and scale efficiencies). The major focus in various agriculture studies is on technical efficiency alone. However, allocative efficiency, economic Efficiency and scale Efficiency are also pointed out in numerous researches and various types of efficiencies are estimated in different combinations. Many efficiency studies on agriculture touch these concepts and numerous studies attempt to measure and discuss more than one type of efficiency.

A number of researchers estimated the technical efficiency of crop production in different parts of the world. Bogale (2005) measured the TE of irrigated potato in Ethiopia by applying SPFA. Adzawla *et al*., (2013) for Cotton production in Northern Ghana by applying SPFA. Technical efficiency of Tanzanian Urban agriculture is quantified by (Mwajombe & Malongo, 2015) by the use of SPFA. SPFA has also used in various other studies to only estimate the technical efficiency of the farms (Hassan and Ahmad, 2001; Tijani, 2006; Idiong 2007; Rehman and Umar 2009; Okon et al., 2010; Hussain et.al 2012 and Kitila & Alemu 2014). Through the application of DEA, technical efficiency is estimated by (Alemdar & Oren, 2006; Koc.B 2011; Ajibefun 2008; Javed et al., 2011; Ayaz, 2010; Houshyar et al., 2010; Hasanov and Ahmad 2011; Kelly t al., 2012 and Cobanoglu, 2013).

The concept of allocative efficiency deals with profit maximization and represent that how optimally production inputs can be combined in right way to maximize profits (Inoni, 2007). Thus, the allocatively efficient farm operates at the least-cost combination of inputs. Especially, Allocative Efficiency is measured together with the Technical Efficiency in several studies (Hasanov & Ahmed, 2011; Jha *et al*., 2000; Bashir & Dilawar, 2005; Bakh and Serajul, 2005; Dhungana *et al*., 2004; Henderson & Ross, 2002; Mokgalabone, 2015 and Fatima *et al*., 2017). Economic efficiency also known as cost efficiency is a product of technical and allocative efficiency. To see the possibility of cost reduction in a farming system, the concept of Economic Efficiency is considered together with the Technical and Allocative Efficiencies in number of researches (Ahmad *et al*., 2002; Javed *et al*., 2008; Islam *et al*.,2011; Ogundari & Ojo, 2007; Watkins *et al*., 2013; Mburu *et al*., 2014; Thabethe *et al*., 2014 ; Khan *et al*., 2016 and Khan *et al*., 2016)

TE can further be divided into Pure Technical Efficiency and Scale Efficiency. The CRS model provides an estimate of Technical Efficiency as it assumes constant returns-to-scale. Pure Technical Efficiency, (which represents the score obtained through VRS model) and Scale Efficiency are the two components of Technical Efficiency. Scale Efficiency is calculated through the ratio of Technical

Efficiency and Pure Technical Efficiency. A scale efficient unit operates at the same level of technical and pure technical efficiency (Cooper *et al*., 2000).

Scale Efficiency is considered in a number of studies applying DEA in agriculture (Fandel, 2003; Krasachat 2004; Galanopoulos *et al*., 2006 Javed *et al*., 2011; Rahman and Brodrick ,2015; Madau, 2015; Lansink *et al*., 2002; Umanath & David, 2013; Umanath & David, 2013; Linh *et al*., 2015 and Khan *et al*., 2016). In these studies, scale efficiency is evaluated by considering both constant and variable returns-to-scale assumptions to check whether the farm is operating at an optimal operation size or not.

2.4.3.1: Water Use and Environmental Efficiency

Water use is an essential to agriculture production process. This fact motivated the researchers to evaluate the efficiency of water use at both farm and regional level. Therefore, irrigation efficiency or water use efficiency is one of the major subjects studied in several DEA studies. Water use efficiency of small-scale irrigation schemes of South Africa was evaluated by Speelman *et al* (2007) using DEA sub vector approach and second stage analysis of Tobit regression revealed that Farm size, landownership, fragmentation, the type of irrigation scheme, crop choice and the irrigation methods applied are the major significant factors affecting the sub-vector water use efficiency. Manjunatha *et al* (2011) measured and compared the sub vector-efficiency of water use across three groups; water sellers, water buyers and a control group of non-traders, by using Data Envelopment Analysis. Chemak (2011) investigated the technical efficiency, the water use efficiency and the dynamic of the productivity of the irrigated areas of the Sidi Bouzid region for the years 2003 and 2007. DEA was used to assess the performance of the farms. Productivity change was measured through Malmquist index. More recent study of Hamid *et al* (2016) also measured the water use efficiency and productivity indices by collecting time series data over the period 2005-13 from Tehran. DEA with input-orientation was applied. Meanwhile, the gross regional domestic product index was employed to see the correlation between water uses and regional economic activities. The results indicated that the total productivity was improved 1.8% and 1.68% aspect of technical efficiency change and scale efficiency change respectively. The indices results suggested a possible decrease of 22 million cubic meters in water uses without decreasing in the level of gross products.). In addition to these studies, irrigation water use efficiency (IWUE) is also estimated by Frija *et al* (2009; Naceur & Sghaier, 2013), Chebil *et al* (2014). At second stage, Tobit regression analysis is employed in most studies to find the determinant of water use efficiency (Speelman *et al*., 2007; Mahdi *et al*., 2009; Chebil *et al*., 2014)

In addition to technical and water use efficiency, environmental efficiency is considered in number of studies (Pitman, 1983; Fare *et al*., 1993; Fare *et al*., 1989; Hetemaki, 1996; Reinhard et al., 1999; Kuo *et al*., 2014 and Dong *et al*., 2015). The production process involves various kinds of inputs that can have either positive or negative impact on the environment. Thus, data envelopment analysis (DEA), which has the ability to handle data with multiple input and outputs, was used to incorporate the undesirable outputs that negatively affect the environmental (Kuo et al., 2014). CO2 emissions and agrochemical residual are the outcome of the production process, cause negative external impacts to the environment, and called undesirable outputs.

The studies of the Pitman (1983) Fare *et al*. (1993), Fare *et al*. (1989), Hetemaki (1996) and Tyteca (1996) were considered the earliest studies that attempt to incorporate the environmental effect in efficiency estimate. Pitman (1983) by taking into consideration a “multilateral productivity” indicator considered both desirable and undesirable outputs. Environmental effects were treated as additional undesirable outputs whose disposability is costly and shadow price is considered since undesirable outputs are not generally priced in markets. Fare *et al* (1989) developed an “enhanced hyperbolic productive efficiency measure” and performance evaluation is done by seeing the possibility of a reduction in undesirable outputs and an increase in desirable outputs, subject to the available technology. Fare *et al* (1993) and Hetemaki (1996) used a distance function to calculate the shadow prices of undesirable output. Tyteca (1996) claims the approach could be modified to derive an environmental performance indicator as the ratio between the overall productivity measure, (using both desirable and undesirable output), to the gross productivity index where the undesirable output is ignored. Reinhard *et al*., (2000) assessed the Environmental efficiency of Dutch dairy farms by using SFA and DEA. The total energy use (direct or indirect), nitrogen and phosphorus surplus were used to derive environmental efficiency. The mean technical efficiency scores (output-oriented, SFA 89%, DEA 78%) and the mean comprehensive environmental efficiency scores (SFA 80%, DEA 52%) differ between the two methods. Kiatpathomchai, (2008) assessed the economic and environmental efficiency of the rice growers in Thailand by collecting data from 247 rice households. DEA input models are considered at the first stage and Tobit regression is applied at the second stage to find the determinants of Environmental efficiency. The negative externalities caused by the excessive use of nitrogen fertilizers are focused in this research. Picazo-Tadeo *et al*., (2011) evaluated eco-efficiency of Spanish farmers in the rain-fed agricultural system of Campos County by applying truncated regression and bootstrapping to find out the determinants of eco-efficiency.

2.4.4: Methodological Approaches Used

Data Envelopment Analysis and Stochastic Frontier Analysis (SFA) are two approaches that have been used in wide range of literature to estimate the efficiency of farms (Solıs *et al*., 2009; Solís & Corral, 2009; Byma and Tauer 2010; Reddy and Bantilan, 2012; Aung, 2012; Rahman *et al*., 2012; Kashiwagi et., al 2012 and Mohapatra, 2013). SFA developed by Aigner *et al*. (1977) and Meeusen and Van den Broeck (1977) is parametric technique and it requires to specify a priori functional form for the frontier production function. The parametric method can be either deterministic or stochastic (Thiam *et al*., 2001), the latter is more popular. SFA has an advantage over DEA is that it takes into account measurement errors and other noise in the data (Latruffe *et al*., 2004). Accommodation of error terms in the model allows differentiating between inefficiency and factors beyond the control of manager in assessing performance. In several countries located in Europe, America, Asia, Africa and Australia DEA and SFA are widely applied in agricultural sector. A number of studies in agricultural sector of different countries are presented in this section.

From the review of the literature, it is observed that the SFA is the most common approach used in various agricultural studies. in the context of African, Asian and Middle East agriculture, the Cobb Douglas production function, stochastic frontier function, constant elasticity of substitution function, Tobit model, translog, cost, profit and perhaps revenue functions and bootstrapped frontier functions are the most common models estimated under parametric approach. The major models used to analyze cross-sectional data are corrected ordinary least square (COLS) or the modified ordinary least square (OLS) and two-stage least squares, while maximum likelihood estimation (MLE), corrected ordinary least square (COLS) and stochastic frontier analysis (SFA) is usually applied to time series data under parametric approach (Ali and Byerlee, 1991).

In Africa, the studies that used parametric approach for the estimation of efficiency are: (Seyouma *et al*., 1998; Bogale *et al*., 2005; Kibaara, 2005; Chirwa,2007; Ogundari & Ojo, 2006; Ogundari & Ajibefun, 2006; Onyenweaku & Asumugha, 2006; Ogundari, 2006; Amos, 2007; ogundari & Ojo, 2007; Ogundari, 2008; Idiong, 2007; Okoye *et al*., 2008;Tchale, 2009; Giroh and Adebayo , 2009; Alao & Kuje, 2010; Okon *et al*., 2010; Marchand 2010; Olarinde ,2011; Ali *et al*., 2012; Feel and Basher, 2012, Asogwa *et al*., 2012; Asekenye, 2012; Boundeth *et al*., 2012; Fuseine & Donkoh, 2013; Enwerem And Ohajianya , 2013; Adzawla *et al*., 2013; Etwire *et al*., 2013; Trujillo and Wilman, 2013; Kitila, G. & Alemu 2014; Mwajombe & Malongo, 2015; Thabethe *et al*., 2014; Chiona *et al*., 2014; Ngenoh *et al*., 2015; Tiruneh and Endrias, 2015; Tesso et al., 2015 ; Itam *et al*., 2015; Adegbite and Adeoye, 2015; Taphe *et al*., 2015; Danso-Abbeam *et al*., 2015; Dossah & Ibrahim,2016, Najjuma *et al*., 2016;Rajendran *et al*., 2015; Rahman, 2016; Abdul-Rahaman, A. & Abdul-Hanan , 2016 and

Binuyo *et al*., 2016). The efficiency in Asian and Middle East countries using SFA are conducted by (Bakhshoodeh & Thomson, 2001; Goyal & Suhag, 2003; Udayanganie *et al*., 2006; Jha , 2007; Rahman, 2003; Croppenstedt, 2005; Kea *et al*., 2016; Reddy and Bantilan, 2012; Aung, 2012; Rahman *et al*., 2012; Kashiwagi et., al 2012; Mohapatra, 2013; Rodríguez & Elasraag 2014; Dinarvand & Sabbaghi, 2015; Nurwahidah *et al*., 2015; Hazneci and Vedat 2015; Rajendran 2014; Rashid *et al*., 2016; Yang *et al*., 2016: Alemdar *et al*., 2010 and Dhehibi *et al*., 2014). In Europe and America, the following researchers applied parametric approaches (Wilson *et al*., 2001; Binam *et al*., 2005; Nchare, 2007; Bravo-Ureta & Antonio 1997, Lambarraa *et al*., 2006; Jaime & César, 2011; Lambarraa *et al*., 2011; Solıs *et al*., 2009; Solís & Corral, 2009 and Byma and Tauer 2010).The parametric approaches are used In the context of Pakistani agriculture by (Hussain ,1995; Parikh *et al*., 1995; Burki and Shah, 1998; Mari and Heman 2007; Ahmad, 2002; Ahmad, 2003; Hassan & Ahmad, 2005; Bashir and Dilwar, 2005; Abedullah *et al*., 2006; Abedullah *et al*., 2007; Iqbal *et al*., 2009; Shaheen *et al*., 2011; Hussain *et al*., 2012; Naqvi and Ashfaq 2013; Saddozai *et al*., 2013; Rauf *et al*., 2014; Battese *et al*., 2014, Ali and Munir, 2014, Miraj and Ali , 2014; Khan and Ghafar, 2013; Buriro *et al*., 2013; Khan and Farman., 2013; Dilshad and Afzal 2012; Bakhsh *et al*., 2014; Saddozai *et al*., 2015; Elahi *et al*., 2015; Gill, 2015; Ali *et al*., 2013; 2016 and Fatima *et al*., 2016).

With the aim to compare results across different approaches, a large number of studies are implementing more than one method. Stochastic Frontier Analysis (SFA) is remarkably applied together in combination with DEA in agricultural efficiency studies and presented in Table 2.2. Ajibefun (2008) by applying both SPFA and DEA compared the efficiency of small-scale food crop production in Nigeria. The efficiency of Spanish Horticulture farms is estimated by (Iraizoz *et al*., 2003) with the application of both methods. Similarly, Latruffe *et al*. (2004) measured and compare the technical efficiency of Polish crop and livestock farms separately through SFA and DEA approaches. Henderson & Ross, 2002 found no significant difference in efficiency score across both approaches in Australian farms, however, the results through DEA found to be more stable. The study of Ismail *et al* (2013) used data envelopment analysis (DEA) and Stochastic Frontier Analysis (SFA) and compared the technical efficiency of paddy farms in east and west coast of Peninsular Malaysia and found a sharp difference in scores across both approaches. Performance of 315 New Zealand dairy farms in 2006-07 computed and compared by Wei (2014) employing both DEA and SFA. Many studies in agriculture sector implied that the choice of the method does not affect the efficiency score considerably (Henderson & Ross, 2002). However, some other studies investigated that the choice of models might affect the results in agriculture sector.

2.3: Combine use of DEA and SFA to Evaluate Efficiency of Farming systems

Area	*DEA and SPFA*
Africa	Ajibefun, 2008, Mulwa *et al*., 2009;
Asia	Wadud & white, 2000; Theodoridis & Anwar, 2011; Hossain *et al*., 2012; Adhikari and Bjorndal; 2012; Ismail *et al*., 2013
Europe	Iraizoz *et al*.,2003; Odeck ,2007; Latruffe *et al* 2004; Masterson, 2007; Bojnec and Latruffe 2008; Jarzębowski , 2013:Wei, 2014; Madau, 2015
America	Langemeier,2010;
Australia	Henderson & Ross, 2002
Middle East	Alemdar & Oren 2006; Cobanoglu 2013;
Pakistan	Shafiq, 1998

In the context of agriculture, economics, and operational research, a large volume of literature presented here have employed DEA and related approaches for efficiency evaluation in various types of farming systems. A review of studies that have applied DEA in agriculture is discussed in this section. Studies are reviewed taking different dimensions into consideration, which generally can be classified into two main dimensions; 'general characteristics' and 'methodology and model specifications'. Contrast to SFA, non-parametric approach has been used by various researchers in different parts of the world. The DEA methodology has some important advantages over the econometric approach to efficiency measurement. Firstly, because it is nonparametric there is no need to make assumptions concerning the functional form of the frontier technology or the distribution of the inefficiency term (Dong *et al*., 2015). Secondly, the approach permits the construction of a surface over the data, which allows the comparison of one production method with the others in terms of a performance index (Dong *et al*., 2015). The studies that used DEA are presented in Table

2.4: Application of DEA to Evaluate Efficiency of Farming systems

Area	**DEA**
Africa	Yusuf & Malomo, 2007; Haji,J 2007; Rahman and Brodrick,2015, Brodrick & Sanzidur, 2014; Clemente *et al*., 2015; Chebil *et al*., 2016
Asia	Llewelyn & Williams, 1996; Jha *et al*., 2000; Krasachat, 2004; Rios & Shively, 2005; Brázdik & EI , 2006; Murthy *et al*., 2009, Houshyar *et al*., 2010; Taraka *et al*., 2010;Adachi *et al*., 2010; Sarker and Alam 2016; Khan *et al*., 2016; Umanath & David, 2013; Islam *et al*.,2011, Hasanov & Ahmed, 2011
Europe	Fandel, 2003; Fogarasi, 2006; Martinez & Tadeo, 2004; Błażejczyk-Majka *et al*., 2011; Galluzzo N 2013;; Burja & Vasile,2016
America	Langemeier,2010; Watkins *et al*., 2013
Australia	(Fraser & Cordina, 1999; Avkiran,2001)
Middle East	(Uzmay *et al*., 2009, Gul *et al* ., 2009; Koc *et al*., 2011
Pakistan	Shafiq and Rahman ,2000; Ayaz *et al*., 2010; Watto, 2013; Bhatt and Shaukat, 2014; Hameed *et al*., 2014; Fatima, 2015; Hashmi *et al*., 2015; Usman *et al*., 2016.

2.4.4.1: Variation in DEA Models

Depending on the type of farming system, inputs and output used, the scope of the research and evaluation context, variation exit among scholars in terms of using the DEA models. Assuming that the farmers have more control over inputs and can adjust their quantity by their choice, input-oriented models are preferred. To see the possibility of input reduction without any alteration in output, an increasing number of studies used input-oriented DEA models in different farming systems of the world (Krasachat 2004; Javed *et al*., 2008; Rios & Shively, 2005; Gul *et al* ., 2009; Murthy *et al*., 2009; Hasanov & Ahmad, 2011; Koc *et al*., 2011; Umanath & David, 2013a; Umanath & David, 2013b and Linh *et al*., 2015). However, various researchers preferred output oriented DEA model over input models and provided various justification for considering the concept of output maximization in their study. Abatania (2013) argued that the farmers have meager input resources (land, labour and capital) in developing countries agriculture settings, under this situation focus is largely on maximizing their output to fulfill household consumption requirement and cash need. Output oriented DEA models would be the most appropriate instead of input models, under this condition. Similarly, Melkaw (2014) also preferred output DEA models under a situation of imperfect input market and stressed that the use of input oriented DEA, in that case, is not appropriate. Moreover, input-oriented DEA does not make sense, since family labor and land are the two most important inputs for subsistence agriculture. Therefore, output-oriented DEA models are more suitable for efficiency calculation for smallholders (Melkaw, 2014). A similar set of other studies also considered output models to explore possible expansion in output by the utilization of inputs (Alemdar & Oren 2006; Ayaz *et al*., 2010; Candemir & Ertugrul, 2007; Ismail *et al*., 2013; Abatania, 2013 and Melkaw, 2014). Both input and output orientation of DEA models are used in some studies. Fraser and Cordina (1999) assess the technical efficiency of 50 irrigated dairy farms in Australia using both input and output orientated models under the CRS and VRS assumption for two consecutive years using DEA. In their work, they compared DEA with the more frequently reported partially indicators of farm efficiency concluding that DEA provides a more consistent measure of farm efficiency. Manevska-Tasevska (2012) used both input, output DEA models to estimate the TE of Macedonian grapes farms, and estimated TE at .71 under input orientation and at .53 under output specification.

A slack is the outcome of DEA models and represents the excess of an input; a farm can further reduce its level of input by the amount of slack without any alteration in its output. Input slack-based models have been used in a number of studies. Umanath & David (2013) measured the possibility of input reduction using input slack-based DEA model in Indian agriculture and found that all the inputs were used excessively. The inputs slacks were highest in the usage of farmyard manure followed by potash, the cost for plant protection, machine hours, nitrogen, woman labour, working capital, man labour, seed cost, water requirement and phosphorus usage. Watto (2013) used sub-vector and slack-based DEA model to estimated ground water efficiency in Pakistan and highlighted that sub-vector efficiency captures relatively lower degrees of efficiency compared to the slack-based model.

Sub-vector approach is applied in several agricultural efficiency studies and one of the variations of DEA models. Sub-vector variation of DEA enables to find the possible reduction or expansion in a subset of inputs or outputs, holding all other inputs and output constant (Lilienfeld and Asmild, 2007). The following studies also applied the sub-vector approach of DEA in their studies (Asmild & Hougaard 2006; Speelman *et al*., 2008; Mahdi *et al* 2008; Chebil *et al*., 2011; Chemak 2012: Kuo *et al* 2014 and Dong *et al*., 2015). To accommodate the environmental factors beyond farmers control Islam *et al* (2011) used Non-Discretionary DEA Models.

In most studies, DEA studies, relative measurement efficiency in the farming systems is measured at the same point in time. However, various authors developed a motivation to investigate the change in the productivity over different periods. Instead of general DEA models, Malmquist Productivity Index (MPI) approach developed by (Malmquist, 1953; Caves *et al*., 1982; Färe *et al*., 1992) is widely applied to see the changes in productivity during a period of time. An example of the studies dealing with productivity change in agricultural sectors is Balcombe *et al*. (2008) evaluate the productivity change between years 1996 and 2000 in Polish crop and livestock farms. A considerable amount of studies in the agricultural efficiency literature deal with the evaluation of the productivity changes over time (Millian & Aldaz, 2003, Odeck 2007, Odeck 2009 and Zhang *et al*., 2011).

2.4.4.2: Bootstrapping in DEA

Several studies have pointed out that the performance of DEA deteriorates in the presence of measurement error and other statistical noise. The DEA approach is criticized because it produces point estimates of efficiency that are biased and lack statistical properties (Abatania *et al*., 2012). Simar and Wilson (1998; 2007) highlighted that the efficiency scores derived from input and output oriented standard DEA models are biased estimates of the actual efficiency scores. They further argued that the complex serial correlations of the DEA estimates and lack of use of a coherent data generating processes in the standard DEA model lead to misleading and invalid statistical inferences. In DEA framework, efficiency is computed relative to an estimate of the true unobserved production frontier. According to Simar and Wilson (1998) and Balcombe *et al* (2008), because the statistical estimators are derived from finite samples, therefore the measures of efficiency are sensitive to sampling variations. Simar and Wilson (1998) suggested that the technique of bootstrapping put forward by Efron (1979) is more valid and attractive method for obtaining a statistical consistent estimate and valid statistical inference. The sensitivity of efficiency scores can be analyzed relative to the sampling variations of the estimated frontier through bootstrapping.

Keeping in mind this deficiency of standard DEA estimate, Simar and Wilson (1998; 2007) proposed a bootstrapping approach which allows constructing confidence intervals for DEA efficiency scores, by smoothing the empirical distribution (Balcombe *et al*., 2008). Bootstrapping refers to a method where the DGP is repeatedly simulated through resampling and applying the original estimator to each simulated sample so that the estimates mimic the sampling distribution of the original estimator (Simar and Wilson, 1998). Bootstrapping is a method of testing the reliability of a dataset by creating a pseudo-replicate data set. Bootstrapping provides an opportunity to check whether the stochastic effects influence the distribution and this method also help to build confidence intervals for point estimates, which normally cannot be derived analytically (Gocht and Balcombe, 2006). Although Lothgren (1998) and Lothgren and Tambour (1999) have used the method of "naive" bootstrapping, this has been criticized by Simar and Wilson (1999) as inappropriate since it does not provide consistent results. This is due to the bounded nature of the distance functions. Unfortunately, this "naïve" bootstrap yields inconsistent estimates. Therefore, SW introduced a homogeneous smoothed bootstrap procedure.

Bootstrapping approaches to DEA has been widely in DEA literature to calculate the biased corrected technical efficiency and for the construction of confidence interval in different countries. Melkaw (2014) applied an output oriented bootstrapping DEA method of Simar and Wilson (1998; 2007) to investigate household level technical efficiency (TE), allocative efficiency (AE), economic efficiency (EE) and scale efficiency (SE) by using empirical data from a sample of 118 households from Dessie Zuria district, Ethiopia. At farm level, the mean bias-corrected EE, original AE, original SE and bias-corrected TE scores are 36.3%, 60.4%, 88.4% and 55.9%, respectively. At household level, the corresponding efficiency scores are 37.6%, 58.3%, 88.9% and 60.4%, respectively.

In Asian countries, Balcombe *et al* (2008b); Karimov (2013); Linh *et al*., (2015) applied the bootstrapping method. In Vietnam, Linh *et al*., (2015) used both standard and smooth bootstrap DEA models at the first stage to quantify the TE and SE of crop farms and Tobit regression model at the second stage to identify factors influencing efficiency. While the technical efficiency of Bangladesh rice farms is investigated by Balcombe *et al*. (2008) by using bootstrapping DEA method. The technical efficiency of crop and livestock farms is measured by Davidova and Latruffe (2007) and Latruffe *et al*. (2008a) in the Czech Republic, located in Europe. Simar and Wilson (1999) adapted the bootstrapped procedure for the estimation of the MI of TFP in order to account for possible temporal correlation arising from the panel data characteristics (Balcombe *et al*., 2008a). Moreover, the adapted models of bootstrapping to Malmquist Index approach is applied by Odeck (2009) to Norwegian grain farms and Similarly, using bootstrap DEA Balcombe *et al*. (2008) computed the efficiency of Polish crop and livestock farms.

2.5: Application of Bootstrap DEA in Agriculture Sector

Area	Bootstrap DEA
Africa	Abatania *et al*, 2012; Jirgi *et al*, 2015; Ndjodhi, M. 2016; Anang *et al*, 2016; Melkaw, 2014
Asia	Balcombe *et al*. (2008b);Karimov 2013; Dao, 2013; Tung, 2013; Gabdo *et al*., 2014; Linh *et al*., 2015; Gabdo *et al*., 2017
Europe	Balcombe *et al*., 2005; Davidova and Latruffe (2007); Latruffe *et al*. (2008a); Latruffe *et al*., 2008, Manevska-Tasevska 2012; Baležentis & Irena, 2012
America	Olson and Vu, 2007; Mugera and Michael, 2011;
Australia	Balcombe *et al*. (2006)
Middle East	
Pakistan	**Research Gap**

In Pakistan's agriculture, the studies of Shafiq and Rahman (2000); Ayaz *et al* (2010), Bhatt and Shaukat, (2014); Hameed *et al* (2014), Fatima, (2015); Hashmi *et al* (2015), Usman *et al*., (2016) used the standard DEA models to evaluate the technical efficiency of farming system. None of the efficiency studies have found in Pakistan that attempted to use the technique of bootstrap in DEA to correct the efficiency from bias and to establish confidence interval.

2.4.4.3: Determinants of Efficiency – Second Stage Contextual Analysis

Impact of various explanatory variables on the level of technical efficiency is of paramount importance in farm efficiency studies. These explanatory variables are exogenous factors and supposed to responsible for efficiency differences among farmers and are different from the input-output variables included in the first stage efficiency calculations. This section presents an empirical review of a wide range of factors that influence the technical efficiency of the farmers in developing and developed countries. An empirical review of studies in developing and developed countries revealed that the efficiency of a farming system is determined by a series of socioeconomic and farm characteristics, environmental, physical and non-physical factors (Jema, 2008 and Rahman *et al*., 2009). These factors directly/indirectly influence the management ability of the farm manager and, therefore, supposed to have an effect on the level of TE, AE, and EE. In addition to inefficiency in terms of misallocation of inputs, management, physical, institutional and environmental aspects could be the source of inefficiencies in farming systems (Bakhsh, 2007).

Age and education are supposed to influence the management capacity of the farmers and these factors were included in a number of studies. The following studies found age as a factor associated with higher level of technical efficiency (Asogwa *et al*., 2012; Naqvi & Ashfaq 2013; Miraj & Ali, 2014 and Yang *et al*., 2016). These studies found a positive and significant relationship between age and TE. However, negative impact of age on TE is found by (Okoye *et al*., 2008; Byma and Tauer 2010; Saheen *et al*., 2011, Bakhsh *et al*., 2014; Khan & Farman., 2013; Rahman *et al*., 2012; Itam *et al*., 2015 and Linh *et al*., 2015).

Education is an important factor responsible for variation in TE among farmers as it enhances the managerial ability of the farmers. An educated farmer tends to adopt improved technology and modern innovation that tends to affect their efficiency level. A positive association between TE and education was declared by the studies of (Bashir & Dilwar, 2005; Bakhsh 2006; Okoye *et al*., 2008; Solıs *et al*., 2009; Saheen *et al*., 2011; Byma and Tauer 2010; 2011; Asogwa *et al*., 2012; Naqvi & Ashfaq 2013; Saddozai *et al*., 2013 ; Kibaara, 2005; Mohapatra, 2013, Ali and Munir, 2014; Kitila & Alemu 2014; Rajendran 2014; Khan and Farman., 2013; Watto, 2013; Itam *et al*., 2015; Linh *et al*., 2015 and Yang *et al*., 2016). While Rahman *et al* (2012) highlighted inverse relationship between education and TE.

Farmers with greater experience supposed to have greater TE because their knowledge related to crop production is greater than non-experienced farmers. A number of studies positively associated TE with farming experience (Okoye *et al*., 2008; Shaheen *et al*., 2011; Saddozai *et al*., 2015; Itam *et al*., 2015; Miraj & Ali, 2014 and Fatima *et al*., 2016). Mohapatra (2013) and Adzawla *et al* (2013) negative impact of farming experience on level of technical efficiency in their study.

Tenancy status of the farm operator is included in the model by Rahman (2003) and Fatima *et al* (2016) and owner of the farms found more efficient. While, Solıs *et al* (2009) found tenant more efficient because they tend to produce more output from the land. These results contradict the idea that land ownership reduces risks and consequently high return from the land due to investment in improved technologies. Asogwa *et al* (2012), Itam *et al* (2015) and Linh *et al* (2015) used the variable of household size in regression analysis and observed that the level of TE increases with the size of the family. The possible explanation might be the availability of more family labour on these farms. However, Rahman *et al* (2012) highlighted the inverse relation between household size and TE.

The relationship between farm size, productivity and efficiency is a topic of immense debate in farm management literature and huge numbers of studies were conducted in different parts of the world to explore this relationship. Direct relationship between farm area and efficiency found by (Bashir & Dilwar, 2005, Okoye *et al*., 2008; Byma & Tauer 2010; Adzawla *et al*., 2013; Hashmi *et al*., 2015; Błażejczyk-Majka *et al*., 2011; Rajendran 2014; Rajendran *et al*., 2015; Bakhsh *et al*., 2014; Burja & Vasile, 2016 and Itam *et al*., 2015).They found that efficiency increase per unit of land. While, an increasing number of studies proved "Schultz hypothesis" and declared the inverse relationship between farm size and TE in different countries (Tsimpo, 2010; Gul *et al* 2009; Okon *et al*., 2010; Sarker & Alam 2016; Kitila, & Alemu 2014 and Hameed *et al*., 2014).

Institutional and Policy factors such as extension, training, credit utilization and input access have been considered in numerous studies with mixed findings. Extension and access to credits are expected to influence efficiency positively (Tchale, 2009). The positive and significant effect of extension contact on TE was explored by (Rahman , 2003; Solıs *et al*., 2009; Byma and Tauer 2010; Asogwa *et al*., 2012; Naqvi & Ashfaq 2013; Croppenstedt, 2005; Battese *et al*., 2014; Bakhsh *et al*., 2014; Usman *et al*., 2016, Yang *et al*., 2016; Watto, 2013; Khan & Farman., 2013 and Kitila & Alemu 2014). However, Saddozai *et al* (2013) found a negative relationship between extension and TE in cotton-wheat cropping system of Pakistan. Khan & Farman (2013), Rajendran (2014); Usman *et al*., (2016), Yang *et al*., (2016), attempted to investigate the impact of credit on the performance of the farmers and found positive association between the two, while Bakhsh *et al* (2014) and Linh *et al* (2015) found negative relation.

2.4.4.4: Two Step Contextual Analysis

A vital part of efficiency analysis is to correlate the various factors to the estimated TE. For this purpose, two approaches are very common to explore the factors determining the efficiency. The one-step approach can easily be adopted in SFA framework and very famous in literature. In DEA studies, the two-step contextual analysis is very common to account for the impact of various farm specific, socio-economic and environmental variables on the level TE. In two-step contextual DEA framework, efficiency scores are generated by running either input or output-oriented models under CRS or VRS assumptions, at the first step. The DEA scores generated are then regressed over a set of explanatory variables during the second step by using various regression models. However, in literature two-step approach is criticizes due to persistent bias linked with efficiency estimate at first step that is brought forward at second step (Greene, 2008). Even then, the most researchers favour two-step contextual procedure and this approach is employed in number of DEA Studies in different regions (Krasachat 2004; Dhungana *et al*., 2004; Rios & Shively, 2005; Galanopoulos *et al*., 2006; Balcombe *et al*., 2008b; Javed *et al*., 2008; Latruffe *et al*., 2008; Speelman *et al*., 2009; Watto, 2013; Melkaw, 2014; Rahman & Brodrick, 2015; Mirza *et al*., 2015 and Khan *et al*., 2016). The choice and selection of second stage regression models. Similar to the difference in the use of DEA models at the first step, a large variation also exists in terms of using regression models at the second step. In the DEA literature, a range of standard regressions like ordinary, generalized, or ordinary least squared regressions, ordered logistic regression and Tobit models are employed to explain DEA scores.

Because the efficiency scores fall in the range 0 to 1, Tobit a form of censored regression model has been preferred in most of the DEA studies. At second stage regression ,Tobit regression model is used by the (Krasachat 2004; Dhungana *et al*., 2004; Javed *et al*., 2008; Rios & Shively, 2005; Speelman *et al*., 2008; Mahdi *et al*., 2009; Gul *et al* ., 2009; Ayaz *et al*., 2010; Koc *et al*., 2011; Mirza *et al*., 2015; Linh *et al*., 2015 and Khan *et al*., 2016). However, the use of the Tobit regression during the second stage has been criticized by different researchers. Particularly, McDonald (2009) and Natarajan, (2008) argues that the DEA scores are not a result of censoring, but rather, normalization and the use of Tobit is inappropriate to find the potential determinants of efficiency. DEA Scores are particular kind of fractional data instead of censored data and Tobit Model is not the valid model to produce reliable results when the data is fractional. McDonald (2009) suggested the use ordinary least squares regression under fractional data

Murthy *et al* (2009) used ordinary least square analysis at the second stage to estimate the regression equation, but Dhungana, *et al* (2000) and Krasachat (2003) indicate that the OLS regression would lead to a biased parameters estimate because the dependent variable in regression model does not have a normal distribution. To deal with the problems connected with using OLS and Tobit models, the Fractional model is suggested in the DEA framework, in many studies. This model was proposed by Papke and Wooldridge (1996) to deal with dependent variables defined on the unit interval, irrespective of whether boundary values are observed. Fractional Logistic model with robust standard errors is applied by Ayele & Muriithi (2010) and Rahman & Brodrick (2015) in their studies.

Simar and Wilson (2011) criticized the assumption of McDonald, (2008) and Banker & Natarajan, (2008) proposed that Ordinary Least Squares (OLS) produce more valid and consistent results as compared to Tobit regression in a second stage. They suggested that the results produced through OLS are only consistent only under very peculiar and unusual assumptions of the data-generating process. In an earlier paper, Simar and Wilson, (2007) highlighted that the use of traditional models at the second stage to investigate the factors, determining efficiency level of the DMUs are invalid due to the lack of knowledge and information about the data generating process and the complex and unknown serial correlation among estimated efficiencies. The two development paths merged into the two-step contextual analysis applied by Dhungana *et al*. (2004), Galanopoulos *et al*. (2006), Speelman *et al*. (2008) that used Tobit regression analysis to determine the environmental factors that are correlated with the DEA technical efficiency estimates

Hence, Simar and Wilson (2007) suggested double bootstrapping to improve the statistical efficiency of the second-stage regression instead of using OLS and Tobit models at second-stage nonparametric efficiency analysis. They faced heteroscedasticity problem because the variables used to construct the efficiency scores are correlated to the error term in the second-stage regression. Therefore, Simar and Wilson (2007) suggested the use of double bootstrapped truncated regression in the two-step contextual analysis instead of other models, to produce authenticated and reliable results. Truncated Regression Model has been applied in their studies by (Latruffe *et al*., 2008; Bojnec and Latruffe, 2009; Melkaw, 2014. Manevska-Tasevska 2012). In the most recent study, Jirgi *et al* (2015) applied both Tobit and truncated regression models and both models were considered applicable.

2.4.5: Evaluating the Policy

An agricultural policy was formulated (five-year plan 1960-65) aiming at to promote higher agricultural productivity and growth rate. The productivity increased considerably through technological developments introduction of high-yielding crop varieties, fertilizers, pesticides, mechanization, and the expansion of irrigation networks by the construction of canals and the installation of tubewells by farmers (Sami, 2016). However, Agricultural growth dropped in the 1970s due to political instability and failures in implementing agricultural policies; extension services, training, research, and education were all neglected (Sami, 2016). The uncertainty due to the selective implementation of land reforms also affected agricultural growth. To tackle serious water shortages in the agriculture sector, a number of irrigation projects were also constructed. However, the agriculture sector failed to grow due to a lack of integrated policy (Sami, 2016).

Land and water resources are vital to agriculture sector growth and optimal use of these resources is not only crucial for intergenerational food security, high productivity goals but for food, fiber shelter and to improve the overall ecological environment (Khan *et al*., 2012). As discussed in the previous chapter, Pakistan is sharply heading towards a condition of land and water scarcity. The National

Action Plan has been launched by the government as a policy measure, to cope with desertification. In this land policy plan, three policy dimensions such as conservation of natural resources, sustainable development and improved efficiency in the use and management of resources were considered, to overcome degradation. The major projects implemented under this plan for degraded land recovery include projects of rehabilitation and reclamation of saline/sodic soils, afforestation, improved crop production in drylands, soil and water conservation, increased water use efficiency, improved range/livestock feeding and management , improved drainage and on-farm management, improved biodiversity, improved production of horticultural crops. The natural resource base of Pakistan is very complex and inter-linked To sustainably manage this resource base needs the development of world-class capacity in adaptive management of the natural resources, development and management of water resources and new institutional arrangements involving communities in natural resource management (Briscoe and Usman, 2008 and Khan et al., 2012). Pakistan has been struggling to streamline the use of natural resources in a manner to provide a decent to living to its rapidly growing population (Briscoe and Usman, 2008 and Khan et al., 2012). There is real urgency in merging the economic and the environment in decision making and in the use of economic instruments rather than regulation to control land degradation (Khan *et al*., 2012)

Pakistan adopted a variety of approaches to land degradation over the past 40 years. A state-centric, technocratic solution was followed to the problem of land degradation and project under the name of Salinity Control and Reclamation Project (SCARP) was implemented in the 1960s (Niazi 2003). The purpose of this project was to evacuate drainable saline water by digging irrigation pumps all across the country (Khan, 2001; Mughal, 2002, Niazi 2003). The project failed to achieve the objective of land reclamation by incurring a cost equivalent to U.S. $4.3 billion (Khan, 2001, Niazi 2003). The drained saline groundwater that was pumped through Irrigation pumps contained high sodium content (IUCN, 1992). Approximately, 45 million acre-feet (MAF) of water was pumped. Of which, 70% of the pumps discharge water contain high salt content (Khan, 2001, Niazi 2003). After the failure of SCARP, a new programme under the name of National Drainage Program (NDP) replaced SCRAP in 1995 (Mughal, 2002; World Bank, 1997). An amount equivalent to U.S. $785 million allocated to this project. Under this project, an autonomous Provincial Irrigation and Drainage Authorities (PIDAs) with significant farmers' representation were established by restructuring the Provincial Irrigation Departments, dominated by government bureaucrats (World Bank, 1997). To develop a linkage between PIDAs and representative farmers from farmer's organizations (FOs), NDP also established an intermediary institution of Area Water Boards (AWBs) for each canal command area. The FOs were responsible for managing the local irrigation and drainage operations by their own efforts. Since 1997, these structures have been legislated, but only met a partial success. Khan (2001) mentioned the NDP as dead on arrival. The water flow in the canals slows down during the drought years of 1999, 2000, and 2001. To cope with water shortage and to meet crops' water needs, NDP subsidizes the digging of irrigation pumps (Randhawa, 2002). The large farmers with an abundant and surplus supply of irrigation water benefited from these subsidies (Kugelman & Hathaway, 2010). Under this initiative, large farmers benefited not only in terms of irrigating their own fields but also for sale of water to small and subsistence farmers at higher rates (Niazi 2003). Despite past failures, these approaches have the potential to work in Pakistan, provided these approaches recognize the causal significance of land tenure to land degradation. The state, public interest groups (such as FOs), and the market have their respective role to play in combating land degradation. The state has the monopoly over technical and financial resources and as such has the lead role. Farmers are victims and agents of land degradation, and their participation in planning and executing conservatory initiatives is equally important (Niazi 2003).

The Indus basin rivers system and its tributaries are the major sources that irrigate a large proportion of cultivated land in Pakistan (Asghar, 2014 and Piesse 2015). This system is considered the world's largest contiguous irrigation system. The five major tributaries are Jhelum, Chenab, Ravi, Beas and Sutlej, which spreads it across the whole country (Asghar 2014 and Raza, 2016). Indus River largely depends upon the concentration of rainfall in the monsoon season, about 85 percent of annual river flows occurring during this season (IMF 2015). The irrigation system of Pakistan comprises of three major reservoirs, 16 barrages, two head works, two siphons, 12 inter-river link canals, 44 canal commands, and more than 140,000 watercourses (Latif *et al* 2016). FAO, (2011) defined three dimensions that determine the water scarcity in any country: physical (when supply is less than the demand), Infrastructural (infrastructure in place does not allow for satisfaction water demand by all users, institutional) that, and (when institutions and legislation fail to ensure reliable, secure and equitable supply of water to users. However, in my point of view, there are two other dimensions as well environmental and political. It is evident that areas with hot weather and low annual rainfall have water scarcity issues. Some nations depend upon other for water, like in a case of Pakistan, where India has the upper hand to control Pakistan's water.

Pakistan irrigation system is facing all the challenges in the context of above-mentioned dimensions. Although Pakistan has one of the largest irrigation networks but it is confronted with many infrastructural issues such as low irrigation efficiency, under-designed capacity and old infrastructure (Latif *et al* 2016). This infrastructure of Indus river system was effective for 75% cropping intensity, however, in the recent years; the average national cropping intensity has reached near 159 % to 200

% or even more in some areas (Asghar, 2014). The volume of surface water supply to agriculture sector i.e. 107189.57 million m^3 as compared to average water demand that is 133216.04 million m^3 (GOP, 2012)

Tarbela and Mangla are the two large reservoirs, designed to store water, for use during the summer and during the Rabi/winter growing season (Raza, 2016). The water demand has increased by more than 50 percent, since the completion of the nation's irrigation system in the 1970s, while storage capacity has decreased by about one-third due to silting. During the last two years, supplies of irrigation water have been relatively better, but over the long term, Pakistan is likely to face water-related challenges. These water challenges, if not addressed, could become a key factor affecting crop production (Raza, 2016). For any sustainable irrigation system, 1000 days are estimated as recommended storage capacity (Khan, 2014; IMF, 2015; Sukhera, 2016). Indus' massive irrigation system has a storage capacity only for thirty-day supply (Khan, 2014). This capacity is extremely low than India, Egypt and USA that can store water for 220, 700 and 900 days, respectively (Mustafa *et al*. 2013). The gap between water supply and demand is widening. Water demand in Pakistan is estimated to be growing at an annual rate of 10 percent according to UN. The demand is projected to rise to 274 MAF from the current 191 MAF by 2025. This gap of about 83 MAF is almost two-thirds of the entire Indus River system's current annual average flow (Mustafa *et al*. 2013)

Politically, Pakistan faced immense challenges right from the independence in 1947. The first challenge arose when the water supply of three major rivers (Ravi, Beas, and Sutlej rivers) detached from Punjab and these rivers had become part of India at the time of partition of the Indo-Pak subcontinent (Iqbal, 2010). Indus Water Treaty (IWT) was signed between Pakistan and India in 1960, under the mediation of World Bank to resolve the long-standing water issues – often regarded as a remarkable example of conflict resolution (Shadman, 2016). The key objective of IWT was to protect the rights and obligations of each country's use of waters in relation to other. According to terms of the Treaty, the three rivers, i.e. Jhelum, Chenab and the Indus were given to Pakistan and has unrestricted access to water from these rivers, while India has unrestricted control over the three eastern rivers, i.e. Ravi, Sutlej and Beas (Asghar, 2014; Shadman, 2016). However, the current Indian intentions of constructing "chain of dams" on Pakistani (western) rivers have once again posed a serious challenge for Pakistan (Iqbal, 2010; Shadman, 2016). The current projects give India the control to block Pakistani water that can cause an acute shortage of water for winter crops by badly affecting water inflow at Marala Head Works/ Mangla Dam. Most recently, India has constructed over a dozen of hydropower projects on upstream water and the water flow in Chenab has declined by 40 percent to about 6,000 cusecs from a 10 year average of about 10,000 cusecs

(Kiani, 2010). If Indian stops this water, a total of 7.0 million acres of fertile land will become barren due to drying 406 of Canals and 1125 distributaries (Nizami, 2008). In addition to these projects, the government also considers the option of resource conservation through improvement in efficiency of farmers in terms of management and use of these resources. In this context, various projects and crop management practices such as Best Management Practices (BMP), Organic Agriculture, National integrated pest management practices and Farmer Field Schools (FFS) are practiced through the assistance of agricultural extension for high crop production through the optimal use of resources (Buhler *et al*. 2000). Empirical evidence concerning extension and farm efficiency has been sought out to have the concrete evidence of the role of extension in promoting farm efficiency, increasing agricultural productivity and consequently contributing to rural development (Hassan and Ahmad 2001; Galanopoulos *et al*., 2006; Rahman, 2003; Croppenstedt, 2005; Chirwa, 2007; Solıs *et al*., 2009; Byma and Tauer 2010; Nyagaka *et al*. 2010; Asogwa *et al*., 2012; Naqvi & Ashfaq 2013; Khan & Farman., 2013; Kitila& Alemu 2014; Battese *et al*., 2014; Bakhsh *et al*., 2014; Usman *et al*., 2016; Yang *et al*., 2016 and Sami, 2016).

Government of Pakistan has implemented various extension models like Village-Aid programme (V-AID), Basic Democracies System (BDS), People Works Programmes (PWP) , Rural Works Programmes (RWP), Integrated Rural Development Programme (IRDP), T & V System and Devolution Plan, overtime under the supervision of Department of Agricultural Extension with an objective to increase production efficiency and uplift the living standard of the rural population (Luqman *et al*., 2005). The aim of the Government was to reach as many smallholder farmers as possible, in a relatively short time. Due to traditional linear approach, and top-down orientation, these programmes have met with partial success and were abandoned one after another (Davidson, 2001). Antholt, (1994) argued that public sector extension services unable to reach the bulk of the small farmers due to poorly motivated staff, inadequate operational funds, lack of relevant technology, top-down planning, centralized management, and weak accountability system. PARC (2012) also mentioned that farmers are not aware of modern technologies because of weak extension services system. Khan and Muhammad (2012) also found extension ineffective. Anjum *et al* (2016) also reported that majority of small farms always face troubles in seeking the field solutions from extension agent. SaddozI *et al.,* (2013) collected the data from 400 respondents from cotton-wheat farming System of Pakistan, to evaluate and compare the technical efficiency of farmers participating in the extension programme. He observed that the farmers participating in Farmers Field School (FFS) are more inefficient as compared to non-participants. Extension department contributes for high inefficiency shows the weak linkages between extension staff and the cotton growers of the study area. It is recommended that FFS approach should be a non-developmental programme and should be executed under the umbrella of the single institution for its proper implementation and monitoring. Abedullah *et al* (2007) estimated the efficiency of rice production and linked the technical inefficiency to the poor dissemination of extension services that lead to an improper combination of input use on rice farms.

The above studies reveal that Government extension services play an important role in agriculture and rural development. However, Governments extension is facing numerous challenges: in raising the efficiency of agricultural organizations, enhancing rural incomes and cutting poverty. This condition, stresses that state must have to play a central role in the up gradation of the current system of extension. In addition to dissemination of information on farm practices and integrated pest management to the small farmers, the extension services can play a critical role in establishing markets for commercial and farmer-to-farmer extension services, providing rural communication infrastructure, and developing human resources and providing facilities of credit. This condition asserts the need that institutional reform deserves reconsideration. In this regard, governments, as well as international organizations, need to benchmark the pros and cons of institutional arrangements for agricultural and rural extension systems and learn from each other.

2.5: SUMMARY AND CRITICAL ANALYSIS OF LITERATURE REVIEW

This chapter starts with the definitions of small farms prevailed in the different countries of the world and it appears that there is no mutual consensus present on the definitions of small farms and every country has its own criteria to define the small farms. Recent trends occurring in the world showed that the size of the farms in Asian countries reducing very sharply due to the law of inheritance as compared to the European countries. Review of various studies related to farm size, productivity and efficiency revealed that the small farms produce more than the large farms and this relationship has become “stylized fact”. Despite having numerous advantages, small farms facing several challenges in the current dynamic world where the policies and the technologies are continuously changing. After describing the status of small farms in the world, challenges that small farming community is facing in Pakistan is discussed. From the discussion, it appears that there is “yield gap” between potential and actual yield and providing clues of inefficiency in the agricultural system. In a resource constrained economy where the resources are meager, improvement in efficiency is an important tool to achieve sustainable agricultural development. The concept of efficiency was initiated by Farrell and Debreu and further advancement was led by various other economists in the Models. The concept of efficiency is relative and tell that how productivity can be maximized with the resources available. Parametric (Stochastic production function) and nonparametric (Data Envelopment Analysis) are the two approaches used worldwide to quantify the level of efficiency. The core purpose of this chapter was to identify the research gap by reviewing the available and relevant literature. In this context, farm efficiency literature has been reviewed in order to grasp information about the small farms, status of small farms, situation of agriculture in Pakistan, policies, and issues, methodological approaches used for efficiency evaluation and their development, DEA models and variation in models in different efficiency studies.

In agricultural sectors, efficiency studies are conducted in different countries located in Europe, America, Asia, Africa and Australia and farms evaluated are involved in producing various kinds of enterprises. Various kind of farming systems were considered in these studies and based upon the nature and scope of the research, different enterprises were considered like crops (either single or multiple crops), livestock, crops and livestock, dairy, fishery, horticultural and organic products. Different types of efficiencies such as Technical Efficiency (Houshyar *et al*., 2010; Hasanov and Ahmad 2011; Kelly et al., 2012 and Cobanoglu, 2013), Allocative Efficiency (Henderson & Ross, 2002; Mokgalabone, 2015 and Fatima *et al*., 2017), Economic Efficiency (Mburu *et al*., 2014; Thabethe *et al*., 2014 ; Khan *et al*., 2016 and Khan *et al*., 2016) and Scale Efficiency (Lansink *et al*., 2002; Umanath & David, 2013a; Umanath & David, 2013b; Linh *et al*., 2015 and Khan *et al*., 2016) are pointed out in the studies. in addition to these efficiencies, some specific type of efficiencies are also identified as the environment, irrigation, productivity change in literature.

It is evident from the literature that SFA and DEA are the most methodologies that are adopted in the previous researches. However advantages nexus to SFA make it more popular to investigate TE, and in the majority of studies, SFA is applied in different part of the world. In line with these studies, SFA is also most widely used methodology in Pakistan that is used by (Hussain ,1995; Parikh *et al*., 1995; Burki and Shah, 1998; Mari and Heman 2007; Ahmad, 2002; Ahmad, 2003; Hassan & Ahmad, 2005; BASHIR and Dilwar, 2005; Abedullah *et al*., 2006; Abedullah *et al*., 2007; Iqbal *et al*., 2009; Shaheen *et al*., 2011; Hussain *et al*., 2012; Naqvi and Ashfaq 2013; Saddozai *et al*., 2013; Rauf *et al*., 2014; Battese *et al*., 2014, Ali and Munir, 2014, Miraj and Ali, 2014; Khan and Ghafar, 2013; Buriro *et al*., 2013; Khan and Farman., 2013; Dilshad and Afzal 2012; Bakhsh *et al*., 2014; Saddozai *et al*., 2015; Elahi *et al*., 2015; Gill, 2015; Ali *et al*., 2013; 2016 and Fatima *et al*., 2016). Stochastic Frontier Analysis (SFA) is applied together with DEA in a significant amount of studies (Iraizoz *et al*.,2003; Latruffe *et al* 2004; Masterson, 2007 and Jarzębowski, 2013). DEA techniques first adopted by Färe *et al*. (1985) in agriculture, has been considered in a number of agricultural efficiency studies. DEA models developed over time and commonly used DEA models in the agricultural sector are the additive model (Haag *et al*., 1992), the allocative efficiency models (Henderson & Ross, 2002;

Mokgalabone, 2015), the sub-vector model (Lansink *et al*., 2002; Asmild & Hougaard, 2006; Kuo *et al* 2014 and Dong *et al*., 2015), the bootstrapped DEA models (Balcombe *et al*., 2008b; Karimov 2013; Linh *et al*., 2015), weight restricted models (Garcia & Shively, 2011) and the use of DEA techniques to calculate the MI of TFP (Balcombe *et al*., 2008a; Odeck, 2009). A prevailing approach in the DEA literature is the adoption of the two-step contextual analysis to estimate the drivers of efficiency (Dhungana *et al*., 2004; Galanopoulos *et al*., 2006; Balcombe *et al*., 2008b; Speelman *et al*., 2009; Latruffe *et al*., 2008; Bojnec and Latruffe, 2009; Melkaw, 2014 and Manevska-Tasevska 2012). The literature on DEA studies in Pakistan revealed that the use of classical DEA models are still most popular practice and studies of Shafiq and Rahman (2000); Ayaz *et al* (2010), Bhatt and Shaukat, (2014); Hameed *et al* (2014), Fatima, (2015); Hashmi *et al* (2015), Usman *et al*., (2016) used these basic DEA models. The use of bootstrapping in DEA models is not considered by any research in the agriculture sector of Pakistan. Opposite to conventional DEA models, this study will employ the bootstrap DEA models and truncated regression model to find the determinant of TE. In conclusion, DEA is a well-established non-parametric method used in agricultural studies in order to evaluate the performance of farming systems. The flexibility of DEA techniques to account for multiple inputs and outputs and the various model specifications which allow the evaluation of efficiency for specific purpose make it useful method over other approaches. In addition, most of the studies have taken the single or two crops as the unit of analysis and have used either per acre or per farm data. It was evaluated from the literature review that the efficiency of the farming systems has not been measured by any study at both crop and aggregated level in Pakistan.

In Pakistan, the concept of the Agricultural Innovation System still not clear and still the traditional linear approaches of technology transfer prevail. In this research attempt is made to understand the role of various actors in the context of innovation systems which help to find the relationships, interaction, and discrepancies among various actors, on the one hand; and productivity on the other. The understanding of this framework will provide a guideline to various stakeholders (public research organizations, private companies, nongovernmental organizations (NGOs), civil society organizations and smallholders themselves) that contribute to agricultural innovation processes that how effectively they can make the innovation process more effective by coordination and interaction. This study provides information to how Pakistani smallholders can use of new or existing knowledge and technology to reframe their agricultural decisions; how their social networks contribute to innovation processes; and how various actors can play their role to enhance the efficiency of the farming community.

CHAPTER 3

DATA ENVELOPMENT ANALYSIS

In this research, Data Envelopment Analysis has been adopted to estimate the relative efficiency of the decision-making units. This chapter has been written with the aim to explain the concepts that are relevant to Data Envelopment Analysis. This chapter comprised of various sections that provide deep insight to understand the various Data Envelopment Analysis models usually applied to measure the technical, allocative, Scale, cost and biased corrected efficiency of the DMUs. The first section starts with explaining the performance evaluation of farms through Data envelopment analysis leading to a brief history and theoretical developments in DEA. The section 3.2 includes various terminologies that are relevant to the technique of DEA and comprised of eleven sub-sections. These sub-sections help to understand the following terminologies related to DEA.

1) Concept of production function and production possibility set
2) Efficient frontier in DEA
3) Lambda value and Decision making units in DEA
4) Importance of slacks in DEA
5) Benchmarking process in DEA
6) Variables selection in DEA and Set of inputs and output in farming systems
7) Different assumptions on returns to scale

The sections from 3.3 to 3.7 are designed to explain the models that are used in this study to evaluate the efficiency of the farming system. For a better understanding of the DEA model, the section 3.3 starts with explaining the first basic input oriented models in ratio and primal form. Further, the constant returns to scale (CRS) model devised by the Charnes, Cooper, and Rhodes is discussed and presented in ratio, primal and dual form. This input oriented model under the assumption of constant returns to scale is further upgraded by Banker, Charnes, and cooper by the addition of convexity constraint that assumes variables returns to scale in modeling. This model is also explained in this section. The model used to measure the output efficiency of the DMUs is also discussed. These models provide information about output maximization while keeping the input level constant. In the next section, these DEA models are explained with the help of an illustrative example. This example can be used to understand that how inputs and outputs variables can be modeled in DEA to measure the efficiency of the DMUs. The next sub-section includes an explanation about the Slack-based models that, on a solution, provide information about additional input reduction and output expansion by the amount of slack. The models used to measure the scale, allocative and cost efficiency of the DMUs are presented in section 3.5 and 3.6, respectively. In section 3.7, the bootstrap DEA models developed by Simar and Wilson (1998; 2000) to correct the efficiency from bias and to construct confidence interval are discussed. At the second stage, regression analysis (most often Tobit) is often conducted in DEA for the inclusion of parametric components that influence efficiency level of the farmers. However, Simar and Wilson (2007) argue that the results can be invalid, and lead to incorrect inference by the use of a Tobit regression in a two-stage analysis because it fails to account for serial correlation in DEA efficiency estimates. Therefore, instead of Tobit, a truncated regression model is used in this research and discussed in this chapter. The last section of this chapter elaborates the merits and limitations attributed to DEA.

3.1: PERFORMANCE EVALUATION OF FARMS THROUGH DATA ENVELOPMENT ANALYSIS

Productivity ratio is one of the most common measures to evaluate the performance of the farms that simply take the ratio of outputs to its inputs (Cooper, Seiford, and Tone, 2000). One of the major drawbacks of this approach is that it becomes necessary to "weight" each measure while shifting from single-input/single-output case to multiple inputs and outputs case to arrive at some composite, or virtual, input and output measure. When these weights are unknown, then prior assumptions should be made to perform an empirical analysis. Researchers choose a particular functional form for the production function (e.g., Cobb-Douglass or Leontief) and implicitly restrict the values the weights can take based on what economic theory suggests should be employed.

Index number method is another method for a measure of productivity that compares an aggregate output index to an aggregate input index (Latruffe, 2010). The index number approach is an explicit method for aggregation that how to aggregate together various outputs and various inputs. Several ways of aggregation lead to different TFP indices. Laspeyre, Paasche, Fisher, Tornqvist and Eltetö-Köves-Szulc indices are most common in the literature (Latruffe, 2010). In contrast to index number method where TFP indices measure only the technological change, Malmquist indices introduced by Caves *et al*. (1982) decomposes the productivity change into efficiency and technological change. Malmquist indices also not require that data about prices, costs, and revenues. Their decomposition into efficiency change and technological change was proposed by Nishimizu and Page (1982) and Färe *et al*. (1992)

However in literature, Stochastic Production Frontier Analysis (SPFA) and Data Envelopment Analysis (DEA) are the two broader methodologies that have been frequently applied to quantify the technical efficiency of the Decision Making Units (Abatania, 2013; Trujillo and Wilman, 2013; Mwajombe & Malongo, 2015 and Linh *et al*., 2015). The SPFA was introduced by Aigner *et al*. (1977) and (Meeusen & Vandenbroeck, 1977). This approach is statistical in nature (Chiona *et al*., 2014; Mwajombe & Malongo, 2015) and provides a strong framework for hypothesis testing and the establishment of the confidence interval (Trujillo and Wilman, 2013; Chiona *et al*., 2014 and Lanker and Gunner, 2015). It assumes a priori functional form in the estimation of production efficiency instead of the nonparametric approach (Data Envelopment Analysis) which is based on fractional linear programming (Demircan *et al* 2010; Mwajombe & Malongo, 2015).

DEA has recognized as a powerful nonparametric methodology which involves piecewise linear programming and is preferred over statistical approaches because it can be adopted for multiples inputs and outputs (Coelli 1996; Awerije & Sanzidur, 2014). DEA has also explored possibilities for use in cases that have been resistant to other approaches because of the complex relationship between the multiple inputs and multiple outputs involved in DMUs (Cooper *et al* 1978). All observations in the data set are used to identify the farms on efficient frontier and benchmark the remaining farms relative to the farms located on production possibility frontier (Awerije & Sanzidur, 2014). To define the functional relationship between inputs and outputs, DEA requires only a restricted number of a-priori assumptions and the production frontier is constructed as a piecewise linear envelopment of the observed data points. DEA is independent of the unit of measurements for inputs and outputs and does not require knowledge about their prices (Lanh 2009). Output oriented DEA maximizes output for a given level of the inputs used, while input-oriented DEA minimizes inputs for a given level of output (Latruffe, 2010; Olasup & Carolyn, 2013). Technical efficiency alone can be measured from the data set when only the physical quantities of the inputs and outputs are available (Lu, 2012). Economic efficiency can be estimated when the reliable price data available about inputs and outputs (Ali *et al*., 2012). The DMUs enclosed by the envelope are the ones considered inefficient and, depending on the model of DEA used (either input or output-oriented), should adjust their inputs or outputs to move on the frontier. While using DEA two different approaches can be considered based on the assumptions taken on returns to scale: constant returns to scale (CRS) and variable returns to scale (VRS) (Banker *et al*., 1984). DEA and SFA each has its own advantages and disadvantages so the choice of implementation depends on the data and individual perceptions and consideration of these advantages and disadvantages (Reinhard *et al*., 2000)

3.1.1: Rationale behind Preferring DEA in This Study

In this study, Data Envelopment Analysis (DEA) is used for the estimation of technical, allocative and cost efficiency of the farmers due to a number of reasons. First, the most of the researchers in Pakistan have applied stochastic production frontier instead of data envelopment analysis (Saheen *et al*., 2011;Hussain *et al*., 2012;Naqvi and Ashfaq 2013; saddozai *et al*., 2013; Rauf *et al*., 2014; Battese *et al*., 2014, Ali and Khan, 2014, Miraj and Ali , 2014; Khan and Ghafar, 2013; Buriro *et al*., 2013; Khan and Farman., 2013; Dilshad and Afzal 2012; Bakhsh *et al*., 2014; Saddozai *et al*., 2015; Elahi *et al*., 2015; Gill, 2015; Ali *et al*., 2013; 2016 and Fatima *et al*., 2016). Only in a few studies, DEA is exercised (Shafiq & Rahman ,2000; Ayaz *et al*., 2010; Bhatt and Shaukat, 2014; Hameed *et al*., 2014; Fatima, 2015; Hashmi *et al*., 2015 and Usman *et al*., 2016) and these studies have only used standard DEA models.

The significance of performing statistical inference on efficiency scores is ignored in these studies and performance of farms can be heavily influenced by measurement errors and effects like weather, shocks, and diseases. Furthermore, most agricultural scientists have ignored the sampling noise in DEA estimates. None of the studies have tried to use bootstrap DEA models for bias correction and construction of confidence interval. Second, this research relies on the primary data from four major crops in Pakistan and DEA provide a very strong platform to handle to multiple inputs and outputs in a single model, with or without different units of measurement (Lu, 2012). Therefore, it is decided to exercise DEA in this research to measure the relative efficiency of the farmers and to use Bootstrap DEA models for bias correction, to see the credibility of the results, provided by the standard DEA models.

3.2: CONCEPTS RELATED TO DATA ENVELOPMENT ANALYSIS

This section explains some important concepts and definitions repeatedly used in DEA models. Therefore, to understand DEA models, it is necessary to acknowledge these definitions beforehand.

3.2.1: Production Function

The production function donates the physical or technical relationship between output and inputs or the function that gives the maximum output that is technologically feasible (Coelli *et al*., 2005). The production functions have certain properties that are vital to any economic analysis. The main properties are

1) Nonnegativity: the value of y = f (x) is a finite, non-negative number.

2) Weak essentiality: the production of positive output is impossible without the use of at least one input.

3) Quasiconcavity in x : any linear combination of x_0 and x_1 each of which is capable of producing y will produce an output that is no less than y .

4) Nondecreasing in x : also known as monotonicity, this property means that additional use of an input would not decrease output.

5) The output set is closed

6) Outputs are weakly disposable

(Chambers, 1988)

3.2.2: Production possibility Set

Before understanding the concept of efficiency and inefficiency, there is need to understand and define the technology. Production Possibility Set (PPS) is defined as the set of all inputs and outputs of a system in which inputs can produce outputs (Jahanshahloo *et al*., 2007). Data Envelopment Analysis models implicitly use PPS to evaluate the relative efficiency of Decision Making Units (DMUs). DEA is designed for evaluating DMUs that perform similar tasks and for which measurement of inputs and outputs are available. Assume a set of n observed DMUs, DMUj (for each $j \ \ (1, \dots, n)$) is associated with input vector of x_j = x_j^1, ..., x_j^m) and output vector of y_j = (x_j^i, ..., x_j^s). Also, let P be the production possibility set

$$\mathbf{P}=\{(\boldsymbol{x}, \boldsymbol{y}) \in \mathbb{R}_+^{\boldsymbol{j}} \times \mathbb{R}_+^s \ |\boldsymbol{x\ can\ produce\ y}\}$$

In many applications, the production possibility set is unknown. The DEA approaches, therefore, estimate P from the set of observed DMUs and evaluate the observed productions relative to the estimated technology.

Assumption 1: Feasibility

Combination of observed set of inputs and outputs is possible

Consider the case where each DMU consumes inputs to produces outputs. when input x can produce y, the input output set (x, y) is feasible. Suppose a set of n observed DMUs, using j inputs to produce s outputs. Suppose x^i= $(x_1^i$, ..., $x_j^i)$ represent the observed input bundle and observed output bundle is y^i= $(y_1^i$,..., $y_s^i)$. In these equations, subscript represents the different DMUs and inputs and output that used by the DMUs. Based upon assumption 1, $(x^i\ , y^i)\ i = (1, \ldots, n)$ is the possible input output combination.

Assumption 2: Convexity

The convexity is one of the underlying assumptions of the Production Possibility Set. P is convex, if any two points

$$(x^A, y^A) \in P, (x^B, y^B) \in P, \text{ \& any weight } 0 \leq \lambda \leq 1,$$

Then the weighted sum of any two plans $(1-\lambda)(x^A, y^A) + \lambda(x^B, y^B)$, is also on P, i.e.,

$$(x^A, y^A) \in P, (x^B, y^B) \in P, 0 \leq \lambda \leq 1 \Rightarrow (1-\lambda)(x^A, y^A) + \lambda(x^B, y^B) \in P$$

The weighted sum of two plans (x^λ, y^λ) = $(1-\lambda)(x^A, y^A) + \lambda(x^B, y^B), (0 \leq \lambda \leq 1)$ donate convex combination of $(x^A, y^A)\ and$, (x^B, y^B) with weight λ

Assumption 3: Free disposability

(inputs and outputs are freely disposable) when $(x, y) \in P, x' \geq x, y' \leq y \Rightarrow (x', y') \in P$ i.e

$$(x, y) \in P, x' \geq x, y' \leq y \Rightarrow (x', y') \in P$$

This highlights free disposability of inputs and outputs that implies that we can produce fewer output with more inputs.

Assumption 4: if (x, y) is feasible then for any β≥0, $(\beta_x\ , \beta_y)$ is also feasible. These above assumptions are used to construct production possibility set without any explicit specification of production function.

3.2.3: Efficient Frontier

Efficient frontier in Data Envelopment Analysis is a surface that represents “best practice” and established by connecting all the efficient DMUs present in the group against which all DMUs are benchmarked (Yang 2009; Soteriades, *et al*., 2015). The efficiency of all the other units present in the data set is measured relative to this surface and any deviation from this surface provides an evidence of inefficiency of the firms (Soteriades, *et al*., 2015). DMUs on the efficient frontier can serve as empirical benchmark targets for inefficient DMUs (Park and Sung, 2016).

3.2.4: Decision Making Units (DMUs)

The DMU is an abbreviation of the decision making unit and used to represent the peer entities (Lu, 2012). The organizations, firms, farms under evaluation in DEA are called Dumps (Lu, 2012). The decision-making units may be the firms, banks, industries or farms. Hence, the definition of a DMU is generic and flexible (Cooper *et al*., 1978). In Table 3.2, the decision-making units are the maize farmers. This table represents the data of first 10 DMUs (10 maize farmers)

3.2.5: Benchmarking in DEA and Efficient Peer

The benchmarking analysis normally includes the methods to answer the following three questions:

1) How best practice is properly determined in a specific analysis.
2) What characterizes best practice?
3) How much and in which way does each DMU deviate from the norm?

Benchmarking process has three basic steps

1) identifying the best performers
2) setting benchmarking goals; and
3) implementation

In the context of agriculture, the first step in process of benchmarking entails identifying a farm that is acknowledged as the best performer in terms of agriculture production. At the second step, the efficiency of the inefficient farms compared with the best performer. The third step, Implementation involves emulating the practices of the best performance in order to increase the efficiency of the inefficient farms. The benchmarking assist managers in setting goals in specific areas by identifying the best-performing peer group (Villano, 2009). A benchmarking tool should have the ability to analyze multiple inputs and multiple outputs that determine efficiency and provide insight about the areas that need improvement (Rayeni and Saljooghi, 2013). A linear programming problem on solution constructs unique benchmarks for each farm in the sample. A benchmark can reflect the contributions of a number of farms however, only best-practice farms, that has $\lambda = 1$, can contribute to the benchmark of individual farms. The reason is that the performance of a non-best practice farm can be improved upon, and hence will not be a benchmark for any farms (Rayeni and Saljooghi, 2013).

An inefficient DMU inside the frontier can select efficient DMUs on the frontier, and selected efficient DMUs is named its reference set or peer DMUs (Villano, 2009; Osamwonyi & Kennedy, 2015). Hence, depending on the size and scope of a DMU, each DMU will have a different set of reference set (Martic *et al*., 2009; Rayeni and Saljooghi, 2013). The efficient peers act as a benchmark for the inefficient units and provide information that how the inefficient units can be converted into an efficient unit by adopting the way of efficient peers (Martic *et al*., 2009; Villano, 2009). For each inefficient DMU, DEA identifies the closest efficient firms located on the frontier (Villano, 2009; Huguenin, 2012; Osamwonyi & Kennedy, 2015). These efficient firms are called peers or benchmarks. If inefficient DMU wants to improve their performance, they have to look at the best practices developed by their respective peers. In DEA input and output models the following constraints ($\sum_{j=1}^{n} y_{rj}\lambda_j$, $\sum_{j=1}^{n} x_{ij}\lambda_j$) on the right-hand side of the formula Identify the referent units or a peer group for the firm o under evaluation (Osamwonyi & Kennedy, 2015). A few excellent farms as compared to others may represent a reasonable benchmark for comparison. The value of the corresponding variable λj in the optimal solution of the dual model determines the relative significance of a unit belonging to a reference group (Martic *et al*., 2009; Osamwonyi & Kennedy, 2015).

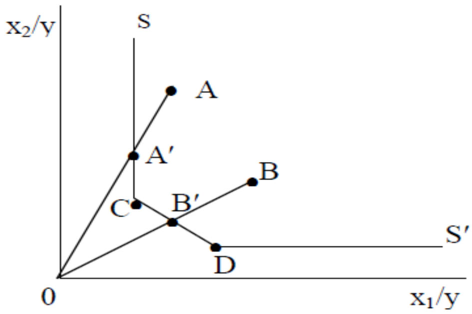


Figure 3.1: Efficient Peers for firm A and B

This figure illustrates the peers for the inefficient DMUs. The DMU C and D located on the frontier and marked efficient, while firms A and B are inefficient because they lie outside the efficient frontier line. According to the figure, two peers: C and D has assigned to the inefficient DMU, because the projected point of B on the frontier lies between these two DMUs. Similarly, the inefficient farm A has only one peer C, because of the projected point for A lies close to firm C.

The Table shows that the DMU 1 (Maize farmer) is technically efficient and is marked as a peer for himself. The DMU 2 has three efficient peers (DMU 93, DMU165 and DMU187) as they are appearing against his reference set after solving DEA model. Similarly, DMU54, DMU58, DMU 98 and DMU 165 are marked as peers against DMU3. This shows that by following the way of their efficient peer, inefficient farmers can increase their efficiency.

Table 3.1: Peers For First Ten Maize Farmers out of 196

DMUS	PEER1	PEER2	PEER3	PEER4	PEER5
[1,]	1	NA	NA	NA	NA
[2,]	93	165	187	NA	NA
[3,]	54	58	96	165	NA
[4,]	58	165	184	NA	NA
[5,]	58	165	184	187	NA
[2,]	93	165	187	NA	NA
[6,]	165	184	NA	NA	NA
[7,]	93	165	187	NA	NA
[8,]	165	184	NA	NA	NA
[9,]	1	58	80	150	184
[10,]	80	150	184	187	NA

3.2.6: Robustly Efficient

The units in the data set that appear most frequently as a reference peer for the inefficient units are called robustly efficient. For example, in Table 3.2, DMU58, DMU165, and DMU184 are robustly efficient as they are appearing most of the time as peers in the reference set of other DMUs.

3.2.7: Lambda Value

The lambda values are attached to the efficient peer and obtained by running and solving the linear programme models. These are the multiplication factors and used to multiply the inputs and outputs of the efficient units to get better input usage level for the inefficient ones.

3.2.8: Slacks in DEA

The slacks are the outcome of DEA models and gives an indication that the amount of output and input can be increased or decreased by the amount of slack without disturbing any constraint (Huguenin, 2012). If the slack related to the output Y appears positive, it means that the output can be increased by the amount of slack. Similarly, is the case with input slack, the positive input slack value shows that the amount of input can possibly be decreased by the amount of slack attached to the input (Cooper *et al* 2004).

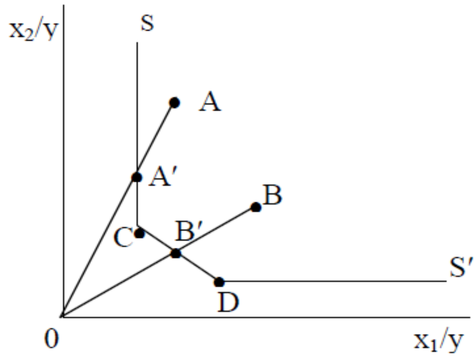


Figure 3.2. Input Slacks and the measurement of efficiency (Coelli, 1996).

The figure is designed to illustrate the slacks that are the outcome of DEA models. In this figure, the DMUs located on the position C and D are the two technical efficient DMUs which define the frontier, and DMUs on positions A and B lie outside the frontier and hence inefficient. The technical efficiency for DMUs A and B can be represented as OA'/OA and OB'/OB, based on Farrell (1957) measurement of TE. It is interesting to note that the position A′ is also an efficient point but the amount of input x_2 can be reduced by the amount CA′, without any alteration in the output level. In DEA literature, this situation donates the input slack or input excess. If we include and consider more inputs and/or outputs to this figure, the diagram would not be that simple anymore and become complex due to the appearance of output slacks as well. Thus, to present an accurate calculation of TE of a DMU in a DEA analysis, both Farrel measure of TE (θ) and any non-zero input or output slacks should be counted, otherwise, the results can be misleading (Huguenin, 2012). For the i-the firm, the input and output slacks will be equal to zero only if it satisfies the conditions ($\theta x_i - x\lambda = 0$) and ($y\lambda - y_i = 0$), respectively, for the given optimal values of θ and λ. (Huguenin, 2012).

Table 3.2 shows the input and output slacks against the first 10 maize farmers. It can be seen that one solution of DEA model, output slack against each DMU is zero, which shows that the output cannot be increased. Similarly, the input slacks against first DMU are zero, which shows that this DMU cannot further reduce its input level and is fully technically efficient. However, the input slacks against the DMU2 are positive for input 1, input 4 and input 5. This shows that the DMU can reduce the input 1, 3 and 5 by the amount of slack shown against these inputs. Similarly, DMU3 has positive slack against input 3 and 5 and can reduce the level of these inputs while achieving the similar output level.

Table 3.2: Input and Output Slacks against First ten Maize Farmers

DMUS	*Sx1*	*sx2*	*sx3*	*sx4*	*sx5*	*Sy1*
1	0.00E+00	0.00E+00	0	0.00E+00	0	0
2	4.13E+01	0.00E+00	0	1.40E+00	1.285033	0
3	0.00E+00	0.00E+00	1.1193862	0.00E+00	1.679903	0
4	5.86E+01	1.39E+01	0	9.08E+00	0	0
5	3.60E+01	0.00E+00	0	6.97E+00	0	0
6	4.69E+01	3.19E+01	0.39435952	3.65E+00	0	0
7	8.12E+01	1.35E+01	0	0.00E+00	1.196569	0
8	5.98E+01	1.55E+01	11.83590963	3.31E+00	0	0
9	1.26E+00	0.00E+00	0	0.00E+00	0	0
10	1.03E+02	0.00E+00	0	2.42E+00	0	0

3.2.9: Sample Size and Variables in DEA

Since performance evaluation through DEA directly considering input and output data and the results largely depend on the input/output choice and the number and homogeneity of the DMUs under evaluation (Martic *et al*., 2009; Osamwonyi & Kennedy, 2015). The DEA appears to be sensitive to sample size and the variables (Martic *et al*., 2009; Osamwonyi & Kennedy, 2015). The data envelopment analysis performs well as the number of DMUs increases and tries to improve the personal ranking of the individual DMUs as the number of input and output variables increased in the analysis (Martic *et al*., 2009; Osamwonyi & Kennedy, 2015). The number of inputs and outputs used in DEA models should be kept at a reasonable level in order to safeguard the discriminatory power of DEA (Osamwonyi & Kennedy, 2015). The DEA approach has preference over the other conventional efficiency measuring approaches because multiple numbers of inputs and outputs can be handled in DEA (Rayeni and Saljooghi, 2013). However, this merit of DEA leads to a problem, in selecting the variables because DEA does not supply any guidelines about the variable selection. Therefore, it only depends on the researcher to select the input and output variables of their own choice. The inclusion of all the variables has not seemed to be the rational approach due to the following reasons. First, the number of DMUs should be three times greater than the sum of input and output variables, but in real life application, DMUs are restricted (Raab & Lichty 2002; Osamwonyi & Kennedy, 2015). Secondly, the availability of the data for all DMUs is difficult. Third, the discriminating power between efficient and inefficient DMUs was purely relying on the number of variables used in the DEA models and the inclusion of an excessive number of variables in the DEA models would tend to make all DUMs efficient (Martic *et al*., 2009). However, the results of technical efficiency are also affected by the omission of some important inputs from the model (Dyson *et al* 2001). The omission of appropriate variables and insertion of irrelevant variables and wrong assumption on returns-on-scale are the main causes of model misspecification (Galagedera *et al* 2003). The DEA efficiency scores are affected considerably and are biased when misspecified models are used (Sexton *et al* 1986, Smith, P. 1997 and Nataraja, *et al* 2011.). Therefore, the input and output variables included in the model has had a significant effect on DMUs efficiency. The selection of appropriate or best set of variables for input and output is one of the crucial tasks in DEA.

To overcome this problem, several methods have been proposed by various authors on the topic of relevant variables selection. Shafiq (1998) suggested that the variables in the DEA models could be selected through regression analysis or by thoroughly observing the data. The inputs that are used in excess by the farmers relative to others can be used as input variables in the DEA. Ruiz *et al* (2002) developed a new method to find relevant variables based on the variables contributing to efficiency. Jenkins *et al* (2003) suggested that removing highly correlated variables, will certainly affect the efficiency scores greatly and he developed a technique which uses partial correlation for reducing the number of variables (a multivariate statistical approach). A simple technique of regression analysis can be applied to regress the input variables on output variable and statistically significant variables are then selected (Ruggiero *et al* 2005). Edirisinghe *et al* (2007) based on the maximizing principle of correlation between the external performance index and DEA scores proposed a generalized DEA approach to select inputs and outputs". In this research, the variables are selected by carefully observing the key variables used in other studies conducted in the agriculture sector.

3.2.10: Type of farming system and selection of inputs and output variables

A farm has diversified activities and can choose a set of different inputs to produce a set of different output also referred as production plan. To explain this in formulation, let us consider multi input-output case and there are n farms $i = (1, \dots, n)$ that has set of j inputs $x^i = (x_1^i, \dots, x_j^i)$ and s outputs $y^i = (y_1^i, \dots, y_s^i)$ then $x^i = (x_1^i, \dots, x_j^i) \in \mathbb{R}_+^j$ and $(y_1^i, \dots, y_s^i) \in \mathbb{R}_+^s$ represents the j-vector of inputs and s - vector of outputs for the i^{th} farm, respectively. $then\ (x^i, y^i) \in \mathbb{R}_+^j \times \mathbb{R}_+^s$ is the pairs of input and output vector and denoted as the production plan for the i^{th} farm. It is to note that the inputs and outputs for the i^{th} farm are non-negative numbers (positive or zero). The input and output data matrix for the n farms can be arranged as under:

$$X = \begin{bmatrix} x_1^1 & x_2^1 & \dots & x_j^1 \\ x_1^2 & x_2^2 & \dots & x_j^2 \\ . & & \dots & . \\ . & & \dots & . \\ x_1^n & x_2^n & \dots & x_j^n \end{bmatrix} \qquad Y = \begin{bmatrix} y_1^1 & y_2^1 & \cdots & y_j^1 \\ y_1^2 & y_2^2 & \cdots & y_j^2 \\ . & & \dots & . \\ . & & \dots & . \\ y_1^n & y_2^n & \cdots & y_j^n \end{bmatrix}$$

It is assumed in efficiency studies that farms under study must be homogeneous. However, in the actual situation, farms appear non-homogeneous, producing more than one type of product. Fixed and variable resources are used to produce multiple products in considerable amounts. This is very common in mixed crop systems where farmers rely on the product from crops, livestock, forest plants, and fisheries. It is complicated to calculate efficiency independently for each type of products. Therefore, it is inevitable in the efficiency assessment process to consider all types of products together. Several studies can be found in the literature that are dealing with these type of farms under some common considerations. Some examples of these studies dealing with farms produce either multiple crops or multiple products (which includes livestock as well as crops).

Farming systems analysis and the comparison is not possible unless the heterogeneous products are not bringing into some common units of measurement. Farm economics provides a good conceptual framework for most farm-household systems analysis. The base usually most convenient - and in the case of commercial farm systems most relevant and which has the highest degree of universality - is money or financial value. However, several other bases for systems analysis are possible and in certain circumstances, they might well be more relevant than monetary value. The four most important bases of comparison are as follows:

One of the ways dealing with non-homogenous production is to consider agricultural output in monetary terms. The use of financial values in commercial farm systems analysis will be obvious because it allows aggregating the various system inputs (e.g., seed, fertilizer, power, labour etc.). Some studies aggregated all the outputs and output variable included in monetary form in the models (Fandel, 2003; Javed *et al*., 2008; Fatima *et al* 2016; Dao, 2013; Latruffe *et al*., 2008), whereas some researcher separately considered the value for each product in monetary form as outputs (Iraizoz *et al*., 2003; Ali *et al*., 2012; Mohapatra, 2013; Spicka & Lubos, 2014). Aggregation of outputs and conversion into monetary form is most common practice in studies dealing with non-homogeneous outputs (crop and livestock products together). The studies dealing with multiple crop-raising farms also used this approach. Numerous studies in the literature considered each crop output separately as output variables in evaluating the efficiency of non-homogeneous farms (Binam *et al*., 2005; Lilienfeld and Asmild, 2007; Luik *et al*., 2009; Hasanov and Ahmed, 2011).

On the other hand, the studies dealing with the homogeneous products have used physical quantity as an output variable in the analysis. Physical production such as kilograms or tonnes is considered as output variable in number of such studies (Bogale *et al*., 2005; Idiong, 2007; Chirwa., 2007; Dang, 2011; Kashiwagi *et al*., 2012; Kashiwagi *et al*., 2013; Thabethe *et al*., 2014; Rahman & Brodrick, 2015; Clemente *et al*., 2015; Kea at al., 2016). Whereas, physical production per unit of area is used in the models as output by number of researchers (Murthy *et al*., 2009; Gul *et al*., 2009; Koc *et al*., 2011; Umanath & David, 2013; Ali and Munir, 2014; Chebil *et al*., 2016). Total milk production in liters or kilograms is mostly considered as outputs when the units are dairy farms (Fraser and Cordina, 1999; Solis and Corral, 2009; Demircan *et al*., 2010; Balcome *et al*., 2006).

Depending on the nature and scope of the research study, numerous inputs have been considered in efficiency evaluation studies implying DEA (Salleh, 2012). Capital, pesticides, fertilizers, seed, land, and labour are the prominent variables that are most often used in the majority of the studies. However, different units of measurement are used to define these variables. The land is measured in hectares or acres and generally described as the utilized agricultural area (Umanath & David, 2013; Spicka & Lubos, 2014). Labour is measured by different means such as labour hours (Fraser and Cordina, 1999; Shafiq and Tahir, 2000; Koc *et al*., 2011; Reinhard *et al*., 2000; Lansink *et al*., 2002; Iráizoz *et al*., 2003; Asmild and Hougaard, 2006; Galanapoulos *et al*., 2006; Luik *et al*., 2009) number of workers (Dang, 2011), labour costs (i.e. wages) Fandel, 2003 (Hasanov &Ahmed, 2011; Kleinhanß *et al*., 2007; Artukoglu *et al*., 2010), annual working units (Murthy *et al*., 2009; Martinez & Tadeo, 2004;Ali *et al*., 2012; Umanath & David, 2013; Spicka & Lubos, 2014; Balcombe *et al*., 2008; Latruffe *et al*., 2008). The cost of various variables is among the fundamental factors that have been used as inputs in agricultural DEA studies. The costs are included in the DEA models through different means and labels. In many studies, aggregated cost variable included in the models by labelling it as total expenses' (Amores and Contreras, 2009), 'cultivation costs' (Iráizoz *et al*., 2003), 'materials' (Petrovska *et al*., 2013; Spicka & Lubos, 2014), 'purchased inputs' (Helfland and Levine, 2004; Adhikari and Bjorndal, 2011), 'variable input cost' (Heidari *et al*., 2011; Bojnec and Latruffe, 2009; Mwajombe & Malongo, 2015), capital inputs (Idiong, 2007, Murthy *et al*., 2009), Fixed cost (Murthy *et al*., 2009) or 'other expenses' (Kelly *et al*., 2012). These aggregated cost variables mentioned above, represent the sum of costs on spent on items like energy, fertilizer, feed, fuel, seed, machinery, pesticides, water. However, what item to include in the aggregation of cost input varies between studies. Tractor hours and irrigation hours (Shafiq and Tahir, 2000; Javed *et al*., 2010; Koc *et al*., 2011), tractor cost (Hasanov &Ahmed, 2011), Irrigation number/ha (Shafiq and Tahir, 2000; Ali *et al*., 2012), Environmentally related inputs are used in number of studies with aim to minimize the undesirable input such as nitrogen, phosphorus or potassium variables (Umanath & David, 2013;; Asmild and Hougaard, 2006). These variables are measured in Kg or ton per unit of land.

On the other hand, various studies did not take into consideration the aggregated costs but the various inputs involved in the production process are taken into account as separate inputs. Examples of such variables are pesticides (Brodrick & Sanzidur, 2014; fertilizers (Murthy *et al*., 2009; Javed *et al*., 2010; Hasanov & Ahmed, 2011; Islam *et al*.,2011; Koc *et al*., 2011; Umanath & David, 2013; Brodrick & Sanzidur, 2014), fuel (Dang, 2011; Andersen and Bogetoft, 2007), pesticides (Javed *et al*., 2010; Martínez and Tadeo, 2004), seed (Murthy *et al*., 2009; Javed *et al*., 2010; Hasanov &Ahmed, 2011; Koc *et al*., 2011; Dang, 2011; Islam *et al*., 2011; Umanath & David, 2013; Brodrick & Sanzidur, 2014) and FYM (Murthy *et al*., 2009). In a significant number of studies, these variables are taken as inputs themselves. The items such as fertilizers, seeds and pesticides are represented in either monetary terms or the physical amount purchased.

Another important variable used as an input is the capital factor. It has been considered in different forms in several studies. One way undertaken by some studies is to incorporate the sum of depreciation of fixed assets and the interest payments as a capital factor (Murthy *et al*., 2009; Demircan *et al*., 2010; Spicka & Lubos, 2014; Latruffe *et al*., 2004; Latruffe *et al*., 2008b; Balcombe *et al*., 2008a). Another way is to relate capital factor to the machinery and other fixed capital such as hours of used machinery (Spicka & Lubos, 2014), annual costs on capital (Lilienfeld and Asmild, 2007) or book value of machinery and material (Petrovska *et al*., 2013; Iráizoz *et al*., 2003). The use of total assets (Fandel, 2003; Bojnec and Latruffe, 2009), and depreciated value of total assets (Davidova and Latruffe, 2007; Luik *et al*., 2009) are the other ways considered by the researchers to incorporate capital input into their models. Inputs identified also vary depending on the product type of the units evaluated.

In the research dealing with farms producing livestock or dairy products, it can be observed that animal-related inputs are also taken into consideration. Common examples of these variables are number of animals (Fraser and Cordina, 1999; Galanopoulos *et al*., 2011; Kelly *et al*., 2012), veterinary cost (Gul *et al*., 2016) and feed, fodder and concentrates (Dang, 2011; Javed *et al*., 2010; Demircan *et al*., 2010; Galanopoulos *et al*., 2011; Kelly *et al*., 2012; Petrovska *et al*., 2013; Gul *et al*.,

2016) either in terms of amount or expenditures made for it. Feed is usually considered as a separate variable, whereas in some studies it is included in aggregated costs as mentioned above. Furthermore, the inputs identified for DEA studies in agriculture exhibit slight differences depending on the evaluation context of the study. Another example can be given the studies dealing with the evaluation of irrigation efficiency. In these type of studies, it is inevitable to consider variables related to water. Rodríguez-Díaz (2004), in which the irrigation districts in Spain are assessed, water applied in each district is considered as an input variable. Similarly, Lilienfeld and Asmild (2007) take water use and precipitation in evaluating the irrigators in Kansas, USA. Recently, in an irrigation efficiency work by Frija *et al*. (2011), water use is considered as an input.

3.2.11: The Different Assumptions in DEA on Returns to Scale

Returns to scale are used to describe the behavior to increase in the output with a subsequent increase in the level of inputs (Lakner & Gunnar, 2015). Returns to scale is of three kinds, increasing returns to scale (IRS), decreasing returns to scale (DRS) and constant returns to scale (CRS) (Lakner & Gunnar, 2015). If the output increases by more than the proportional change in inputs, then increasing returns to scale occur. If the output increases by the same proportional change in inputs, it is constant returns to scale. Decreasing returns to scale occur when the input increases by less than the proportional change in inputs (Shafiq 1998).

Two basic assumptions of constant returns to scale (CRS) and variable returns to scale (VRS) can be considered on returns to scale while applying DEA models to evaluate the performance of farming systems (Charnes et al., 1978; Banker et al., 1984). A significant number of DEA studies in agriculture consider both assumptions for the same data (Fandel 2003; Murthy et al., 2009; Houshyar et al., 2010; Koc et al., 2011; Islam et al., 2011; Umanath & David, 2013).

The estimation of efficiency under CRS and VRS enables the decomposition of technical efficiency into pure technical and scale efficiency (Cooper *et al*., 2007). In the case of agriculture, the VRS assumption introduced by (Banker *et al*., 1984) in the DEA models are considered as the most appropriate assumption (Asmild & Hougaard, 2006; Lilienfeld & Asmild, 2007; Houshyar et al., 2010; Koc et al., 2011). The alternative assumption of CRS is not a valid assumption in the context of agriculture because doubling inputs lead to doubling in output is not possible in actual farm level condition.

Table 3.3: Assumptions on returns to scale and specification in DEA models

S.NO	***DEA ASSUMPTIONS***	***Specification in Model***
1	CRS	λ≥0
2	VRS	λ=1
3	DRS	λ≤1
4	IRS	λ≥1

3.3: DEA MODELS FOR PERFORMANCE EVALUATION

The relative performance of the DMUs can be estimated by using various DEA models. Two alternative models are available in DEA to determine the efficient frontier that is characterized by the assumptions in Table 3.1.3. Hence, under this heading, the attention is on elucidating the fundamental DEA models (input and output oriented). These models are specified in both Primal and dual characterization. Comparison of the models is also discussed based on their envelopment surface, returns to scale properties and projections onto the efficient surface.

3.3.1: Input oriented DEA model under CRS

Charnes, Cooper, and Rhodes are considered pioneers of the present form of DEA. Charnes(1978) developed Farrell's contribution further to specify a DEA model known as Charnes, Copper and Rhodes model (CCR) which assumes constant returns to scale. In this model, the ratio of inputs and outputs are used to measure the efficiency of the DMU under evaluation relative to the ratio of the other DMUs present in the group. The ratio model under generates the single 'virtual' output and single 'virtual' input by reducing the multiple-output/multiple-inputs (Cooper *et al* 2004; Houshyar *et al*., 2010).The mathematical representation of the ratio model can be written as:

Model 3.1

$$Max\ ho = \sum_{r=1}^{s} u_r y_{ro} \Big/ \sum_{i=1}^{m} \mathrm{v}_i x_{io} \qquad (3.1)$$

Subject to:-

$$\sum_{r=1}^{s} u_r y_{rj} \Big/ \sum_{i=1}^{m} \mathrm{v}_i x_{ij} \leq 1 \qquad (3.2)$$

$$\textstyle\sum_{j=1}^{n} \lambda_j \geq 0$$

$$u_r, v_i \geq 0 \quad j = 1, \ldots, n \qquad r = 1, \ldots, s \qquad i = 1, \ldots, m$$

Source:(Cooper *et al* 2004; Cesaro *et al.*, 2009; Houshyar *et al.*, 2010; Hasanov & Ahmed, 2011; Bhatt and Shaukat, 2014)

ho= ratio of weighted outputs to weighted inputs for the DMU "o" under evaluation

u_r = variable weight associated to output to be estimated for the DMU under evaluation

v_i=variable weight linked to inputs to be estimated for the DMU under evaluation

y_{ro} =observed quantities of the r-th output produced by DMU "o", under evaluation r=1,..., s

x_{io} = observed quantities of the i-th inputs used by DMU "o" under evaluation=1, ..., m

Here in the above formulation, x_{ij} is the known level of input 'i' used by the j-th DMU in a group andy_{rj} is representing the level of output 'r' produced by j-th DMU. The constants $u_r$and v_i are the unknown weights attached to the outputs and inputs, respectively (Houshyar *et al.*, 2010; Bhatt and Shaukat, 2014). The equation (3.2) is stressing that the ratio of virtual outputs to virtual inputs must be less or equal to unity. The above equation involves finding the values for the input and output weights in such a manner that the efficiency measure for i-th DMU is maximized (Bhatt and Shaukat, 2014)

The constant returns to scale restriction in this model implies that a proportionate increase in outputs can be achieved by a proportionally increasing the level of inputs (Wen, 2015). A limitation of measuring efficiency using this ratio form of the model is that it has an infinite number of solutions, and is nonlinear in nature (Bhatt and Shaukat, 2014). This nonlinear fractional model could easily be converted into linear form by incorporating new constraint($v_i x_{io}$ = 1) in the formulation (Coelli 2005; Bhatt and Shaukat, 2014). The linear representation of the above model is as under:

Model 3.2

$$Max\ ho = \sum_{r=1}^{s} u_r y_{ro} \qquad (3.3)$$

Subject to:-

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0 \qquad (3.4)$$

$$\sum_{i=1}^{m} v_i x_{io} = 1 \qquad (3.5)$$

$$\sum_{j=1}^{n} \lambda_j \geq 0$$

`

$$u_r, v_i \geq 0 \quad j = 1, \ldots, nr = 1, \ldots, ni = 1, \ldots, n$$

Source: (Cooper *et al* 2004; Cesaro *et al*., 2009)

The optimal solution obtained by solving this model and value of ho signifies the largest factor by which the level of the output could possibly be increased by exploiting the current level of inputs. Data Envelopment Analysis (DEA) on solution assigns a value to each Decision Making Unit included in the analysis. This value or score represents whether the DMU is efficient or not, for inefficient DMUs, it identifies an efficient unit as a target and thus provides suggestions for improvements to their efficiency. However, for efficient DMU, no further enhancement can be indicated based on a DEA analysis. For example, the score ho = 0.74 highlights that the DMU is inefficient in utilizing the resources and can increase its level of output up to 26 % by using the same level of inputs. For a firm, two conditions must need to be fulfilled to declare as efficient:

(a) ho= 1, and
(b) All slacks variables in the LP solution must be zero

(Fandel 2003; Soteriades, *et al*., 2015)

The inefficiency of the DMUs can be seen by the amount of slack, if the slack value attached to the input and outputs appears positive, then it is evident that the unit is not using its resources efficiently and efficiency of that particular unit can be increased from its present level (Soteriades, *et al*., 2015)

The above output maximization linear model can be converted into input minimization model or a dual model, whose solution specifies by what proportion the level of inputs can be reduced without any alteration in its current output level (Coelli 1996). The lambda (λ) values generated by the input DEA model identify the efficient and inefficient users of inputs, by implication provides information on how the inefficient units could become efficient. This formulation of the DEA model is regarded as a more feasible approach for measuring the efficiency of the decision making units, and it is stated as:

Model 3.3 (This CRS model is used in chapter 6 and 7 to estimate TE)

$$Min_{\theta\lambda} \tag{3.6}$$

Subject to:

$$\sum_{j=1}^{n} y_{rj}\ \lambda_j \geq y_{ro} \tag{3.7}$$

$$\sum_{j=1}^{n} x_{ij}\,\lambda_j \;\leq\; \Theta x_{io} \qquad (3.8)$$

$$\sum_{j=1}^{n} \lambda_j \geq 0$$

$$\boldsymbol{\lambda_j > 0 \qquad i = 1,\ldots,m \quad r = 1,\ldots,s \quad j = 1,\ldots,n}$$

Source : (Koc *et al.*, 2011; Umanath & David, 2013a; Umanath & David, 2013b; Linh *et al.*, 2015)

The model (3.3) is the dual representation of the primal model (3.2). If primal is a maximization problem then dual will be a minimization problem. The value of θ is the desired efficiency score for i-th farm in this model (Hasanov & Ahmed, 2011; Koc *et al.*, 2011). To calculate the efficiency of the every unit, this linear programming model must be solved individually for all unit (Gul *et al* 2009; Koc *et al.*, 2011). The value θ = 1 implies that the firm is fully efficient under available technology, and is on the production frontier, and θ < 1 represents the inefficiency of firm under available technology and indicating room for further increase in productivity by utilizing the same available technology (Gul *et al* 2009; Rios and Shively 2005; Ajibefun, 2008; Hasanov & Ahmed, 2011; Koc *et al.*, 2011).

The constant returns to scale assumption in the model is appropriate when all DMUs operate at an optimal scale level, which is practically not possible as numerous factors like financial constraints, imperfect competition may hinder the DMUs to operate at an optimal level (Umanath & David, 2013). The measure of technical efficiency by considering CSR assumption in the model and results obtained may be confounded by scale efficiencies (Oduol *et al* 2006; Umanath & David, 2013). The value of Ɵ obtained by solving the input minimization model can easily be interpreted, for example, if the value of Ɵ is 0.74, it is depicting inefficiency level of the particular unit and this DMU can decrease its level of input up to 26 percent. In this case, the DMU has converted only 74 % of its inputs into output and the rest of the inputs are inefficiently allocated.

Recently, the dual or the envelopment approach is mostly used in the research to quantify the efficiency scores. It is because this model is less computational, as it contains m and s constraints, as compared to the primal or fractional model, which consists of n constraints. Envelopment model is more significant as it measures the amount of slack associated with each input and output thereby providing information to the administration for improving the efficiency.

3.3.2: Input DEA models with VRS assumption

To overcome the problem attributed to CRS model devised by the Charnes, Copper, and Rhodes which supposes that all firms have the same scale of operation, which is impossible practically, Banker *et al* (1984) modified the CRS model. This model is known as the VRS model and has added the element of convexity (∑λ = 1) to the CRS version.

The practice of the variable returns to scale specification in DEA models will allow the estimation of technical efficiency devoid of scale efficiency effects (Asogwa, 2011; Kamur and Richta 2008; Umanath & David, 2013). The VRS model incorporates variable returns to scale assumption and envelopment of the surface is tighter as compared to the CRS formulation. It is also free from the scale efficiency effects. The mathematical specifications of the model are:

Model 3.4: (This VRS Model is used in Chapter 6 and 7 to estimate efficiency)

$$Min_{\theta\lambda} \qquad (3.9)$$

Subject to:-

$$\sum_{j=1}^{n} y_{rj}\,\lambda_j \geq y_{ro} \qquad (3.10)$$

$$\sum_{j=1}^{n} x_{ij}\,\lambda_j \leq \theta x_{io} \qquad (3.11)$$

$$\sum_{j=1}^{n} \lambda_j = 1 \qquad (3.12)$$

$$\lambda_j > 0 \qquad i = 1, \dots, m \qquad r = 1, \dots, s \qquad j = 1, \dots, n$$

Source : (Linh *et al.*, 2015; Wen, 2015)

j = Represents the number of DMUs in the sample which are 1,..., 250 for wheat, 1,..., 216 for cotton, 1,...,196 for maize and , 1,..., 220 for sugarcane in this study)

m = is the number of outputs used in the DEA models and in case of all crops, quantity of output produced is used as output variable. Hence, the number of output variables for wheat, cotton, maize, and sugarcane is 1.

i =is the number of inputs used in the DEA models which are (1,..., 6 for wheat and cotton and 1,..., 5 for maize and sugarcane in this study

x_{ij} = is a number of i-th inputs used by the J-th DMU

y_{rj} = is the amount of r-th output produced by J-th DMU

y_{ro} = is the level of output produced by the DMU under “o” evaluation$r = 1, \dots, s$

x_{io} = observed quantities of the i-th inputs used by DMU “o” under evaluation $i = 1, \dots, m$

In the equation (3.10), y_{ro} on the right hand side of the formula is depicting the known level of output "r" being produced by the DMU "o" under evaluation. Similarly, in equation (3.11),x_{io} is the known level of input "i" utilized the firm "o" under evaluation. The θ is the efficiency score of the n-th DMU under evaluation and in a linear programming language; it may also be called as a decision variable. Because the farms have more control over their inputs in agriculture. Therefore, the use of Input oriented DEA models in this study, is in line with the following studies (Krasachat 2004; Javed *et al*., 2008; Rios & Shively, 2005; Gul *et al* ., 2009; Murthy *et al*., 2009; Hasanov & Ahmad, 2011; Koc *et al*., 2011; Umanath & David, 2013a; Umanath & David, 2013; Linh *et al*., 2015).

3.3.3: Output Orientation In DEA Model

The VRS output-oriented model has a similar envelopment surface as compared to VRS input oriented, but the projection of the DMU on the envelopment surface is different. The VRS output oriented model based upon the assumption of maximizing the output by absorbing the same level of inputs. However, the input model predicts the reduction in inputs keeping the same output level. Both the input and output models almost produce the same efficiency score when the models assume CRS but different results when VRS is considered (Martic *et al*., 2009). The input formulation can easily be converted into output orientation by inducing minor changing in the input model. The formulation specifying primal output orientation is as under:

Model 3.5: Output oriented DEA model with VRS assumption)

$$max\ \phi \qquad (3.13)$$

Subject to:-

$$\sum_{j=1}^{n} x_{ij}\,\lambda_j \le x_{io} \qquad (3.14)$$

$$\sum_{j=1}^{n} y_{rj}\,\lambda_j \ \ge\ \phi . y_{ro} \qquad (3.15)$$

$$\sum_{j=1}^{n} \lambda_j \ = 1 \qquad (3.16)$$

$$\lambda_j\,, \ge 0 \qquad i = 1, \dots, m \quad r = 1, \dots, s \quad j = 1, \dots, n$$

Source: (Candemir & Ertugrul, 2007; Gullipalli 2011: Ismail *et al*., 2013; Abatania, 2013; Melkaw, 2014)

In contrast to input orientation, this model finds the possibility of proportional expansion in output by keeping the level of all inputs constant. The efficiency score is obtained by dividing 1 with ϕ and lies between 0 and 1. (Fraser and Cordina 1999) highlighted that the same number of efficient farms are observed in output orientation as observed in input orientation but the difference lies in the efficiency estimation. The assumption of CRS represents that if the amount of inputs increased by K unit, the output will also be increased by the same unit K and inproportionate increase or decrease in the output level with respect to a unit increase or decrease in inputs in case of variable returns to scale. The output-oriented model is considered by the following authors in their studies (Alemdar & Oren 2006; Ayaz *et al*., 2010; Candemir & Ertugrul, 2007; Ismail *et al*., 2013; Abatania, 2013; Melkaw, 2014)

3.3.4: SLACK BASED MODELS

DEA models are of two common types, radial and non-radial. The major drawback of the radial approach is that it does not consider slacks when measuring efficiency. This led Charnes *et al* (1985) to develop the additive DEA model, which deals with slacks variables directly. Although this approach uses slacks to discriminate between the efficiency and inefficiency of a decision-making unit (DMU), it fails to provide an efficiency estimate that can help to determine the DMUs performance. This motivated Tone (2001) to propose a non-radial model, popularly known as the slacks-based measure of technical efficiency, for DEA that deals directly with slacks (excess inputs and output shortages) in efficiency estimation. DEA not only estimate the relative efficiency of the farm but also suggests the distance between inefficient farms and efficient farms through the slacks. The inefficient farms can reach the efficiency frontier and become efficient by adjusting the slacks. In the input-orientated model, the slacks suggest the input redundancy, which is the difference between actual input and target input (Lu, 2012)

Slacks variables are the terminology used in the linear programming and inequality constraints can be converted to equality constraints by the inclusion of these slack variables Sr+ and Si- in the model (Cooper *et al* 1978). This DEA terminology indicates the possibility of additional augmentation in the specific input and output. The standard linear programming equation is presented on next page:-

Model 3.6: Slack Based Model

$$\mathrm{Min}_{\theta\lambda}\left(\sum_{i=1}^{m} \mathrm{Si}^{-} + \sum_{r=1}^{s} \mathrm{Sr}^{+}\right) \qquad (3.17)$$

Subject to:-

$$\sum_{j=1}^{n} x_{ij}\,\lambda_j + Si^{-} = \theta x_{io} \qquad (3.18)$$

$$\sum_{j=1}^{n} y_{rj}\,\lambda_j - \mathrm{Sr}^{+} = y_{ro} \qquad (3.19)$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\boldsymbol{\lambda_j}, \boldsymbol{Sr^+}, \boldsymbol{Sr^-} \geq \mathbf{0} \qquad \boldsymbol{i = 1, \dots, m} \quad \boldsymbol{r = 1, \dots, s} \quad \boldsymbol{j = 1, \dots, n}$$

Source: (Umanath & David, 2013; Wen, 2015)

If the $\Theta = 1$ for a particular decision making unit but the slack variables Sr^+ and Si^- are not equal to zero, it indicates that the DMU is not fully technical efficient and efficiency of this DMU could be improved by reducing some of its inputs. From the development of these models, "relative efficiency" of the DMU is defined as follow:-

("DMU said to be 100 % efficient if and only if both $\Theta = 1$ and slack variables Sr^+ and $Si^- = 0$ and DMU is weakly efficient if value against Θ is 1 but the Sr^+ and $Si^- \neq 0$"). Slack Analysis is performed by the application of DEA by (Alemdar and Oren, 2006; Dağistan, 2010; Koc *et al*., 2011; Watto, 2013: Umanath & David, 2013; Hameed *et al*., 2014; Ogunniyi *et al*.,2015; Wen, 2015; Soteriades, *et al*., 2015; Ahmed *et al*., 2017).

3.4: AN ILLUSTRATIVE EXAMPLE OF DEA APPLICATION

In this section, it is explained that how "input-oriented DEA model" can be used after collecting data to estimate the production efficiency of the decision-making units and how from these results, interpretation can be made. Here in this example, the decision-making units are the farmers. These farmers are using a certain level of three inputs (seed, phosphorus, and nitrogen fertilizers) to produce two outputs wheat and maize. Production of these crops also depends upon various factors but in this example, it is assumed that the seed, phosphorus, and nitrogen fertilizers are the basic inputs causing variability in the yield. Therefore, these inputs were considered in this example, keeping the other variables constant. The input and output quantity used and produced by the farmers is presented in the table below in table 3.4.

Table 3.4: Level of inputs used and output Produced by Famers

DMUS	Seed (cost/acre)	Phosphorus (Kg/acre)	N (Kg/Acre)	Maize yield Kg/Acre	Wheat yield (Kg/acre)
Farmer 1	2000	345	343	2200	1678
Farmer 2	1200	432	483	3999	3234
Farmer 3	1123	234	287	1800	1876
Farmer 4	2563	354	478	2345	1987

To estimate the efficiency level of the farmers, the VRS DEA input-oriented model is adopted. This model is run for each farmer to calculate the efficiency score. This model can also be specified under the assumption of constant returns to scale for the estimation of the technical efficiency by the elimination of convexity constraint. The formulation below is done using the input-oriented model and assuming variable returns to scale ($\lambda 1+ \lambda 2+ \lambda 3+ \lambda 4 = 1$). The same formulation mentioned below for four farmers can be used to measure the efficiency under the assumption of constant returns to scale, the only need is to change the convexity constraint ($\lambda 1+ \lambda 2+ \lambda 3+ \lambda 4 = 1$) keeping the other formulation same for every farmer.

Formulation for Farmer 1

Min θ

With respect to

Seed level of the farmer 1

$$\lambda 1*2000 + \lambda 2*1200 + \lambda 3*1123+ \lambda 4*2563 \leq \theta*2000$$

Phosphorus nutrient level used by the farmer 1:-

$$\lambda 1*345 + \lambda 2*432 + \lambda 3*234+ \lambda 4*354 \leq \theta*345$$

Nitrogen use level of the farmer 1:-

$$\lambda 1*343 + \lambda 2*483+ \lambda 3*287+ \lambda 4*478 \leq \theta*343$$

The output level of Maize and Wheat produced:-

$$\lambda 1*2200 + \lambda 2*3999 + \lambda 3*1800+ \lambda 4*2385 \geq 2200$$

$$\lambda 1 *1678+ \lambda 2*3234 + \lambda 3*1876+ \lambda 4*1987 \geq 1678$$

Convexity Constraint:

$$\lambda 1+ \lambda 2+ \lambda 3+ \lambda 4 = 1$$

Thus, the above formulation represents that the DMU 1 had been using 2000 rupees, 345 kg phosphorus and 343 kg of Nitrogen fertilizer to produce the current level of the Wheat and Maize output. On solution, the linear programming equation will depict whether the DMU I had been using these inputs efficiently to convert them to current output, relative to the other DMUs.

The formulation for the second farmer can be done by changing the value on the right-hand side and keeping the left-hand side same in the above equations. The input and output utilized and produced by the second farmer can be put on the right-hand side for measuring the efficiency of the second farmer and the formulation is as under.

Input and output level of DMU 2 in Formulation

Min θ

With respect to

$$\lambda1*2000 + \lambda2*1200 + \lambda3*1123+ \lambda4*2563 \leq \theta*1200$$

$$\lambda1*345 + \lambda2*432 + \lambda3*234+ \lambda4*354 \leq \theta*432$$

$$\lambda1*343 + \lambda2*483+ \lambda3*287+ \lambda4*478 \leq \theta*483$$

$$\lambda1*2200 + \lambda2*3999 + \lambda3*1800+ \lambda4*2385 \geq 3999$$

$$\lambda1* 1678+ \lambda2*3234 + \lambda3*1876+ \lambda4*1987 \geq 3234$$

$$\lambda1+ \lambda2+ \lambda3+ \lambda4 = 1$$

Similarly, Input and output level of DMU 3 in Formulation

Min θ

With respect to

$$\lambda1*2000 + \lambda2*1200 + \lambda3*1123+ \lambda4*2563 \leq \theta*1123$$

$$\lambda1*345 + \lambda2*432 + \lambda3*234+ \lambda4*354 \leq \theta*234$$

$$\lambda1*343 + \lambda2*483+ \lambda3*287+ \lambda4*478 \leq \theta*287$$

$$\lambda1*2200 + \lambda2*3999 + \lambda3*1800+ \lambda4*2385 \geq 1800$$

$$\lambda1* 1678+ \lambda2*3234 + \lambda3*1876+ \lambda4*1987 \geq 1876$$

$$\lambda1+ \lambda2+ \lambda3+ \lambda4 = 1$$

Input and output level of DMU 4 in Formulation

Min θ

With respect to

$$\lambda1*2000 + \lambda2*1200 + \lambda3*1123+ \lambda4*2563 \leq \theta*2563$$

$$\lambda1*345 + \lambda2*432 + \lambda3*234+ \lambda4*354 \leq \theta*354$$

$$\lambda1*343 + \lambda2*483+ \lambda3*287+ \lambda4*478 \leq \theta*478$$

$$\lambda1*2200 + \lambda2*3999 + \lambda3*1800+ \lambda4*2385 \geq 3*2385$$

$$\lambda1 *1678+ \lambda2*3234 + \lambda3*1876+ \lambda4*1987 \geq 1887$$

$$\lambda1+ \lambda2+ \lambda3+ \lambda4 = 1$$

This above data presented in the linear formulation entered into Microsoft Excel and then excel solver is used to define the constraints. This equation runs four times, once for each farmer to calculate the efficiency level of the farmers. The results obtained by running excel solver results were also confirmed using software DEA (Xldea) to confirm the correctness of the results. The value of θ gives the efficiency score and the value of λ helps in finding the efficient peer to the particular firm under studied (Kamur and Rachita 2008).

For a firm to be efficient, it's all λ optimal value must be zero, The Technical Efficiency of the DMU 1 is .940, it elaborates that the farmer 1 is not fully technical efficient and still have the possibility to reduce its inputs up to 6 percent without any alteration in the current level of output. On the solution of the equation, it was seen that the farmer 1 can reduce the seed cost from PKR 2000 to PKR 1881, similarly phosphorus fertilizer from 345 kg to 324 kg and nitrogen use level from 343 to 322.

Table 3.5: Efficiency Score for Decision Making Units

Decision Making Units	Efficiency Score (variable returns to scale)
Farmer 1	0.9407
Farmer 2	1.0000
Farmer 3	1.0000
Farmer 4	0.7996

Table 3.5 is depicting that the farmers 1 and 4 are both technical inefficient and have the possibility to decrease their inputs level but farmer 2 and 3 are both fully efficient and have no room for further improvement.

3.5: IMPACT OF SCALE ON FARM PRODUCTIVITY

It is motivating to find out whether the inefficiency of DMU is caused by the inefficient operation of the DMU itself or by the detrimental circumstances under which the DMU is operating (Bhatt and Shaukat, 2014). For this reason, we can compare CRS and VRS models if a unit is fully efficient in both CRS and VRS models; it is operating in the most productive scale size (Banker et al 1984). The concept of scale efficiency was introduced by Lovell and Sickles (1983) and later elaborated by Färe et al. (1994).

If a DMU is VRS efficient, but inefficient in the CRS model for a particular, then it is locally efficient, but not globally and this is due to its scale size. Scale efficiency can be measured by dividing the technical efficiency score obtained under CRS with the result under the assumption of VRS (Islam *et al*., 2011). Scale efficacy is the ratio of technical efficiency under constant and variable returns to scale (Islam *et al*., 2011; Koc *et al*., 2011).

$$\text{Scale Efficiency (SE)} = \frac{TEcrs}{TEvrs} \quad \text{(Islam } et\ al.\text{, 2011)}$$

If the technical efficiency scores are dissimilar after solving the CRS and VRS model, then the DMU under evaluation is scale inefficient (Fandel 2003: Bielik & Rajčániová, 2004; Krasachat 2004, Abatania *et al*., 2012, Abatania, 2013). Scale Efficiency =1 shows that the unit is scale efficient in combining the input and outputs resources under the condition of CSR and VRS and a value below 1 represents that the combination of inputs and outputs is scale inefficient (Fandel 2003; Bielik and Rajčániová, 2004; Krasachat 2004; Koc *et al*., 2011; Abatania *et al*., 2012, Abatania, 2013). The difference in the technical efficiency under CRS and VRS indicates scale inefficiency (Krasachat 2004; Coelli 2005). Furthermore, from this measure of scale efficiency, it is not possible to make any prediction about whether the unit operate in an area of Increasing Returns to Scale (IRS), Decreasing Returns to Scale (DRS) or Constant Returns to Scale (CRS functioning under Increasing or decreasing returns to scale (Coelli *et al*., 1998; Murthy *et al*., 2009; Umanath & David, 2013). This problem can be solved by running another linear DEA model by adding restriction $N1'\lambda \leq 1$(Non-increasing returns to scale) instead of $N1'\lambda = 1$ (VRS) in the model (Fandel 2003; Krasachat 2004; Murthy *et al*., 2009; Krasachat 2004, Abatania *et al*., 2012, Abatania, 2013; Dao, 2013; Umanath & David, 2013) and then calculating the relevant technical efficiency (TE_{NIRS}).

The results obtained by running NIRS model can be used to predict the characteristics of the scale inefficiencies for a particular unit (Krasachat 2004, Abatania *et al*., 2012, Abatania, 2013). The nature or characteristics of the returns to scale can be identified by comparing the results of technical efficiency obtained through estimating NIRS, CRS and VRS models. Coelli (2005), Fandel (2003), Abatania *et al* (2012) Abatania, (2013) mentioned the following conditions to identify the nature of returns to scale:

1) Decreasing Returns to Scale if $TEnrs = TEvrs \neq TEcrs$
2) Increasing Returns to Scale if $TEnrs \neq TEvrs = TEcrs$
3) Constant Returns to Scale if $TEnrs = TEvrs = TEcrs$

The firm operating under increasing returns to scale implies that that the size of the firm is “too small” to effectively use the resources available and decreasing returns to scale implies that the size of firm “too large” and have less resources as required (Oduol, Hotta *et al*. 2006). Scale Efficiency in different farming system of the world is estimated in the studies of (Wadud and White 2000 ;Fandel, 2003; Krasachat 2004; Galanopoulos *et al*., 2006 Javed *et al*., 2011; Rahman and Brodrick ,2015; Madau, 2015; Lansink *et al*., 2002; Umanath & David, 2013a; Umanath & David, 2013b; Dao, 2013; Bhatt and Shaukat, 2014; Linh *et al*., 2015; Khan *et al*., 2016)

3.6: ALLOCATIVE AND ECONOMIC EFFICIENCY DEA MODELS

The most efficient way of production is determined by following different decision criteria by the farmers. In neoclassical and conventional theories, small farmers' behaviour and objectives in farm management decisions are explained by assuming the profit maximization and work were carried out on the premise that farmers give priority and mostly focuses on profit maximization in decision making rather putting more attention on other objectives (Mendola 2007). Behind production decisions, small farmers have different economic and non-economic motives and objectives varying from profit maximization to meet the basic household needs, children's education and self-satisfaction for being in farming etc. The profit maximization requires cost minimization and by observing the cost minimization behavior of the farmers would help to decide that whether their decision on the allocation of resources is based on the rationale of profit maximization. Allocative efficiency also known as price efficiency differs from technical efficiency and it is "the ability of a producer to produce a given level of output by selecting that set of inputs which minimize the cost of production "(Coelli 2005). Allocative efficiency also represents the ability of a producer to utilize the inputs in optimal proportions, given their respective prices (Coelli 1996; Awerije & Sanzidur, 2014). According to Bojnec and Latruffe (2009), allocative inefficiency reveals divergence of the firm from frontier under given the market price of end product and inputs. They further argued that allocative efficiency determines how the output can be maximized by combining and utilizing the factors of production at given market price of inputs and output. On multiplication, technical and allocative efficiency is conceptualized as overall economic or cost efficiency (Ajibefun 2008; Coelli 1996; Shafiq1998). Economic efficiency deals with profit maximization and is achieved when a firm appears efficient both technically and allocatively (Asogwa, 2011).

The price information about the various inputs is collected from the respondents to measure the economic and allocative efficiency of the farmers. The economic efficiency is the multiplicative of allocative and technical efficiency, so

Model 3.7 (This model is used in Chapter 6 to derive cost and allocative efficiency)

$$\mathrm{Min}_{\lambda xi*} \quad w'_i x_i^* \qquad (3.20)$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j \geq y_{ro} \qquad (3.21)$$

$$\sum_{j=1}^{n} x_{ij}\lambda_j \leq x_i^* \tag{3.22}$$

$$\sum_{j=1}^{n} \lambda_j = 1 \tag{3.23}$$

$$\lambda_j > 0 \qquad i = 1, \ldots \ldots m; \qquad r = 1, \ldots \ldots, s; \qquad j = 1, \ldots \ldots n;$$

Source:(Coelli, 2005; Islam *et al*., 2011; Umanath & David, 2013a; Awerije & Sanzidur, 2014)

w'_i represent the input price of the i-th farm and x_i^* is a cost minimization vector of the input quantities for the i-th farm calculated by DEA model under the price w'_i and output y_{ro} (Coelli, 2005; Islam *et al*., 2011; Umanath & David, 2013a). The cost efficiency can be derived as:

$$\text{Economic Efficiency} = \frac{w'_i x_i^*}{w'_i x_{i*}}$$

(Coelli, 2005; Islam *et al*., 2011; Umanath & David, 2013a; Awerije & Sanzidur, 2014)

The ratio of minimized cost to observed cost gives cost efficiency (Umanath & David, 2013a; Awerije & Sanzidur, 2014). The allocative efficiency can be measured easily by dividing the cost efficiency score with the technical efficiency score, which is obtained running variable returns to scale (Umanath & David, 2013)

$$\text{Allocative efficiency} = \frac{\text{Economic Efficiency}}{\text{Technical Efficiency}}$$

(Islam *et al*., 2011; Umanath & David, 2013a; Awerije & Sanzidur, 2014; Thabethe *et al*., 2014)

The cost efficiency has been measured in the study of (Ahmad *et al*., 2002; Javed *et al*., 2008; Islam *et al*.,2011; Ogundari & Ojo, 2007; Watkins *et al*., 2013; Mburu *et al*., 2014; Thabethe *et al*., 2014 ; Khan *et al*., 2016; Khan *et al*., 2016) while allocative efficiency is estimated by (Jha *et al*., 2000; Bashir & Dilawar, 2005; Bakh and Serajul, 2005; Dhungana *et al*., 2004; Henderson & Ross, 2002; Olson and Vu, 2007; Javed, 2009; Langemeier, 2010; Hasanov & Ahmed, 2011; Mokgalabone, 2015; Fatima *et al*., 2017).

3.7: SIMAR AND WILSON BOOTSTRAP MODELS FOR DEA

The statistical properties of the estimators have been ignored in a large number of DEA studies and any divergence from the frontier is linked with inefficiency. Excluding statistical properties and noise in the estimation can lead to biased DEA estimates and misleading result. Recently, some attempts have been made to establish theoretically and empirically the statistical properties of DEA estimators. To overcome this problem, Simar and Wilson (1998, 2000) put forward a smoothed bootstrapping method to get consistent estimation and to enable statistical inference. To correct the bias in DEA estimators and establish their confidence interval, Simar and Wilson (1998, 2000) smoothed bootstrap procedure that is used is as under. The Algorithm 1 of Simar and Wilson (1998, 2000) is applied by a number of researchers (Brümmer 2001; Ortner *et al*., 2006; Oslon and Vu, 2007). A detailed procedure is presented below:

1) Calculate the DEA efficiency scores $\hat{\theta}_i$ for the ith farm under constant returns to scale (CRS) or (VRS) for each farm among N farms ($i = 1, \dots, n$)
2) Let $\beta_1 \dots\dots \beta_k$ be a simple bootstrap sample from $\hat{\theta}_1 \dots\dots \hat{\theta}_k$ Generate a random sample of size k for the random generator:

$$\tilde{\theta_l} = \begin{cases} \beta_i + h\varepsilon_i \\ 2 - \beta_i + h\varepsilon_i \end{cases} \quad \text{if } \beta_i + h\varepsilon_i \leq 1 \; otherwise$$

Whereε_i is a random deviation from the standard normal and h is the bandwidth of a standard normal kernel density.

3) Construct another sequence to correct the variance of the generated bootstrap sequence when kernel estimators are used,

$$\theta_i^* = \bar{\beta} + \frac{1}{\sqrt{1 + \mathrm{h}^2/\hat{\sigma}_\theta^2}}\left(\theta_i - \bar{\beta}\right) where \; \bar{\beta} = (1/n)\sum_{i=1}^{N}\beta_i$$

Thus, the sequence θ_i^* is obtained by the smoothed bootstrap. It has better properties than the simple bootstrap sequence in the sense that the variance of θ_i^* is asymptotically correct.

4) For i=1,..,N, a pseudo data set of $(x_{i,b}, y_{i,b})$ where $x_{i,b} = \left(\hat{\theta}_i / \theta_i^* \right) x_i$ and $y_{i,b} = y_i$ with x_i , y_i the original input and output vectors of the ith farm, respectively

5) Calculate the new DEA score $\hat{\theta}_i^*$ for each farm by taking the pseudo data as reference

6) Repeat step (i) to (iv) for B times to yield B new DEA technical efficiency scores $\hat{\theta}_i^*$ for i=1,…,N.

$$\widehat{bias}_b(\hat{\theta}_i) = B^{-1} \sum_{b=1}^{B} (\theta_i^* - \hat{\theta}_i)$$

The bias-corrected estimator of $\hat{\theta}_i$ can be computed as $\hat{\hat{\theta}}_i = \hat{\theta}_i - \widehat{bias}_b(\hat{\theta}_i)$

7) The percentile method is involved in constructing a confidence interval. The confidence interval for the true value of $\hat{\theta}_i$ can be established by finding value a_α , b_α such that Prob$(-b_\alpha \leq \hat{\theta}_i^* - \hat{\theta}_i \leq -a_\alpha)$ = 1-α. Since we do not know the distribution of $(\hat{\theta}_i^* - \hat{\theta}_i)$, we can use the bootstrap values to find $\hat{a}_\alpha$, $\hat{b}_\alpha$ such that Prob $(-\hat{b}_\alpha \leq \hat{\theta}_i^* - \hat{\theta}_i \leq -\hat{a}_\alpha)$ = 1-α. It involves sorting the value of $(\hat{\theta}_i^* - \hat{\theta}_i)$, for b =1,…,B in increasing order and deleting ((α)2/ ×100 percent of the elements at either end of this sorted array and setting - $\hat{a}_\alpha$ and - $\hat{b}_\alpha$ at the two endpoints, with $\hat{a}_\alpha \leq \hat{b}_\alpha$.

To ensure the low variability of the bootstrap confidence intervals the models is solved for 2000 bootstrap iterations. The value of bandwidth of the density estimate h is found by Simar and Wilson (2000)'s method of minimizing an approximation to the mean weighted integrated square error.

3.7.1: Statistical Inference at second stage

In this research, the truncated regression presented below is used to regress the set of independent variables on dependent variables. The efficiency estimate in this research is $\hat{\theta}_i$ where (1-$\hat{\theta}_i$) donate the potential input saving (Gadanakis, 2013).

$$\hat{\theta}_i = z_i\beta + \varepsilon_i \leq 1$$

ε_i is The error term and this error term, ε_i for each observation i is drawn from a distribution N (0, $\hat{\sigma}_\varepsilon^2$) within the bootstrap algorithm, for which we assume a left-truncation at $(1 - z_i\beta)$ (Zschille, *et al*., 2009; Gadanakis, 2013). Where β is a vector of parameters and z_i is a vector of independent variable influencing the choice and use of $x \, and \, y$. The double bootstrap procedure in literature referred to as Algorithm 2 (Simar and Wilson, 2007) and used in this research to drive the determinants of technical efficiency. The seven steps of the double bootstrap algorithm are as follows. The Algorithm 2 of (Simar and Wilson, 2007) applied in the studies of (Latruffe *et al*., 2005, Balcombe *et al*., 2008; Gadanakis, 2013; Ndjodhi, 2016).

1) A DEA input-orientated efficiency score $\hat{\theta}_i$ is calculated for each farm ($i = 1, \ldots, n$), (VRS case):

2) Employ Maximum likelihood in the truncated regression of $\hat{\theta}_i$ on z_i, to drive an estimate of $\hat{\beta} \; of \; \beta$and an estimate $\hat{\sigma}_\varepsilon$ o fσ_ε.

3) The below mentioned four steps (a-d) are repeated B1 times to obtain a set of B1 bootstrap estimates $B_i = \{\hat{\theta}_i^*\}_{b\,=\,1 \ldots B1}^{B1}$ for each farm ($i = 1, \ldots, n$)

   a) ε_i is drawn from the N (0, $\hat{\sigma}_\varepsilon^2$) distribution with left-truncation at $(1 - z_i\beta)$
   b) Compute $\hat{\theta}_i$ = z_iβ +ε_i for each farm ($i = 1, \ldots, n$)
   c) A pseudo data set (x_i^*, y_i^*) is constructed, where $x_i^* = x_i$ and $y_i^* = y_i(\frac{\hat{\theta}_i}{\theta_i^*})$
   d) A new DEA estimate $\hat{\theta}_i^*$ is computed on the set of pseudo data(x_i^*, y_i^*), i.e. Y and X are respectively replaced by $Y^* = \{\; y_i^* \; i = 1, \ldots, n\}$, and $X^* = \{\; x_i^* \; i = 1, \ldots, n\}$, in program (2).

4) For each farm i=1,…,n, the bias-corrected estimator $\hat{\hat{\theta}}_i = \hat{\theta}_i - \widehat{bias}_b(\hat{\theta}_i)$ is computed as follows: where $\widehat{bias}_b(\hat{\theta}_i)$ is the bootstrap estimator of bias obtained as (Simar and Wilson, 1998):

$$\widehat{bias}_b(\hat{\theta}_i) = B^{-1} \sum_{b=1}^{B} (\theta_i^* - \hat{\theta}_i)$$

5) Maximum likelihood is used in the truncated regression of $\hat{\theta}_i$ on z_i, to provide an estimate$\hat{\hat{\beta}}$ of β and an estimate$\hat{\hat{\sigma}}$ of σ_ε

6) The next three steps (a-c) are repeated B2 times to yield a set of B2 bootstrap estimates $k = \{(\hat{\beta}^*, \hat{\sigma}_\varepsilon^*)b\}_{b\,=\,1 \ldots B2}^{\mathrm{B2}}$

   a) For each farm $i = 1, \ldots, n$ ε_i is drawn from the N (0, $\hat{\hat{\sigma}}_\varepsilon^{2)}$distribution with left truncation at $(1 - z_i\hat{\hat{\beta}})$.

b) For each farm $i = 1, \ldots, n$, $\theta^{**i} = z_i\hat{\beta} + \varepsilon_i$ is computed.

c) Maximum likelihood is used in the truncated regression of θ^{**i} on z_i, to provide an estimate $\hat{\hat{\beta}}^*$ of β and an estimate $\hat{\hat{\sigma}}^*$ of σ_ε

7) Confidence intervals are constructed. The estimated $(1-\alpha)$ per cent confidence interval of the j-th element β_j of the vector β, is as follows: Prob$(lower_{\alpha j} \leq \beta_j \leq upper_{\alpha j}) = (1-\alpha)$ where $lower_{\alpha j}$ and $upper_{\alpha j}$ are calculated using the empirical intervals: Prob $(-\hat{\beta}_\alpha \leq \hat{\hat{\beta}}_j^* - \hat{\hat{\beta}}_j \leq -\hat{a}_\alpha) \approx 1-\alpha$ where $upper_{\alpha j}$=$\hat{\hat{\beta}}_j + \hat{b}_\alpha$ and $lower_{\alpha j}$=$\hat{\hat{\beta}}_j + \hat{a}_\alpha$. The same method is applied to construct confidence intervals for the efficiency scores (Simar and Wilson, 2000).

Sources: (Gadanakis, 2013; Ndjodhi, 2016)

3.8: ADVANTAGES AND DISADVANTAGES OF DATA ENVELOPMENT ANALYSIS

Data Envelopment Analysis has numerous advantages and disadvantages linked to it. These advantages and disadvantages must be kept under consideration while measuring the relative efficiency of the decision making units using DEA. These are summarized below:

1) DEA can be used with any type of data that involves inputs and outputs (Rayeni and Saljooghi, 2013)
2) DEA contrary to parametric approach, capable of handling multiple inputs and outputs which make it more appropriate tool for efficiency estimation (Banker *et al* 1984; Coelli 1996; Lu, 2012; Rayeni and Saljooghi, 2013)
3) Furthermore, compared to parametric approaches, DEA is independent of any prior assumption about the functional form, i.e. it does not require any explicit specification of the production function that shows the technological relationship between the inputs used and output produced (Rayeni and Saljooghi, 2013). Instead, the efficiency of the DMUs is measured relative to the other units in the group by imposing the restriction that all DMUs lie on or below the efficient frontier (Reig-Martinez and Picazo-Tadeo 2004; Brock *et al* 2007).
4) Unlike the regression analysis models providing focus on mean values of the group, DEA estimates the efficiency and inefficiency related to each individual unit (Gullipalli 2011).
5) In DEA methodology, the efficient peer can be identified for the inefficient unit and it provides an insight that how inefficiency of the inefficient unit can be removed (Martic *et al*., 2009; Villano, 2009; Huguenin, 2012; Osamwonyi & Kennedy, 2015)

6) The most distinguishing features of the DEA, which make it preferable over other conventional methodologies is its independence upon the unit of measurement used (Coelli 1996; Lanh 2009).

However, like any empirical method, DEA consists of a number of simplifying assumptions that need to be acknowledged when interpreting the results of DEA studies. DEA's main limitations include the following:

1) Direct hypothesis testing in DEA methodologies is not possible as in stochastic production frontier. In DEA, the efficiency score is measured at first instant and then the hypothesis is tested using regression equation, usually censored regression is recommended (Rios and Shively 2005; Ajibefun 2008)
2) The data envelopment analysis appears to be highly sensitive to the selection of variable and secondly, the increase in the number of inputs and output variables tend to improve the personal ranking of the DMUs by pushing them on the efficient frontier (Shafiq, 1998). There are different rules to overcome on this issue; one rule is that the number of DMUs in the analysis should be at least three times greater than the number of outputs and inputs (Nunamaker 1985).
3) DEA has the ability to measure relative technical efficiency and it is not capable of estimating absolute efficiency. This implies that 100% technical efficient units are best among the peers, but may not be 100% absolutely efficient (Gullipalli 2011).

3.9: SUMMARY

In this chapter, the framework for the analysis of various kind of efficiency with particular reference to agricultural production is presented. As stated early in the chapter, data envelopment analysis is preferred over SFA in this study to measure the relative efficiency of the farms in the mixed farming system of Pakistan. Initially, the basic input and output oriented CRS and VRS models were explained and specified in the primal and dual form. Then, the dual linear DEA model was illustrated with the help of an illustrative example. With the passage of time and advancement in the DEA literature, Additive, multiplicative and non-discretionary, subvector, MI and bootstrap models made their roots in the efficiency literature. However, only the DEA models that are used in this study were discussed comprehensively. In this research, the following DEA models described in section 3.3 and its sub-sections were considered to evaluate the efficiency of the mixed farming system at the individual crop and aggregated level later in Chapter 6 and 7:

i) Input oriented conventional DEA CRS model (3.3)

ii) Input oriented conventional DEA VRS model (3.4)

iii) The Slack-based DEA model (3.6)

iv) Scale Efficiency is estimated by comparing CRS and VRS models

v) Models related to cost and Allocative efficiency Estimation (Model 3.7)

One of the major reasons for selecting DEA in this research is to perform the bootstrapping in order to enable statistical inference to correct the efficiency from biases. The efficiency literature that has used SFA and conventional DEA models is enormous in Pakistan (Hussain, 1995; Parikh *et al*., 1995; Burki and Shah, 1998; Mari and Heman 2007; Ahmad, 2002; Ahmad, 2003; Hassan & Ahmad, 2005; Bashir and Dilwar, 2005; Abedullah *et al*., 2006; Abedullah *et al*., 2007,Iqbal *et al*., 2009; Shaheen *et al*., 2011;Hussain *et al*., 2012; Naqvi and Ashfaq 2013; Saddozai *et al*., 2013; Rauf *et al*., 2014; Battese *et al*., 2014, Ali and Munir, 2014, Miraj and Ali , 2014; Khan and Ghafar, 2013; Buriro *et al*., 2013; Khan and Farman., 2013; Dilshad and Afzal 2012; Bakhsh *et al*., 2014; Saddozai *et al*., 2015; Elahi *et al*., 2015; Gill, 2015; Ali *et al*., 2013; 2016; Fatima *et al*., 2016; Shafiq and Rahman ,2000; Ayaz *et al*., 2010; Watto, 2013; Bhatt and Shaukat, 2014; Hameed *et al*., 2014; Fatima, 2015; Hashmi *et al*., 2015; Usman *et al*., 2016). Therefore, it is assumed that the results through conventional DEA model may be influenced by sampling variation, therefore, the bootstrapped DEA procedure developed by Simar and Wilson (1998; 2000) is adapted to correct the efficiency from potential bias in the efficiency estimates. The bootstrap DEA models of Simar and Wilson (1998; 2000) mentioned in section 3.7 are used for two purpose:

1) To correct the efficiency from bias and compare results generated by conventional and bootstrap models
2) To establish confidence intervals for each estimated efficiency score to compare farms in the sample

One of the major components of DEA analysis is to incorporate the various socio-economic, agronomic, and environmental factors at the second stage to identify major factors that are vital in improving the efficiency of the farms. At the second stage, the use of Tobit regression model is quite famous among researchers and a large number of studies emphasized on this models at second stage (Krasachat 2004; Dhungana *et al*., 2004; Javed *et al*., 2008; Rios & Shively, 2005; Speelman *et al*., 2008; Mahdi *et al*., 2009; Gul *et al* ., 2009; Ayaz *et al*., 2010; Koc *et al*., 2011; Mirza *et al*., 2015;

Linh *et al*., 2015; Khan *et al*., 2016). However, Simar and Wilson (2007) suggested that a double bootstrapped truncated regression should be used instead of the Tobit model in the two-step contextual analysis. The ordinary regression models do not take into consideration the serial correlation among the DEA estimates and correlation of the inputs and outputs used in the first stage with second-stage environmental variables (Melkaw, 2014). Therefore, in this research, the following model described in section 3.7 is used at the second stage to find the determinant of TE.

1) Truncated Regression Model in second step contextual analysis

In addition to these models, the concepts and terms related to the technique of DEA are discussed in Section 3.2. The sub-section 3.2.10 helped to identify the set of inputs and outputs used in different cropping systems. A huge volume of literature is studied to grasp information about the important variables that can be used in DEA models with particular reference to crop production. Based on this knowledge, the variables that are included in the DEA models in Chapter 6 are selected. One of the important features of the DEA is that it identifies the "Peer Farms or referent units" for the inefficient farms through benchmarking analysis. In section 3.2.5, the benchmark analysis that is later used in Chapter 6 and 7 is elaborated comprehensively. The benchmark analysis is included in this research because it provides an opportunity to the inefficient farms to rectify their mistakes or evaluate their decisions related to crop production to operate on the efficient frontier. This can be achieved by evaluating the production technology that is used by the peer farms and then making adjustments in the level of inputs as used by their benchmarked farms. At the end of this Chapter, numerous advantages and disadvantages that are nexus with the technique of DEA are elaborated.

CHAPTER 4

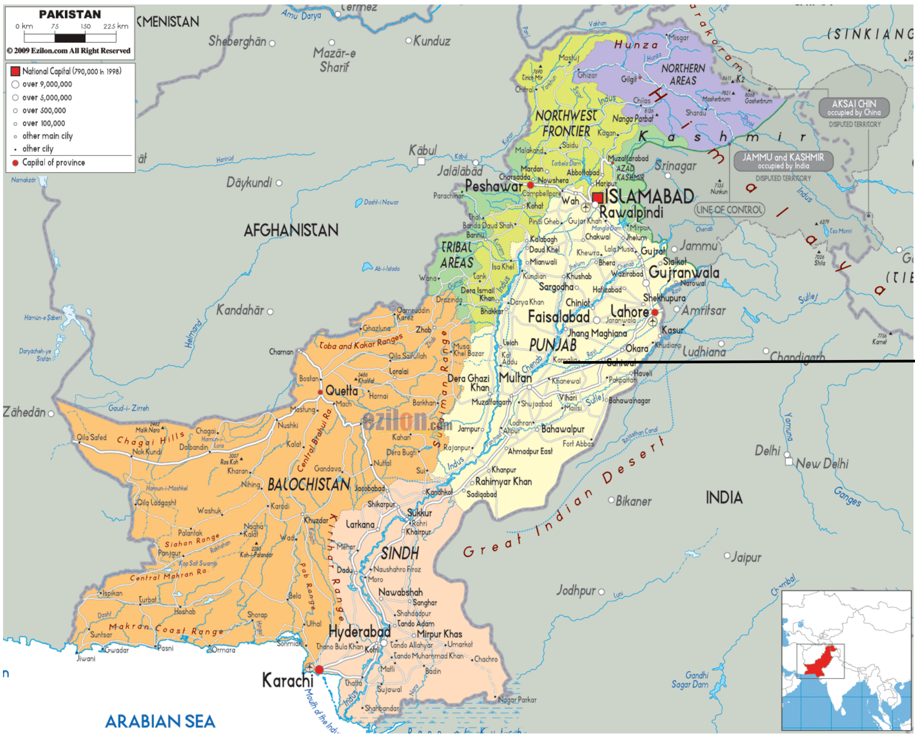
SURVEY METHODOLOGY

Research is a tool to expose hidden facts, theories, and application about something in a systematic and investigating manner. Research methodology encompasses an explicit system of techniques and procedures which govern the conduct of research and important to achieve the desired goals. A well-defined research methodology provides an opportunity and confidence to the researcher to move forward in the right direction for the successful accomplishment of tasks related to research objectives (Qazi, 1996).

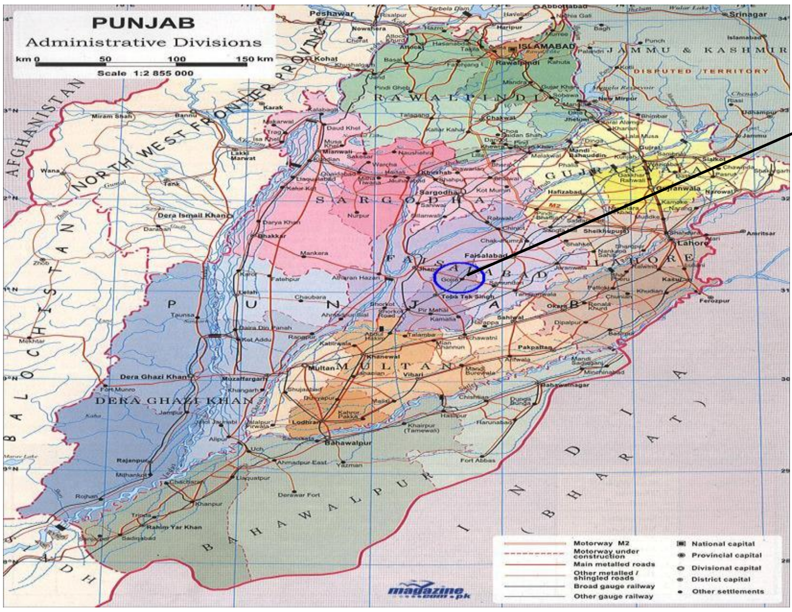
The research design is a plan, structure, and strategy of the investigation so conceived as to obtain answers to research questions and problems. Research design constitutes sketch of what the researcher will do from writing the hypothesis and their operational implications to the final analysis of data and provides a procedural layout to answer the research questions objectively, accurately, economically and validly (Kumar, 2010). This chapter is designed to describe the survey methodology that is adopted in this research for the attainment of fundamental and specific objectives of the study. This chapter comprised of five sections, the first section includes the detail about the study area followed by the sampling methods used to draw samples: the third section provides the detail about the sampling tool used and procedure by which the survey is employed; the whole summary of this chapter is discussed at the end of this chapter.

4.1: DESCRIPTION OF STUDY AREA

The present empirical study is conducted in Punjab of Pakistan. Geographically Punjab is the second largest province in Pakistan, where about 56 percent of the country's population lives (Piesse, 2015). Nearly 60 percent area of this province is under cultivation, constituting 56% of the total cultivated area. It contributes significantly towards agricultural output and shares more than 76 percent of cereal, around 73 percent each of the sugarcane and nearly 82 percent each of the cotton, pulses, and vegetable output (Mekonnen et.al 2016).



PUNJAB PROVINCE



FAISALABAD DISTRICT

1-Faisalabad city
2-Faisalabad sadar
3-Jaranwala
4-Chack jhumra
5-Samundri
6-Tandlianwala

Figure 4.1: Map of Pakistan and District Faisalabad

The Punjab province plays an important role in agricultural development, and it is a recognized area in terms of providing food for the country (Ahmad, 2001). Punjab province is divisible into three crop production zones, namely cotton-wheat, rice-wheat and mixed cropping (Hussain *et al*., 2012; Elahi *et al*., 2015; Aslam, 2016). The cotton-wheat cropping system consists of growing cotton along with wheat, in the well-known area of Multan, D.I. Khan and Bahawalpur divisions located in the southern part of the Punjab. The Rice and wheat cropping system are followed in Lahore and Gujranwala Division where rice is the major cash crop grown due to the availability of plenty of canal and good quality groundwater (Imtiaz *et al*., 2012). The mixed cropping system prevails in Faisalabad and Sargodha divisions where sugarcane wheat, potatoes, and maize along with cotton and fodder crops are grown (Ahmad, 2001)

For the present study, Faisalabad district, located in the center of the mixed farming system is selected as a study site because over here 81 percent of farmers operate small farms which are intensively cultivated. The estimation of efficiency in this area will give new insight into the problem that how much reduction and expansion in output is possible, where the farmers are already trying to gain maximum output. Faisalabad (formerly known as Lyallpur) is the third largest city after Karachi and Lahore in Pakistan. It is also called the Manchester of Pakistan due to its textile Industry. It is located in the central Punjab with an area of 5856 Sq km with an average maximum temperature of 50 °C in summer and minimum of 6 °C in winter (Government of Punjab, 2016). The annual average rainfall is recorded at 400 mm.

4.2: RESEARCH DESIGN

There are three paradigms that are applied in the scientific research. These extensively used paradigms are qualitative, quantitative and mixed method research. The choice of one of these paradigms or both, in the research based upon the nature of the study to be conducted (Photakoun 2010). Quantitative paradigm was dominant for the most of the 20th century, but afterward, the qualitative study design often conceptualized as the polar opposite of quantitative research came as an alternative to quantitative research during 1980,s (Seale *et al*., 2007). Campbell & Holland (2005) explained: "quantitative research produces data in the form of numbers that can be collected and analyzed to explain and guess relationships while qualitative research tends to produce data in prose or text forms and can help to search and explain those relationships, and to explain contextual differences in their quality". In this research, I decided to use the mixed method paradigm to answer the research questions. Mixed method is research in which the researcher applies the qualitative research paradigm for one phase of a research study and the quantitative research paradigm for another phase of the study (Leech & Onwuegbuzie, 2008, Creswell, 2013). In this study, quantitative research method is applied to estimate the technical, allocative and economic efficiency of the farmers by collecting quantitative data. In the second part of the research, which is to explore the role of extension in efficiency improvement? Qualitative data are collected through various sources to meet this research objective.

4.3: SAMPLING PROCEDURE

Negash (2007) stated, “A clear and precise identification and definition of the population is an important prerequisite for research sample design”. “Population” is defined as the whole set of individuals, units or items having similar characteristics to be studied (Burns & Grove 1997). In this study, all farmers in Faisalabad District are considered as the population of this study. To study the whole population is cumbersome and not feasible in an empirical investigation. Therefore, to make inferences and generalizations, the information is usually derived from a representative sample of the population. The representative sample in terms provides detailed knowledge about the whole population (Kumar, 2010).

Therefore, Sampling is a process of obtaining information about the entire population by selecting a part of that population (Barreiro et. al 2001). Sampling can be a powerful tool for precisely measuring opinions and characteristics of a population. However, there is a genuine hazard for misuse of sampling techniques by researchers who do not comprehend the limitations of various sampling procedures (Barreiro et. al 2001). In the statistical survey, it is, therefore, necessary to keep in mind the certain factors like time, the resources available before starting the data collection. Probability and non-probability sampling are the common types of sampling used in the research (Saunders et al., 2012; Andersson, 2014). A probability sample is a method in which every entity in the population has a possibility (greater than zero) of being selected in the sample, and its probability can be measured precisely (Saunders et al., 2012). Non-probability sampling is a sampling technique in which several units of the population have no chance of selection (these are sometimes referred to as 'out of coverage'/'undercovered'), or where the probability of selection can't be precisely defined. It includes the selection of individuals relies on assumptions regarding the population of interest, which forms the criteria for selection.

The differences between non-probability and probability sampling procedures are often complicated to distinguish, but extremely necessary for determining how the results of the research can be used (Barreiro et. al 2001). Non-probability sampling techniques can give important information, but the results cannot be generalized to a larger population, nor can statistics indicating the reliability of the results be calculated (Saunders et al., 2012). However, well-conducted probability samples provide the researcher confident to collect data from a relatively small portion of a large population and the result can be generalized to the entire population (Fox *et al*., 2009).

In this research, two sampling designs, purposive (non-probability) and simple random (probability) sampling were applied for the selection of the study area and the respondents. A multi-stage sampling procedure is followed to draw a representative sample from the population. Faisalabad city, Faisalabad Sadar, Chak Jhumra, Tandlianwala, Jaranwala and Samundri are the six tehsils* in Faisalabad District. Out of these 6 tehsils, two tehsils named Jaranwala and Saumandri were selected purposively as a representative of this district. These tehsils are selected because farmers in these areas are involved growing cotton, wheat, sugarcane, and maize crops. Because, the focus of this study is to estimate the efficiency of these four crops, therefore these two tehils are selected. The purposive technique was also employed by (Tesso et al., 2015; Mwajombe & Malongo, 2015). After making the selection of these tehsils, the data regarding union councils present in each tehsil were collected from the Extension and Adaptive Research (Extension and adaptive research Department is located in Faisalabad and list of union councils and villages are collected by personally visiting the office). From the list of union councils, five union councils were selected by simple random sampling from each tehsil. Therefore, a total number of ten union councils were selected, five from each tehsil. After selection of union councils, it is decided to choose one village from each union council through random sampling to make a total of ten villages. Random sampling was also used in different efficiency study (Idiong, 2007; Islam et al., 2011; Umanath & David, 2013; Thabethe et al., 2014)

4.3.1: Sample Size

After deciding sampling design, the decision about sample size is a challenging and crucial task (Gupta 2002). Fox *et al* (2009) and Xu (1999) stated that to make inferences about the population and to generalize the results with a given level of confidence, it is very much essential to select the appropriate sample size. There is no fixed rule and every method provides a rough estimation. One method usually adopted is to take a sampling fraction equal to 1/10 of the total population, however, there are exceptions to this criterion depending on the size of the population and time and resources available (Shafiq, 1998). Statistical formulae to obtain the required sample can also be used. In statistics it is evident that larger the sample size lesser will be the sampling error and more authentic the results will be, because larger sample size helps in an efficient measurement of the parameters (Gupta 2002; Xu 1999 and Fox *et al* 2009)

Therefore, an important consideration needs to be taken while selecting a sampling technique is about the size of the sample (Andersson, 2014). The selection of appropriate sample size is influenced by various factors relating to the subject under investigation like the time aspect, the cost aspect, the degree of accuracy desired, etc. (Rangaswamy, 1995; Sarantakos, 1998; Andersson, 2014). In this study, to determine sample size, different factors were taken into consideration, including research cost, time, human resource, accessibility, and availability of transport.

Based upon the above-discussed facts, it was decided to survey 250 respondents that would provide enough information to conduct the analysis. This sample size is enough because DEA is independent of the numbers of DMUs used in models. In all total number of 10 villages were selected from the list of union councils through simple random sampling technique. In each selected village, a complete list of the small farmers was prepared by getting help from the Numberdar (Representative of Government in the village) of each village and the person involved in collecting irrigational bills. From this list, total numbers of 25 farmers were selected through random sampling technique from each village. On many occasions, there were lots of absentee farmers, whose name was on the list, but the land is actually cultivated by another person. In that case, the person who is actually cultivating the land was interviewed. During the interview process, an attempt was made to cover all the dimensions of the village. So, total numbers of 250 farmers were surveyed from 10 villages.

4.4: DATA COLLECTION INSTRUMENTS

Research data can be collected through various means like a focus group, telephone and e-mails, personal observations, questionnaires and group discussion. The major portion of this research is quantitative; therefore, it is decided to use the questionnaire to collect the relevant information by because the carefully designed questionnaire is best when the purpose is to collect quantitative data.

4.4.1: Questionnaire Development

A questionnaire is a research tool comprised of a set of questions and other prompts for gathering data from the population. The questionnaire was the tool used in this research to collect the data from the farmers. The questionnaire is developed keeping in mind the objectives of the study and contained carefully designed questions in order to collect data from the respondents. Saunders, Lewis, and Thornhill (1997) maintain that a questionnaire is the best method of collecting data, especially if the survey strategy is used and if the respondents cannot read or write. According to FAO (2005) published in his report that without a well-structured and well-planned questionnaire, it is impossible to get success in the survey. The background created by the questionnaire has a great influence on how individual questions are interpreted and answered. As a result, survey researchers must carefully design the questionnaire as well as individual questions. There are no hard-and-fast rules for a well-designed questionnaire. Nonetheless, some key principles should guide the design of any questionnaire, and some systematic measures should be considered for refining it. These points are:-

i. The questions in the questionnaire should be in line with the research objectives. Many researchers omit important points from the questionnaire due to inadequate preparatory work and do not bring forth particular issues due to poor understanding. To provide a base for further research, some questions remain unanswered in a survey, but the aim of high-quality questionnaire design is to 'minimize' these issues
ii. The questionnaire should obtain the most complete and accurate information possible. The researcher needs to ensure that questions are completely understood by the respondents and are not likely to refuse to answer, lie to the interviewer. Reliable questionnaire gives respondents a confidence to provide accurate and unbiased information.
iii. The questionnaire should be organized so that sound data analysis and interpretation be possible.
iv. The questionnaire must contain easy and clear language that can be understood instantly.
v. The ordering of the questions must be correct. The interesting questions must be during the start so that to develop the interest of respondents in the study.

Keeping in mind all the aspects, a well-structured and comprehensive questionnaire was prepared by reviewing different online literature and Ph.D. thesis. The developed questionnaire has the abilities to provide enough information that can be used to fulfill the study objectives. The questionnaire designed for the study was subjected to a validation process. The copies of the questionnaire were submitted to the supervisors to check the validation of the instrument. These academic supervisors thoroughly studied the content and research questions to ascertain the appropriateness, completeness, and adequacy of the questionnaire. After receiving feedback several times, the questionnaire was ready for pilot testing. To produce both qualitative and quantitative data, respondents of the area were interviewed using a validated questionnaire. The questionnaire was divided into various parts to collect the information on various aspects needed to fulfill the objectives of the study. The detail of the questions included in each part is as under.

i. The first part includes a set of questions designed to obtain information about the personal, socioeconomic and farm characteristics of the respondents.
ii. The second part of the questionnaire contains comprehensive questions concerning production technologies used to grow wheat, sugarcane, cotton, and maize. The Information will be collected about resources (land, labour, fertilizer, seed, and farm machinery) and time of application of various physical inputs, physical quantities of inputs used along with cost estimates and quantities of output produced.
iii. The third part contains series of open-ended, closed and rating scales questions to collect information about the market, credit agency and preferred source of communication channel for information to cover the objective of the study related to agricultural extension. Explicit response categories were created in case of closed-ended questions, but open-ended questions were without explicit response choices and respondents were free to provide their response in their own words.
iv. In the last part of the questionnaire, detailed questions are included to probe out the relation of a farming community with the extension service providers in that area. It also contains the question to identify the factors responsible for the low interaction between extension staff and farmers and to check what type advisory services are rendering by the extension services in the study area.

Similar to this study, the different empirical studies also collected the data through survey by developing a questionnaire (Binam et al., 2005; Ogundari & Ojo, 2007; Javed et al., 2008; Koc et al., 2011; Hussain et.al 2012, Mohapatra, 2013; Mwajombe & Malongo, 2015; Brodrick & Sanzidur, 2014;Samie, 2016). Contrast to survey, the different efficiency studies preferred secondary sources of (Burki & Shah, 1998; Ahmad *et al*., 2002; Iraizoz *et al*., 2003; Martinez & Tadeo, 2004; Bhushan, 2005; Fogarasi, 2006; Latruffe *et al*., 2008; Bojnec and Latruffe, 2009)

4.4.2: Pre-Testing Of Questionnaire

After the development of the questionnaire, the next step was to pre-test the questionnaire on pilot respondents in order to identify weaknesses, errors, and ambiguities in the newly constructed questionnaire (Casley and Kamur 1988). Therefore, before the conduct of the formal survey, the importance of pre-testing or piloting the questionnaire is paramount. The aim of the pilot testing is to check whether the developed questionnaire is workable and applicable at the field level, and secondly, pilot-testing of the questionnaire provides an opportunity to the researcher to refine the problematic area in the questionnaire. Any problems relating to the content, wording, layout, length, instructions, or the coding can be explored after pilot-testing and should be amended accordingly. Finally, a pilot study may reveal problems relating to the sample size (variability), non-response rate and more practical issues, such as the cost of administering. “Do not take the risk. Pilot test first” (Van *et al*., 2001). The main intention thus seems to save some time, effort and money, which can be lost if a major research study fails because of unforeseen attributes. The aim is thus to conduct a study on a small level to find the shortcomings in the research.

Therefore, in this study, the questionnaire was pre-tested before the start of final data collection by having interviews with the 20 farmers. During the interviews, various questions on which farmers were unable to answer due to the involvement of tedious calculations were identified. This visit also helped to identify unrelated questions and some other errors in the questionnaire. Furthermore, the pre-test enabled to know whether farmers had clearly understood the interview schedule. On completion of pre-testing, a complete report was prepared and sent to the academic supervisor to get necessary feedback to finalize questionnaire. As a result of suggestions and feedback from the supervisors on the result of pre-testing, some questions were deleted or otherwise overlooked due to the language problem, but those found important were incorporated in the final version of the questionnaire. Similar to this study, to ascertain the reliability of the instrument Pilot testing was also carried out by (Umanath & David, 2013; Tesso et al., 2015; Mwajombe & Malongo, 2015; Samie, 2016)

4.4.3: Ethical Consideration

The consideration of ethical issues in research is a matter of great deal, which involves the member of the community (Patton, 2002). (Maf, 2007) define ethics as “a code of behaviour considered correct”. It is vital that researchers must be aware of the ethical issues in research. It is the obligations and responsibility of the researcher to protect the basic right of the respondents participating in the research. It is, therefore, essential to eliminate all potential risks by conducting research with justice. The respondents participating in the research must be informed of their rights. Ethical issues usually observed in most studies include “informed consent, the right to anonymity and confidentiality, the right to privacy, justice, beneficence and respect for persons” (Brink & Wood 1998).

Before going for data collection, the ethical permission was sought from the university ethical research committee. A combined consent form and the questionnaire were submitted to the committee for review of any potential hazard that research might cause. After a detailed review of the questionnaire, the committee granted the permission to conduct research. Before interviewing the farmers; they were taken into confidence and promised after defining the importance and nature of the research: The terms that were defined prior to data collection are:

i. Your identity will not be revealed to anyone other than the interviewer collecting your form.
ii. You are free to withdraw from the questionnaire at any time you feel uncomfortable or unwilling to participate, and you do not have to specify a reason.
iii. Any contribution can be withdrawn at any stage and removed from the research if desired.
iv. If you wish to withdraw, please contact to the researcher by quoting your name or reference at the top of the page. Your name and reference will only be used to identify your questionnaire and information will not be revealed to anyone.
v. The respondents were assured that their data will only be used for research purposes.

During the interview phase of the research, the full explanation was provided to the respondents about research and participants were asked to give consent of their willingness to participate in the research. It was described to respondents that application has been reviewed according to the procedures specified by the University Research Ethics Committee and has been given a favourable opinion for conduct. By answering the interview questions/completing the questionnaire, you are acknowledging that you understand the terms of participation and you consent to these terms**.** The respondents were then asked to sign the consent form before the start of the interview. Only those respondents were interviewed that showed their willingness to participate and signed the consent form.

4.4.4: Formal Survey and Data Collection

This research was relayed on a household survey and field observation conducted from December 2012 to April 2013, for four and half months. Survey and interviews are the extensively used methods in agriculture research to collect flawless and quantitative data (Fox *et al*., 2009). Survey research deals with the gathering of data from a representative sample of individuals through their responses to questions and results emerged from this are supposed to be generalized to the whole population. Similarly, defines the survey as a process of measuring public views or individual characteristics by means of a questionnaire and sampling methods. Hence, Survey is a resourceful technique for systematically collecting data from a wide range of population and educational settings. Survey research owes its continuing popularity to its versatility, efficiency, and generalizability. Many variables can be estimated without significantly increasing the time or cost in survey research. Survey data can be collected from various groups of people relatively quickly and at low cost, depending on the survey design. Thus, survey research is very demanding when the central research objective is the sample generalizability. In fact, survey research is often the only method available for developing a representative picture of the attitudes and characteristics of a large population. Therefore, after the completion of all the possible procedures necessary to improve the quality of the questionnaire, a formal survey of the sampled farm was started.

4.4.5: Data Collection from Tehsil Samundri

The data collection was completed in two phases. Initially, during the first phase, data were collected from the Tehsil Samundri. The total land area of this Tehsil is 202,211 hectares and as a result of its bifurcation, it reduced to 89,880 hectares in 1994. The Tehsil Samundri derives its name from the presence of three (Seh=three) Hindu temples (Mandr=temple). Hence, called Seh-Mandri means a three temple small city. Later on, this name was converted to Samundri. Tehsil Samundri was the Tehsil of District Jhang during the British rule but with the creation of Lyallpur District, the Samudri Tehsil came under the administration of this district. Samundri comprises of a level plain sloping gently towards the Ravi and the Deg on the south, and Chenab Canal is the major source of irrigation, except for a few scattered plots in the Ravi lowlands that still depend on wells. The soil is generally a fine loam. The boundaries of the tehsil were somewhat modified at the time of the formation of the new District.

This tehsil consists of a total number of 24 union councils according to the list obtained from Extension Department. By applying Simple random sampling technique five union councils named 468/GB, 441/ G.B, 388/ G.B, 203/ G.B and 142/ G.B were selected from this tehsil. From each of the selected union councils, one village is selected. Five villages' 472/ G.B, 443/ G.B, 388/ G.B, 210/ G.B and 140/ G.B were selected from union councils 468/ GB, 441/ G.B, 388/ G.B, 203/ G.B and 142/ G.B, respectively through simple random sampling technique. From each of the selected villages, 25 farmers were interviewed. From this tehsil, the researcher collected the data by himself to fully grasp the understanding about the farmers and the information they provided about the production practices. In Pakistan, primary data collection is a difficult job as a major portion of the farming community is illiterate. They do not have a trend of bookkeeping and their responses were based on their memory recall.

4.4.6: Data Collection from Tehsil Jaranwala

In the second phase of the formal survey, Tehsil Jaranwala was surveyed. This Tehsil is located on the north bank of river Ravi with an area and population of 437,386 acres (1,770.04 km2), 1,186,514 people, respectively, Due to the scarcity of the time, it is decided to get the assistance of the enumerator during the survey of this Tehsil. For this purpose, one enumerator with a background in agricultural education was hired from University of Agriculture, Faisalabad. For an effective and reliable collection of data, the enumerator was given training and briefings on the objectives, contents of the questionnaire and acquainted with the basic techniques of data gathering and interviewing techniques and on how to approach farmers. The questionnaire was administered by using trained enumerator. In order to reduce technical and linguistic errors and to increase the reliability of the data, the researcher spent much time with enumerator during a survey of Tehsil of Jaranwala.

Tehsil Jaranwala was subdivided into 57 union councils but later it reduced to 42 union councils (see appendix B). Union councils 93/ R.B, 37/ G.B, 363/ G.B, 68/ R.B and 151/ R.B were selected out of 42 UC,s by simple random sampling. By applying the same sampling method, the village 95/ R.B (Tajpur), 36/ G.B, 585/ G.B, 66/ R.B (Awagat) and 72/ G.B (Bhamni Wala) were selected from the sampled union councils. The total numbers of 125 respondents were interviewed from this tehsil, 25 from each village. Collectively, 250 farmers were interviewed from both tehsils.

4.4.7: Interviews with Agriculture Officer (Department Of Agricultural Extension)

A separate interview sheet containing a number of open-ended questions was compiled to collect the qualitative information regarding different extension activities carried out in the research area. The purpose of these interviews was to grasp the understanding about the working of extension department, to probe out that what type of assistance is available to the farmers and what are the issues and problems facing by the extension field staff. Thus, total numbers of four agriculture officers were interviewed, two from each Tehsil, during the office time.

4.4.8: Other Data Sources

With the aim to validate the research findings after data analysis, various agricultural sites were visited to collect the literature and relevant information about Wheat, Cotton, and Sugarcane and Mize crops. The sites visited to gather the research material are:-

i. Ayub Agriculture Research Station to get literature about the production technology of the crops under study.
ii. Punjab Agriculture Department also named Agriculture House(Lahore)
iii. Agronomy and Agricultural Extension Department of University of Agriculture, Faisalabad

To collect other relevant qualitative and quantitative data, Ph.D. thesis, reports, research articles, books were downloaded and reviewed to extract the information, to be used in this research study.

4.5: DIFFICULTIES FACED DURING DATA COLLECTION

It is almost impossible in a survey research to collect the data without facing any hurdles. The researcher has to cope with various challenges while in the field for data collection. Therefore, various challenges faced and strategies adopted by the researcher to overcome these challenges during the field visit are as under:-

i. The questionnaire was too lengthy and researcher spent approximately two to three hours to fill one questionnaire. Initially, the pace to fill in the questionnaire was slow due to suspicious behaviour of farmers and reluctance to provide the answer to certain questions like income from crops. On the progression of data collection, the pace to fill in the questionnaire was improved.
ii. During the period of the field visit, Pakistan was facing energy crises and most the time CNG is not available at stations and using petrol in the car is expensive.
iii. The researcher bought the USB internet device to download necessary data and to communicate with the supervisors, but this internet device has limited internet coverage at researcher's home location (village) and at data collection sites. Therefore, to check important emails and to download other research material, the researcher must have to travel to the city to use an internet cafe or some friend's home for better internet connectivity. There was no connectivity issue in a nearby city.
iv. Due to seasonal field activities (sowing of wheat, maize, and sugarcane) farmers were busy; therefore, they showed a somewhat lack of enthusiasm in providing

information. To overcome this, the researcher tried to approach the farmers when they have spare time.

v. During data collection, sometimes, the roads were blocked due to Political or some other strikes. This study site was about 35 KM away from the researcher's residence. To overcome this issue, it was tried to stay near the study sites in some hotel or friend's home. This move saved lots of time and cost.

vi. In some cases, there were some absentee farmers or land is owned by women. Their name was present on the list of farmers, got from the representative of Revenue Department (involved in getting water bills). But In the actual situation, some of them were not involved in cultivating their land. They handed over their land to any other person like son, brother, etc. In these cases, the farmers to whom the land is handed over were interviewed.

vii. Most of the respondents were doubtful about the purpose of research. Therefore, a great deal of time was spent on the preliminary discussion to remove their doubts. To win the confidence of the farmers, it was explained to them that the data will only be used for research purposes. It was also tried to get help from the influential farmers of that area, who explained to the farmers that the data will be used for the betterment of the agricultural system.

viii. Some of the farmers were not accessible during the first visit for data collection. Therefore, the researcher had to arrange follow-on visits in such cases.

4.6: DATA ENTRY OF COLLECTED DATA

Wambani (2011) stated that huge efforts, resource, and time are usually devoted to data collection, but the little efforts are done in planning, data analysis, and data archiving, which resultantly deteriorate the quality of data produced at the end of the research process. Poor management and handling of data lead to the biased results. Therefore, the most important task remains after successful completion of the survey is to enter the raw data in suitable data analysis software. Data entry refers to the process of computerizing the data (Wambani 2011).The data entry was started with assigning individual study identification numbers to the questionnaire for maintaining the anonymity of the respondents. The Software Statistical Package for Social Science (SPSS) was used to enter the raw quantitative data from the questionnaire. A Microsoft Excel spreadsheet was also used to cross-check the data. Various activities like data screening and cleaning, cross-checking and data coding were carried out during data entry.

4.6.1: Data Coding

Initially, during the data entry, the first step was coding and labeling of the variables. The names of the variables like education, tenancy status**,** quality of water etc. were coded**.** For example, in case of tenancy, "code 1" is assigned if the farmer is the owner of the land, code 2 is for tenant and 3 is for owner cum tenant (1=Owner, 2=Tenant, and 3=Owner cum tenant). Similarly, in the case of quality of water 1=Good quality, 2=Bad quality and 3 stands for medium quality), After completing this task, each type of the variables was indicated clearly as strings or numeric. Furthermore, the coded variables were labeled to supply full description and understanding of what the codes represent.

4.6.2: Data Cleaning

The quality of the research results compromises if data is entered without checking errors and mistakes. Therefore, the preventative measure should be taken in identifying and correcting errors before data analysis. Prior to data analysis, cleaning of data helps to identify and avoid problems. The following actions were followed during and after data entry.

i. Unnecessary and irrelevant data not aligned with the study objectives was not entered.
ii. Decimal points and range of values were established to minimize the entry of wrong values.

On completion of data entry, the information provided by the farmers was cross-checked for the individual variables, as there is a chance of errors due to the wrong punching of keys. The following information was cross-checked to identify errors:-

i. The farm area under various crops in a particular cropping season was checked in relation to the total farm area
ii. It is checked that the farmers provide the correct sowing time of the winter and summer crops;
iii. To assure that the farmer provided the correct information, prices of various inputs like fertilizer, seed etc as mentioned by the respondents is matched with the price list (Year 2012-13) obtained from the market.
iv. Total irrigation to crops as reported by the farmers was checked in relation to the number of irrigations from various sources like canal, tube well and both (Tubwell+canal).
v. The total labour involved in growing one crop was checked with the labour involved in carrying out different farm operation like ploughing, planking, harvesting, irrigation, and fertilizer broadcasting etc.

vi. The ownership of various farm tools, in relation to the tractor ownership. For example, if the farmer doesn't have tractor then he was not supposed to have trolly, rotavator, cotton drill etc.

4.7: PROCEDURE FOR CALCULATION OF INPUTS AND OUTPUT VARIABLES

Crop production is a complex process and farmers use a different combination of inputs to produce the desired output. The variables responsible for variation in the crop yield include fertilizer, irrigation, pesticide, and herbicides, as farmers have more control over these inputs and able to adjust their amount. These variables are calculated and entered into the SPSS to further use the in efficiency analysis. The procedure followed to calculate the each variable is presented below:

4.7.1: Output Variable

It is decided to use the physical quantity of cotton, maize, sugarcane and wheat in the efficiency analysis. The detailed procedure that is followed to calculate output variables is mentioned in Appendix C.

4.7.2: Input Variables

4.7.2.1: Labour Hours

Labour in the Pakistan is categorized into family labour, temporary and permanent hired labour. The permanent labour is hired on an annual basis to carry out operations like the handling of livestock, irrigation and fodder arrangement for the livestock. The temporary labour is recruited partly particularly in the sowing and harvesting season for seed, fertilizer broadcasting, and irrigation, harvesting, and threshing. The family labour is further categories into persons involved in full-time farming and member of household involved in part-time farming. The people who are engaged in full-time farming is considered to have agriculture as profession and people who partly supervise their farms also consider to have some other profession as well besides farming. The total number of labour hours were calculated by adding up the hours spent by the labour for different farm operation like ploughing, planking, irrigations, threshing, etc. The detailed procedure is described in Appendix C. The farmers were asked to provide information about the number of the person hired and time spent by the each person to perform above operation.

Figure 4.2: Multistage Sampling Design for Sample Selection

TEHSILS IN FAISALABAD DISTRICT					
Faisalabad city	Faisalabad Sadar	Samundri	Chak Jhumra	Jaranwala	Tandlianwala
Selection of Tehsil samundri and Jaranwala through purposive sampling					

TEHSIL SAMUNDRI

S.No	UCs Selected (Random sampling)	Villages in Union council	Village selected (Random sampling)	Respondents interviewed
1	468/GB	472/GB,469/GB,468/GB,470/GB	472/GB	25
2	441/G.B	444/GB,442/GB,445/GB,471/GB443/GB,441/GB,447/GB,446/GB,448/GB	443/GB (Warichanawala)	25
3	388/G.B	386/GB,373/GB,136/GB,388/GB387/GB	388/GB(Dulchi Majral)	25
4	203/Gb	211/GB,488/GB,210/GB,203/GB212/GB	210/GB(Khiderwala)	25
5	142/GB	141/GB,142/GB,139/GB,140/GB,143/GB	140/GB	25
Total	5		5	125

Note:-There are 24 union councils in Tehsil Samundri and out of these UC,s five union councils were selected through simple random sampling

TEHSIL JARANWALA

S.No	UCs Selected Random Sampling)	Villages in Union council	Village selected (random Sampling)	Respondents interviewed
1	93/RB	92/RB,95/RB, 93/RB,94/GB, 90/RB,91/RB	95/RB(Tajpur)	25
2	37/G.B	34 G.B,37 G.B,35 G.B 36 G.B	36/GB	25
3	363/G.B	377/GB,363/GB,585/GB, 367/GB	585/GB	25
4	68/RB	69/RB,71/RB, 66/RB,68/RB, 70/RB	66/RB(Awagat)	25
5	151/RB	151/RB,149/RB,150/RB,72/RB65/RB	72/GB(Bhamni Wala)	25
Total	5		5	125

Note:- There are 42 union councils in Tehsil Jaranwala and out of these UC,s five union councils were selected through simple random sampling

4.7.2.2: Irrigation Hours

Canal and groundwater are two major sources of irrigation used by farmers in Pakistan. The fields are irrigated either with the canal, tubewell or by mixing both canal and tubewell water. In this study, the numbers of hours of irrigation applied from land preparation to maturity are calculated by using the criteria mentioned in Appendix C. The data were collected about the number of canal and tubewell irrigations applied to each crop. Secondly, the time needs by the canal and tubewell water to irrigate one acre.

4.7.2.3: Tractor Hours

The tractor hours are calculated by adding up the hours spent on different farm operation like ploughing, planking, cultivation, rotavation for a particular crop. The detailed procedure, how the tractors hours are measured with reference to particular cops is mentioned in the Appendix C. To calculate tractor hours, the farmers were asked to provide information about the time taken by the tractor to perform each field operation like ploughing, planking, rotavation etc.

4.7.2.4: Fertilizer

Fertilizers are critical inputs for better crop production balance. The inappropriate, overdose and underdose adversely affect yield. Urea and DAP are most important fertilizer usually used by farmers as a source of nitrogen and phosphorus, respectively. The basal dose is used during land preparation and rest of the amount usually applied at different stages of crop growth. The total amount of fertilizer applied is calculated by adding up fertilizer used as basal and top dose (See Appendix C).The data were collected about the total phosphorus, nitrogenous, and potash fertilizers used on one acre.

4.7.2.5: Weedicides and Pesticides

The pesticides and herbicides are available in Pakistan in the form of either liquid or granules. Therefore, the aggregation of these inputs is difficult due to different units of measurement. As liquids are usually measured in liters and granular pesticides are measured in Kg. To overcome this problem, the amount of pesticide applied either in liquid or granular form is converted into the price by multiplying the amount of pesticide used with the unit price. (See Appendix C).

4.8: SUMMARY

In the preceding chapter, the technique of Data Envelopment Analysis and various DEA models was discussed in detail with an illustrative example. This chapter provides information about the study area, sampling technique, research design, data-collecting tool, ethical issues in research, data entry and difficulties faced during field visits. A sample of 250 respondents was drawn out through simple random method from ten villages of the purposively selected tehsils (Samundri and Jaranwala). Both qualitative and quantitative data were extracted from the respondents with the aid of well-defined, pre-tested and ethically approved questionnaire. The ethical research committee, after reviewing the questionnaire, granted permission to carry out the research. The last two sections of this chapter provide detail about the problems faced during the data collection and procedures and precautions kept in mind while entering data. The data entry process included data coding, data cleaning, and calculation of various inputs and output variables.

CHAPTER 5

PRODUCTION ENVIRONMENT IN THE MIXED FARMING SYSTEM

Results and Discussion

This chapter describes the production technology that is used by the sampled farmers in the mixed farming system, for growing wheat, cotton, sugarcane and maize crops. The results presented in this chapter are obtained by using a number of analytical and statistical techniques by taking into account both primary and secondary data for comprehensively explaining the production of the selected crops. This chapter is organized into various sections:

The first section describes the importance of wheat, cotton, maize, and sugarcane crops in Pakistan. The overall farmers (age, education, family size) and farm-specific characteristics (land description, fragmentation, tenancy status, etc.) are discussed in section 5.2. information regarding the production technology that is used by farmers. This section is divided into subsections and includes the results regarding land preparation operations, time of sowing, seed sources, the level of fertilizer used, pesticides, herbicides used, irrigation sources, and yield, cost, and profit from these crops. These topics are discussed in detail using both descriptive and inferential statistics, and the results are further aided by charts in this section. The information about farm mechanization, credit sources, and major agricultural constraints in the study area, as well as an overall summary of this chapter, is discussed in the last four sections.

5.1: STATUS AND IMPORTANCE OF CROPS UNDERSTUDY

Important crops, such as wheat, rice, maize, cotton, and sugarcane make 23.55 percent of the value added in overall agriculture and 4.67 percent to GDP while the other crops account for 11.36 percent of the value added in overall agriculture and 2.25 percent of GDP (Government of Pakistan, 2016). Cotton is the major exporting commodity of Pakistan and the economy highly relies on the production of this crop. Its contribution to value added and GDP is 5.1 percent and 1 percent, respectively (Government of Pakistan, 2016). Cotton was cropped on an area of 2917 thousand hectares in 2016 and shown a decrease of 1.5 percent as compared to 2015 (2961 thousand hectares) (Government of Pakistan, 2016). The production of cotton has decreased from 13. 96

million bale in 2015 to 10.07 million bales in 2016, showing a decline of 27.8 percent (Government of Pakistan, 2016). This decline was due to multiple shocks faced by the cotton crop. The prolonged and frequent rains badly destroy the standing cotton crop, additional crop losses came from a severe attack of pink bollworm (Government of Pakistan, 2016). Wheat is the second major staple crop in the country and meets the dietary needs of the population. Wheat share 9.9 percent to the value added and 2.0 percent to GDP (Government of Pakistan, 2016). During the growing season 2015-16, it was grown on an area of 9260 thousand hectares as compared to 9204 thousand hectares in season 2014-15 (Government of Pakistan, 2016). This shows an increase of .6 percent as compared to 2014-15. Opposite to cotton, the production of wheat in 2015-16 has increased by 1.6 %, from 25.08 million tons in 2014-15 to 25.48 million tones in 2015-16 (Government of Pakistan, 2016). The sugarcane crop occupies a significant place in the national economy to run the large sugar industry. Its share in value added and GDP is 3.2 and 0.6 percent, respectively (Government of Pakistan, 2016). It was cropped on an area of 1132 thousand hectares in 2015-16, as compared to of 1141 thousand hectares in season 2014-15 (Government of Pakistan, 2016). In the year 2015-16, the production of sugarcane is reported at 65.5 million tones as compared to the production of 62.8 million tonnes in 2014-15 (Government of Pakistan, 2016). This reveals an increase of 4.2 percent. The increase in production was due to the allocation of more land area to sugarcane crop (Government of Pakistan, 2016). Maize contributes 2.2 percent to the value added in agriculture and 0.4 percent to GDP. During 2015-16, the cultivated area under maize crop has increased to 1144 thousand hectares, showing an increase of 0.2 percent over last year's area of 1142 thousand hectares (Government of Pakistan, 2016). Maize crop production stood at 4.920 million tonnes during 2015 showing a decrease of 0.3 percent over the last year's production of 4.937 million tones (Government of Pakistan, 2016). It is evident from the above discussion that these crops have a significant impact on the economy of Pakistan. Therefore, the production technology that is used by the farmers to grow these crops is described in detail in this chapter. The first sections contain information about the farmer and farm-specific characteristics. The detail of each variable is discussed below:

5.2: SOCIOECONOMIC and FARM CHARACTERISTICS of the FARM HOUSEHOLDS

Socioeconomic or demographic characteristics like age, education, farming experience etc are very vital and always remain responsible for not only the cropping pattern but also for the production of crops in a healthy and competitive environment (Mari, 2009). In the following section, the socioeconomic profile of the farmers has been defined and described in order to understand the production environment of these selected crops. The information relating to socio-economic and farm characteristics of the farmers is presented in Table 5.1.

Table 5.1: General Characteristics of Farm Households in Mixed Farming System

Characteristics	Mean	Minimum	Maximum	Std. Deviation
Age	41.74	24	72	10.86
Experience	24.46	1	45	12.84
Household size	8.14	03	17	3.15
Farm area	4.94	00	11	2.19
Rented in land	.60	00	08	1.41
Fellow land	.20	00	1.75	.38
Area under sheds	.13	00	.76	.12
Culturable waste	.066	00	01	.17
Operational Area	5.13	1.21	13.71	2.19
Parcels of land	1.8	1	4	.82
Distance in parcels	3.75	.50	10.50	1.85
Rent of land	28731	19000	450000	6738.01
		NO	**Percentage**	_______
Education	No Education	90	36 %	_______
	Primary	57	22.8 %	_______
	Secondary	67	26.8 %	_______
	College	24	9.6 %	_______
	University	10	4.0	_______
	Other	02	0.8 %	_______
Marital Status	Single	64	25.6 %	_______
	Married	177	70.8 %	_______
	Divorced	09	3.6 %	_______
Sex	Male	250	100 %	_______
	Female	00	00 %	_______
Land fragmentation	Yes	60	24 %	_______
	No	190	76 %	_______
Tenancy	owner	181	72.40 %	_______
	Owner cum Tenant	54	21.6 %	_______
	Tenant	15	6 %	_______
Tractor ownership	Yes	45	18 %	_______
	No	205	82 %	_______

5.2.1. Summary Statistics Socioeconomic and Farm Characteristics

The information displayed in Table 5.1 presents the descriptive statistics of the personal and farm characteristics of the farmers in mixed cropping of Pakistan. The data presented in Table 5.1 indicate that the mean age of the growers in the mixed farming system during the survey period is 41.74 years, with a minimum of 24 and maximum of 72 years. This finding is similar to Hussain *et al* (2011) who also found that the mean age of the respondents in the mixed-farming system is 42 years. The results are also in line with the findings of Hussain *et al* (2012) who also mentioned similar mean age. The farming experience of the growers varies from 1 to 45 years with a mean value of 24.46 years. The results are comparable to the results of Hussain *et al* (2011) who found the mean farming experience of 21 years in the mixed farming system. The results are not consistent with the results of Hussain *et al* (2012) in the case of experience and mentioned average farming experience of 31 years in his research. The average family size of the sampled households is 8.14 persons per family, with a minimum of 3 and maximum of 17 family members. The result related to the marital status of farm families showed that the total number of single, married and divorced households during the survey period was 64, 177 and 9 constituting 25.6, 70.8, and 3.6 percent, respectively. The information related to the gender of the respondents reveal that all the survey respondents were male. It was observed during the survey that many females were the owner of the land in the mixed farming system, but most of them handed over their land to male family members for supervising their farms and females actually do not participate in farming activities. On different occasions, they get their share in terms of money and agriculture produce from the person supervising their farms.

Education is regarded as human capital and has been considered as a growth factor as it tends to increase the farm productivity and reduce income inequality and poverty (Amin & Awung, 2005). Rauf (1991) pointed out that agricultural productivity significantly related with the level of education as it tends to affect the productivity in two distinct ways, it enhances the managerial ability of the farmers to allocate resources in an excellent way and also improve the farmer's ability to utilize available resources more efficiently (technical efficiency). The data presented in Table 5.1 show that 36 % of the farm households in the study area have no formal education. The educational level of 49.6 % respondents range from primary to secondary education. 9.6 %, 4 % and 0.8 % of the respondent obtained college, university and other education, respectively.

The average own land holding of the sample households was about 4.49 acre with a standard deviation of 2.19. The result implies that the average farm size in the study area is relatively smaller as compared to the national average farm size in Pakistan that is 6.4 acre (GOP, 2010). This difference appears because in agricultural census, all categories of farms included to calculate the national average farm size but in this study, data is collected only from small farms that have land less than 12.5 acres. Ajula *et al* (2010) mentioned an average farm size of 5.63 acres in the mixed farming system. The minimum and maximum area owned by any farmer range from zero to 11 acres. The zero value indicates that in mixed farming systems some farmers do not have their own piece of land and hire land from other farmers on rent. Due to this reason, zero value appears against minimum farm area. Average land left fallowed during the survey period is .20 acre, with a minimum of 0 and maximum of 1.75 acres. This minimum value against fellow land implies that some farmers in mixed cropping are too small to left their land fallow. In addition to crop production, rearing of livestock is also one of the most important features of the mixed farming system of Pakistan. For the acquisition of milk, meat, butter and extra income, almost all farm families manage small livestock farm. For this purpose, they designate some area of their land to provide protection to their livestock by constructing sheds and buildings. The average area allocated to shed and building for livestock handling is .13 acres with a minimum of 0 and maximum of .76 acres. The mean operational area available for crop production is 5.13 acres with a minimum of 1.21 and maximum of 13.71 acres. However, Ajula *et al* (2010) mentioned a slightly higher operational area of 6.96 acres in the mixed zone. The value of the maximum operational area is exceeding from the figure (12.5 acres) that is mentioned in the first chapter related to the definition of small farms in Pakistan. This is value is higher because some farmers have augmented their farm area by renting in more land in addition to their own land. This reason tends to increase their operational farm area, beyond the limit of 12.5 acres. The operational Farm area is calculated by adding the own farm area and renting in land and then subtracting the area under shed and building, culturable waste and fallow land.

A remarkable difference in land rent can be seen on the sampled farms when the values of minimum and maximum rent are compared. The rent paid by the farmers in the mixed farming system varies from a minimum of PKR 19000 (US$ 229) to a maximum of PKR 45000 (US$ 542) per acre with mean land rent of PKR 28731 (US$ 346). The large value of standard deviation (RS. 6738) also indicates a large variability of land rent per acre among the sample farms in the mixed farming system. These results are not consistent with the results of Javed (2009) who found an average rent of land PKR 8613 (US$ 103) and PKR 10456 (US$ 126) in cotton-wheat and rice-wheat farming system, respectively. This large difference might be due to a comparison of land rent with other farming systems. The respondents were asked to provide an explanation of this large variation in land rent. The respondents explained that the rent varies from land to land, depending upon the availability of canal water, quality of the soil, availability of good quality groundwater. The land near the canal command area enjoys more rent as compared to land away from the canal and present on the tail. They further explained that the land near the canal area is more fertile and have good quality groundwater, which leads to increase in land rent near canal area.

Land fragmentation is a phenomenon in which the land is divided into various parcels and these parcels are located in different locations. In the literature, land fragmentation is defined in different ways. Bizimana *et al* (2004) defined land fragmentation as where farmers operating two or more geographically separated tracts of land. Schultz (1953) defines fragmentation as a "misallocation of the existing stock of agricultural land." The respondents were asked to provide a close-ended response about the occurrence of fragmentation on their land. Almost 76 % of the respondents mentioned that their land is not fragmented and present on a single location. The remaining respondents highlight the division of land into various parcels, which are scattered in different locations. The land of most farm households is not scattered because they own a very small piece of land, which is present on a single location. Secondly, in some cases, two farmers have common land boundaries on different locations and through mutual agreement; these farmers transfer their segmented land with other farmers. One farmer gets land on one location and other get land on other location. The average number of parcels in the mixed cropping system are 1.8 with a minimum of one and maximum of 4. The fragmentation of the land affects the productivity by different ways. It makes supervision and protection of the land more difficult; it entails long distances, increase-working hours, and the problem in the transportation of agricultural implements and products, which ultimately leads to increase in the production cost (Shuhao 2005; Daniel *et al*., 2015). The minimum distance between the parcels is .5 Km with a maximum distance of 10.50 Km. The data also show that 3.75 Km is the average distance present between the main farm location and the fragmented parcel. Daniel *et al* (2015) support the notion that occurrence of fragmentation minimizes production risk; having an additional parcel is estimated to reduce the likelihood of being affected by a crop shock by about 10 percentage points.

Land tenancy also has a great impact on productivity. With regards to land tenure, farmers can be classified into three tenure classes, i.e. landowner, owner cum tenant, and the tenant or land leases in the mixed farming system. The landowner is a functionary who owns a piece of land. Tenants are those functionaries who do not have their own land and gets the land from other sources on lease for a specific period at an agreed rent. The category of owner cum tenant includes all those farmers, who cultivate the rented in land, in addition to their own land. In the mixed farming system, a vast majority of farmers are owner-operator (72.40 %) followed by owner cum tenant (24.6 %). The smallest number of farm households fall in a category of the tenant (6%). These results are consistent to those of Sharazar *et al* (2012) who indicated that a vast majority of the sample farmers were the owner of the land, in the mixed farming system. The results are also comparable with the findings of Hussain *et al* (2011) who found 86% of the farmers (owner-cultivators), 8% (owner-cum-tenants) and 6% (tenants). Aujla *et al* (2010) also mentioned that majority of the farmers (70 %) were owner in the mixed zone.

The term "mechanization" is used to describe tools, implements, and machinery that are used to improve the productivity of farm labour and of land; it may use either human, animal or motorized power, or a combination of these (Sims and Josef 2006). Mechanization has a key role in shifting the conventional agriculture to profit base agriculture (Shah, 2016). The effective utilization of farm machinery not only improve the productivity but also help to reduce the environmental impacts (Berry *et al*., 2003) The small farmers in Pakistan are considered less innovative in terms of performing field operations on their farms. The major reason is the lack of modern agricultural machinery. They mostly hire the services of farm machinery from other sources to perform various field operations (Shah, 2016). Their high dependence on hired farm machinery does not allow them to behave in an innovative way (Khan *et al* 2009). It is estimated that large farmers possess nearly, 59 % of the tractors and about 39% of the tube-wells. Whereas, only 16 % of the tractors and 35 % of the tube wells are owned by the small farmers (Government of Pakistan 2000). Khan *et al* (2009) reported money as the major constraint for the small farms to purchase farm machinery. Keeping in mind the above, the information was gathered from the respondents about the ownership of farm tools and this information is presented in Table 5.1. The data show that a vast majority of farm household (82%) do not possess tractor and only 18 % possess tractor. This implies that small farmers in mixed farming system mostly hire tractor services from other farmers, to perform tillage and other farm operations on their farms. The information related to ownership of various other farm equipment is depicted in Table 5.1.1.

5.1.1: Ownership of Farm Machinery in Mixed Farming System

Machinery	Frequency				
	Yes	%	N0	%	Total
Trolley	11	2.4	239	95.6	100
Rotavator	25	10	225	90.0	100
Ridger	24	9.6	226	90.4	100
Thresher	13	5.2	237	94.8	100
Leveller	4	1.6	246	98.4	100
Hand sprayer	48	19.2	202	80.8	100
Tractor sprayer	0	00	250	100	100
Seed drill	14	5.6	236	94.4	100
Comb.harvester	00	00	250	100	100
Cotton seed drill	8	3.20	242	96.8	100
Scrapper	22	6.8	228	91.2	100

The ownership of various other farm tools like trolley, seed drill, rotavator, scrapper etc is directly linked with the ownership of tractor. Almost 10 percent of the respondents possess their own rotavator. Khan *et al* (2017) also observed that only small fraction of respondents (3.66%) had their own rotavators whereas the majority of the respondents utilized rotavator hired from FSCs, private sources and fellow farmers. The second major source for rotavator was private sources i.e. 39.63%. More than 95 % of the respondents lack trolleys on their farms in the case of all crops. It is evident from the data that none of the respondents own combine harvester. The reason is that combine harvester is a very costly tool in Pakistan and hence it is beyond the purchasing power of the small farmers. The services of combine harvester are hired from the large farmers and other agencies working in the study area, during the harvesting period. Similar to combine harvester, laser land leveller is also a costly farm tool and high skill is needed to operate it. Less than 2 % of the small farmers possess this tool. Khan *et al*., (2017) reported that only 2.53 % of the small farmers had their own land levelers. Scrapper is also used to level the field and only 6.8 % have their own scrapper. It is also evident from the data that a vast majority (94.8 %) of the farmers do not possess wheat thresher and hire services from other farmers. The tools like hand sprayer do not need a tractor for their operation. About 20 % of the respondents have the ownership of hand sprayer. From the findings, it can be concluded that the small farmers are not fully equipped with the modern agricultural tools, in the study area. The heavily depend on hired farm implements for carrying farm operations. These results are consistent with Aujla *et al* (2010), Khan *et al* (2009) and Government of Pakistan (2000) who also reported the intensive use of hired farm machinery on small farms.

In addition to above information, the respondents were asked numerous questions to obtain different kinds of information about the study area. The respondents were asked to provide information about the canal type, which provides irrigation water in the study area. The respondents replied that the perennial canal is the major source. The perennial canals in Pakistan are those which provide water throughout the year. In Pakistan, there are also present some seasonal canals, which only supply water to some areas in rainy season. The next question to the respondents was about the type and quality of the soil. The growers had their own classification and terminology to define the soil types. For example, the name “Bhari” is designated to clay and clay loam soil, sandy and sandy loam is declared “Maira” whereas, the saline soil is named “Kallarathi”. The majority of the respondents replied that the soil structure varies from clay to clay loam and this soil is good for cultivation. About the quality of the tube well water, the respondents replied that the tube well water is moderately good for irrigation. However, a small portion of the farmers said that their groundwater is perfect for irrigation. About the quality of the groundwater, a vast majority mentioned that the tubewell water causes salinity.

5.2.2: Overall Land Utilization in Mixed Farming System

The land is a factor of immense importance in the crop production (Seth, 2016). The land is enriched with the natural resources and prosperity of a nation directly linked with the richness of her natural resources. The agricultural wealth a country depends on the quality and nature of the soil, climate, and rainfall. The agricultural products produce from agriculture land, form the basis of trade and industry. Thus, all aspects of economic life, i.e. agriculture, trade, and industry are generally influenced by natural resources, which is called as "Land" in economics (Seth, 2016). The importance of land is, therefore, too much as it is influencing finally the standard of living of the people.

The agricultural land can be categorized into arable, fallow and culturable wasteland. The land that can be used for farming is called arable. The land that is left uncultivated in a cropping season to serve some specific purpose is called fallow. Culturable wasteland is the piece of land that can also be used for farming but it is not available may be due to construction. The data given in Table 5.2.2 show the statistics of land utilization in the mixed farming system. It shows the statistics of average farm size, available area for cultivation, the area under shed and building, culturable waste and fallow land. Further, it shows the area cultivated in Rabi and Kharif season out of the total available operational area. In addition to this, Table 5.2.1 also shows the statistics of the net area that is cultivated in one cropping season. The net area that is cultivated in one year is calculated by adding the area under Rabi, Kharif, and Perennial crops.

According to Table 5.2.1, total farm area that is available for cultivation is 1235 acres in the mixed farming system. The farm households further augmented their farm area by renting in 150 acres of land. Out of this area, 52 acres left fallow, while 16 and 33 acres of land are culturable waste and under sheds and buildings, respectively. The operational area is calculated by adding the farm area owned by the farmers and renting in land and then subtracting it from the area under shed and building, fallow land, and cultural wasteland. The results reveal that the total operational area that is available for cultivation in the mixed farming system is 1283 acres. Out of this operational area about 1080, 1076 and 197 acres of land were grown with rabi, kharif and perennial crops (2012-13), respectively.

Table 5.2.2: - Overall land utilization in Mixed Farming System

Characteristics	Land Utilization (in Acres)
Farm area	1235.40
Renting in land	150
Fallow land	51.79
Culturable waste	16.61
Area under shed and buildings	33.71
Operational area (2+3) - (4+5+6)	1283.09
Area under Rabi crops	1080.50
Area under Khraif crops	1076.80
Area under Perennial crops	197.70
Net area sown(8+9+10)	2353.08

The next Table 5.2.2 indicates that the wheat crop was grown by all the 250 respondents. However, the data further reveal that out of 250 sampled farms, 216, 196 and 220 of the farmers had been involved in growing cotton, maize and sugarcane crops, respectively. On sampled farms, the wheat crop had been grown on an area of 658 acres. While in 2012-13, cotton, maize and sugarcane crops were grown on an area of 360, 250.75 and 197 acres respectively. The average farm area that is grown with wheat is 2.63 acres, followed by the cotton crop, which was grown on an average of 1.66 acres. Similarly, the mean farm area on which the maize and sugarcane crops were grown is 1.44 and .89 acres, respectively. The minimum area that is cultivated with wheat, cotton, maize, and sugarcane by the individual sampled farmers is .50, .65, 1 and .5 acres. While, the maximum area that is under wheat, cotton, maize, and sugarcane crops are 7, 4.5, 4 and 3 acres, respectively.

Table 5.3: - Descriptive statistics of the Area Cultivated with Crops under study

Crops	*observations*	*Area under crops*				
		Min	**Max**	**Total**	**Mean**	**Std.Deviation**
Wheat	250	.50	7.00	658.7	2.63	1.15
Cotton	216	.65	4.50	360.2	1.66	0.85
Hybrid Maize	196	1	4.00	250.75	1.44	0.69
Sugarcane	220	.50	3.00	197.4	0.89	0.63

5.3: PRODUCTION TECHNOLOGY ADOPTED BY SAMPLED FARMERS

The understanding of production environment and technology is an essential indicator for grasping the information about the background status of the production system. The production technology that is used by the farmers for growing wheat, cotton, maize and sugarcane crops are discussed in the next sections.

5.3.1: Labour Information

Labour in Pakistan can be categorized into family, temporary and permanent hired labour. The permanent labour is hired annually (for one year). Throughout the whole year, this labour handles the livestock along with other farm activities like irrigation, fertilizer application, and cleaning of the water channel. The temporary labour is recruited, particularly, in the sowing and harvesting season of the crops for the broadcasting of seeds and fertilizer, irrigation, harvesting, and threshing. The wages are paid to temporarily hire labour on a daily basis, after the completion of the tasks assigned to them. However, permanent hired labour gets their incentives annually.

The family labour is further categories into full and part-time family labour. The full-time family labours have adopted agriculture as a profession and full-time supervise their farms. Agriculture is the only means of income for these family members. In contrast, the part-time family labour also relies on other professions besides farming for their livelihood.

Table 5.3.1: -Descriptive Statistics of the labour Use on sampled farms

Crops	*Obs*	*Part Time family Lab*				*Full-time Family Lab.*				*Hired Labour*			
		Min	**Max**	**Mean**	**S.D**	**Min**	**Max**	**Mean**	**S.D**	**Min**	**Max**	**Mean**	**S.D**
Wheat	250	1.0	4.00	3.04	0.75	.00	5.00	1.24	0.65	.00	2.00	0.75	0.52
Cotton	216	.00	3.00	2.01	0.76	.00	5.00	1.26	0.65	.00	2.00	0.80	0.50
Maize	196	.00	5.00	2.12	1.15	1.00	4.00	1.53	0.67	.00	2.00	0.85	0.48
sugarcane	220	.00	3.00	1.75	1.34	.00	3.00	1.45	0.89	.00	2.00	0.76	0.52

The labour information presented in Table 5.3.1 indicates that the wheat, cotton, maize, and sugarcane growers, on an average, have hired at least one person (permanent labour) to carry out farm operations. The maximum of 2 permanent labour is hired by the some sampled farms and some have hired no permanent labour. The farms with no permanent labour show that some of the family members are involved in full-time farming on these farms.

In the literature of farm productivity, the small farmers are well renowned in terms of using the family labour on their farm. The average number of family labour engaged in part-time farming, in the case of wheat, cotton, maize, and sugarcane crops is 3.04, 2.01, 1.15 and 1.34 persons, respectively. Similarly, the results also indicate that, on some sampled farms, none of the family members is engaged in part-time farming. This may be because either the family members are engaged in full-time farming or they have other business besides agriculture. The column showing the data of full-time family labour clearly indicates that, on an average, in the case of all crops, at least, 1 family member is engaged in full-time farming. Further, the data show that maximum numbers of a family member engaged in full-time farming are 5, 5, 4, and 3 persons in case of wheat, cotton, maize, and sugarcane. This is an indication that on some sampled farms, the incidence of full-time family labour is higher as compared to the others that might be due to their high dependence only on agriculture for livelihood.

5.3.2: Land Preparation Practices on Sampled Farm

Proper land preparation activities ensure increased farm productivity by taking care of the soil and providing favorable soil conditions for plant growth (Ignatius, 2011; Bautista, 2016). Land preparation practices in a right way improve the water retaining capacity of the soil and permit the proper circulation of air (Ignatius, 2011). Water and warmth in the soil are vital for proper plant germination and growth. There are various methods in Pakistan by which a farmer can prepare their land for growing crops. However, the choice of each method depends upon the soil structure and crop to be grown. There are many merits linked with proper land preparation. One of the fundamental merits of soil cultivation is that it accelerates the activity of soil organisms; it also tends to reduce evaporation and penetration of the water into the soil (Ignatius, 2011). Soil cultivation also helps to control weeds and soil pests (Steckel *et al.*, 2007). Hardpan in the soil created by previous cultivation is also repaired through land preparation.

However, Soil fertility can be affected by intensive cultivation (Ignatius, 2011). Therefore, farmers need to ensure that there is a minimum disturbance of the soil life during cultivation. Working on the soil will always affect its structure in one way or another. The Table 5.3.2 shows the statistics of the farm operations performed by the sampled farms.

Table 5.3.2: Descriptive statistics of Land Preparation Practices on Sampled Farms

Crops	obs	Ploughings			Planking			Rotavations			Levelling			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Yes	%	No	%
Wheat	250	2.00	5.00	2.9120	1.00	3.00	2.140	.00	2.00	.7480	35.0	14.0	215	86.0
Cotton	216	3.00	6.00	3.0880	1.00	2.00	2.125	1.0	2.00	1.1481	63.0	29.166	153	70.83
Maize	196	4.00	8.00	4.452	0.00	2.00	1.872	1.00	3.00	1.84	37.0	18.877	159	81.12
Sugarcane	220	0.00	3.00	2.635	0.00	2.00	1.345	.000	3.00	1.534	44.0	20.0	176	80.0

The data in the Table 5.3.2 reflect that the average numbers of ploughings performed by the wheat, cotton, maize, and sugarcane growers are 2.91, 3.08, 4.45, and 2.63, respectively. From the table, the difference in minimum and a maximum number of ploughings shows huge variation among the sampled farms, in performing the ploughing operation. The ownership of farm equipment like tractor might be the cause of this variation. The farmers with their tractor tend to perform more ploughings as compared to those with no tractor because the cost of performing field operations is less with the own tractor as compared to the hired tractor (see Appendix D). Secondly, this variation might also be due to the difference in the use of farm operations. The farmers who perform rotavations prior to ploughings tend to perform less number of ploughings as compared to those with no rotavations. Hussain *et al* (2012) found an average number 7 ploughings for seedbed preparation for wheat and this figure is higher as compared to this study. Memon *et al* (2016) found an average number of 3.55 ploughing, with a minimum of 2 and maximum of 5 to prepare maize field and these results are comparable to this study.

The rotavator provides a fine degree of pulverization, enabling the necessary rapid and intimate mixing of soil and is considered most important tool (Khan, 2017). The average numbers of rotavations performed by the wheat, cotton, maize, and sugarcane growers are .74, 1.14, 1.84, and 1.53, respectively. The data further reveal no rotavation on some farms that might be due to the use of ploughing only, while seedbed preparation. The operation of planking is done after the field is properly ploughed and rotavated. This operation is usually carried out to break the large clods of the soil that are not broken after ploughings and rotavations. Secondly, this operation also helps in conserving soil moisture that is very much necessary for seed germination. The mean numbers of two planking are done by the sampled farmers on these crops.

The value of a minimum number of ploughings on sugarcane crop represents that the operation of ploughing is not performed on some sampled farms. Because these farmers have Ratoon crop instead of fresh crop and this crop is developed from the stubble of previous sugarcane crop and hence require no ploughings. Leveling is one of the vital field operations to eliminate the ups and downs of the soil. The leveling of the seedbed results in uniform distribution of irrigation water and better supply of other inputs to the crops. The data show that only 14, 18, 29, and 20 % of the wheat, cotton, maize, and sugarcane growers had done leveling before sowing, respectively. In response to the question, about the time spent for leveling, the farmers replied that the leveling time varies from field to field depending upon field topography. The leveling of one acre with more ups and down may take 5 to 6 hours. The average time spent by the respondents to level their wheat, cotton, maize, and sugarcane fields is 1.12, 2.43, 2.98, and .89 hours, respectively.

The sources used by the sampled farmers for land preparation are also presented in next Table 5.3.2.1. The information was collected from the respondents about the sources that are used in the study area for land preparation. The farmers mentioned tractor as a major cultivation source. However, they also mention that the bullocks (draft power) were used in the past for field preparation. Recently, the bullocks have not been used for field preparation, because it is laborious and time-consuming. Therefore, own or hired tractor is mostly used for land preparation, in the study area. The data show that a vast majority of the respondents rent in the tractors services from other sources like fellow farmers, government agencies. Almost, 80% of the wheat, cotton, maize, and sugarcane growers rely on the rented tractor for land cultivation. The results are almost similar to the findings of Abdullah *et al* (2006) who found that 82 % of the small farmers use hired tractor for cultivation, in the mixed farming system. Similar results produced by Ajula *et al* (2010) that tractor (owned/rented) was the major source of ploughing and over 98% of the farmers used the tractor as a power source. Ajula *et al* (2010) further stated that majority of the farmers use hired tractors as a source of cultivation. Khan *et al* (2017) also mentioned tractor as major cultivation source.

Table 5.3.2.1: Distribution of the Respondents based on Source of Cultivation

Crops	obs	Own Tractor		Hired Tractor		Total %
		No	Percentage	No	Percentage	
Wheat	250	45	18.00	205	82.00	100.00
Cotton	216	39	18.05	177	81.94	100.00
Maize	196	42	21.4	154	78.6	100.00
Sugarcane	220	37	16.81	183	83.18	100.00

Abedullah *et al* (2006) also reported that ownership of tractor has a direct relationship with farm size and ownership of tractor increases with increases in farm size. He found 10, 27 and 60 percent of small, medium and large farmers having their own tractor, respectively.

5.3.3: Area under Crop Variety

The crop production also depends on the choice of a crop variety in addition to other factors. If the choice is right as recommended by the experts for a particular area, then there will definitely be higher yield otherwise vice versa (Mehmood *et al* 2006). The results show that Faisalabad 2008 (FSD2008), Lasani 2008, Bhakar 2002, Sehar 2006 and Punjab 11 were the leading wheat varieties grown by the farmers in 2012-13. These varieties were cropped on an area of 603.14 acres, out of the total 658 acres that are under wheat. The leftover area had been grown with Shafaq, Pasban, Millat 11, Inqlab and other varieties. The area cultivated with Faisalabad 2008 (FSD2008), Lasani

2008, Bhakar 2002, Sehar 2006 and Punjab 11 is 188, 45, 123, 215, and 31.25 acres, respectively. The Faisalabad 2008 is the most popular wheat variety that is grown by the farmers, in the mixed farming system. The results are consistent with the results of Battese *et al*., 2014 who mentioned that Sehar, Inqlab, Watan, Bhakar, FSD 2008, Lasani are the leading varieties. The cotton crop was grown on a total of 360 acres in the study area. BT 121, BT 142, BT 703, I.R 3701 and other varieties (varieties whose name is not known by the farmers) were the major breeds that were grown by the farmers. Out of the total cotton area, 106, 68, 23, and 24 acres were cultivated with varieties BT 121, BT 142, BT703 and IR 3701 in 2012-13, respectively. The varieties whose name is forgotten or not known by the farmers were grown on 69 acres. The rest of the cotton area is planted with IR 1524, BT 802, MNH 886, FH 113, MG 6 and IR 1524. The use of vigorous and healthy seed of improved varieties tends to increase cane yield from 20 to 25 percent (Arain, 2012). HSF 240, CPF 237, CPF240, CP90 were the prominent sugarcane varieties grown in the study area. The area that is grown with HSF 240, CPF237 and CP 240 is 34, 62, and 18 acres, respectively. The results revealed that the respondents mostly had grown the varieties among the list of varieties as recommended by Arain (2012) in his study (CP 77-400, CP 72-2086, CP 43-33, CPF-237, HSF 240, SPF-213, SPSG-26, CPF 240, SPF 237, CPF 237, COJ-84). The Pioneer and Monsanto are the leading multinational companies involved in the distribution of hybrid maize seed in Pakistan. The farmers mostly rely on the seed provided by these companies. The Table 5.3.3 shows that the Poineer-30-Y- 87, DK-919, P-30R50, P-31R88, and P- 3025 are the major corn varieties that were grown on 58, 42, 20, 24 and 20 acres in 2012-13, respectively.

Table 5.3.3: Area under different crop varieties

WHEAT											
varieties	**Fsd2008**	**Lasani 2008**	**Sehar 06**	**Inqlab 91**	**Shafaq 2006**	**Pasban 90**	**Watan**	**Bhakar 02**	**Punjab11**	**Millat 11**	**Others**
Number	91.00	20.00	101.0	11.00	3.000	8.000	11.00	61.00	20.00	5.00	12
Area (Acres)	188	45.25	215.94	19.25	2.12	3.50	11.75	123.50	31.25	7.25	10
Cotton											
varieties	**IR3701**	**BT 703**	**MG6**	**FH113**	**BT121**	**BT 802**	**MNH886**	**IR1524**	**BT 142**	**BT 555**	**Others**
Number	19	31	8	3	67	4	9	14	51	12	73
Total Area	24	23.5	9.25	5	106.5	6.5	13	17.25	68.25	17.75	69.25
MAIZE											
varieties	**Dk 6789**	**P 3025**	**P30y87**	**M5219**	**DK919**	**P-30K08**	**P 3025**	**FSH-523**	**P31R88**	**P30R50**	**Others**
Number		18	47	14	34	8	12		19	28	25
Area		20	58	18	42	13	14		24	30	31
SUGARCANE											
varieties	**HSF 240**	**CPF237**	**CPF240**	**CP 43-33**	**CP44-77**	**SPF213**	**SPF 234**	**SPF245**	**CP90**	**L116**	**Others**
Number	61	54	22	24	12		24		33		56
Area	34	62	18	14	10		13		18		28

5.3.4: Method of Sowing

The wheat, cotton, maize, and sugarcane crops are grown in Pakistan by using different methods of sowing. The use of any method depends on the choice of the farmers. Wheat crop is mostly planted through broadcast and drill method (Badar *et al*., 2005). In rice areas, zero tillage technology is also popular, but it is not common in the study area. In the broadcast method of sowing, the seed is broadcasted in the field manually and then the operation of ploughing and planking is performed to cover the seed with soil. Usually, this method is not recommended by the experts because of various drawbacks. The broadcasted seed leads to poor germination and irregular plant stand due to its non-uniform distribution below the soil (Tanveer *et al*., 2003). The seed is also wasted because most of the seed remains on the soil surface where they cannot germinate and may, therefore, be picked up and eaten by the birds. This method is not recommended, but still it is the most popular method prevailed in Pakistan.

Opposite to broadcast, the drill method results in uniform germination and regular stand, because the seed is dropped at a regular depth with the help of a drill (Tanveer *et al*., 2003). Before using this method, it is ensured that the seedbed is well prepared, leveled, and free from clods and weeds. Therefore, planting with the drill is recommended for better crop production (Tanveer *et al*., 2003; Mahmood *et al.,* 2006).

Maize and cotton can be grown on both flat soils as well as on the ridges. Ridge sowing is better for water saving. The results of different studies reported that ridge planting considerably increased the yield of maize when compared with other planting methods (Abdullah *et al*., 2008; Liu & Young 2008 and Belachew & Abera., 2010). The ridges are made 70 cm apart with a tractor-drawn ridger (Azam *et al*., 2007). Choka method or manual sowing is practiced for ridge sowing. A plant population of 25,000 to 30,000 per acre is inevitable to harvest optimal yield. Sugarcane is planted mostly by making ridges and stripes. The sets of sugarcane are dropped in the spaces between the ridges by joining their ends. After germination, the base of the plant is covered with the soil by breaking these ridges. Recently, the pit planting is also introduced in Pakistan. However, pit planting is not common in the study area, as it requires various farm machinery to dig the pits and farmers are required to have exact knowledge of this method.

Figure: 5.1: Ridge Sowing Cotton

Figure5.2: Ridge Sowing Maize

Figure: 5.3: Sugarcane Ridge sowing method

Table 5.3.4: Distribution of the Respondents based upon Method of Sowing

Crops	*Obs*	Broadcast	%	Ridge	%	Bed	%	Drill	%	Stripe	%	Mixed	%	Tot.
		Method of sowing												
Wheat	250	166	66.4	------	----	-----	----	53.0	21.2	-----	-----	31.0	12.4	100
Cotton	216	56	25.9	80.0	37.0	42.0	19.4	15.0	6.94	-----	-----	23.0	10.6	100
Maize	196	------	-----	196	100	------	-----	------	-----	-----	-----	------	-----	100
Sugarcane	220	-----	------	146	66.3	-----	-----	-----	------	74.0	33.7	-----	----	100

The data given in Table 5.3.4 show that the traditional method of wheat sowing is still popular in the mixed farming system and 66.4 % of the wheat growers used the broadcast (Chatta) method followed by the drill method which is used by 21.2 % of the respondents. About, 12.4% of the farmers have used both methods to grow the wheat crop. They had grown some of their fields by using broadcast and some with drill method. The results are in line with those of Badar *et al* (2005), that above 70% of the progressive and traditional farmers applied the broadcast method to sow wheat near mixed farming system and only 16 % of the respondents used drilled method of sowing.

In the case of the cotton crop, 37 % of the respondents practiced ridge method of sowing followed by the 25.9 % of the farmers, who used the conventional broadcast method. Bed and drill method is practiced by 19.4 % and 6.94 % of the respondents, respectively. The mixed planting methods are applied by 10 % of the farmers. The broadcast method is preferred in the study area might be due its cost-effectiveness or the unavailability of the seed drill implements.

The seed of hybrid maize is very costly in Pakistan. The companies provide a bag that contains 10 kg seed of hybrid maize that is sufficient to grow one acre. Therefore, ridge planting is the only method used to grow hybrid maize. Ridges are made 75 cm apart with a tractor-drawn ridge. The seed is then sown on the ridges with the help of hired labour (Choka method). All the respondents in the study area had used the ridge planting method for growing hybrid Maize.

Most of the respondents (66%) implemented the ridge planting method for sugarcane sowing. The sets of sugarcane crop are dropped in the space between the furrows and then set are covered with a small layer of soil. When sugarcane starts germinating and gains some reasonable height, the furrows are then broken manually or with the plough to cover the crop with soil. This practice is also called earthling-up. The stripe planting method is used by the 37% of the respondents. Some farmers have ratoon crop in 2012-13.

5.3.5: SEED RATE

From an agronomic point of view, a key element which results in high production, from the crops is the well understanding of early crop establishment factors (Badar *et al*., 2005; Soomro *et al.,* 2009) including time of planting, soil characteristics, seed germination and availability of farm machinery (Sulieman, 2010). It is, therefore, essential to keep in mind the optimal sowing date and a seeding rate of the crops (Kristo *et al.,* 2006). The study of Yan *et al*. (2008) also uncovered that appropriate sowing date brings the highest protein content.

Use of appropriate seeding rate is one of the most vital practices for crop production (Badar *et al*., 2005; Afzal & Shahid, 2009). Excessive or underutilization of seed, delay sowing, inappropriate sowing method will result in poor production performance (Badar *et al*., 2005; Hussain *et al*., 2011). Usually, research recommends a specified level of seeding rate for a given variety or crop with a given range of seed viability. The extension also advises farmers based on this research recommendations.

Table 5.3.5: Statistics of Seed Rate, Sowing time and percentage germination

Crops	***Obs***	***Seed rate (Kg/acre)***			***Time of Sowing***						***Percent germination***		
		Min	**Max**	**Mean**	**Early***	**%**	**Mid**	**%**	**Late**	**%**	**Min**	**Max**	**Mean**
Wheat	250	45	70	53.32	73	29.2	61.0	24.4	116	46.4	48 %	95 %	78 %
Cotton	216	6.00	16	6.43	46	21.3	102	47.2	68	31.5	24 %	90 %	81.5 %
Maize	196	8	10	9.45	98	50	65	33.1	33	16.8	44%	95%	92.2%
Sugarcane	220	10 M	13 m	11.8M	124	51.8	58	26.7	38	17.3	65	90%	87.6%

The Table 5.3.5 shows that the average rate at which the seed is applied by the sampled wheat farmers is 53.32 kg/acre, ranges from a minimum of 45 to a maximum of 70 kg/acre. The seed rate depends upon the sowing time of wheat crop. The early growers generally use less seed per acre and late planters had to increase the quantity of seed per acre in order to compensate the loss due to delayed sowing. The results are in line with the results of Hassan and Ahmad (2005) who reported that the average seed rate used by the wheat farmers was 52.4 kg per acre. The same results showed by the Badar *et al* (2005) who reported that the average seed rate used by the traditional and progressive farmers in the irrigated area is 50 kg/acre and 53 kg/acre, respectively. Hussain *et al* (2011) also mentioned that the farmers were used mean seed rate of 50.1 kilograms per acre in mixed-cropping. The more recent study conducted by Usman *et al* (2016) also revealed that small farmers used 51.44 kg seed per acre for wheat.

Wheat crop sown before 15 November is considered as early, from 15 November to 1 December mid and in the month of December is considered as late sowing. The majority of the wheat respondents, 46.4 % had planted their crop in December. The percentage of farmers who had planted their crop before 15 November is only 29.2 %. 24.4% of the wheat grower completed their sowing between 15 November and 1 December. The percentage germination of seed varies from 48 % to 95 % with an average value of 78 %. The low percentage of seed germination on some farms may be attributed to improper land preparation, late sowing or use of low-quality seed. A delay of one day in the planting of wheat beyond the proper sowing time reduces yield by 1 percent. By assuming an average wheat yield of 2500 kg per hectare, every 15 days delay in sowing reduces farm yield by 375 kg/ hectare(Byerlee and Siddiq, 1994). Similarlay, Abid *et al* (2016) mentioned that late sowing of wheat causes a yield reduction of 40 to 50 kg per hectare per day. The results are almost in line with the study of Sharazar *et al* (2012) who indicated that 23.3% sowings were early, 54.4% sowings were timely and only 22.2% farmers had sown late and the reason behind the late wheat sowing were late harvesting of sugarcane crop, as well shortage of canal water and non-availability of tractor services. Badar *et al* (2005) also mentioned that traditional wheat farmer mostly did mid and late sowing.

The average seed rate used by the sampled maize farms is 9.45 kg/acre. The minimum and maximum values of seed rate show a minor fluctuation in the use of seed rate. This is due to the fact that the hybrid seed is only planted on the ridges and 10 kg seed bag is sufficient to sow one acre of maize crop on the ridges. Secondly, the time of sowing, of maize crop has no effect on the quantity of seed rate/acre. About half of the maize farmers had grown their crop early on early dates, 33% mid and 16.8 % late. Late sowing has no effect on the germination rate of maize crop but other factors like fungal attack, weather can affect its germination rate. Memon *et al* (2016) mentioned 7 Kg of maize seed to grow one acre. Kibaara (2005) found an average seed rate of 9.11 Kg applied by maize farmers.

Like wheat crop, the seed rate for cotton also depends upon the sowing method that is used to grow the crop. Normally, 10 to 14 kg/acre of cottonseed is used when the crop is planted using broadcast sowing method. However, in the case of bed, ridge and drill sowing the seed rate range from 4 to 8 kg/acre. The average seed rate used by the cotton growers in the mixed zone is 6.43 Kg/acre with a minimum of 6 and a maximum of 16 Kg/acre. In other cropping systems, Abedullah *et al* (2006) and Saddozai *et al* (2013) mentioned an average seed rate of 6 and 4.77 kg/acre, respectively and close to the findings of this study. in other countries Adzawla *et al*., 2013 mentioned seed rate of 5.31Kg

Cotton is usually grown in April, May, and June. April planting is considered as early, May as mid planting and June as late planting. A vast majority, about 78% had mentioned the mid and late sowing of the cotton crop. The late sowing might be due to the late harvesting of the wheat crop because the field can only be available for cotton sowing after harvesting of the wheat crop.

There is no hard and fast formula to calculate the exact seed rate for sugarcane crop, in the study area. When farmers were asked to provide information about the seed rate used for sugarcane crop, they replied that, on an average, sugarcane crop present on 12 to 14 Marlas of space is harvested and then cut into small sets containing 2-3 buds. The sets obtained after cutting of 12-14 Marlas of the sugarcane crop are sufficient to grow one acre. However, they also mentioned that the area of sugarcane crop that is needed to prepare sugarcane seed for one acre also depends upon the height and plant population of the sugarcane in that area. On an average, 11.8 Marlas of the sugarcane crop are harvested and used as a seed to grow one acre, by the sampled sugarcane farmers. Hussain *et al* (2011) recorded an average seed rate used by the sugarcane farmers was 67.6 maunds per acre. There are various sources of seed acquisition in Pakistan. However, the farmers tend to approach those sources that are easily accessible and provide seed on time. The major government institutions that are involved in seed distribution are Punjab Seed Corporation and the research stations (Hussain *et al*., 2011; Khan *et al*., 2017). The private institutions include local traders or commission agents, fellow farmers, and private seed company. The Table 5.3.5.1 shows the sources from where the seed is acquired by the sampled farms.

Table 5.3.5.1: Distribution of the respondents Based upon the source of Seed

Sources	***Wheat***		***Cotton***		***Maize***		***Sugarcane***	
	No	***%***	***No***	***%***	***No***	***%***	***No***	***%***
Self produces	205	82.0	30	13.8	-----	----	131	59.54
Local Trader	32	12.80	186	86.11	196	100	----	-----
Fellow farmers	72	28.88	54	25.00	-----	----	89	40.45
Punjab seed corporation	3	0.12	2	.925	-----	-----	----	----
Research Stations	0	0.00	3	.138	-----	----	-----	-----

The data in the Table 3.3.5.1 depict that majority of the wheat (82 %) and sugarcane farmers (59.54 %) used the self-produced seed held for self-consumption, respectively. About 28.28 % of the wheat and 40 % of the sugarcane growers bought the seed from the fellow farmers. Khan *et al* (2017) also reported that almost 50% sugarcane farmers relay on self-produce seed. Fellow farmers are the next major source of seed for these two crops. Hussain *et al* (2011) observed that majority 42.3 % and 75 % in mixed and Rice-Wheat farming system rely on last year’s produce, respectively.

A vast majority of cotton (86.11%) and maize farmers (100 %) rely on the local trader or input dealers to purchase the seed. The seed of the hybrid maize crop is not prepared locally and usually imported from the foreign country. This seed is then distributed in the country by the multinational seed companies. These companies supply this seed to the authorized dealer present in every city. Therefore, all the maize farmers purchased the seed from the local dealers or traders. The data show that the Punjab Seed Corporation and research station are not the popular sources among the farmers. These institutes do not directly provide seed to the farmers. Therefore, farmers usually get seed from these sources with the assistance of some influenced authorities. Hussain *et al* (2011) recorded that none of the wheat respondents obtained seed from Punjab Seed Corporation. The results are consistent with Ajula *et al* (2010) and Hussain *et al* (2011) who reported that majority of wheat farmers use last year's produce as seed. Raza (2016) also mentioned that farmers in Pakistan retain about 60 percent of their wheat production for seed and household food consumption. Hussain *et al* (2011) also reported consistent results with this study that majority of sugarcane farmers mostly use their own seed to grow sugarcane crop.

5.3.6: Level of Fertilizer Application

Roberts (2009) pointed out that the food requirement of the world will not be achieved without biotechnology and improved genetics, and without fertilizer. The use of the commercial fertilizer is responsible for 40 to 60 % of the world's food production (Reetz, 2016). There is a need to develop and employ management practices that make it possible to use the fertilizer effectively and efficiently. Therefore, an application of the required chemical fertilizers on time and in balanced proportion is essential for realizing the potential of the crop under cultivation (Reetz, 2016). Numerous factors like soil fertility, water availability and crop rotation or cropping intensity determine the type of fertilizer to be used.

The use of Phosphoric fertilizer at the time sowing initiates the root growth and vigorous plant growth (Rose *et al*., 2009). Inadequate amounts of P lead to a reduction in leaf expansion and leaf surface area, as well as the number of leaves. Shoot growth is more affected than root growth, which leads to a decrease in the shoot-root dry weight ratio. Nonetheless, root growth is also reduced by P deficiency, leading to less root mass to reach water and nutrients. The use of nitrogen fertilizers increases the vegetative growth of the plant and lead to lush green crop. While, potash tends to increase the grain weight (Gebreslassie, 2016). Table 5.3.6 below depicts the level of different fertilizers used on the sampled farms. The main phosphoric fertilizers available in Pakistan are DAP (DI ammonium Phosphate), SSP (Single Super Phosphate) and Nitrophos. Therefore, the amount of phosphoric fertilizer is calculated by adding these different fertilizers applied by the farmers.

Table 5.3.6: Level of Fertilizer Use on sampled Farms

Crops	Phosphoric fertilizer (Kg/acre)			Nitrogen fertilizer (Kg/acre)			Potash Fertilizer (Kg/acre)		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Wheat	50.00	200.0	108.70	25.00	150.00	82.20	0	75	22.76
Cotton	25	150	101.60	50	150	97.40	0	50	18.23
Maize	100	175	124.36	100	200	128.2	0	120	30.5
Sugarcane	0	125	83.63	0	125	78.53	0	50	9.78

The average amount of the phosphorus fertilizer applied by the respondents in different splits (base or top dose) to the wheat crop is 108.7 Kg (2.16 bags) with a minimum of 50 Kg and a maximum of 200 kg/acre. Similarly, the mean quantity of urea applied by the wheat growers is 82 Kg/acre (1.6 bags/acre), vary from 25 kg/acre to 150 kg/acre. The results with some variation are in line with the findings of Khan *et al* (2008), Badar *et al* (2005), and Hassan *et al* (2005) who almost mentioned the same level of fertilizer use on the wheat farms. The results are not consistent with Battese *et al* (2014) reported a very higher quantity of nitrogen (328 kg/acre) and phosphorus (160 kg/acre use) on sampled wheat farms, respectively.

In cotton, the average amount of phosphoric and nitrogen fertilizer applied by the sampled farms is 101.6 Kg/acre (2 bags) and 97.40 kg/acre (1.94 bags), respectively. The minimum and maximum values in the case of both fertilizers show the difference in the use of these fertilizers among the farmers. Saddozai *et al* (2013) found a similar level of fertilizer use among the cotton growers. They found that the farmers, on an average, applied 1.91 bags of phosphoric and 2.43 bags of nitrogen fertilizer, respectively.

Hybrid Maize is exhaustive crop and requires intensive use of fertilizer application both at the time of sowing and after the emergence of the crop. Fertilizer can be applied in different splits at different stages of the crop growth. Arain (2013) recommended 2 bags of DAP, 3.5 bags of Urea, 2 bags of SOP and one bag of Zinc sulfate for the maize crop. However, in the study area, the maize growers have used the 2.48 bags (124 Kg/acre) of phosphoric fertilizer and 2.56 bags (128 Kg/acre) of nitrogen fertilizers. The results indicate that the farmers are using the higher level of phosphoric fertilizer and less amount of nitrogen fertilizer compared to the recommended dose mentioned by Arain (2013).

In sugarcane, the average dose of phosphoric and nitrogen fertilizer applied by the farmers is 83 and 78 kg per acre, respectively. Akhtar *et al* (2000) recommended that the use of 200-100-100 kg of NPK per hectare lead to high yield from sugarcane crop. Ali *et al*. (2000) recorded maximum yield of cane when NPK is applied at the rate of 250-112-112 kg per hectare. Similarly, Chaudhry and Chattha (2000) recorded yield (71.12 t/ha) using NPK level 200-100-150 kg per hectare. However, Hussain *et al* (2011) suggested recommended levels of 92, 46 and 50 kilograms per acre for N, P, and K, respectively. Hence, the level of P used by farmers in this study is similar as recommended by (Akhtar *et al*., 2000; Hussain *et al*., 2011). However, farmers are using a higher level of N as compared to these studies. Ali and Abbas (2017) mentioned an average quantity of phosphorus (82 Kg) and Nitrogen (109 Kg) that is similar to this study in the case of Phosphorus and higher against Nitrogen.

The Table 5.3.6 further shows that the use of potash fertilizers on all crops is very low. The farmers have used 22, 18, 30 and 9 kg/acre of potash on wheat, cotton, maize and cotton fields. The limited use of potash fertilizer might be due to its high prices or unawareness about the importance of potash fertilizers. (Ali *et al*., 2012) highlighted that the low quantity of potash fertilizer used may be due to its high prices, lack of knowledge about its importance and the recommended rate applied.

5.3.6.1: Application of Farmyard Manure

It is very much essential to maintain the fertility level of the soil for vigorous plant growth and productivity (Afzal & Shahid, 2009; Nazir *et al*., 2013). Farmers take care of the soil fertility levels to grow crops in a more productive and sustainable manner. FYM is the most common and the oldest method applied by the farmers for growing crops because it is easily available at farm level and contains all the essential nutrients necessary for plant growth. Farmyard manure consists of a decomposed mixture of dung and urine of farm animals along with their litter and leftover material from roughages or fodder fed to the cattle. Application of FYM improves the physical, chemical and biological condition of the soils. FYM can provide all the nutrients needed by the plant, however with low quantity.

Table 5.3.6.1: Distribution of the Respondent Based upon Application of FYM

Crops	Growers	FYM				Trolleys applied		
		Yes	Percent	No	Percent	Mean	Min	Max
Wheat	250	65	26.00	185	74.00	2.913	2	4
Cotton	216	83	38.42	133	61.52	3.215	2	4
Maize	196	72	36.74	124	63.26	3.543	3	4
Sugarcane	220	54	24.51	166	75.45	1.865	1	3

The Table 5.3.6.1 shows that 26 %, 38.42 %, 36.74 % and 24.51 % of the respondents applied the FYM before sowing of wheat, cotton, maize, and sugarcane crops, respectively. The rest of the respondents did not apply the FYM. The reason may be the limited availability of the FYM or intensive use of chemical fertilizer on these farms. The respondents were asked to provide information about the number of trolleys applied per acre. The results indicate that the mean number of trolleys applied per acre by the farmers in wheat, cotton, maize, and sugarcane are 2.9, 3.21, 3.54, and 1.86, respectively. Some farmers also indicated that they have used the carts to broadcast FYM instead of a trolley. Farmers mentioned that approximately 6 to 8 carts of FYM make one trolley of FYM. The information was converted into trolleys for those farmers who have mentioned the use of carts for FYM application. Nazir *et al* (2013) mentioned that sugarcane growers on an average apply 2.5 trolleys per acre and results are close to this study.

5.3.7: Use Of Herbicides and Pesticides

A plant considered undesirable, unattractive, or troublesome, especially one that grows where it is not wanted and often grows or spreads fast or takes the place of desired plants is called weed. Weed infestation is a major hazard in crop production (Cheema et al., 2008; Nadeem et al., 2013). Weeds compete with the crop plants for CO2, water, light, and nutrients, reducing production and quality of crops, hosting insects and disease organisms, damaging irrigation systems and depreciating land values (Cheema et al., 2008; Iftikhar et al., 2010; Nadeem et al., 2013). The damage caused by weeds through the loss of nutrients and water is a major cause of concern to the growers. Schwerzel and Thomas (1971) observed that weeds consume three to four times more nitrogen, potassium, and magnesium than a weed-free crop. They also noted that weeds removed more moisture from the soil.

According to an estimate, weeds reduce the wheat yield by 12 to 35 percent, depending on their intensity (Khan, 2003). Oerke (2006) mentioned 20 and 40 % yield losses in global agricultural productivity caused by pathogens, animals, and weeds. Ibrahim (1984) reported that weeds cause

40% losses in cane yield. In sugarcane, 12 to 72 % reduction in cane yield depending upon the severity of infestation is reported by (Government of India, 2013). Similarly, Weeds reduce maize yield by 29-43 percent or even more. Paller *et al*., (2001) reported 15 to 30 % loss in maize yield. Banga *et al* (2003) reported 25–30% wheat yield loss in Pakistan and India due to Weed infestation.

Tunio (2000) reported losses caused by weed could be minimized through proper weed management. Crop yields are not reduced by weed competition if enough weeding is done at the optimal times (Prasad *et al*., 2008). Judith *et al* (2001) and Hossain (2015) highlighted that herbicide use is an efficient method for controlling weeds and the world is rushing to adopt herbicides for the upcoming developed agriculture. The information related to herbicide and pesticide use is presented in Table 3.3.7.

Table 5.3.7: Statistics of Herbicides, Pesticides and fungicides Application on sampled Farms

Crops	Obs.	Herbicides (no of times)			Pesticides (no of Times)			Seed treatment with fungicide			
		Min	Max	Mean	Min	Max	Mean	Yes	%	No	%
Wheat	250	0	3	1.13	----	----	----	36	14.40	214	85.6
Cotton	216	0	1	.632	3	6	4.34	192	88.88	24	11.12
Maize	196	1	2	1.27	2	3	2.23	196	100	0	0.00
Sugarcane	220	0	2	.872	0	2	0.94	24	10.90	196	89.10

For wheat cotton, maize, and sugarcane, the average number of herbicides sprayed by the sampled farms is 1.32, .632, 1.277, and .872, respectively. The data show that the use of herbicides on cotton crop is low. The reason is that most herbicides that are available to control weeds in cotton must be used within 24 hours after sowing. If these herbicides are not sprayed within this time, then weeds have to remove with any other method like interculturing. The use of herbicides after the emergence of cotton plants also damages the crop along with weed. Saddozai *et al* (2013) mentioned that cotton farmers apply herbicide, on an average 1.10 times. Adzawla *et al*., 2013 found a mean number of pesticide are 2.55.

The respondents were asked to provide the name of the herbicides sprayed on each crop. The majority of the respondents sprayed puma super (*69 g/l fenoxaprop-p-ethyl*) (700ml/acre), *Bucktrl super (*Bromoxynil), *Topik (*240 g/LClodinafop-Propargyl+60 g/LCloquintocet-Mexyl*), Bromoxynil and Flisto gold* on wheat crop. The major pre-emergence herbicides used by the farmers in the cotton crop are *Dual Gold (*960 g/lS-metolachlor), *(800ml/acre). Primextra Gold @ 800ml/acre (*290 g/L S-Metolachlor+370 g/L Atrazine) *800ml/acre), Atrazine (350ml/acre) and 2-4 Dichlorophenoxyacetic* *acid* are the most commonly used herbicides on the sampled farms in the case of maize and sugarcane crop.

The farmers were asked whether the seed is treated with fungicides or not before sowing. All the maize respondents replied that the seed present in the bag was already treated with the fungicides. In the case of cotton, 88 % of the respondent treated the seed with fungicide before planting. The most commonly used fungicide on the sampled farms was Imida-caloprid. A small number of the respondents (14 and 10.90 %) in the case of wheat and sugarcane crop treated the seed with fungicide before sowing. The results are appearing consistent with Ajula *et al* (2010) that majority of wheat growers (96%) use seed without any treatment.

The most frequently used fungicides have been the *Imida-caloprid and the Vitavex* (*Carboxin 37.5% + Thiram 37.5%)* for wheat and sugarcane crop. Vitavex is a broad-spectrum dual action (systemic and contact) fungicide for the control of seed and soil-borne diseases, and act as plant growth stimulant (Arysta, 2016). It is highly effective on diseases caused by the species of fungi namely Ustilago, Sphacelotheca, Tilletia, Rhizoctonia, Sclerotium, Helminthosporium, Fusarium, Septoria, Phoma, Diaporthe, Ascochyta, Botrytis, Aspergillus and Penicillium (Dhanuka, 2017).

The wheat crop in Pakistan is free from the attack of insects and pests and hence no pesticide is required. However, opposite to the wheat crop, cotton is heavily attacked by the insects and pests like *pink bollworm, spotted bollworm, whitefly, Affid, Jasid, Red cotton bug, American bollworm and mealy bug.* The severe attack of one of these pests can seriously damage the crops without any preventive measures. The average numbers of pesticides sprayed by the cotton growers are 4.35. The major pesticides used by the respondents to control these pests were the *Taal Star (*Bifenthrin)*, Lambda(Lambda-Cyhalothrin), Emamectin* (*Benzoate*) *Karate (50 g/l Lambda-Cyhalothrin) and Polytrin C (400 g/l Profenofos + 40 g/l Cypermethrin*).

The maize crop is treated with pesticides, on an average, 2.37 times by the sampled farmers and sugarcane crop is sprayed .946 times. After the emergence of the maize crop, the field is sprayed to control fly. After that, when the both crops gain a height of 2 to 3 feet, granular Carbofuran is poured into the spikes or broadcasted in the field. Carbofuran is applied at the rate of 8 Kg/acre. The results are consistent with Memon *et al* (2016) that an average number of pesticides applied to maize field are 2.55.

5.3.8: Thinning, Interculturing and Earthing Up

The mechanical operation for weed control such as hand weeding and interculturing are successful but the factors like unavailability of labour, high fuel consumption and rains normally limit the weeding operations (Goud, 2016). The inter-culturing is a practice that is usually carried out in cotton and sugarcane to eradicate weeds that are not controlled by herbicide application. Despite weed eradication, interculturing also loosen the soil, resulting in better root growth (Government of India, 2016).

Earthing up is done in sugarcane to prevent the crop from lodging and to get the erect crop (Arain, 2012). Lodging of the crop seriously affects the yield and also make it problematic during harvest. Crop lodging might be due to many reasons, i.e., cane variety, sowing time, sowing method, fertilizer application time, irrigation, rain, and storm are common (Arain, 2012). The cane yield increased by 12 percent when earthing up is performed at the height of 30 cm compared to no earthing up. The breaking of ridges during earthing up operation not only buries weeds present in the field but also secure the crop against the fast winds. The yield of sugarcane reduced to 30 percent after lodging (Ahmad 1997). It is very much important to keep in mind the time for ridge breaking and it should not exceed 10-12 weeks after sowing, otherwise, mechanical injuries to roots may adversely affect the cane yield. Aslam *et al* (2005) & Chattha *et al* (2010) reported that lodging reduces cane yield significantly and practicing earthing up in sugarcane increase the yield. The data related to these farm operations is depicted in Table below.

Table 5.3.8: Thinning, Interculturing, and Earthing up Operations

Crops	***Obs.***	***Thinning***				***Interculturing***				***Earthing up***			
		Yes	**%**	**No**	**%**	**Yes**	**%**	**No**	**%**	**Yes**	**%**	**No**	**%**
Wheat	------	-----	-----	------	-----	-----	-----	-----	-----	-----	-----	----	-----
Cotton	216	148	68.51	68	31.5	174	80.55	42	19.45	-----	-----	------	-----
Maize		-----	-----	------	-----	-----	-----	------	-----	-----	-----	------	-----
Sugarcane	220	-----	-----	------	-----	38	17.27	182	82.72	203	92.28	17	7.72

The data in Table 5.3.8 show that 68.51 % of the cotton growers have done thinning with the purpose to maintain appropriate plant-to-plant distance necessary for better crop stand. Similarly, a vast majority 80.55 % and 17.27 % of the farmers performed the interculturing operation in cotton and sugarcane, respectively for the eradication of weeds. Only a few respondents have performed inter-culturing in sugarcane. This might be due to using of herbicides on sugarcane crops for weed eradication. Secondly, earthing up in sugarcane, itself an inter-culturing operation and eradicate the weeds considerably. A vast majority 92.5 % performed earthing up in sugarcane to cover the plant base with soil. The practice of earthing up prevents the sugarcane crop from lodging and also results in increased number of tillers/plant.

Figure: 5.4: Earthing up in Sugarcane crop

5.3.9: Sources and Number of Irrigation Applied By the Sampled Farms

Water is a vital input for all the crops and productivity of the crops directly associated with the availability and effective use of water (Anjum *et al*., 2016). In Pakistan, the demand for good quality water is rising quickly, while the opportunities for further development of water resources are diminishing. In Pakistan, out of the total geographical area of 22.94 million hectares that is available for crop production, 18.84 million hectares that constitute 82% of the total area were irrigated (Govt. of Pakistan, 2005).

Both surface and groundwater are the major sources available to the Pakistan's irrigated agriculture (Aurangzeb, 2007). The surface water (canal) is mainly in the public sector and is the cheapest source of irrigation. However, the surface water is not available to all farms (Mian and Khan, 1981). The groundwater is pulled out by artisan well generally run by Bullock (a traditional method) or electric/diesel or tractor driven pumps (Aurangzeb, 2007). The farmers can apply either canal or groundwater or both, by mixing the canal and groundwater. In Barani areas of Pakistan, where both canal and tubewell water is not available, rainfall is the major source, responsible for growing and irrigating the crops.

Table: 5.3.9: Descriptive statistics of the Irrigation applied by the sampled Farms

Crops	Total irrigation			Canal irrigation			Tubewell Irrigations			Share	
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Tubwell	Canal
Wheat	3.00	6.00	4.4120	2.00	5.00	2.992	2.00	3.00	2.000	28.65	71.35
Cotton	5.00	14.00	9.652	3.00	10.0	5.45	1.00	7.00	4.356	39.53	60.47
Maize	8.00	17.0	14.245	7.00	12.00	8.25	2.00	5.00	5.367	43.87	56.13
Sugarcane	13.0	21.0	18.564	12.00	17.00	15.35	0.00	4.00	3.753	19.23	81.77

Table 5.3.9 depicts that the mean number of total irrigations applied to the wheat crop are 4.4120 ranged from a minimum of 3 and a maximum of 6 irrigations. The data further reveal that canal water is the major source of irrigation followed by the tube well water. The share of canal and tubewell water is 71.5% and 28.5%, respectively for the wheat crop. The average numbers of canal irrigations applied to the wheat crop by the selected farms are three with a minimum of 2 and a maximum of 5 irrigations. The tube well water irrigations range from 2 to 3, with a mean value of 2 irrigations. There are three critical stages for irrigations in wheat i.e. first irrigation normally 20-25 days after sowing, second at booting stage and third at milking stage of grain development (Mojid *et al*., 2013). Irrigation to crop at critical growth stages is highly influential to get optimum crop produce (Abid *et al*., 2016). In the study area, on an average, the wheat growers had applied first irrigation after 32 days of sowing. The results of this study are consistent with the finding of Badar *et al* (2005) who found that the mean numbers of irrigations applied to the wheat crop by the farmers in the irrigated area are 4. The results are also alike with Hussain *et al* (2004) and Noonari *et al* (2014) that mentioned a similar number of 4 irrigations for the wheat crop in the irrigated area, respectively. SaddozaI *et al* (2013) mentioned 12.05 irrigations in cotton-wheat zone that are close to this study. In case of the maize crop, a huge variation is present with the findings of Memon *et al* (2016) who recorded an average number of 5.8 irrigations, varied from 5 to 7 per acre. This huge variation might be due to the difference in cropping systems. Ali and Abbas (2017) almost found a similar number of irrigations (16.35) for sugarcane crop.

Similar to the wheat crop, canal water is the major source to irrigate the cotton, maize and sugarcane crops and any deficit of canal water is supplemented with tube well water. The share of canal water in the irrigating of cotton, maize and sugarcane crops is 60.47 %, 56.13%, and 81.77 %, supplemented with tube well water with a share of 39.53 %, 43.87 %, and 19.23 %, respectively. The average numbers of total irrigations applied to the cotton, maize, and sugarcane crops are about 9, 14, and 18, respectively. The minimum number of irrigations applied by some sampled farms to the wheat, cotton, maize, and sugarcane crops are 3, 5, 8, and 13, respectively. These values indicate that some farmers are not applying the recommended number of irrigations to these crops. It may be due to the fact that either the farmers have limited access to the canal and tubewell water or they do not have the capacity to buy the tube well water. The second reason may be their limited knowledge about the recommended irrigation requirement of these crops.

5.3.9.1: Sources of Irrigation

The data presented in Table 5.3.9.1 is showing the distribution of the selected farms based upon their ownership of tube well and the type of tube well that is installed to irrigate the fields. The data clearly depict that a vast majority of the respondents about 80 %, in the case of all crops, do not own tube well and mostly purchase the tube well water from other farmers to irrigate their crops. Nearly, 20 % of the farmers, in the case of all crops, installed tube well on their farms for the purpose of irrigation. These results depict that either the small farmers have limited or no capital for the installment of tube well or their size of the farm is too small and they feel appropriate to buy tube well water from other farmers rather than installing a new tube well. Aujla *et al* (2010) also reported that the majority of the small farmers use hired tube well water because their income level and small size of holding hinders them to install tube well on their farms.

Table 5.3.9.1: Distribution of Respondent based upon Ownership and Type of tube well

Crops	Obs.	Source of Irrigation				Type of tube well					
		Own	%	Hired	%	Diesel	%	Tractor driven	%	Electric	%
Wheat	250	46.00	18.4	204.0	81.6	26.0	56.5	16.00	34.7	4.00	8.6
Cotton	216	38.00	17.5	178.0	82.4	25.0	65.7	12.00	31.5	1.00	2.63
Maize	196	34.00	17.3	162.0	82.6	21.0	61.7	11.00	32.3	2.00	5.88
Sugarcane	220	42.00	19.0	178.0	81.0	24.0	57.1	15.00	35.7	3.00	7.14

A vast majority of the respondents, nearly 60 %, in the case of all crops, have installed the tube well driven by diesel engine followed by the tractor driven tube well which is installed almost 30 % of the respondents. The data further reveal that the installment of electric tube well is not common in the study area and 8.6%, 2.63%, 5.88 and 7.14 % of the respondents own electric tube well. This may be due to the electricity crisis in Pakistan that prohibits them to install electric tube well on their farms. The results are not in association with Ajula *et al* (2010) that majority of farm households have their own tubewell in the mixed farming system.

5.3.10: Harvesting

This section explains the procedures followed by the respondents during the harvesting of each crop. Wheat crop is usually harvested in April-May. Manual, reaper, and combine harvesters are the mediums that can be used to harvest the wheat crop. The majority of the respondents replied that they have used the manual method of wheat harvesting. The labour is hired to harvest the crop with the help of sickles and approximately 140 Kg (3.5 Munds) of wheat is given to the labour as wages to harvest one acre. This amount of wheat is almost equal to the US$ 34.48-40.22 depending on the price of the wheat. Only a few farmers mentioned the use of Reaper and combine harvester for the harvesting of wheat and the average amount charged by the owner of the reaper and combine harvester for harvesting one acre is US$ 32.75 and US$ 25.28, respectively. The farmers replied that the reaper and combine harvester method is not working well in the case of lodged crop and lead to the wastage of wheat grain and straw. Mahmood *et al* (2006) also mentioned that the wheat growers prefer the manual harvesting method over reaper and combine harvesting and 60 % of the respondents in the mixed zone used manual harvesting.

In the case of cotton crop, usually, female labour is hired to pick the cotton from the field. This labour charge 5 to 7 Rupees for picking one Kg of cotton. The average numbers of pickings in the study area are 4.46. The crop, which has been grown earlier, is picked 7-8 times and the late grown crop is picked 3 to 4 times. After the final picking, the cotton sticks are cut from the field and further used as fuel to make fire at home and farm. It saves fuel cost up to US$ 45.97 to US$ 57.47, which must be paid if the wood is bought from the market for fire purpose.

The farmers mentioned that no amount is paid for the harvesting of maize and sugarcane crop. The fellow farmers participate in the harvesting process and after picking the maize cobs; they took away the remaining plant of maize and use it as fodder for livestock. Similarly, the fellow farmers harvest the sugarcane crop and took away the upper portion of the sugarcane, for their livestock feeding. If labour is hired to harvest these crops, they usually charge US$ 57.47 to US$ 68.96 rupees per acre.

5.3.10: Physical Yield on the Sampled Farms

This section 5.3.10 present the data about the average yield of wheat, cotton, maize, and sugarcane crops. The average yield attained by the sampled farms from wheat, cotton, and maize and sugarcane crops is 1381.44 Kg/acre (34.52 Munds), 1457.18 Kg/Acre (36.42 Munds), 2920 Kg/acre (73 Munds) and 21840 Kg/ acre (546 Munds), respectively. One maund is equal to the 40 Kg.

The results are almost similar to various other studies. Ajula *et al* (2010) also reported a wheat yield of 1312 kg /acre. The study of Hussain *et al* (2011) mentioned an average yield 35.7 maunds per acre for wheat obtained in the mixed cropping system that is very similar to the results of this study. Battese *et al* (2014) found an average harvested yield of wheat about 1,480 kg/acre that is close to the results. Koondhar *et al* (2016) mentioned a wheat yield of 96 mnds/ ha (38 Maunds/acre) in the mixed farming system. The results with some variations are similar to the results of Badar *et al*

(2005) and Hussain *et al* (2012) in the case of the wheat crop. They reported a yield of 41.03 Munds and 40.02 Munds, respectively for the wheat crop. The results are consistent with Mahmood *et al* (2006) who mentioned a yield of 33.56 Munds from per acre of wheat.

Abedullah *et al* (2006) who reported an average yield of 19.88 Munds from the cotton field. Zulfiqar and Thapa (2016) have mentioned 2263 kg (916 kg per acre) yield from one hectare of cotton that is less than the yield obtained in this study. Fatima *et al* (2016) recorded Non-BT yield (22 maunds per acre); whereas the BT cotton yield (25.4 mounds per acre). These figures are also less than the findings of this study. Sattar et al (2017) found an average cotton yield of 1151 Kg/acre (29 mounds) that is slightly less than this study. In other countries, cotton yield of 344 kg is found by (Adzawla *et al*., 2013)

Memon *et al* (2016) found average maize production of 29.35 mounds, showing a minimum yield of 16 mounds, while the maximum yield of 40 mounds. This level of yield is quite low as compared to this study. The huge difference might be due to the difference in cropping systems. Sattar et al (2017) observed an average maize yield of 2752 kg/acre (68 mounds) that is close to this study.

Hussain *et al*., (2011) recorded a mean sugarcane yield of 707.7 mounds per acre obtained by the farmers in the mixed-farming system. This value is higher than the results of this study. Hussain *et al* (2012) and Naeem *et al* (2007) mentioned an average sugarcane yield of 650 Munds and 590 Munds per acre on small and medium-size farms, respectively. These figures are very close to the results obtained in this research. Ali and Abbas (2017) mentioned average sugarcane yield of 3095.48Kg (577 Munds) that is consistent with this study.

The average price of wheat, cotton, maize, and sugarcane that is received by the respondents in the study area is US$ 12.91, US$ 26.13, US$ 11.21 and US$ 1.69 against per 40 Kg. By taking these prices in the calculation, the average income incurred by the sampled farms from one acre of wheat, cotton, maize, and sugarcane are US$ 445.93, US$ 952.36, US$ 818.10 and US$ 921.03, respectively. In addition to the income from the production, the farmers also incur some additional income by selling the by-product of these crops. The average income that is incurred by the sampled wheat farmers from the sale of wheat straw of one acre is US$ 111.80. In the case of cotton, maize and sugarcane crop, the growers give away the by-product of these crops to the other farmers against the harvesting cost. Therefore, farmers have saved approximately US$ 48.63, US$ 57.47 and US$ 45.98 by giving away the by-product against the harvesting cost of these crops, respectively.

Therefore, the above-mentioned harvesting cost that is saved by the respondents is considered as income from by-product in this research. Finally, the total income (income from produce + income from by-product) incurred by the farmers against wheat, cotton, maize, and sugarcane is US$ 557.73, US$ 1000.99, US$ 875.57, and US$ 967.01, respectively.

Table 5.3.10: Descriptive Statistics of the Yield, Price, and Income on Sampled Farms

Crops	Yield (kg/acre)			Price/ (40kg)	Income (acre)	Income (by product)	Total income
	Min	Max	Mean	Mean	Mean	Mean	Mean
Wheat	360.00	2680.00	1381.44	12.91	445.93	111.80	557.73
Cotton	480.00	2460	1457.78	26.13	952.36	48.63	1000.99
Maize	1080.0	3440	2920	11.21	818.10	57.47	875.57
Sugarcane	12400	28800	21840	1.69	921.03	45.98	967.01

1 maund = 40 Kg (This unit is normally used in Pakistan)

The statistics of minimum and maximum production in this Table 5.3.10 show that some farmers are far behind in fully realizing the potential of these crops as compared to others. They are attaining much lower yield as achieved by other respondents. These results indicate that "yield gap" exists among the farmers under similar resource base and agro-climatic conditions. The Table 5.3.10.1 shows that the "yield gap" is very wide among the farmers, in the case of all crops. The "yield gap" is very wide between the farmers obtaining maximum yield and the lowest yield. The "yield gap" for wheat and cotton crop is 86 % and 80.48 %, respectively. However, "yield gap" is narrow in the case of maize and sugarcane crop when compared to wheat and cotton. The "yield gap" in maize and sugarcane is 68 and 56 %, respectively.

5.3.10.1: Percentage Yield Gap

Crops	Yield (kg/acre)			
	Minimum Yield	Maximum Yield	Yield Difference	Per yield Gap
Wheat	360.00	2680.00	2320	86.56%
Cotton	480.00	2460	1980	80.48%
Maize	1080.0	3440	2360	68.60%
Sugarcane	12400	28800	16400	56.94%

The results are similar to various authors, who also mentioned the existence of yield gap in their study. Luqman *et al* (2005) mentioned that average yield per hectare of wheat, sugarcane and cotton, was 2384, 47927 and 621 kg, as compared with the yield potential of these crops being 5302.69, 107500 and 5261 kg ha-^{1}, respectively. Bakhsh *et al* (2005) reported that cotton yield of progressive farmers is two to three times greater than the national average yield of 570.99 kg ha^{-1}.

Hussain *et al* (2011) also found a yield gap of 34 and 40 percent in the mixed farming system, in the case of sugarcane and wheat crops, respectively.

5.3.11: Cost of Production of Crops

This analysis is carried out to serve two purposes. First, it is decided in this research to use the aggregated output in the form of total income to evaluate the overall efficiency of the mixed farming system. Therefore, the total income is calculated in this section and them used in DEA models in Chapter 7 to evaluate the overall performance of the mixed farming system. Second, it is evaluated from the literature review that a wide variation exists among the researchers in the calculation of total cost and income for wheat, cotton, maize and sugarcane crops. This variation might be due to exclusion of various cost heads in the analysis. Therefore, in this study, it is attempted to calculate the cost of production and income as accurate as possible by including all the relevant cost heads.

Production cost that is incurred on the sampled farms is comprised of fixed and variable costs. The fixed cost of production includes land rent and taxes. While, variable cost comprises the labour and capital cost. Koondhar *et al*., (2016) mentioned variable costs are those costs which depend on a company production volume; they rise and decrease with the supply and demand of products. The cost of labour comprised of the cost that is paid to the labour for land preparation, sowing, inter-culturing, irrigation pesticides applications, and harvesting. The capital cost consists of the cost spent on field operations, seed, FYM, fertilizers, water, pesticides etc. The average per acre cost of land inputs in wheat, cotton, maize, and sugarcane were US$ 55.95, US$ 51.46, US$ 50.67, and US$ 68.13, respectively. The information about the prevalent rent of land/year was collected from the farmers and distributed in the crop-standing period.

Labour cost comprised of the cost paid to the labour for land preparation, water channel cleaning, fertilizer and seed broadcasting, irrigation, sowing of the crop. The average cost of labor inputs for wheat, cotton, maize, and sugarcane was US$ 28.37, US$ 62.38, US$ 31.47, and US$ 27.49, respectively. The results show that cotton and maize were more labor-intensive crops when compared to wheat and maize. The farmers used various kinds of phosphoric, nitrogenous and potash fertilizers with different prices. Therefore, the total fertilizers cost is calculated by adding the cost spent on each fertilizer.

(Conversion Rate- 2012-13   1 US$ = 87 PKR)

Table 5.3.11: Descriptive Statistics of Cost of Production on Sampled Farms

Variables	*Cost of production*			
	Wheat	**Cotton**	**Maize**	**Sugarcane**
Fixed cost				
Land Rent	55.95	51.46	50.67	68.13
Labour cost				
Cost labour	28.37	62.38	31.47	27.49
Capital cost				
Land preparation cost	35.90	49.05	57.74	33.23
Seed cost	16.07	16.42	78.56	100.73
Fertilizer cost	69.69	71.71	100.43	64.80
Irrigation cost	47.15	66.55	100.37	52.15
Pesticides and weedicide cost	9.88	65.86	30.09	11.30
Harvesting cost	43.95			
Threshing cost, Picking, shelling cost,	36.53	72.38	48.43	36.03
Total Cost/acre	343.50	455.81	497.76	370.88
Total income	557.73	1000.99	875.57	967.01
Profit	214.23	545.18	377.82	596.13

The average amount spent on fertilizers by the wheat, maize, cotton and sugarcane growers is US$ 69.70, US$ 71.71, US$ 100.43, and US$ 64.80, respectively. In case of wheat crop, the results are similar to Noonari *et al* (2014) who found that fertilizers accounted for a major proportion of total cost as it was an average of PKR 7779.33 per acre (US$ 89.41). Khan *et al* (2012) mentioned an average fertilizer cost of PKR 5484 (US$ 64) for wheat and is almost consistent with the findings. Abedullah *et al* (2006) found an average fertilizer cost of PKR 23769/hec (US$ 110.61 per acre) in cotton that is close to the results found in this study. The total irrigation cost is calculated by adding the cost spent on tube well and canal water irrigation. The data show that the irrigation cost in maize is US$ 100.37 that is much higher as compared to wheat (US$ 47.15), cotton (US$ 66.55) and sugarcane (US$ 52.15). This shows that the hybrid maize is water intensive crop and requires successive irrigation from germination to crop maturity. The total irrigation cost for wheat in line with the cost reported by Noonari *et al* (2014) that Irrigation cost was the second major contributor to the total wheat production costs Rs. 4290.07 per acre (USD $ 49.31). The irrigation cost for cotton found in this study is exactly similar to the study of Abedullah *et al* (2006) who found an irrigation cost of PKR 14484/ha (US $ 66.47 per acre). The total land preparation cost is the aggregation of the cost incurred on ploughings, planking, rotavations, leveling, drilling and ridge making. The Table shows that the land preparation cost incurred on cotton (US$ 49.05) and maize (US$ 54.74) is more as compared to wheat (US$ 35.90) and sugarcane (US$ 33.23). The reason is that these crops require intensive cultivation before sowing and secondly, the formation of ridges in the case of these crops tends to increase the land preparation cost. Noonari *et al* (2014) also found land preparation cost Rs.

3482 (US$ 40.02) for wheat crop that is similar to this study. In case of cotton crop, Zulfiqar and Thapa (2016) has mentioned a higher land preparation cost of cotton field PKR 14650/ha (US$ 68.17 /acre) as compared to this study. However, results are almost consistent with Abedullah *et al* (2006) who reported land preparation cost of cotton PKR 4867.5 (US $ 55.94 /acre). The more recent study of Sattar *et al* (2017) found higher land preparation cost of cotton PKR 5521 (US$ 63.45) and almost equal cost PKR 4358.8 (US$ 50.09) for maize as compared to this study. The cost of seed in the case of wheat (US$ 16.07) and cotton (US$ 16.42) crops is low when compared with the cost incurred in buying maize (US$ 100.43) and sugarcane seed (US$ 64.80). The reason is that the maize seed is imported which results in its high seed cost. The cost of sugarcane seed is also high because high seed rate is required per acre compared to cotton and wheat. The cotton requires more number of pesticides and herbicides. Therefore, the pesticides and herbicides cost are much higher on cotton than the other crops. The results are not consistent with the finding of Usama *et al* (2016) who mentioned relatively higher seed cost (US$ 30.18) as compared to this study. However, Khan *et al* (2012) mentioned wheat seed cost of (US$ 14) that is near to the finding of this study. The cost of maize seed is high due to use of hybrid seed varieties. The similar reason for high seed price of maize is reported by (Sattar *et al*., 2017). The cost of harvesting and threshing is higher on the wheat and cotton crops that are US$ 80.48 and US$ 72.38, respectively. The rates prevailed for harvesting in the study area for each crop is already mentioned in the Table 5.9.8. In case of cotton crop, the findings are almost similar to those of Abedullah *et al* (2006) and Awan *et al* (2015) that reported harvesting cost of PKR 13179/ha (US $ 61.32 per acre) and PKR 5273 (US$ 60.60 per acre), respectively. However, Sattar *et al* (2017) found higher harvesting cost for cotton 7841 (US$ 90.70) than this study. The total cost incurred is calculated by adding up all the above-mentioned costs. Hence, the total cost spent by the respondents to grow one acre of wheat, cotton, maize, and sugarcane is US$ 343.50, US$ 455.81, US$ 497.76, and US$ 370.88, respectively. The results with little fluctuation are consistent with the findings of Koondhar *et al* (2016) who estimated average cost of wheat production US$ 780/ha (US $ 316/acre) in the mixed farming system. Similarly, Noonari *et al* (2014) found the total per acre average cost for wheat production was PKR 23375.26 (US$ 269/acre) which is quite low as compared to this study. The cost of production of wheat PKR 27674(US$ 318/acre) as reported by Khan *et al* (2012) is close to the findings of this study. The total cost for cotton found in this study is higher than the cost PKR 20065 (US$ 231/acre) recorded by (Awan *et al*., 2015). However, Zulfiqar and Thapa (2016) recorded a total cost of 101,165 PKR /ha (US $ 470) for cotton and consistent with this study. Chaudhry and Muhammad (2009) calculated quite low cost of production PKR 16426 (US$ 188) to grow one acre of cotton. The total cost calculated in this study is very high as compared to this study. In recent year, Sattar *et al* (2017) calculated very high production cost against cotton (US$ 789) and maize (US$ 661). This implies a many fold rise in the prices of all inputs over a period of time. The cost of production found in this study for all crops is higher as compared to other studies. The high cost of production might be due to higher input costs. Kibaara (2005) highlighted that poor allocative efficiency could be the cause of higher production cost and reduction in economic inefficiency can reduce the costs of production. This implies that the current levels of technical efficiency have to be measured to approximate the production losses that could be caused by inefficiencies due to differences in farmers' management practices and socio-economic characteristics. The farm income refers to the total annual earnings of the family from the sale of agricultural produce after meeting family requirements. This is believed to be the main source of capital for purchasing agricultural inputs. Thus, those households with a relatively higher level of farm income are likely to purchase improved seeds or other essential agricultural inputs.

In this study, the total income incurred from one acre of wheat, maize, cotton, and sugarcane is calculated by adding the income from yield and income from by-product. The Table 5.9.8 shows that the total income obtained from one acre of wheat, cotton, maize, and sugarcane is US$ 557.73, US$ 1000.99, US$ 875.57, and US$ 967.01, respectively. Koondhar *et al*., (2016) calculated that the total income that is incurred by the wheat growers in the mixed farming system is USD$ 1248/ha (US$ 505.26/acre). There is a slight difference in the results that might be due to the conversion rate. The results are also consistent with Noonari *et al* (2014) who mentioned wheat revenue of PKR 48190 (US$ 554/acre). Zulfiqar and Thapa (2016) mentioned that total income from one hectare of cotton is 169913 PKR (US$ 790/acre) and is close to this study. Sattar *et al* (2017) found a total income of US$ 793 and US$ 746 from cotton and maize crops, respectively. The net profit (total income-Total cost) achieved by the farmers from one acre of wheat, cotton, maize, and sugarcane is US$ 214.23, US$ 545.18, US$ 377.82, and US$ 596.13, respectively. The results indicate that the sugarcane and cotton crops are more profitable as compared to the wheat and maize crops. Koondhar *et al*., (2016) reported a net return of USD$ 481/ha (US$ 194.73/acre) from the wheat crop in mixed farming systems and these findings are comparable with this study. Awan *et al* (2015) mentioned a net profit of PKR 41987.5 (US$ 483/acre) from a cotton crop that is less than this study. The net profit for cotton found in this study is higher than the profit 68744 PKR/ha (US$ 319/acre) recorded by (Zulfiqar and Thapa, 2016). Sattar *et al* (2017) calculated a gross margin of PKR 24892 (US$ 286) and

PKR 21318 (US$ 245) from maize and cotton crops, respectively and this is less as compared to this study.

5.4: MARKETING PLACE OF THE PRODUCE

Farmers rely on various sources to sell their produce. The choice of each source depends on various factors like price, accessibility of the source, availability of equipment for the transportation of produce etc. The farmers were asked to provide information about the sources that were preferred to sell their products and results are asunder.

Table 5.4: Distribution of Respondent based upon Selling Place of Produce

Selling Place	Wheat		Cotton		Maize		Sugarcane	
	No	%	No	%	No	%	No	%
Mill	4	1.6	156	72.2	45	22.9	95	43.18
Commission Agent	146	58.4	38	17.5	147	75	46	20.90
Fellow farmers	78	31.2	23	10.6	19	9.6	26	11.81
Beopari	36	14.4	8	3.70	14	7.14		0
Government Agency	23	9.2	00	0	00	0		0
(self consumption)	17	6.8	4	1.85	2	.76	66	30

The majority of the wheat and maize respondents 58.8 % and 75 % sold their produce to the commission agents. The commission agents are often available in the town near to the village. The commission agents charge their fees from both the farmers and the trader. The price is determined by direct negotiations between the traders and farmers. Since the quantities of the produce involved are small, a farmer may not mind small price differentials. However, for larger quantities, farmers try to access wholesale markets, or at least, try to compare prices with those markets before selling the produce. The cotton and wheat growers in the study area prefer cotton and sugar mills, to sell their produce. About, 72 % and 43.1 % of the respondents sold the produce of cotton and sugarcane to the mills. The mills are preferred because these are the major sources, involved in the purchase of these crops. Badar *et al* (2005) also found that the progressive farmers mainly disposed of their produce to village dealers, nearby consumers and local village fellows etc. The results are inconsistent with the results of Raza (2016) that government is the main buyer of farmers' wheat. The farmer in the study area held some of their produce at home for self-consumption. The part of this produce is also used as a seed to grow the next year crop. A small percentage of the farmers, 6.8 %, 1.85 %, .76 % and 30 % in the case of all crops, hold all of their produce for self-consumption. This percentage is high for sugarcane because farmers used sugarcane as fodder for livestock during the period of wheat straw deficiency. The data show that the government agencies (PASSCO) are only involved in the purchase of wheat and 9.2 % of the wheat grower sold their produce to PASSCO.

5.5: SOURCES OF AGRICULTURAL CREDITS

The farmers require finances to apply modern agricultural technologies and inputs on their farms that are responsible for rapid growth of the farming sector (Karimov *et al*., 2014). These finances come either from their own savings or by obtaining credit. In developing economies like Pakistan, small farmers have negligible or limited savings and agricultural credit found to be vital input for investment in agriculture (Iqbal *et al*., 2003). Shortage of credit availability or capital constraint faced by the farmers is one of the major problems in the adoption of modern technologies and efficiency improvement in the agriculture sector (Karimov *et al*., 2014). The credit constraints hinder farmers from regular and smooth consumption of inputs, therefore, undermining their ability to achieve maximum potential yield from crops (Malik, 1999; Karimov *et al*., 2014). Recently, formal and informal are the two sources available in Pakistan for borrowing loans. The formal agricultural credit institutions comprise of Zarai Taraqiati Bank Limited (ZTBL), Commercial Banks, Federal Bank for Cooperatives and also some non-governmental organizations (NGOs).The informal sector includes input dealers, friends, fellow farmers relatives, and commission agents, etc (Iqbal *et al* 2003). The data show that the 35.6 %, 48.6 %, 63.7 % and 33.6 % of the respondents were obtained credit to grow wheat, cotton and maize and sugarcane crop. The results reveal that the most of the farmers obtained loans for cotton and maize crop. The reason might be the high cost of production on these crops as clear from the data in section 5.3.11. These crops require a high amount of fertilizers, pesticides, and irrigations that influence the farmers to obtain credit.

A vast majority of the respondents gets the loan from the informal sources and only 13%, 22 %, 13% and 10 % of the respondents used banks as a credit source. Among the informal sources, the inputs dealers and the fellow farmers were the major sources for credit acquisition. The farmers in the study area prefer fellow farmers, friends, and relatives to obtain a loan because they provide credit without any interest rate compared to banks who charge interest rate ranging from 9 % to 14 % annually. The inputs dealers and commission agents are preferred because they timely provide them with fertilizers, herbicides, and pesticides. An informal contract (verbal) is made between the farmers and the dealers before the supply of inputs. In this verbal contract, the farmers were bound to bring their produce to the dealer for sale after harvesting.

5.5: Sources of Agricultural Credit

Crops	*Obs*	*Credit*				*Sources of Credit*									
		Yes	**%**	**No**	**%**	**Bank**	**%**	**Fellow farmers**	**%**	**Commission agent**	**%**	**Input Dealer**	**%**	**Multiple**	**%**
Wheat	250	89	35.6	161	64.4	12	13.4	21	23.5	12	13.48	45	50.5	9	10.11
Cotton	216	105	48.6	111	51.3	24	22.8	32	30.47	8	7.61	38	36.1	3	2.85
Maize	196	134	63.7	71	36.2	18	13.4	17	12.68	22	16.41	62	46.2	15	11.19
Sugarcane	220	74	33.6	146	66.3	8	10.8	38	51.35	4	5.40	20	27.0	4	5.45

The input dealers and commission agents deduct the cost of inputs, supplied to the farmers and commission money is also charged for the sale of produce. About 50%, 36%, 46% and 27 % of the respondents get the inputs on credit from dealers. The farmers who borrowed the loans from fellow farmers constitute 23.5%, 30.47%, 12.68% and 51 % for wheat, cotton, maize, and sugarcane, respectively. Some farmers mentioned that they borrowed the loan from two or more than two sources. These types of respondents are 10.11%, 2.85%, 11.19 and 5.85% for wheat, cotton, maize, and sugarcane, respectively.

5.6: YIELD LIMITING FACTORS ON THE SAMPLED FARMS

The respondents were asked to identify the factors responsible for low yield of wheat, cotton, maize, and sugarcane. The respondents identified that the limited access to resources, lack of farm machinery, small farm size, water scarcity, and high prices of the inputs are the major hurdles that hinder them from attaining the maximum production from the wheat crop. According to the ranking, limited resources, lack of farm machinery, high prices of the inputs, small farm size, and water scarcity are ranked 1st, 2nd, 3rd, 4th, and 5th, respectively by the wheat growers. In addition, improper management practices, low rainfall, poor quality seed and weed infestation are also identified by the farmers. The Table 5.6 indicated that limited resource, lack of farm machinery, high input prices, the size of the farm, attack of insect pests and weeds were ranked 1st, 2nd, 3rd, 4th, and 5th and 6th by the farmers, respectively in cotton. However, maize grower identified high input pricing, the size of the farm, water scarcity, lack of farm machinery and limited resources as major problems. Sugarcane is water exhaustive crops and majority of the respondents declared water shortage as the major problem and hence it is ranked 1st followed by the limited resources, small size of the farm, lack of farm machinery, weed infestation and low rainfall which are ranked as 2nd, 3rd, 4th, and 5th and 6th, respectively.

Table 5.6: Distribution of the sampled farms Based upon Problem faced

S.No	Farm machinery	Wheat			Cotton			Maize			Sugarcane		
			250			216			196			220	
		No	%	Rank	No	%	Rank	No	%	Rank	No	%	Rank
1	Water scarcity	122	48.8	5	92	42.59	7	137	69.89	3	168	76.36	1
2	Low soil Fertility	18	7.2	10	22	10.18	10	32	16.32	9	32	14.54	10
3	Limited access to resources	203	81.2	1	157	72.68	1	123	62.75	5	167	75.90	2
4	Poor quality Seed	23	9.2	9	12	5.55	13	0	0	14	7	3.181	14
5	High input Pricing	174	69.6	3	153	70.83	3	147	75	1	32	14.54	9
6	Size of holding	167	66.8	4	138	63.88	4	142	72.44	2	154	70	3
7	Improper Management	45	18	6	26	12.03	9	34	17.34	8	27	12.27	11
8	Weed infestation	34	13.6	7	104	48.14	6	44	22.44	7	64	29.09	5
9	Labour shortage	12	4.8	12	9	4.16	14	15	7.65	12	24	10.90	3
10	Insufficient Machinery	179	71.6	2	154	71.29	2	132	67.34	4	105	47.72	4
11	Low Rainfall	27	10.8	8	19	8.79	11	54	27.55	6	47	21.36	6
12	Insect pest attack	8	3.2	13	122	56.48	5	22	10.77	1	33	15	8
13	No access to information	14	5.6	11	37	17.12	8	27	13.77	10	34	15.45	7
14	Others	7	2.8	14	16	7.40	12	4	2.04	13	25	11.36	12

The results are in line with the results of Sharazar *et al* (2012) who divided the problems faced by the farmers in three categories i.e. Agronomic, socioeconomic and institutional. He reported that the major agronomic problem faced by the farmers in the mixed farming system is water scarcity followed by the adverse environmental effects and adulteration of seed and pesticides. The major institutional problems reported were the high input prices and credit unavailability. The major socioeconomic problem that was identified by the Sharazar *et al* (2012) is the small farm size. Dogar *et al* (2016) conducted constraints analysis and found that adulterated pesticides, lack of extension services, lack of credit, shortage of canal and tubewell water, high input and oil prices were the main constraints being faced by the wheat farmers. The results came out from this research clearly shows that the small farmers are still far behind in accessing the resources and implementing the modern farm tools on their farms. Their size of the farm is too small. Asim (2010) found that the size of the farm is a factor that determines access to the resources. The access to the resources is highly skewed in Pakistan and large farmers have more access to agricultural inputs as compared to small farmers.

5.7: Summary of Variables Identified to use in second Step contextual Analysis

The efficiency differential among the farmers in the same farming system is a matter of great interest for the policymakers. This difference may be due to managerial ability and skill of a farm's operator and interaction of various socioeconomic factors. This section provides the summary of the key variables that are identified and then used later in double bootstrap truncated regression model. These identified variables hypothesized to have substantial impact on the levels of technical efficiency of the smallholder wheat, cotton, maize and sugarcane farmers. According to Bukhsh (2007) and Jordan (2012) a range of factors like distinctiveness of farms, human and social capital, management, physical, institutional and environmental aspects could be the cause of inefficiencies in the production process of the farmers. The description and detail of the variables that are used and hypothesized to affect technical efficiency include;

- Socio-Economic Factors: Age, level of education, household size, farming experience, marital status
- Institutional Factors: credit, extension contact, extension training, practicing extension recommendation
- Environmental Factors: Water quality, Soil quality, FYM

- Farm specific Factors: Farm area, Land fragmentation, tractor and tubwell ownership, Tenancy
- Agronomic Factor: Early sowing of crops, seed quality

The variable of age hypothesized to be proxy for experience and measured in years. In this case, farmers with more years of experience are expected to be more efficient. On the other hand, older farmers are relatively unlikely to change their long life farming exercise, which is usually traditional and less efficient. The impact of age on TE is also evaluated by (Byma and Tauer 2010; Saheen *et al*., 2011, Asogwa *et al*., 2012; Naqvi and Ashfaq 2013; Miraj and Ali , 2014; Bakhsh *et al*., 2014; Khan and Farman., 2013; Rahman *et al*., 2012; Itam *et al*., 2015). Education is included by thinking it as proxy variable for managerial ability of the farmers. It is assumed that through education, the quality of labour is improved and he/she become active to adopt new technologies. This is may be because of the good management skills acquired over the years, which enabled farmers to reduce their technical inefficiency. Education has been has considered an important variable by (Byma and Tauer 2010; 2011;Fatima *et al*., Asogwa *et al*., 2012; Naqvi and Ashfaq 2013; Saddozai *et al*., 2013 ; Kibaara, 2005;Mohapatra, 2013, Ali and Khan , 2014 , Kitila & Alemu 2014; Rajendran 2014Khan and Farman., 2013; Itam *et al*., 2015; Yang *et al*., 2016). Farming experience refers to production experience of the farmers for growing wheat, cotton, maize and sugarcane and measured in years. The number of years in wheat, cotton, maize and sugarcane farming is also expected to have a positive influence on the technical efficiency of the farmers; hence, a positive sign is expected. As one gets proficient in the methods of production, optimal allocation of resources at his/her disposal should be achieved. The variable of farming experience is also considered in number of studies (Okoye *et al*., 2008;Saheen *et al*., 2011; Mohapatra, 2013; Adzawla *et al*., 2013; Saddozai *et al*., 2015; Itam *et al*., 2015; Miraj and Ali , 2014; Fatima *et al*., 2016). For the variable of household size, it is assumed that the households with greater numbers of family members will be more efficient because the availability of more labour during peak cultivation periods. The family members are an important source of labor supply in a farming system. The studies of Asogwa *et al* (2012), Rahman *et al* (2012) and Itam *et al* (2015) also considered the variable of household size in their study. The variable of marital status is also considered and both type of effect positive or negative is expected for this variable.

To support or reject the inverse relationship between farm size and TE, the variable of farm size is included in the model similar to other studies (Bashir and Dilwar, 2005, Okoye *et al*., 2008; Byma and Tauer 2010; Błażejczyk-Majka *et al*., 2011; Adzawla *et al*., 2013; Rajendran 2014; Rajendran *et al*., 2015; Bakhsh *et al*., 2014; Hashmi *et al*., 2015; Itam *et al*., 2015). The variable of land ownership is considered and hypothesized to have both positive and negative impact on the level of TE. The owner of the farms may be more efficient because they have more security as compared to tenants, but tenants can also be more efficient because they tend to produce more output from the piece of land hired. This variable is considered in number of studies (Rahman , 2003; Solıs *et al*., 2009; Fatima *et al*., 2016). The variable of land fragmentation is selected to include in the regression model and it is considered that its impact on TE can either be positive or negative. Increased land fragmentation can cause inefficiency due to increased use of labour, increase cost of production and difficulty in management (Fekadu and Bezabih, 2009). However, its impact can be positive because different parcels of land have different soil and water quality, which can increase efficiency. Land fragmentation is also considered by Wadud, (2003), Tipi *et al* (2009) and Tan *et al* (2010) as major determinant.

The variable of soil and water quality is included by considering that the soil and water with high quality may have positive response. The fertile land with abundant supply of quality water can enhance production and hence efficiency (Abebayehu, 2011). The variable of farmyard manure also considered in this study and positive sign is expected.

The variables of tractor and tubwell ownership are identified and positive sign is expected for both of these variables. The ownership of tractor helps the farmers to timely preparing their fields for crop cultivation. The timely sowing of crops tends to improve the technical efficiency of the farmers. Similarly, the ownership of tube well enables farmers to timely irrigate their crops that ultimately enhance efficiency. The following studies used these variables (Kibaara, 2005; Hashmi *et al*., 2015; Watto, 2013; Fatima *et al*., 2016).

It is considered that all the variables related to the extension services will have great positive impact on the technical efficiency. This is because, the contact with extension agent in any form allow farmers to access new information and technology that could be helpful in farm management decisions. Similarly, access to credit is also an important institutional factor because; timely credit enables the smallholder farmers to purchase agricultural inputs in time that would increase their productivity. The variables related to extension services are used by the following studies (Rahman , 2003; Croppenstedt, 2005; Solıs *et al*., 2009; Byma and Tauer 2010; Asogwa *et al*., 2012; Naqvi and Ashfaq 2013;; Battese *et al*., 2014; Bakhsh *et al*., 2014; usman *et al*., 2016, Yang *et al*., 2016). The variable of credit has been considered by (Khan and Farman., 2013; Bakhsh *et al*., 2014; Rajendran 2014; usman *et al*., 2016; Yang *et al*., 2016). In addition to these determinants, some agronomic factors like pesticides, seed quality and the variable related early crop establishment factor are also considered.

5.8: OVERALL SUMMARY

In this chapter, the socioeconomic characteristics and the production technology that is followed by the farmers is discussed in detail. The major findings came out from this discussion revealed that variation exists among the farmers in the use of inputs and the level of output produced. The analysis of data showed that some farmers are using the various inputs like seed, fertilizers, water, FYM and herbicides below the recommended level and some are using above the optimal level. Further, the data regarding yield/acre of wheat, cotton, maize, and sugarcane on the sampled farms showed that some farmers are not achieving the maximum potential yield from these crops as attained by some growers. "Yield gap" exists in the case of all crops which is very wider. Cost and profitability analysis showed that sugarcane and cotton are the most profitable crops as compared to wheat and maize. The discussion also showed that the small farmers mostly hired farm machinery from other sources.

CHAPTER 6

EFFICIENCY ANALYSIS OF THE FARMERS IN MIXED CROPPING ZONE

This chapter is devoted to the presentation and discussion of the efficiency analysis results computed through solving various DEA models. This chapter is comprised of various sections and the first section provides summary statistics of the variables that are included in the DEA models. In section 6.2, TE_{CRS} , TE_{VRS} , SE, CE, AE and BCTE of the wheat, cotton, maize and sugarcane crops are estimated and these results are discussed. These results are generated by using per acre and per farm data in the DEA models, because none of the study in Pakistan has tried to compare the results by using both per acre and per farm data. From the results of TE under CRS and VRS assumptions, scale efficiency of the selected wheat, cotton, maize, and sugarcane farms is then computed to see whether the technical inefficiency is due to the mismanagement of the resources or farm's scale of operation. The analysis is further expanded and cost and allocative efficiency of the selected farms is quantified. Bootstrap DEA is applied to correct the efficiency form biases and the results are also discussed and presented comprehensively in this section.

Slack analysis is performed to find the inputs that are used in excess by the sampled wheat, cotton, maize, and sugarcane farms and the results related to this analysis are summarized in section 6.3. DEA also provides very strong framework for benchmarking and identify the areas of improvement for inefficient farms that can guide farm managers to make adjustments in the input mix used. The benchmarking analysis is based on the assumption that the farms use the same type of inputs and difference in level of technical efficiency emerge due to inappropriate use of inputs. DEA identifies the "referent units" for the inefficient farms and thus provides a set of role models that the inefficient units can look to in order to improve its operations. This makes DEA a very useful tool for benchmarking compared to other methods. Therefore, in section 6.4 benchmarking analysis is performed to identify the weak areas of inefficient farms for further improvement. Simar and Wilson (2007) proposed that the estimated efficiency scores of the first stage are correlated with the environmental variables used in the second stage, and thereby the second stage estimates will be inconsistent and biased. Simar and Wilson (2007) proposed a bootstrapping DEA to estimate the efficiency scores in the first stage and a truncated regression (instead of Tobit and OLS) with a bootstrap technique in the second stage regression to overcome this problem. The section 6.5 of this chapter summarized the results related to the determinants of TE investigated by the application of double bootstrap truncated regression.

6.1.: DESCRIPTION OF VARIABLES INCLUDED IN DEA MODELS

The input variables for the DEA models are selected by carefully observing the variation in input use level among the farmers. It is observed that the major variables that might be responsible for yield variation among the farmers include irrigation water (hours per acre), nitrogen (kg /acre), phosphoric fertilizer (kg /acre), labour (hours/acre), pesticide use (numbers per acre) and tractor hours. It can be observed from the data set that some farmers are using 2 to 4 times more quantity of these inputs than the others. The procedure that is followed to calculate these variables is already discussed in chapter 4 (see appendix c).

The descriptive statistics associated with these inputs are presented in Table 6.1 and 6.1.1 that evidently show a huge variation among the farmers, in both the input use and the output produced. The production of some sampled farmers is much greater as compared to the others, in addition to wide variations in the levels at which inputs were being used. The data in the table below show that some farmers are using many times more nitrogen fertilizers as compared to the others, in the case of all crops. Further, the data also show that the use of phosphoric and nitrogenous fertilizer to sugarcane crop is negligible on some farms. The difference in the use of tractors hours show that some farmers might used higher number of ploughings, planking and rotavations as compared to others that enhanced their tractors hours. Such variations in the inputs use level represent a mismanagement of resource use. The Table 6.1 and 6.1.1 contain the summary of the values of key variables that are included in the DEA models. The information about inputs and outputs is presented on per acre and per farm basis in Table 6.1 and 6.1.1, respectively. The data in Table 6.1 clearly show that the average output achieved from one acre of wheat, cotton, maize, and sugarcane crops is 1381.44 Kg, 1457.78 Kg, 2920 Kg, and 21840 Kg, respectively. In the case of all crops, the comparison of minimum and maximum values show much greater output on some farms compared to the others, in the mixed farming system of Pakistan.

Table 6.1: Level of Input Use on Per Acre by the Sampled Wheat, cotton, maize, and sugarcane Small Farmers

Inputs	***Wheat***			***Cotton***			***Maize***			***Sugarcane***		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Tractor hours	5.58	18.17	8.30	3.50	9.17	5.06	7.17	13.19	9.34	2.14	7.12	4.34
Irrigation Hours	10.00	20.00	14.14	8.00	32	19.23	14.00	44.00	29.45	32	52	34.89
P fertilizer	50.00	200.	108.7	25	150	101.6	100	175	124.3	0	125	83.63
N Fertilizers	25.00	150.0	82.20	50	150	97.40	100	200	128.2	0	125	78.53
Seed quantity	40.00	70.00	53.33	------								
Labour hours	35.97	106.2	59.19	44.66	140.5	91.03	68	184.0	108.2	38	105.	78.89
Pesticide use (no)				3.0	6.0	4.345						
Yield (Kg/acre)	360.0	2680.0	1381.4	480.0	2460	1457.7	1080.0	3440	2920	12400	28800	21840

The average number of tractor hours/acre used by the wheat, cotton, maize, and sugarcane are 8.30 5.06, 9.34, and 4.34, respectively. The difference in minimum and maximum values might be due to intensive use of tractor on some farms for leveling, ploughing, planking and rotavations, as compared to the others. Usman *et al* (2016) found average tractor hours of 2.67 used by wheat farmers. These values of tractor hours might be less than this study because the threshing time is not considered in calculation by (Usman *et al*., 2016). The average number of irrigation hours applied to the wheat, cotton, maize, and sugarcane fields are 14.14 hrs, 19.23 hrs, 29.45 hrs and 34.89 hrs, respectively. The values against irrigation hours are higher for maize and sugarcane compared to wheat and cotton crops because these crops require more irrigation from sowing to harvesting. From a large difference in a minimum and a maximum value, it can be concluded that some farmers rely more on tube well irrigations that tends to increase their irrigation hours because tube well water takes more time as compared to canal water to irrigate one acre. However, average irrigation hours applied per acre by small wheat farmers are found to be 19.55 by (Usman *et al*., 2016). The average quantity of phosphoric and nitrogenous fertilizers applied by the sampled farms in different splits is 108.7 Kg, 101.60 Kg, 124.36 Kg, 83.63 Kg and 82.2 Kg 97.40, 128.2 Kg, 78.53 Kg, respectively in the case of wheat, cotton, and maize and sugarcane crops. A considerable difference in the fertilizers use level can also be seen among the farmers. The average amount of seed used per acre was 53.33 kg, with a minimum of 40 kg and a maximum of 70 kg for wheat crop. The variable of seed is excluded from the DEA analysis in the case of cotton, maize and sugarcane because the respondents almost used similar seed rate for these crops. The average number of labour hours spent by the sampled farms to carry out different farm operations (ploughing, planking, harvesting, rotavations, water channel cleaning) are 59.19 hrs, 91.03 hrs, 108.2 hrs and 78.89 hrs in the case of wheat, cotton, maize, and sugarcane crops, respectively. Contrary to the previous table, the next table shows the level of input use on per farm.

Table 6.1.1 Level of Input Use Per Farm

INPUTS	Wheat			Cotton			Maize			Sugarcane		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Tractor hours	14.58	87.54	22.19	4.50	32.67	14.98	7.17	38	11.89	2.14	27.5	9.67
Irrigation Hours	14.00	120.	37.12	8	84.00	31.66	14	140.0	36.98	32	212	67.56
P fertilizer	50.00	11200	295.1	25	567.22	172.1	100	500	146.7	0	365	156.87
N Fertilizer	50	8750	217.1	25	525.00	158.1	75	600.5	217.2	0	287	154.7
Seed quantity	40.00	420.0	140.4									
Labour hours	35.97	743.7	159.2	44.6	544.04	154.6	44.92	582	138.9	38	384.	142.6
Pesticide (no)				3	20.00	7.52						
Yield (Kg/acre)	360*	12320.	3708.95	480*	9920	2234.78	1080.0	12000.0	3343.00	12400	76543	63550

(*Minimum yield per acre and per farm appeared same in both cases because some farmers had grown only one acre of wheat, cotton, maize and sugarcane crops)

The mean quantity of the output that is produced on per wheat, cotton, maize, and sugarcane farms, by using a certain level of inputs is 3708.95 Kg, 2234.78 Kg, 3343 Kg, and 63550 Kg, respectively. The mean number of irrigation hours that are applied on per wheat and cotton farms is 37.12 hrs and 31.66 hrs, respectively. While, maize and sugarcane growers used, on an average, 36.98 and 67.66 hours of irrigation water per farm, respectively. The average number of tractor hours used by the wheat, cotton, maize, and sugarcane growers on per farm are 22.19, 14.98, 11.89 and 9.67 hours, respectively. The amount of phosphorus fertilizer used per farm to grow wheat, cotton, maize, and sugarcane crop is 295.13 Kg, 172.08 Kg, 146.6 Kg and 156.8 Kg, respectively. The average number of labour hours spent / farm are 159.2 hrs, 154.6 hrs, 138.9 hrs and 142.6 hrs in the case of wheat, cotton, maize, and sugarcane crops, respectively. Table 6.1.2 provides information about the input and output variables that are included in the DEA models for wheat, cotton, maize, and sugarcane crops.

Table 6.1.2: Output and Inputs Variables for DEA Models

Crops	**DUMs**	**Output variable**	**Common input variables for per acre and per farm analysis included in DEA models**							**Per farm**
		Physical yield(Kg)	**Tractor hrs**	**Irrig. hrs**	**Phosphoric fertilizer(Kg)**	**Nitrogen fertilizer(Kg)**	**Pesticide use(no)**	**Seed Rate(kg)**	**Labour hrs**	**Farm Area**
Wheat	250	√	√	√	√	√	x	√	√	√
Cotton	216	√	√	√	√	√	√	x	√	√
Maize	196	√	√	√	√	√	x	x	√	√
Sugarcane	220	√	√	√	√	√	x	x	√	√

The output variables used for the estimation of technical, allocative, and economic efficiency of the wheat, cotton, maize, and sugarcane growers are the total output (Y) produce of these crops. The inputs that are included in the DEA models for all crops include tractors hours (X1), irrigation hours (X2), Phosphoric fertilizer (X3), nitrogenous fertilizer (X4), and labour hours (X5). However, seed variable is only included in DEA models for wheat and pesticide (numbers) is used only for cotton crop. The numbers of Decision Making Units (DMUs) for wheat, cotton, maize, and sugarcane crops are 250, 216, 196 and 220, respectively. In comparison to the variables used in per acre analysis, per farm analysis includes an additional variable of farm area for all crops. The variables that are selected in this study to include in the DEA models are also considered by various other researches and hence the use of these variables is justified.

Table 6.1.3: Variables used by other Studies

Variable	*Various Studies that Used these Variables*
Land	Bogale *et al* 2005; Idiong, 2007; Idiong, 2007; Ogundari & Ojo, 2007; Ali *et al*., 2012; Islam *et al*.,2011; Adzawla *et al*., 2013; Mwajombe & Malongo, 2015; Umanath & David, 2013; Ray & Ghose, 2014; Rahman and Brodrick ,2015
Fertilizer	Idiong, 2007; Chirwa 2007 ; Mohapatra, 2013; Adzawla *et al*., 2013; Umanath & David, 2013; Umanath & David, 2013; Ray & Ghose, 2014; Islam *et al*.,2011; Rahman and Brodrick ,2015; Murthy *et al*., 2009 ; Koc *et al*., 2011
Irrigation	Bogale *et al* 2005; Lilienfeld & Asmild, 2007; Ali *et al*., 2012; Nargis & Lee, 2013 Bolandnazar *et al*., 2014
Tractor	Tipi & Rehber 2006; Abedullah *et al*., 2006; Armagan *et al*., 2010; Headey *et al*., 2010; Koc *et al*., 2011; Ray & Ghose, 2014;
Labor	Bogale *et al* 2005; Lilienfeld & Asmild, 2007; Chirwa 2007 Idiong, 2007; Ogundari &Ojo, 2007; Murthy *et al*., 2009; Koc *et al*., 2011; Ali *et al*., 2012; Latruffe *et al* 2012; Islam *et al*., 2011; Adzawla *et al*., 2013; Mohapatra, 2013; Mwajombe & Malongo, 2015; Umanath & David, 2013; Rahman and Brodrick ,2015; Guesmi *et al*., 2015;
seed	Abedullah *et al*., 2006; Murthy *et al*., 2009; Islam *et al*.,2011; Ali *et al*., 2012; Umanath & David, 2013; Nargis & Lee, 2013 ; Rahman and Brodrick ,2015
Pesticide	Ali *et al*., 2012; Gómez-Limón *et al*., 2012; Adzawla *et al*., 2013; Skevas *et al*., 2014; Khoshnevisan *et al*., 2015.

The DEA dual input orientated model has been solved for quantifying the relative efficiency of the wheat, cotton, maize, and sugarcane growers. The results of the efficiency analysis that are generated after solving the model for wheat, cotton, and maize and sugarcane crop are presented in the next section.

6.2: EFFICIENCY OF WHEAT PRODUCTION

The mean efficiency scoring presented in Table 6.2.1 depicts a degree of inefficiency on the sampled wheat farms. It is evident from the results that the inputs are not fully converted into output by the wheat farmers. The estimated mean technical efficiency of the wheat growers under constant returns to scale is 0.59 with minimum of .13 under both per acre and per farm analysis. These scores indicate that resource- use efficiency could possibly be improved to a great extent on the wheat farms. Under VRS, a wider fluctuation in TE can be observed in per acre and per farm analysis and TE is estimated at .89 and .66, respectively. The lower TE in per farm analysis compared to per acre implies that the TE decreases as the farm area under wheat increases. This might be lower because greater numbers of plots under wheat require more supervision and capital as compared to single plot. The lack of proper supervision and lower yield from different acres could be the cause of lower efficiency under per farm analysis. The frequency distribution of TE under CRS is almost similar in both per acre and per farm analysis and more than 80 percent of the farmers fall in a efficiency range of .1<= E <0.8. A small number of wheat farmers about 15 percent lies close to the efficient frontier in both cases and lie in the range of 0.8<= E < 1. Only few wheat farmers 3.6 and 2.8 percent attained the maximum efficiency level under per acre and per farm analysis, respectively.

To validate the results, the findings of this study are compared with the findings of other studies conducted in Pakistan and worldwide. It is necessary to mention that the results of TE_{VRS} (per farm basis) are compared with other studies. As compared to efficiency studies conducted in Pakistan on wheat, Ahmad (2002) found TE level of 68 percent that is very close to this study. Ali and Khan (2014) also found an average TE of 64 percent that is near to this study. In comparison to other countries, TE recorded in this study found very close or equal to the findings of (Jaime & César, 2011 (60); Feel and Basher, 2012 (63); Kelemu & Negatu , 2016, (.66), Tavva *et al*., 2017 (.67)). However, Hassan & Ahmad (2005) quantified very high TE of 93 percent in mixed farming system as compared to this study. Similarly, Hussain et al (2014) also estimated higher mean technical efficiency of 78 percent, in mixed farming system. A similar set of other studies in Pakistan also found higher TE than this study (Hussain *et al*., 2012 (76), Usman *et al*., 2016 (84); Gill, 2015 (78); Fatima, 2015 (88), Mirza *et al*., 2015 (.93)). In other countries Goyal & Suhag (2003), Bakh & Serajul (2005); Alemdar & oren (2006) Dinarvand & Sabbaghi, (2015) Croppenstedt, (2005), Mburu *et al* (2014), Wang *et al* (2016) also estimated higher TE at 92, 88, 83, 88, 80, 85 and 78 percent respectively. Buriro *et al*., (2013) found a very low average TE (36) on wheat farms than this study. A similar set of other studies in the world also estimated lower TE than this study (Tiruneh and Endrias, 2015 (.57); Sabouhi *et al*., 2014 (.42)).

From the Table 6.2.1, a large variation in minimum and maximum TE values is an indication towards the existence of wider yield gap between the wheat farmers in mixed farming system. The per acre analysis elucidate narrow yield gap, but it is quite wider in per farm analysis. When the TE under VRS is compared between the least and full efficient farm, a sharp difference of .34 and .78 can be seen under per acre and per farm analysis, respectively. The frequency distribution under VRS assumption reveals a different picture as compared to CRS distribution. Under per acre analysis 18.4 percent of the farmers are fully efficient, while in per farm analysis 7.6 percent can be found efficient. A vast majority (68.8 %) tend to fall near to efficient frontier ($0.8 <= E < 1$) in per acre analysis, while majority pushed back to lower efficiency level and 61 percent wheat farmers has attained efficiency level less than .7, in per farm analysis. The results of frequency distribution and a large variation in minimum and maximum TE values imply that some farmers might be securing much lower outputs from the input resources that tend to push them towards lower efficiency range. Such large variation in the efficiency scores represents a crop failure on some farms, which might be due to factors like weather, insect pest attack or improper use of inputs. Wheat efficiency is highly responsive to various factors and significantly, decreases if farmers do not sow wheat on time, delay the first fertilizer and irrigation application and select poor quality seed. Fraser & Cordina, (1999) highlighted that the efficiency score derived under constant returns to scale, is either less than or equal to the efficiency score derived for the VRS, because the efficiencies of the DMUs are only compared to DMUs with similar size. For this reason, more farms tend to produce on the efficient frontier under the variable returns to scale formulation.

It is motivating to find out whether the inefficiency is caused by the inefficient operation of the DMU itself or by the detrimental circumstances under which the DMU is operating. Inappropriate scale or misallocation of resources can be the cause of inefficiency for the inefficient farms. Inappropriate scale suggests that the farm is not taking advantage of economies of scale, while misallocation of resources refers to inefficient input combinations (Gul *et al*., 2016). For this reason, we can compare CRS and VRS models, if a unit is fully efficient under both CRS and VRS models; it is operating at the most productive scale size (Banker *et al* 1984; Fandel, 2003). If a DMU is VRS efficient and CRS inefficient, then it is locally efficient, but not globally and this is due to its scale size. Thus, the scale efficiency of the wheat farmers is quantified in order to see the presence of pure technical or scale inefficiency in the mixed farming system. The results derived from DEA analysis imply that the sampled wheat farms are 66 and 88 percent scale efficient in per acre and per farm analysis, respectively. The lower SE index in per acre analysis suggests that the lower technical efficiency on the sampled wheat farms is mainly due to scale inefficiency implying that TE can be improved by increasing farm's scale of operations. The mean TE score under VRS is less than the average SE scores in per farm analysis. This conclusion indicates that the technical inefficiency of wheat farms is mainly affected by management rather than the operating scale. The frequency distribution clearly shows that the most of the scale inefficient wheat farmers (97 out of 250) fall in the scale efficiency range of 0.5<= E < 0.7 in per acre analysis. In per farm analysis, most farmers (121 out of 250) have achieved the score very close to the scale efficient frontier and fall in efficiency range of 0.9<= E < 1. The occurrence of most farmers in lower efficiency range under per acre might be due to their farm size that is too small to use all the resources efficiently and this pushed more farms towards lower scale efficiency range. When the results of this study are compared with others, the exactly same level of SE was found by (Wang *et al*., 2016 (88)). Opposite to the findings of this study, Fatima (2015) found high level of scale inefficiency (47 percent) on wheat farms. Mirza *et al* (2015) found wheat farmers 96 percent scale efficient. The lower scale efficiency of wheat farms than this study is found by (Alemdar & Oren, 2006 (.78); Dağistan, 2010 (.72)).

Allocative inefficiency arises, if farms fail in allocating inputs that minimize the cost of producing a given output, given relative input prices. This results from not allocating the inputs in most efficient manner, i.e., there exists resource misallocation or allocative inefficiency. Failure in allocating resources optimally results in increased cost and decreased profit. The dissimilarity between technical and allocative efficiency provides four ways of explaining the relative performance of farms. First, a farm might show both technical and allocative inefficiency; second, it may be technically efficient, but allocatively inefficient; third, it may display allocative efficiency, but technical inefficiency; and fourth it may be both technically and allocatively efficient.

It is interesting to note that there is no wide difference in the allocative efficiency level of the wheat farmers in both type of analysis and mean AE is estimated at .82 and .81 in per acre and per farm analysis, respectively. The distribution of farms in relation to the frontier is nearly the same in both cases and a large number of farmers occur in a efficiency range of (0.8<= E < .9). However, from the current AE level, it can be concluded that inputs are not optimally combined in the production of wheat and a reallocation of inputs results in some improvement in the farm level inefficiency. The optimal and balanced use of these resources would enable the small-scale wheat farmers to maximize their profit by equating the marginal revenue product to the marginal input cost. When the AE level is compared with other studies, Usman *et al*., (2016) found exactly same AE level (81) on wheat farms. However, Bashir and Dilwar (2005) estimated lower wheat AE (72 percent) as compared to this study. The studies of Ali *et al* (2012), Ali *et al* (2012), Gautam et al (2012) also found lower .72, .68 and .70, respectively. The study of Mburu *et al* (2014) estimated higher AE (.85) than this study.

Table 6.2.1: Frequency Distribution of Wheat Farms on Per Acre and Per Farm Analysis

RANGE	PER ACRE ANALYSIS							PER FARM ANALYSIS						
	TE (CRS	TE (VRS)	SE	CE	AE	BCTE (CRS)	BCTE (VRS)	TE (CRS	TE (VRS)	SE	CE	AE	BCTE (CRS)	BCTE (VRS)
Less than .5	95	0	54	1	1	154	0	93	44	2	113	4	158	141
0.5<= E <0.7	81	2	97	80	10	56	10	84	109	16	93	7	52	65
0.7<= E <0.8	29	30	29	95	62	21	63	30	33	26	23	83	21	30
0.8<= E < .9	20	109	35	58	127	13	108	19	28	78	12	131	15	22
0.9<= E <1	16	63	26	11	46	6	69	17	17	`121	4	20	4	2
TE=1	9	46	9	4	4	0	0	7	19	7	5	5	0	0
% farms on frontier	3.6	18.4	3.6	1.6	1.6	0	0	2.8	7.6	2.8	2	2	0	0
Mean Efficiency	.59	.89	.66	.73	.82	.41	.84	.59	.66	.88	.54	.81	.42	.49
Minimum Efficiency	.13	.66	.16	.21	.24			.13	.22	.37	.17	.32		
CI Lower bound						.50	.82						.50	.55
CI Upper bound						.58	.88						.58	.65

The analysis also shows that the cost inefficiency persists on the sampled wheat farms and reasonable potential is present to reduce their cost of production without any alteration in the output level. The cost inefficiency appeared higher in per farm analysis (CE= .54) as compared to per acre analysis (CE= .73). Similarly, the frequency distribution also has very wide variation and a vast majority of farmers (82 percent) found in lower efficiency range of (0.1<= E < .7) in per farm analysis while 93 % farms occurred in higher efficiency range of (0.5<= E < .9) in per acre analysis. The low CE in per farm analysis might be due to wastage of more cost on some acres that had been grown with wheat and when the data of these individual acres are aggregated and converted into per farm data, it tends to decrease the CE. As cost efficiency is the product of technical and allocative efficiency, therefore, it can be predicted whether the cost inefficiency is due to technical inefficiency or misallocation of input resources. Thus, the results obtained show that the allocative inefficiency is the dominant component in overall cost inefficiency compared to technical inefficiency, in case of per acre analysis. This finding shows that the main problem is the inability of the farms to allocate inputs in the most cost minimizing way rather than using the inputs in a technically efficient way. In contrast to per acre analysis, technical inefficiency is the major reason of lower CE on wheat farmers, in per farm analysis. In wheat production, approximately similar level of CE is observed by (Gautam et al., 2012, (.51)). As compared to this study higher cost efficiency was found by (Kamruzzaman et al., 2006 (.86), Mburu *et al*., 2014 (.84) & Usman *et al*., 2016 (68)). The lower CE than this study was found by (Ali *et al*., 2012 (.41), Ali *et al*., 2012(.45).

It is observed that the statistical properties in the estimators have been largely ignored while applying the DEA models for efficiency estimation and DEA produce biased results when statistical noise is not considered in the process and all inefficiencies are associated to deviation from the efficient frontier (Finn et al., 2005; Cesaro et al., 2009; Qayyum and Khalid, 2012; Abatania *et al*., 2012 & Dao, 2013). To see whether the bias is present in the efficiency score, bootstrap DEA models developed by the (Simar and Wilson, 1998; 2000) are applied to explicitly take into consideration the statistical properties of the efficiency scores. This advancement provides an opportunity for bias correction from the efficiency scores and confidence intervals and helps to avoid drawing the wrong conclusion from standard DEA estimation and thus, enhance the quality of the analysis (Finn et al., 2005 & Balcombe et al., 2005).

To correct the efficiency from bias and to establish C.I, bootstrap DEA model was solved for 2000 bootstrap samples through the aid of software R 3.03 by considering CRS and VRS assumptions. The descriptive statistics of the original and bias corrected efficiency along with the lower and upper confidence interval is depicted in Table 6.2.1. From Table 6.2.1, a significant difference in original and bias-corrected technical efficiency score can be seen after solving bootstrap model for 2000 iterations. The bias-corrected efficiency score (CRS) with a bias of .18 and .17 points from original TE is estimated at .41 and .42 in per acre and farm analysis, respectively. This implies that the wheat farmer can further reduce their input level up to 18 percent against per acre and 17 percent per farm as compared to the reduction suggested by original TE. However, the upper and lower values established at 95% confidence interval show that the input level could be reduced further, from 42 percent to 50 percent without any alteration in the level of output under both analysis. Similarly, the biased corrected efficiency (VRS) is recorded at .84 and .49 with a bias of .05 and .17 between original and bias corrected TE in per acre and per farm analysis, respectively. Latruffe, (2010) explained the reason of downward movement of biased corrected TE and argued that due to sampling variation, the original TE are likely to be biased towards higher scores and bias arises when the most efficient firms within the population are not contained in the sample at hand. Consequently, inefficient firms form the envelopment frontier. The efficiency degree of all other firms is then measured relative to the sample frontier instead of the true population frontier, and therefore might be biased. As compared to this study, Karimov & Miguel (2017) estimated higher biased corrected TE of .69 under VRS assumption and implied that the initial TE score has upward bias. Similar to this study, bias corrected technical efficiency score lower than the initial DEA score is supported by (Abatania et al., 2012 & Bagchi & Zhuang, 2016).

6.2.2: Efficiency of Cotton Production in Mixed Farming System

According to findings displayed in Table 6.2.2, the mean TE under CRS and VRS assumption is estimated at .53 and .82 with a minimum TE of .10 and .50, in per acre analysis, respectively. A very low minimum efficiency level implies that some farmers are misusing 90 and 50 % of their inputs resources as compared to most efficient farms and huge opportunity exists for cotton farmers to increase their production by improving the input usage efficiency. A greatest number of cotton farms (67 %) occur in an efficiency range of 0.1<= E < .7 and only 6 % of the farms has attained TE= 1, in CRS per acre analysis. Under VRS per acre analysis, about 16 % farms are fully efficient and majority of cotton farms (45 %) fall in higher efficiency range of 0.8<= E < .1. The occurrence of most farmers in lower efficiency range in CRS analysis might be due to higher scale inefficiency. However, VRS analysis is devoid of scale efficiency effect, therefore majority of farms fall close to frontier. Under per farm analysis, an average cotton grower found to be 64 and 71 percent efficient in the use of input resources, in CRS and VRS DEA models, respectively. A small difference in average TE under

CRS and VRS reveals that the impact of scale is not the major source of inefficiency and identical frequency distribution of TE in both cases also confirm the above-mentioned findings. It can be seen that under per farm analysis, most of the farmers (65 %) and (55 %) fall in efficiency range of 0.1<= E < .7, in CRS and VRS analysis, respectively. The fully technical efficient cotton farms are 6 and 11 percent in both type of analysis. A number of conclusions can be drawn from these findings. When TE (farm basis) is compared with per acre analysis, it is found that the mean TE of the farms increases in CRS while decreases under VRS assumption. Because in per acre analysis, all farmers have similar farm size with different input levels and due to impact of scale some of them might not be able to use all the resource fully that contribute towards higher technical inefficiency under CRS analysis. However, due to improvement in farm size, scale inefficiency has less impact in determining the overall TE (CRS), in per farm analysis. TE (VRS) under per farm analysis is lower as compared to per acre analysis that might be due to overutilization or wastage of inputs on different acres that tend to lower the overall TE. A very high difference between minimum and maximum TE values reflects greater heterogeneity in the use of inputs and output level achieved by the cotton farmers and this large variation might be connected with complete crop failure on some farms due severe weather, insect pest attack or improper use of inputs. Fatima *et al* (2016) estimated exactly similar level of TE (70) as compared to this study. The finding is dissimilar to the following studies who estimated higher TE level on cotton farms in Pakistan and other countries (Solakoglu, 2013, (65); Saddozai *et al*., 2013 (77); Abedullah *et al*., 2006 (91); Adzawla *et al*., 2013(88); Singh *et al*., 2015 (88), Sarker and Alam, 2016 (89); Dilshad and Afzal 2012 (.87) and Hameed *et al*., 2014 (94)).

The results shown in Table 6.2.2 reveal that the mean scale efficiency of cotton farms is .76 and .92 with a minimum of .11 and .33 in per acre and per farm analysis, respectively. This conclusion highlights that size of the farm is not very much important in changing the technical efficiency of the cotton farms in per farm analysis, but has major contribution in determining the TE level of cotton farmers in case of per acre measure of TE. The mean TE score under VRS is greater than the average SE scores in per acre analysis, which indicates that the technical inefficiency is greatly determined by farm size rather than management but in case of per farm analysis, inefficiency can be decreased by improving and managing the inputs.

Table 6.2.2: Frequency Distribution of Cotton Farms on Per Acre and Per Farm Analysis

RANGE	PER ACRE ANALYSIS							PER FARM ANALYSIS						
	TE (CRS)	TE (VRS)	SE	CE	AE	BCTE (CRS)	BCTE (VRS)	TE (CRS)	TE (VRS)	SE	CE	AE	BCTE (CRS)	BCTE (VRS)
Less than .5	49	0	15	16	0	114	10	42	24	6	60	1	102	93
0.5<= E <0.7	95	45	54	154	42	70	63	99	93	3	109	10	84	77
0.7<= E <0.8	38	40	41	34	87	16	54	40	34	11	21	30	10	28
0.8<= E < .9	9	62	61	8	77	12	71	12	27	28	13	90	19	18
0.9<= E <1	12	35	32	1	7	4	18	9	11	152	9	81	1	0
TE=1	13	34	13	3	3	0	0	14	27	16	4	4	0	0
% farms on frontier	6.02	15.74	6.02	1.39	1.39	0.00	0.00	6.48	11.57	7.41	1.85	1.85	0.00	0.00
Mean Efficiency	.53	.82	.76	.63	.77	.46	.74	.64	.71	.92	.60	.86	.49	.52
Minimum Efficiency	.10	.50	.11	.43	.51			.084	.23	.33	.17	.46		
CI Lower Bound						.53	.73						.55	.57
CI Upper Bound						.62	.81						.63	.68

Similarly, the minimum values of SE indicate that the size of the farm in mixed farming system is too small to absorb the available inputs fully. The frequency distribution reveals that in per farm analysis the farms are mostly scale efficient and occur near to the efficient frontier (153 fall in range of 0.9<= E < 1) as compared to per acre analysis where most of the farmers are fairly efficient and fall in lower range of efficiency. This is because the farmers are better able to adjust and accommodate the available input resources on farm of greater size as compared to farm of one acre. Sarker and Alam (2016) also found similar level of SE (93) on cotton farms. Hashmi *et al* (2016) found SE of 88 percent that is less but close to this study. Hameed *et al* (2014) found quite less SE (.71) on cotton farms than this study.

The results related to cost and allocative efficiency are comparable to some extent with minor variations and the average CE of the cotton farms is estimated at .63 and .60 in both type of analysis, respectively. These results suggest that the cotton farmers are not operating on a technical and allocative efficient frontier that leads to economic inefficiency and these farms had wasted 37 and 40 percent of production cost relative to the cost efficient farms that are producing the same output level with the same technology and market prices. The misallocation and inefficient use of the resources leads to higher cost per unit output (cost inefficiency) and hinders the cotton farmers to maximize profit. The improvement in overall economic or cost efficiency would enable the farmers to maximize profit through a reduction in production cost that would occur when farmers operate on technical and allocative efficient frontier under the given technology. These results elucidate that the profit can be maximized by reducing the production cost further up to 37 and 40 % that is wasted in achieving the current output level. The frequency distribution of CE is almost identical in both type of analysis and majority of the cotton farmers (71 percent) and (51 percent) attained CE score close to the average efficiency score and fall in the range of 0.5<= E < .7. In order to achieve full cost efficiency level, cotton farmers would require adjustments the input mix against the relative prices of inputs. In contrast to CE, cotton farmers are found reasonably allocative efficient with a mean score of .77 and .86 in per acre and farm analysis, respectively. These results imply that the cotton farmers can produce on the allocatively efficient frontier by allocating 23 and 14 percent of their resources properly on per acre and farm, respectively. A vast majority of the cotton growers (76 %) tend to fall in the efficiency level of 0.7<= E < .9 in per acre analysis, while 79 % of the farms lie in the efficiency range of 0.8<= E < .1 in per farm analysis. An improvement in AE that is observed in per farm analysis as compared to per acre analysis might be due to the selection of optimal input bundle on different acres that tend to increase the AE of the farmers. The minimum values of AE (.51

and .46) in both cases reveal that some farmers are quite irrational in the allocation of their resource compared to best practice farms that might be due to lack of awareness about the recommended amount of input, poor socio- economic characteristics (less experience, limited extension contact, education etc). Sarker and Alam (2016) found higher cost (.69) and lower allocative efficiency (78) level as compared to found in this study. Hameed *et al* (2014) found mean CE (.54) and AE (.57) that is not consistent with this study.

The results depicted in Table 6.2.2 reveal that biased corrected TE is lower than the original TE in both type of analysis. In per acre analysis, the mean bias corrected TE is estimated at .46 and .74 under CRS and VRS assumptions with a bias of .07 and .08 from original TE, Implying further reduction in input level. However, this bias in narrow as compared to per farm analysis where percentage bias is found at .15 and .19 in CRS and VRS specifications, respectively. A substantial reduction in TE is found when corrected form bias with a mean values of .49 and .52 under CRS and VRS assumptions, respectively. The lower and upper bound values of confidence interval (VRS) highlight that the cotton farms can reduce their inputs level from 32 to 43 percent. In addition, the means scores with relatively large bias and confidence intervals imply wide variation in efficiency scores and demonstrate the additional justification for bootstrapping. Consistent to the results of this study, Abatania *et al*., (2012) also found lower bias corrected TE score than original DEA score, after using bootstrap technique to DEA.

6.2.3: Efficiency of Maize Production in Mixed Farming System

The results related to all types of efficiency and frequency distribution of the sampled maize farms based upon their occurrence in each category of efficiency range is presented below in the Table 6.2.3. In contrast to wheat and cotton crops, the maize farmers found reasonably efficient as evident from the mean efficiency scores that show little opportunity for input reduction, in both per acre and per farm analysis. The results of TE under CRS represents that the average maize farmers can reduce their inputs level up to 26 % per acre and 22 % per farm. The least technical efficient farm has an efficiency score of .32 and .33 in per acre and per farm analysis, respectively and the large deviation of least efficient farm from the maximum efficiency level might be due to excessive use of all inputs and less output compared to best practice farms. However, under VRS assumption, the maize farmers are reasonably efficient and attained efficiency score of .89 in per acre analysis and .83 in per farm analysis. This improvement in efficiency in VRS analysis implies that the results are largely confounded with scale efficiency that tend to decrease the efficiency scores in CRS analysis.

Maize crop is highly input intensive and due to high cost of production farmers tend to perform recommended production technology as approved by the state that might be responsible for higher TE on maize farms as compared to wheat and cotton crops. Secondly, various seed distributing companies circulate pamphlets and literature about the approved production technology of maize among the farmers in order to impart technical knowledge and skill regarding balance and optimal use of inputs that can also be the cause of higher TE on maize farms. Almost, 18 and 12 percent of the farmers secure full efficiency level in per acre and per farm analysis under VRS assumption, respectively. Nearly, 65 and 51 percent of maize farms have TE efficiency score in the range of 0.8<= E < 1 in per acre and per farm analysis, respectively and the remaining maize farmers occur in lower ranges of TE. Similar frequency distribution in per acre and per farm analysis might be due to fact that the most of the farmers devoted only one or two acre of land to maize crop and this factor tend to produce less fluctuation in frequency distribution.

When the TE level (.83) is compared to other studies, the findings appear similar to those of (Binam *et al*., 2005 (80); Koc *et al*., 2011 (81); Viengpasith *et al*., 2012(85); Olapade *et al*., 2013 (.81); Naqvi and Ashfaq 2013 (81); Ahmed *et al*., 2015 (84); Ahmed *et al* (2017) (.79)). However, the studies of Chirwa (2007) (46), Fatima (2015) (.91), Memon *et al* (2016) (.48), Kibaara, (2005) (49), Boundeth *et al*., 2012 (65); Chiona *et al*., 2014 (50); Kitila & Alemu 2014 (66), Linh *et al*., (2015) (.54), Martey *et al*., (2015) (.62), Ahmed *et al* (2017) (.69), computed either low or high TE level than this study.

Similar to wheat and cotton crops, the scale inefficiency is higher in per acre analysis as compared to per farm analysis and estimated at .83 and .93, respectively. The scale inefficiency in maize crop is lower in comparison to wheat and maize crops and such lower level of scale inefficiency suggests that the farms are almost operating on an optimal scale and inappropriate scale is not the cause of low technical efficiency on maize farms. Similar results were also produced by Linh *et al* (2015) that management issues were the main cause of technical inefficiency on maize farms rather than the operating scale. However, Gabdo *et al* (2014) attributed inefficiency with operating scale rather than management and linked the technical inefficiency with the managerial ability of the farmers (misallocation of input resources).

6.2.3: Frequency Distribution of Maize Farms on Per Acre and Per Farm Analysis

RANGE	PER ACRE ANALYSIS							PER FARM ANALYSIS						
	TE (CRS)	TE (VRS)	SE	CE	AE	BCTE (CRS)	BCTE (VRS)	TE (CRS)	TE (VRS)	SE	CE	AE	BCTE (CRS)	BCTE (VRS)
Less than .5	11	0	7	0	0	30	0	8	2	0	22	0	19	15
0.5<= E <0.7	67	4	24	78	19	63	13	46	36	1	92	28	55	39
0.7<= E <0.8	33	29	30	58	42	45	42	47	34	8	47	61	50	48
0.8<= E < .9	48	69	57	40	80	50	81	51	54	28	18	70	57	76
0.9<= E <1	27	59	62	16	51	8	60	34	47	149	12	32	15	18
TE=1	10	35	16	4	4	0	0	10	23	10	5	5	0	0
% farms on frontier	5.10	17.86	8.16	2.04	2.04	0.00	0.00	5.10	11.73	5.10	2.55	2.55	0.00	0.00
Mean Efficiency	.74	.89	.83	.74	.84	.67	.84	.78	.83	.93	.67	.81	.71	.75
Minimum Efficiency	.32	.59	.36	.54	.59			.33	.36	.68	.26	.56		
CI Lower Bound						.67	.82						.71	.74
CI Upper Bound						.74	.88						.78	.82

The distributions of scale efficiency differ markedly in the case of maize crop and a vast majority 76 % (149 out of 196) are lying in an efficiency range of 0.9<= E <1 in per farm analysis while only 31 percent fall in this range in per acre analysis. The scale inefficiency is more prevalent in acre analysis due to similar size of all farms. Fatima (2015) found maize farmers only 76 percent scale efficient and results are inconsistent with this study.

Table 6.2.3 also depicts the summary of cost efficiency scores for the maize farms and the mean CE of the farms is quantified at .74 and .67 in per acre and per farm analysis, respectively. This implies that an average maize farmer in the mixed farming system has costs that are about 26% and 33% above the minimum defined by the frontier or in other words, 26% and 33% of their input costs are wasted relative to the best practice farms achieving the same output (maize) under the same technology. In per farm analysis, the frequencies of occurrence of 83% of the sampled maize farmers in the cost efficiency range of .1 to .8, imply that majority of the farmers are fairly efficient in producing at a given level of output using cost minimizing input ratios. However, in per acre analysis, a greatest number of farms (89%) found in higher cost efficiency range of 0.7<= E < 1 which might be due to wastage of less cost as compared to per farm analysis. The maize farms, on an average, 84 and 81 percent AE efficient in the allocation of their input resources in per acre and per farm analysis, respectively. It is interesting to note that the technical efficiency score (VRS) is greater than the average AE score in both analysis which implies that CE could be improved significantly and allocative inefficiency constitutes a more serious problem in overall less CE than technical inefficiency. In comparison to this study, different cost efficiency level was found in the studies of (Ogundari & Ajibefun, 2006 (84); and Olarinde, 2011 (.55)). Ahmed *et al* (2015) estimated quite lower AE (37) and EE (31) level than this study.

The findings depicted in Table 6.2.3 reveal that the average bias-corrected TE results are lower than the original TE scores and none of the farms have attained TE=1 under both conditions. Similar results were found by Linh (2012), Olson and Vu (2009), Linh *et al*., (2015) for single and double bootstrap. Under CRS and VRS assumptions, an average bias-corrected TE with a difference of .07 and .05 from initial TE is computed at .67 and .84, respectively, in per acre analysis. Similar to reduction in the efficiency score, most of farmers tend to fall back in lower efficiency range when TE is corrected from bias. With a percent bias of .07 and .08 from initial TE, bias corrected efficiency found to be .71 and .75 under CRS and VRS conditions, respectively in per farm analysis. It can be concluded that additional input saving of up to 7 and 8 % is possible as compared to input reduction suggested by original TE score. The results are inconsistent with Linh *et al* (2015) who estimated bias corrected TE of maize farms at .46. Karimov (2013) suggested that recommendations for policy makers should be based on bias-corrected efficiency scores rather than initial TE scores.

6.2.4: Sugarcane production Efficiency in Mixed Farming System

It is interesting to note that majority of the sugarcane farmers in the mixed farming system allocated less than one acre of land to sugarcane crop as evident from the mean value of area under sugarcane crop (.89). There are two mode of sugarcane cultivation in the study area. Due to abundant availability of land, large and medium farms mostly grow sugarcane crop for commercial purpose, however, the situation is different in the case of small farms. Livestock rearing is very important feature of small farms in mixed farming system and due to land scarcity and food requirement of their livestock, small farms allocate small area of land to sugarcane for forage production. In winter season, when the dry forage is short, they use the topping of sugarcane or whole sugarcane plant to feed their animal. Due to unavailability of per acre data in majority of cases, it is decided to quantify the efficiency of the farms on per farm basis only and the results pertaining to this analysis are depicted below in Table 6.2.4.

Table 6.2.4: Distribution of Efficiency on sugarcane Farms

RANGE	PER FARM ANALYSIS						
	TE (CRS)	TE (VRS)	SE	CE	AE	BCTE (CRS)	BCTE (VRS)
Less than .5	151	84	33	142	1	173	150
0.5<= E <0.7	42	75	19	33	22	26	26
0.7<= E <0.8	9	12	17	10	10	6	9
0.8<= E < .9	5	7	34	7	52	8	14
0.9<= E <1	8	4	95	24	126	7	21
TE=1	5	38	22	4	9	0	0
% Farms on frontier	2.27	17.27	10.00	1.82	4.09	0.00	0.00
Mean Efficiency	.44	.58	.80	.51	.89	.25	.39
Minimum Efficiency	.02	.20	.019	.19	.32		
CI Lower Bound						.39	.48
CI Upper Bound						.44	.57

After examining the distribution of results, it is appeared that sugarcane producers in the mixed farming system are somewhat more inefficient in the use of inputs resources as compared to other three crops. Input resource use efficiency is predicted at .44 and .58 after solving DEA under the assumption of CRS and VRS, respectively. The fully efficient farms increased from 5 (2.27) to 38 (17.27%), under VRS assumption that improvement might be due to elimination of impact of scale in VRS analysis. In CRS analysis, majority of farms 151 (69%) tend to occur in lower efficiency range (less than .5) that might be due to scale inefficiency. The poor performance of sugarcane farms in terms of resource use efficiency might be due to practice of traditional methods. Secondly, majority of farms do not grow sugarcane crop for commercial purpose and hence pay less attention in managing the sugarcane crop. The lack of proper management and supervision lead to low efficiency on these farms. However, Naeem *et al* (2007) linked it with high prices of inputs and poor quality of ground water. Thabethe *et al* (2014) associated declining performance in the sugarcane production with inadequate use of available and recommended technologies, high input costs, poor infrastructure, and poor market information. However, Nyanjong & Lagat, (2012) found that 1% increase in land acreage under sugarcane increase output by 0.839 percent and land under sugarcane cultivation was the single most important contributor to farmers' efficiency. It is also found that no significant farm area is devoted to sugarcane crop in mixed farming system; therefore, it is required in the study area to bring more acreage of land under sugarcane cultivation in order to increase efficiency. The results of this study are inconsistent with the study of Dlamini *et al* (2010) Thabethe *et al* (2014), Ali *et al* (2013), Nyanjong & Lagat (2012); Padilla-Fernandez & peter, (2012); Supaporn, (2015); Mutenheri et al (2017) and Ali and Abbas, (2017) who estimated TE of sugarcane farmers at 73, 68, 77, 67, 75, 74, 90 and 84 percent, respectively.

An average SE score (.80) is higher than the TE (VRS) score (.58) which indicates that the technical inefficiency of the sugarcane farms is mainly affected by management rather than the operating scale. This is also evident from the frequency distribution of SE as 53 percent of farms found close to the frontier 0.9<= E < 1. Padilla-Fernandez & peter (2012) estimated higher SE (94) than this study. The mean cost and allocative efficiency is quantified at .51 and .89, respectively which implies that the reduction in cost of production through eliminating resource use inefficiency could add about 49 % of the production cost to their annual income. The technical efficiency score appears less than the average allocative efficiency score, which implies that management problem contribute more towards overall cost inefficiency as compared to allocative issues. Majority of the farms (65%) are not fairly cost efficient and occur far from efficient frontier with CE less than the average score of .51. In contrast to CE distribution, AE scoring of most sugarcane farmers found in the range of 0.9<= E < 1. As compared to this study, Thabethe *et al* (2014) and Nyanjong & Lagat (2012) found different cost efficiency level of sugarcane farmers 41 and 58 percent, respectively. They also estimated AE of sugarcane farmers at 61 and 82 percent, which is also not consistent with this study. Padilla-Fernandez & peter (2012) estimated slightly lower AE (80) and higher CE (60) level of sugarcane farmers than this study. Mutenheri et al (2017) found AE (85) close to this study and higher CE (77).

Similar to other crops, the bias corrected TE for sugarcane farmers is also lower than the initial TE and computed at .25 and .39 under CRS and VRS model specifications. This implies that the sugarcane farmers in the sample could achieve full technical efficiency by reducing their inputs by another 19% in both cases. Gabdo *et al* (2014) provided the justification for low biased corrected score than original TE score and pointed that the traditional DEA models do not consider noise components while bootstrap DEA model take care of noise component in the model and accounts for the inefficiency caused by exogenous factors. The consideration of exogenous factors like weather, insect pest in the bootstrap models correct the efficiency from bias and hence, produce less bias corrected TE score than the original TE score. The similar reason was mentioned by (Abatania, 2012).

The analysis revealed that resource use inefficiency exists in the mixed farming system for all the crops under study (wheat, cotton, maize and sugarcane) and farmers have great opportunity to increase their production with the existing available resources. However, the efficiency analysis in the previous section based on radial DEA model and the problem of slacks arises in any optimal solution of this model because this expand all outputs or contract all inputs by the same proportion. In economics, the concept of efficiency is associated to the idea of Pareto optimality that if there is the possibility of any net increase in outputs or decrease in inputs, an input-output bundle is not Pareto optimal (Gadanakis, 2013). Tone (2001) proposed Slacks-Based Measure of efficiency (non-radial) which captures slacks variables directly and estimates efficiency scores more accurately than the conventional DEA. Therefore, slack analysis is carried out to identify the possible slacks attached to each input in order to see the possibility of further reduction in inputs and the next section gives the summary of input slacks under the VRS specification (per farm analysis).

6.3: INPUT SLACKS AND EXCESSIVE INPUT USE

The slack based models are also used by (Padilla-Fernandez & Peter, 2009; Alemdar & Oren, 2006; Dağistan, 2010; Li *et al*., 2011; Soteriades, *et al*., 2015; Ogunniyi *et al*., 2015; kaneva, 2016 and Ahmed *et al*., 2017). The results related to slacks are obtained by converting inequality constraints to equality constraints and adding slack variables in DEA models (Walden and Kirkley, 2000). After the proportional reduction or expansion in the input and outputs, respectively “slack” identifies excess input or missing output that exists (Shim, 2003; kaneva, 2016). Slack variables determine excessive input use and farms can reduce its resources on an input by the amount of slack without any change in output (Alemdar & Oren, 2006; Padilla-Fernandez & Peter, 2009, Dağistan, 2010; kaneva, 2016). In this section, the numbers of farms are identified that have positive input slacks and results are presented in Table 6.3. In next Table 6.3.1, mean input slacks associated with each variable are presented.

Table 6.3: Farms with Positive Input slacks

Inputs	Wheat		Cotton		Maize		Sugarcane	
	Farms with S^+	Rank	Farms with S^+	Rank	Farms with S^+	Rank	Farms with S^+	Rank
Labour hours	196 (78%)	1st	105 (49%)	3rd	144 (73%)	1st	132 (60%)	3rd
Irrigation hrs	184 (74%)	2nd	124(57%)	2nd	136 (69%)	3rd	108 (49%)	4th
P Fertilizer	182 (73%)	3rd	84 (39%)	6th	144 (73%)	2nd	153 (70%)	2nd
Seed Rate	168 (67%)	4th						
Tractor Hours	104 (42%)	5th	98 (45%)	4th	77 (39%)	5th	98 (45%)	5th
Farm area	99 (40%)	6th	83 (38%)	7th	55 (28%)	6th	89 (40%)	6th
N fertilizer	94 (38 %)	7th	84 (39%)	5th	109 (56%)	4th	161 (73%)	1st
Pesticides			132 (61%)	1st				

The data in Table 6.3 reveal a positive input slacks against all the inputs and for all the crops. In case of wheat crop, a vast majority of farms 196 (78%) have positive slack against labour hours which implies that wheat farms are highly inefficient in the use of labour. The irrigation and phosphoric fertilizer stand at 2nd and 3rd position and 184 (74%) and 182 (73%) of the wheat farms respectively, can reduce these inputs by the amount of slack, without any variation in current output level. The slacks appeared positive against 168 (67%), 104 (42%), 99 (40%), and 94 (38 %) of the wheat farmers in case of seed rate, tractor hours, farm area and nitrogenous fertilizer, respectively. The data reveal that the pesticides are used in surplus on cotton farms, as slack against 61% (132) of the farms found positive. The cotton crop is highly subject to insect pest attack in Pakistan and farmers intensively use pesticides, depending on the severity of attack. Similar to wheat crop, irrigation is ranked 2nd for cotton crop and reveal water use inefficiency. The next misused inputs are labour and tractors as 49 % and 45% farms have slacks against these inputs, respectively. However, to some extent, fertilizer use efficiency is better on cotton farms as compared to the use of other inputs and only 39% of the farms are using nitrogenous and phosphoric fertilizer in excess. In case of maize crop, labour hours, phosphoric fertilizer and irrigational hours are ranked 1st, 2nd and 3rd and the slack value appeared against 73, 73 and 69 percent of the farms, respectively. For sugarcane crop, the results highlight a high dependency on nitrogenous, phosphoric fertilizer and labour hours as 73%, 70 % and 60 % of the sugarcane farms used these inputs in higher amount, respectively. This might be due to fact that most of the sugarcane farmers had Ratoon crop in the study area and hence their production largely depends upon fertilizer application and less on other inputs like tractor. The input of tractor hour is at position 5th with positive slack against 45% farms.

Analysis of slack share and input saving potential provides useful information whether there is any economic and technical incentive exists for the farms to decrease its input level to the technical efficient levels (Soteriades, *et al*., 2015). If the farm has greater slack share against particular input, then decreasing the amount of that input by its slack would be highly beneficial for that farm to reduce the overall cost. However, the farm has little opportunity to reduce its overall cost with a small slack share and large input saving potential (Tsutsui and Mika, 2009).

It is evident from Table 6.3.1 that phosphoric fertilizer is the most excessively used input in wheat production and farmers can reduce 165 kg (56 %) of phosphoric fertilizer per farm based on the results of input saving potential and slack share. This indicates that the farmers tend to get higher production through the application of P fertilizer and unawareness about the recommended dose of this fertilizer lead to its excessive use. The labour is the next over exploited input as farmers have used in excess 76 hours of labour per farm. The use of labour vary across farms and various factors can contribute to increase in labour hours like fragmentation of land, water channel cleaning, difference in cultural practices, intensity of weeds, method of sowing and harvesting method used etc. About, 61 kg (43 %) seed/ farm is used excessively that can be linked with late sowing of wheat crop that tend to increase the amount of seed rate. The next excessively used inputs are irrigational hours, N fertilizer and tractor hours as 15 hours, 90 kg and 8.91 hours of these inputs are wasted per farm, respectively. The last excessively used input is land and the result related to excessive land use can be interpreted in two different ways. First, the farms can reduce their inputs that are used to grow .89 acre with wheat crop or the farmers can achieve the same output level per farm by reducing 37 % (.89 acre) of the area under wheat. Ogunniyi *et al* (2015) also found positive slack against farm area and interpreted that same level of output could be realized if the farm size were reduced by 0.06 ha. Various studies also used the slack-based models to find the slacks in wheat production (Alemdar and Oren, 2006 & Dağistan, 2010). Similar to this study, Alemdar and Oren (2006) also found that wheat farmers were over utilizing the inputs like machinery, P and N fertilizers, labour and seed. Dağistan (2010) also found greatest slack for P fertilizer followed by N fertilizer, labour, seed and machinery in wheat production.

Table 6.3.1: Excessive Input use and percent Slack Share

Inputs	*Input used (Mean)*	*Input saving Potential (ISP)*	*Inputs slacks (IS)*	*Total Reduction Possible (ISP+IS)*	*Total Reduction (%)*
Wheat Crop					
P Fertilizer	295.13	104.71	61.07 (20.7 %)	165.78	56.17
Labour hours	159.23	56.15	20.68 (13.0%)	76.83	48.25
Seed Rate	141.40	49.53	11.62 (8.2%)	61.15	43.25
Irrigation hrs	37.12	12.85	2.67 (7.2%)	15.52	41.81
N fertilizer	217.15	77.04	13.31 (6.1%)	90.35	41.61
Tractor Hours	22.19	7.62	1.29 (5.8%)	8.91	40.15
Farm area	2.63	.90	.08 (3%)	0.98	37.26
Cotton Crop					
Pesticides	7.52	2.34	.86 (11.4%)	3.2	42.55
Irrigation hrs	31.66	9.58	2.86 (9.0%)	12.44	39.29
P Fertilizer	172.80	51.34	14.63 (8.5 %)	65.97	38.18
N fertilizer	158.1	47.91	11.91 (7.5 %)	59.82	37.84
Labour hours	154.6	45.90	8.84 (5.7 %)	54.74	35.41
Farm area	1.66	.49	.060 (3.6 %)	0.55	33.13
Tractor Hours	14.98	4.44	.50 (3.3 %)	4.94	32.98
Maize Crop					
P Fertilizer	146.68	26.23	38.43 (26.2 %)	64.7	44.08
Irrigation hrs	36.98	6.71	7.89 (21.3%)	14.6	39.48
Labour hours	138.9	24.37	18.53 (13.3%)	42.9	30.89
N fertilizer	217.2	39.30	23.61 (10.9 %)	62.9	28.96
Tractor Hours	11.89	2.06	.35 (2.9 %)	2.4	20.27
Farm area	1.27	.22	.019 (1.5 %)	0.2	18.82
Sugarcane Crop					
N fertilizer	154.7	64.33	28.67 (18.5%)	93	60.12
P Fertilizer	156.8	65.31	24.56 (15.7%)	89.87	57.32
Labour hours	142.6	59	21.23 (14.9 %)	80.23	56.26
Irrigation hrs	67.52	28.4	8.19 (12.1%)	36.59	54.19
Tractor Hours	9.67	3.96	0.78 (8.1 %)	4.74	49.02
Farm area	0.89	0.37	0.05 (5.6 %)	0.42	47.19

For cotton crop, a greatest slack is present against pesticide followed by irrigation, P and N fertilizer, labour, farm area and tractor hours. These results pointed out that the cotton farmers can reduce pesticide use up to 3.2 times. Similarly, 12 hours of irrigation, 65 and 59 kg of P and N fertilizer, 54 and 4.94 hours of labour and tractor hours, respectively can be saved without any change in output level. However, Hameed *et al* (2014) reported greatest slack for nitrogen followed by irrigation, labour, and farm area in cotton production.

Maize crop is highly input intensive and requires proper, timely, and balance use of fertilizer and irrigation (Bempomaa & Henry, 2014). Slack analysis reveals that fertilizer, irrigation and labour are the most excessively used inputs in maize production and farms can reduce 44% phosphorus, 39% irrigational water, 30% labour use, 28% Nitrogen and 20% machinery hours per farm, without worsening the output level. Ahmed *et al* (2017) performed Slacks analysis and also found fertilizer usage 32.34%, and labour (7.79 %) in excess. Koc *et al* (2011) also found excessive slack against phosphorus (56 Kg), nitrogen (25.25 Kg) and labour hours (9.11) in maize production.

The use of P and N fertilizer is very important for sugarcane production and the greatest slack is observed against fertilizer. Approximately, 60 and 57 percent of N and P respectively are misused indicating farmer's inability to choice appropriate input mix that can reduce their production cost. In Pakistan, high weed infestation is major problem in sugarcane production and labour is usually employed for manual eradication of weeds and may be due to this reason 56% of the labour resources are inappropriately used. About 54% of irrigational water is used in excess, which implies that the farmers applied surplus water and deviate from the recommended number of irrigations. In the study of Padilla-Fernandez & Peter (2009) NPK fertilizer also appeared surplus for many farms (63%), followed by power, labor and land.

The farmers perhaps encounter problems while selecting the most appropriate input levels for production and sometimes find it problematic to make a decision on the right quantity of inputs to be used on their farms (Padilla-Fernandez & Peter, 2009). However, all farms are considered homogeneous; operating in a similar environment and technical efficiency analysis is a realistic approach to identify the farms with the best practice and can be used as benchmark for comparison (Villano, 2009). This simply means that in order to enable inefficient farms to achieve full technical efficiency, it is suitable to set input targets for inefficient farms that can provide information on input adjustment required for inefficient farms to operate on the production frontier (Iliyasu and Zainal, 2016). Therefore, inputs targets for inefficient farms are identified by performing benchmarking analysis and the results pertaining to this analysis are described below in section 6.4.

6.4: PEER FARMS IDENTIFICATION

Several different interactive approaches and models can be used in DEA methodology for the assessment of the relative efficiency of farms and on solution, DEA provides valuable information for managing the farm operations of both efficient and inefficient farms (villano, 2009 & Padilla-Fernandez & Peter 200). DEA identifies a set of relatively efficient units for each inefficient unit, thus making a referent unit or peer group, identical to the inefficient farms in terms of homogeneity in production mix used (Rouse *et al*., 2007; Martic *et al*., 2009 & Villano, 2009). Therefore, as a farm management tool, the procedure of benchmarking has been developed to recognize the areas where individual farm could increase their efficiency by following the practices of their peers who are achieving better results (Villano, 2009; Banaeian *et al*., 2010). The benchmarking procedure in DEA permits to find the targets for improvements for inefficient farms. Osamwonyi & Kennedy (2015) argued that in benchmarking process, the first step is to perform peer count analysis to recognize the DMUs that appear number of times as peer and these benchmarked peers act as referent units for other DMUs. The higher the frequency of any DMU in peer count analysis, the more acceptable is it for benchmarking because it is operating at the most desirable point on the frontier (Osamwonyi & Kennedy, 2015). Therefore, this section present the results of peer farms that appeared most of the time as referent units for inefficient wheat, cotton, maize and sugarcane farms. The Table 6.3 shows the detail of first ten farms that appeared more frequently in the reference group of inefficient wheat, cotton, maize and sugarcane farms. However, the actual number of referent units for wheat, cotton, maize, and sugarcane crops are 19, 27, 23 and 14, respectively. A complete list of these referent farms can be seen in appendix (F).

Table 6.4: Referent Units for Inefficient Farms

S. No	Wheat		Cotton		Maize		Sugarcane	
	Peer Farm	No of Times	Peer Farm	No of Times	Peer Farm	No of Times	Peer Farm	No of Times
[1,]	Farm 24	143	Farm 13	89	Farm 165	141	Farm 156	118
[2,]	Farm 36	137	Farm 213	80	Farm 196	95	Farm 9	82
[3,]	Farm 13	113	Farm 1	74	Farm 58	81	Farm 66	71
[4,]	Farm 123	101	Farm 175	70	Farm 184	44	Farm 28	65
[5,]	Farm 190	54	Farm 173	62	Farm 187	35	Farm 16	47
[6,]	Farm 77	43	Farm 26	58	Farm 80	27	Farm 209	45
[7,]	Farm 53	38	Farm 150	57	Farm 31	18	Farm169	31
[8,]	Farm 6	26	Farm 28	35	Farm 73	16	Farm 214	25
[9,]	Farm 68	16	Farm 71	26	Farm 1	8	Farm 68	17
[10,]	Farm 230	15	Farm 196	25	Farm 150	8	Farm 70	13

From the frequency count analysis, displayed in Table 6.4, it is found that F 24, F 36, F 13, F 123 and F 190 occur 143, 137, 113, 101 and 54 times in the peer groups of inefficient wheat farms, respectively. The implication that can be drawn from these results is that these efficient peers could be used as an alternative indicator of good operating practice for inefficient wheat farms. In case of cotton crop, F 13, F 213, F 1 and F 175 found 89, 80, 74, and 70 times as benchmarked units for inefficient cotton farms, respectively. The most frequently occurring referent units in case of maize crop are F 165, F 196, F 158 and F 184 that appeared 141, 95, 81, and 44 times in the peer group of other farms, respectively. In case of sugarcane farms, F 156 is at leading position as it is found 118 times as referent unit for most of the inefficient unit and a satisfactory rating can be given to the F 9, F 66 and F 28 that appeared in 82, 71 and 65 peer groups, respectively.

6.4.1: Benchmarking the Performance of Farms

Although DEA identifies the best performance farms but it provide no information by which inefficient farms can become most efficient and this is one of the major limitations of DEA in the context of peer identification (Rouse *et al*., 2007). For this, further analysis is required to identify the process by which these farms can become most efficient (looking at the input level used and output produced by efficient and peer farms) and then transferring the knowledge of best practice from the efficient to the inefficient farms (Rouse *et al*., 2007). Banaeian *et al* (2010) and Osamwonyi & Kennedy (2015) highlighted that this objective can be achieved by comparing the input level used by the inefficient DMU with its peers while maintaining the same output level. Consequently, the farms involved in the construction of the peer group can be utilized as benchmarks and DEA permits the computing of the necessary improvements in inputs and outputs of the inefficient unit (Osamwonyi & Kennedy, 2015).

In the next Table 6.4.1, comparative analysis is carried out to see the difference in input and output level between the least efficient wheat, cotton, maize, and sugarcane farms and their respective peers. This information is helpful to see how DEA could be used for benchmarking purposes. The data related to inputs and outputs for the least efficient farm are provided in column 1 while data related to their respective peers is presented in columns 2, 3, 4 and 5. The last column in the Table 6.4.1 provides information on the average inputs level used and output level produced by all the peer farms. Before proceeding further, it is important to highlight that the peer farm analysis in Table 6.4 and 6.4.1 is based upon technical efficiency estimate under VRS (Per farm). However, for easy interpretation and understanding of the results, the information on input and output level (per farm) is converted into per acre. According to Table 6.4.1, Farm 248, Farm 45, Farm 25, and Farm 21 are the least efficient wheat, cotton, maize and sugarcane farms with an average TE of .22, .23, .36 and .20, respectively. The Table 6.4.1 reveals that, on solution, DEA has indentified 4 peer farms for least efficient wheat and cotton farm, while 3 peer farms appeared in the reference group of least efficient maize and sugarcane farm. For least efficient wheat farm 248, the following farms (Farm 36, Farm 53, Farm 123, and Farm 190) are benchmarked by the DEA. In the case of cotton crop, Farm 13, Farm 71, Farm 175, and Farm 193 appeared as referent units for least efficient cotton Farm 45. Similarly, DEA marked (Farm 58, Farm 165, & Farm 184) and (Farm 28, Farm 156, & Farm 209) as peer farms for the least efficient maize and sugarcane farm, respectively.

Table 6.4.1: Difference in Inputs between Benchmarked and Least Efficient Farms

Variables		Peer Group or Referent Units				Mean input
Wheat						
	DMU-248	**DMU-53**	**DMU-190**	**DMU-36**	**DMU-123**	
Tractor Hours	08.25	7.08	6.16	10.26	6.84	7.585
Irrigation hrs	18.00	14	14.00	12.00	12	13
Labour hours	85.25	58.75	35.96	59.5	42.84	49.26
Phosphorus Fertilizer	100.00	100	100	75	50	81.25
Nitrogenous fertilizer	75	50	100	100	50	75
Seed Rate	60	50	50	60	60	55
Yield	440	2200	1960	1943	1080	1790
Cotton						
	DMU-45	**DMU-13**	**DMU-71**	**DMU-175**	**DMU-193**	**Mean input**
Tractor Hours	6.66	5.16	5.33	4.75	3.5	4.685
Irrigation hrs	21	13	11	11	24	14.75
Labour hours	70	71.51	44.66	69.5	77	65.66
Phosphorus Fertilizer	125	150	50	50	50	75
Nitrogenous fertilizer	100	50	50	100	125	81.25
Pesticides	2	5	5	6	5	5.25
Yield	480	2150	1400	1920	1800	1817.5
Maize						
	DMU-25	**DMU-58**	**DMU-165**	**DMU184**		**Mean input**
Tractor Hours	8.16	8.67	8.91	7.66	------	8.41
Irrigation hrs	42	18	21	21	------	20
Labour hours	102.5	75.33	89.83	80	------	81.72
Phosphorus Fertilizer	100	100	50	100	------	83.33
Nitrogenous fertilizer	200	150	150	100	------	133.33
Yield	1080	3400	2760	3120	------	3093.3
Sugarcane						
	DMU-21	**DMU-28**	**DMU156**	**DMU-209**		***Mean input***
Tractor Hours	5.47	5.31	4.98	2.97	------	4.42
Irrigation hrs	34	37	38	45	------	40
Labour hours	58.32	54.31	57	28.34	------	46.55
Phosphorus Fertilizer	100	100	75	50	------	75
Nitrogenous fertilizer	125	125	150	75	------	116.66
Yield	17675	23498	27453	32478	------	27809.67

Table 6.4.1 evidently shows that the least efficient wheat farm and its peers almost used similar level of inputs and the variations are not considerable in the use of nitrogenous fertilizer, seed rate, irrigations hours and tractor hours when the input level of Farm 248 is compared with the mean input used by its 4 peer farms. However, the main difference in input usage found for labour hours and phosphorus fertilizer. The least efficient wheat Farm 248 used 100 Kg and 85.25 hours while its peer farms on an average used 81 Kg of phosphorus and 49 labour hours. The high use of labour can be linked with high weed infestation, availability of more family labour, water channel condition and difference in cultural practices. It is interesting to note that a very high yield gap exists between Farm 248 and its peer farms. Almost utilizing the same level of inputs, Farm 248 has wheat production of only 440 kg, while its referent units, on an average, have secured comparatively high

wheat production of 1790 Kg. Such a huge difference in output level between Farm 248 and its peers provides strong evidence to conclude that the main problem is on output side rather than input and lower level of TE on Farm 248 compared to its peers is due to low wheat production. The low level of production on Farm 248 can be associated with factors like high weed infestation, crop lodging, late sowing and late first irrigation.

The results depicted in Table 6.4.1 show that the yield on least efficient cotton Farm 45 is also not impressive as previously benchmarking analysis revealed in the case of wheat crop. The benchmarked farms have attained, on an average, a cotton yield of 1817 kg, while Farm 45 has hardly achieved a yield of 480 Kg. The data further show that Farm 45 has used slightly higher quantities of all the inputs as compared to their respective peers except pesticides. All of the 4 peer farms, on an average, sprayed their cotton field with pesticides above 5 times as compared to Farm 45 who has only used pesticide 2 times. This implies that Farm 45 farm might not applied the pesticides at crucial stages of crop production and heavy insect-pest attack damaged and affected the cotton crop. An important conclusion that can also be drawn from this finding is that if F 45 wants to increase its TE up to the level of its peers then pesticide should be increased by 3 times and the amount of other inputs should be decreased up to the level that is used by its referent units.

The benchmarking analysis for maize shows that all factors of production are excessively used by the least efficient Farm 25 except tractor hours. The most excessively used inputs are irrigation hours and nitrogenous fertilizer and Farm 25 has overexploited 22 hours of irrigation and 67 kg of nitrogenous fertilizer than his benchmarked farms. The higher use of irrigation hours on Farm 25 can be nexus with application of more tube well irrigations as it takes longer time than canal water to irrigate the same land area, hence lead to higher irrigation hours on Farm 25. On an average, peer farms spent more tractor hours to prepare their land for sowing maize crop. From this finding, it can be concluded that proper land preparation practices greatly determine the level of technical efficiency and it is required for Farm 25 to focus on land preparation practices while sowing maize crop.

Almost similar to previous findings, inefficient sugarcane Farm 21 has used slightly higher number of tractor (5.47) and labour hours (58) as compared to peer farms that had utilized 4.42 and 46 hours, respectively. However, the peer farms have used more irrigation hours (40) than Farm 21 (34 hours) Sugarcane is water exhaustive crop and it is required by the Farm 21 to increase its irrigations hours and decrease its other inputs in order to attain the TE level close to its benchmarked farms. The results of this analysis imply that inefficient wheat, cotton, maize and sugarcane farms may save fair amount of resources by adopting the best practices of their high-performing benchmarks.

6.5: DETERMINANTS OF TECHNICAL EFFICIENCY

The efficiency differential among the farmers in a similar farming system is a matter of great interest for policy makers and this difference may be arise due to managerial ability and skill of a farm's operator and interaction of various socioeconomic factors (Javed, 2009). The present study also investigated the impact of various socio-economic, farm specific and environmental related factors on the technical efficiency of the wheat, cotton, maize, and sugarcane farmers. In this study, double bootstrapped truncated regression analysis first used by (Simar & Wilson, 2007) is applied to analyze the impact of various important variables on the level of efficiency. This research is unique from other efficiency studies conducted in Pakistan due to the application of double bootstrapped truncated regression. At the first instant, bootstrapped DEA scores were derived (bias-corrected efficiency scores) for 250 wheat, 216 cotton, 196 maize and 220 sugarcane farms. In the second stage, a double bootstrap truncated regression model is estimated instead to Tobit in order to estimate the sources of the technical inefficiency because the dependent variable has truncated sample of a distribution. The sample is left truncated (0 ≤ biased corrected TE) because none of the farms has attained full efficiency score after solving Bootstrap DEA model, therefore, censored model like Tobit would be inappropriate because data is truncated in nature and use of censored model can produce misleading results (Melkaw, 2014). The inefficiencies in a production process could be due to wide range of factors like distinctiveness of farms, management, physical, institutional and environmental aspects that have direct or indirect impact on the quality of management of farm's operators (Bakhsh, 2007 & Javed, 2009).

In this study, a truncated regression model of the below form is used in the second stage contextual analysis to in order to see the impact of various independent variables on the level of technical efficiency.

$$TE_{bcvrii} = \beta_0 + \beta_1 * Age_{1i} + \beta_2 * Fexp_{2i} + \beta_3 * Dmedu_{3i} + \beta_4 * Hsize_{4i} + \beta_5 * Dmmaritalstatus_{5i} + \beta_6 * Dmowner_{6i} + \beta_7 * farmarea_{7i} + \beta_8 * Dmtractor_{8i} + \beta_9 * Dmtubewell_{9i} + \beta_{10} * Dmcontact_{10i} + \beta_{11} * Dmtraining_{11i} + \beta_{12} * Dmcredit_{12i} + \beta_{13} * Dmsoilquality_{131} + \beta_{14} * Dmwaterquality_{41i} + \beta_{15} * Dmfragmentation_{15i} + \beta_{16} * Dmfym_{16i} + \beta_{17} * Dmextensionrecommendation_{17i} + \varepsilon_i$$

The full description of the explanatory variables used in the above truncated regression model is summarized below in Table 6.5.1. **The full justification of the variables that are selected and used in truncated regression model is already provided in section 5.7 of chapter 5.**

6.5.1: Explanation of Variables used in Truncated Regression Model

Determinants	*Specification in Truncated Regression model*
TE_{bcvrsi}	Is a bias corrected TE under VRS assumption
Age_{1i}	Represents the age of the ith farm's operator in years.
$Fexp_{2i}$	represents the farming experience of the ith farm's operator in years
$Dmedu_{3i}$	is a dummy variable having value equal to one if educated otherwise 0
$Hsize_{4i}$	represents the family size of the ith farm's operator in numbers
$Dmmaritalstatus_{5i}$	is a dummy variable having value equal to one if married otherwise 0
$Dmowner_{6i}$	is a dummy variable having value equal to one if owner otherwise zero
$farmarea_{7i}$	Represent farm area of ith farm
$Dmtractor_{8i}$	dummy variable having value equal to 1 if owner of the tractor otherwise 0
$Dmtubewell_{9i}$	is a dummy variable having value equal to one if owner of the tube well otherwise 0
$Dmcontact_{10i}$	is a dummy variable having value equal to one if have contact with extension agent otherwise zero
$Dmtraining_{11i}$	a dummy variable having value equal to one if participated in training otherwise zero
$Dmcredit_{12i}$	is a dummy variable having value equal to one if credit is availed otherwise zero
$Dmsoilquality_{131}$	a dummy variable having value equal to one if soil quality is good otherwise zero
$Dmwaterquality_{14i}$	a dummy variable having value equal to one if water quality is good otherwise zero
$Dmfragmentation_{15i}$	a dummy variable having value equal to one if land is fragmented otherwise zero
$Dmfym_{16ii}$	a dummy variable having value equal to one if FYM applied otherwise zero
$Dmextensionrecommendation_{17i}$	is a dummy variable having value equal to one if extension recommendations put in to practice otherwise zero
ß's	are unknown parameters to be estimated.
ε_i	Error term
i	refers to the ith farm in the sample

The potential determinants of TE used in the above econometric model were also considered prominent in previous studies conducted in different part of the world and farming systems (Rahman , 2003; Kibaara, 2005; Croppenstedt, 2005; Okoye *et al*., 2008; Solıs *et al*., 2009; Tsimpo, 2010; Byma and Tauer 2010; Błażejczyk-Majka *et al*., 2011; Asogwa *et al*., 2012; Naqvi & Ashfaq 2013; Watto, 2013; Khan & Farman., 2013; Rajendran, 2014; Miraj & Ali , 2014; Battese *et al*., 2014; Bakhsh *et al*., 2014; Kitila & Alemu 2014; Rajendran *et al*., 2015; Itam *et al*., 2015, Hashmi *et al*., 2015; Linh *et al*., 2015; Usman *et al*., 2016, Yang *et al*., 2016; Fatima *et al*., 2016 and Burja & Vasile, 2016). Therefore, the selection of these determinants to include in the regression model at second stage is in line with these studies.

The results of double bootstrap truncated regression model depicted in Table 6.5.2 reveal that the coefficient of age has a positive and non-significant influence on the TE of the wheat, cotton and maize crops. The β values for these three crops indicate that 1% increase in age improve TE by .001, .0001 and .003 points, respectively. This positive relationship indicates that old farmers are better manager than younger and higher TE might be due to greater experience related to crop production. Opposite to these crops, age has negative effect on the TE of sugarcane farmers (β = -.003), implies that the increase in age tends to decrease TE on sugarcane farms and the younger farmers are technically more efficient. The obvious reason for this relationship may be that the younger farmers are mostly less conservative and can easily transform to adopt improved farm practices. They are likely to have some education and try to get more information related to sugarcane production that translated into higher TE. When the results are compared with other studies, Asogwa *et al* (2012), Naqvi and Ashfaq (2013), Miraj and Ali, (2014) and Yang *et al* (2016) found positive association while negative correlation between age and TE was found by (Okoye *et al*., 2008; Byma & Tauer 2010; Saheen *et al*., 2011, Bakhsh *et al*., 2014; Khan and Farman., 2013; Rahman *et al*., 2012 & Itam *et al*., 2015).

The parameter of farming experience has a positive influence on TE of wheat and sugarcane farms but negative impact for cotton and maize crops. It can be concluded that maize and cotton farms greatly relied on their experience to grow these crops and did not apply updated knowledge related to new emerging recommended production technologies and this factor negatively influenced their TE. The positive connection between farming experience and TE is found by (Okoye *et al*., 2008; Saheen *et al*., 2011; Saddozai *et al*., 2015; Itam *et al*., 2015; Miraj and Ali , 2014 and Fatima *et al*., 2016), while Mohapatra (2013); Adzawla *et al* (2013) highlighted negative impact of experience on TE. The impact of household size found positive (non-significant) for wheat and maize crops, and significant for cotton and sugarcane crops at .05 % and .1 % level. These results imply that larger the family size, the greater will be the efficiency because a larger family have the advantage and opportunity to employ more family labour for supervision and farm operations. Asogwa *et al* (2012) and Itam *et al* (2015) also found larger families more efficient, while Rahman *et al* (2012) found less efficient.

6.5.2: Results of truncated Regression

Determinants	Wheat		Cotton		Maize		Sugarcane	
	Estimate	t-value	Estimate	t-value	Estimate	t-value	Estimate	t-value
(Intercept)	0.405***	4.82	0.369**	2.76	0.60***	7.816	0.42*	2.34
Age	0.001	0.30	0.0001	0.06	0.003	1.35	-0.003	-0.55
Experience	0.002	0.83	-0.001	-0.37	-0.003	-1.25	0.003	0.55
Education	.091**	2.95	.0020	.061	-0.003	-0.13	-0.037	-0.71
Household size	0.005	0.987	.0080*	2.04	0.004	1.27	0.012^{0}	1.65
Marital status	0.049	1.58	-0.048	-1.23	0.001	0.03	0.07	1.17
Tenancy	0.023	0.77	0.029	0.85	0.017	0.70	0.17**	3.09
Farm Area	-0.023**	-3.33	-0.015^{0}	-1.78	-0.004	-0.71	-0.06***	-4.75
Tubewell ownership	0.105***	3.27	-0.051^{0}	-1.44	0.001	0.05	0.10*	2.09
Tractor ownership	0.057^{0}	1.87	0.050	1.44	0.059**	2.59	0.04	0.78
Extension contact	0.12***	3.39	0.08*	2.03	0.019	0.48	0.15***	3.15
Extension training	0.098**	2.80	0.115**	2.67	0.067*	2.15	0.06	0.99
Access to credit	0.142^{0}	1.89	-0.008	-0.22	- 0.15***	-5.39	-0.08	-1.63
Soil quality	0.129***	3.65	-0.016^{0}	-0.45	0.005	0.20	0.021	0.38
Water quality	0.095**	2.68	0.057	1.23	-0.014	-0.42	0.003	0.05
Land fragmentation	0.039	1.39	0.007	0.21	0.004	0.18	-0.04	-0.65
Farm yard Manure	-0.187*	-2.47	0.0327^{0}	1.24	0.077**	3.01	0.18**	2.72
Extension Recommendation	0.117**	2.91	0.129***	3.469	0.074**	2.85	0.28***	3.93
Early sowing	0.076**	3.21	.009	2.04				
Seed quality	-0.039	-1.66						
Pesticide			0.024^{0}	1.83				
Sigma	0.152***	21.22	0.167***	19.99	0.120***	19.703	0.230***	14.54
Log -likelihood	119.91		99.40		137.23		73.75	
DF	19		19		18		19	

("***" if P-value < .001), ("**" if P-value < .01), ("*" if P-value < .05), " ^{0} " if P-value < .1)

Education supposed to have positive impact on TE as it increases managerial ability of the farmers. In this research, the variable of education found positively associated with the TE of wheat and cotton while negative for maize and sugarcane farms. The relationship found only significant for wheat crop at .01 percent level (β= .091**, P-value < .01) while non-significant for rest of the crops. A large number of studies found positive impact of age on TE of the farmers (Bashir & Dilwar, 2005; Kibaara, 2005; Bakhsh 2006; Okoye *et al*., 2008; Solıs *et al*., 2009; Byma & Tauer 2010; Saheen *et al*., 2011; Asogwa *et al*., 2012; Naqvi and Ashfaq, 2013; Saddozai *et al*., 2013; Khan & Farman., 2013; Mohapatra, 2013, Ali & Khan, 2014; Kitila & Alemu 2014; Rajendran, 2014; Itam *et al*., 2015 and Yang *et al*., 2016).

In addition to socioeconomic characteristics of the farmers, some farm related variables (tenancy, farm area, soil quality, water quality, FYM and land fragmentation) are also included in the truncated regression model as depicted in Table 6.5.2. The results reveal that the coefficient of tenancy is positive for all the four crops and only significant for sugarcane crop at .01 % level (β = .17**, P-value

< .01). This reveals that the ownership of land tends to increase efficiency because the landowners might be less averse to risks and have more security as compared to non-owners. The relationship appeared positive for all crops because majority of the farms in the data set are owner of the farms. Similar to these results, Rahman (2003) and Fatima *et al* (2016) also found positive impact of ownership on TE, while the study of Binam *et al* (2003), Deininger *et al* (2004) & Solıs *et al* (2009) found owner of the farms less efficient than non-owners. The coefficient of farm size also included in the truncated regression model and the computed results support the Shultz hypothesis "poor but efficient". The variable of farm size found inversely related (negative influence) the TE of all crops, implying that greater the farm size less will be the TE. The results appear significant for wheat, cotton and sugarcane crops while non-significant only against maize crop. The results for wheat, cotton and sugarcane appear significant at .01 % (β = -.023, P-value<.01), .1 % (β = -0.015^{0}, P-value< .1) and .01 % level (β = -.06, P-value<.01), respectively. The negative relationship emerged because the larger farms require more investment, machinery and supervision as compared to small farms. Similar to this study, Tsimpo (2010), Gul *et al* (2009), Okon *et al* (2010) Sarker and Alam (2016); Kitila & Alemu (2014) and Hameed *et al* (2014) also found inverse relationship between farm size and efficiency. Opposite to the findings of this study, a direct relation between farm size and TE is observed by (Bashir and Dilwar, 2005, Okoye *et al*., 2008; Byma and Tauer 2010; Błażejczyk-Majka *et al*., 2011; Adzawla *et al*., 2013; Rajendran 2014; Bakhsh *et al*., 2014; Hashmi *et al*., 2015; Itam *et al*., 2015; Rajendran *et al*., 2015; and Burja & Vasile, 2016). The results pertaining to the dummy variable of land fragmentation reveal that TE increases with increase in the number of the parcels of land for wheat, cotton and maize crops. The increase in efficiency with more fragmentation might be due to different fertility level, good water and soil quality on different parcels. The fragmentation is negatively associated with the TE of sugarcane farms, which might be due to difficulty in handling and managing the sugarcane crop on different parcels of land. The variables of soil and water quality are found positive in most of the cases, which help to conclude the better quality soil and good quality ground water has deep impact in improving the technical efficiency of the farmers. For cotton crop, the farmers with poor quality soil found more efficient that might be due to putting some extra efforts on production activities to make best use of poor quality soil. The dummy variable of FYM is significant for all crops at different significance levels but it is positive for cotton, maize and sugarcane crops. The application of FYM helps to increase soil fertility in addition to improving soil texture and water holding capacity of the land that then tend to increase production and TE.

The impact of tractor and tubwell ownership is also investigated in this research and a positive and significant relationship can be seen between the dummy variable of tractor ownership and the TE of the wheat (β = 0.057^{0}, P-value< .1) and maize farmers (β= .059**, P-value < .01). The relationship for other two crops (cotton and sugarcane) is also positive but non-significant. The ownership of tractor helps farmers to timely prepare their fields for crops cultivation and timely sowing lead to higher production and improve TE. These results imply that 1 percent increase in tractor ownership improves TE by .057, .050, .059 and, .04 points on wheat, cotton, maize and sugarcane farms, respectively. Similar to this study, Kibaara (2005), Hashmi *et al* (2015) and Fatima *et al* (2016) also investigated positive impact of tractor ownership on TE. The coefficient of tubwell ownership appeared positive and significant for wheat and sugarcane at .001 % level (β = 0.105***, P-value< .001) and .01 % level (β = 0.10**, P-value< .01), respectively. The relationship is also positive for maize crop but it is non-significant. The ownership of tubwell enables farmers to timely irrigate their crops at crucial stages of crop production that ultimately increase their efficiency. However, the technical efficiency of the cotton growers is negatively and significantly associated with the ownership of tubwell at .1 percent level. Opposite to prior expectations, the coefficient of credit dummy found negative for three crops (cotton, maize and sugarcane) and positive and significant only for wheat crop at .1 percent level. It can be concluded that that the credit was not used for agriculture purpose and spent on other non-farm activities by cotton, maize and sugarcane farmers but effectively used by the wheat farmers. The following studies associated credit positively with TE (Khan and Farman., 2013; Rajendran 2014; Usman *et al*., 2016 and Yang *et al*., 2016;) while Bakhsh *et al* (2014) found negative relationship.

Three variables were included in the truncated regression model related to extension services (contact with extension, participation in training and putting recommendation in to practice). According to prior expectations, it can be seen that all the three variables are highly positively associated with technical efficiency of all the four crops. The contact with extension agent is positively and significantly related with TE of wheat, cotton and sugarcane at .001 % level (β = 0.11***, P-value< .001), .05 % level (β = 0.08*, P-value< .05) and .001 % (β = 0.15***, P-value< .001), respectively. The relationship is also positive for maize crop but non-significant. It is also evident from the results that the coefficient of participation in training has a positive and highly significant relationship with the level of technical efficiency in the case of wheat, cotton, and maize crops at .01 %, .01 % and .05 %, respectively. For sugarcane crop, this relation is also positive but it is non-significant. The results related to putting extension recommendations into practice also reveal a very strong positive and highly significant relationship for all crops at .001 and .01 % confidence level. These results imply that the farmers having more interactions with the extension services are less inefficient than the farmers with limited or no interaction. The interaction with extension services allows them to get information about the state of approved agricultural technology and help in the choice of right inputs mix. The positive connection between extension services and TE is also explored by the (Rahman, 2003; Croppenstedt, 2005; Solıs *et al*., 2009; Byma and Tauer 2010; Asogwa *et al*., 2012; Naqvi and Ashfaq, 2013; Battese *et al*., 2014; Bakhsh *et al*., 2014; Khan and Farman, 2013; Kitila & Alemu 2014; Usman *et al*., 2016 and Yang *et al*., 2016). The coefficient of pesticide is significant and positive in the case of cotton crop, which implies that higher use of pesticide increase TE and this finding confirms the conclusion made in section 6.4 that least efficient farm under-utilized the input of pesticides. The variable related to early crop establishment factor is also included in this analysis for wheat and cotton crops and it is found positive for both crops, implies that early sowing of wheat and cotton crops tend to increase the efficiency.

6.6: OVERALL SUMMARY

In this chapter, an overall framework was developed to assess the relative performance of the wheat, cotton, maize, and sugarcane growers in mixed farming system of Pakistan. The main objective of this thesis was to evaluate the TE, SE, AE, CE and BCTE of the farmers at crop and farm level and then to find the determinants of TE by selecting suitable model. The objective to evaluate all kinds of efficiencies and to find the determinants of TE at crop level is covered in this chapter. The approach used in this study is different from other Pakistani studies and provide some important innovations over previous studies. This study is unique in a sense that the efficiency of the mixed farming system is evaluated against diversified crops rather focusing on single crop and quality of the analysis is further enhanced by conducting analysis on per acre and per farm basis by using some advanced DEA techniques. The most of the previous efficiency studies had focused single or two crops and major reliance was on either per acre or per farm data to evaluate the efficiency of the farms (Battese et el 1993; Hussain *et al*., 2000; Ahmad *et al*., 2002; Hassan and Ahmad 2001; Hassan and Ahmad 2005; Hassan *et al*., 2005; Ahmed *et al*, 2002; Bashir and Dilwar, 2005; Hussain *et al*., 2012; Hussain, 2014; Buriro *et al*., 2013; Battese *et al*., 2014; Ali & Khan, 2014; Elahi *et al*., 2015; Gill, 2015, Mirza *et al*., 2015; Hashmi *et al*., 2015; Hashmi *et al*., 2016; Usman *et al*., 2016; Fatima *et al*., 2016 and Fatima *et al*., 2017). The average estimated technical efficiency scores generated from input orientated DEA models under CRS and VRS assumptions suggest that the sampled wheat, cotton, maize, and sugarcane farmers are not fully operating on the efficient frontier and a great opportunity is present to reduce their current level of inputs without any change in the current output level. On an average, the sampled wheat, cotton, maize and sugarcane farms can reduce their inputs level up to 34, 29, 17 and 42 percent per farm, respectively. The analysis was further expanded to see the impact of farms' scale operations on TE and the lower scale efficiency values in per acre analysis against per farm analysis reveal that the scale inefficiency is a major cause of overall less TE that also hinder farms to attain maximum production from the available resources. However, comparatively large values of scale efficiency in per farm analysis helps to draw conclusion that most of the detected inefficiencies were purely attributed to the management problems and inefficiency is due to the over usage of resources. In this study, the procedure of bootstrapping as proposed by Simar and Wilson (1998, 2000) to establish the statistical properties of the DEA estimators is applied to correct the efficiency from bias and to establish confidence interval. The results gathered from this analysis revealed that the original efficiency scores have upward bias for all crops and additional input reduction is possible against the reduction that is suggested by standards DEA models.

Further, in this chapter, cost and allocative efficiency is also estimated and it was found that the wheat, cotton, maize, and sugarcane farmers had faced higher cost inefficiency when analysis is based on per farm data as compared to cost inefficiency on per acre basis. The analysis revealed that the allocative inefficiency in maize has major contribution towards overall less economic efficiency but in wheat, cotton and sugarcane production, the cost inefficiency was mainly due to the less technical efficiency rather than allocative inefficiency on these farms. Furthermore, allocative inefficiency suggested that the farmers are not allocating their resources properly, which lead to less profit on these farms as they are not equating the marginal revenue product to marginal input cost. Further, the analysis of input slacks revealed that the inputs like phosphorus and nitrogen fertilizer, hours of irrigation and labour were the most excessively used inputs for all the crops and the amount of these inputs is exceeding from the quantity that is necessary for receiving the same output.

One of the main strength of DEA over statistical approaches is its ability to focus on the performance of individual farm (benchmark analysis). This analysis is informative to identify the best practices in farm management, for the farming system under study. DEA is increasingly being used as a benchmarking tool in different parts of the world but it is rarely used by any DEA studies conducted in Pakistan. In this study, the benchmarked farms often known as peer farms are identified for the least efficient wheat, cotton, maize and sugarcane farms. It is evaluated from the analysis that most factors of production were excessively used by the least efficient farms and surprisingly secured a quite lower level of output as compared to its benchmarked farms. The higher input use and quite lower output than the peer farms is the main cause of low efficiency on least efficient farms. To find the possible determinants of Technical efficiency, a double bootstrap truncated regression analysis devised by Simar and Wislon (2007) recognized as “Alogrithm II” is applied and results pertaining to this analysis are presented in the last section of this chapter. The analysis of the determinants of TE showed that the variables of age, household size, ownership of land, extension contact, participation in training, practicing the extension recommendations, tractor and tubwell ownership, FYM, early sowing of crops have very strong positive significant relationship with the technical efficiency in most of the cases. The farm area and access to credit were found among the variables that are most negatively and significantly associated with the level of technical efficiency.

CHAPTER 7

OVERALL EFFICIENCY OF MIXED FARMING SYSTEM

To cope with the emerging challenges of limited natural resources, climate change and reduced yield, it is imperative to raise the efficiency of farming system by controlling the inputs overexploited and used unsustainably and adopting and utilizing the new emerging, efficient and innovative production technologies (Gadanakis, 2013). The production enhancement in a farming system through intensified cultivation requires balanced farm management options if aim is to make it more sustainable (Garnett & Godfray, 2012). Therefore, proper and balanced use of improved technologies and management practices is more simple and inexpensive way for developing the farming systems (Dao, 2013). This path requires considerable ability to make efficient use of input resources like family labour, machinery, water, and other management resources. Hence, this chapter is written to evaluate the overall efficiency of the mixed farming system.

In the previous chapter, performance of the farms is evaluated at disaggregated level and efficiency of the farms involved in growing wheat, cotton, maize and sugarcane crops measured separately for each crops. In this chapter, the performance is measured at aggregated level to measure the efficiency of the farming system as a whole. This is done by combining the inputs used and outputs produced for all the four crops. This chapter is also divided into different sections that contain results pertaining to different kind of analysis. The first section provides the summary statistics of the aggregated inputs and outputs that are then used in DEA models. The interpretation of the results related to all type of efficiency measures (TE, SE, CE, AE, and BCTE) is discussed in the next section. The sub-sections of the previous section contain results related to slack-based models and benchmarking analysis. In the last, the overall determinants of TE in the mixed farming system were estimated by applying truncated regression model.

7.1: AGGREGATED INPUTS AND OUTPUTS FOR DEA MODELS

In Data Envelopment Analysis, inputs variables can be aggregated into the total amounts of each type of input in a case involving multiple inputs and outputs. For example, if input types 'labour' and 'tractor' are used to produce multiple outputs, the total amount of labour used to produce all outputs is treated as one aggregated input and the total amount of tractor hours as another. Bhatt and Shaukat, (2014) argued that aggregation of inputs and outputs in modeling help to avoid the complications. Therefore, in this study the four outputs variable (income from wheat, cotton, maize and sugarcane) are aggregated into one single output of total income in addition to aggregating the inputs that are used to grow all the four crops. Description of variables used in DEA input oriented models is displayed in Table 7.1.

7.1: Summary Statistics of Aggregated inputs and outputs

Variables	Summary Statistics			
	Min	**Max**	**Mean**	**Std.Dev**
Area	.75	17	5.8707	2.77
Tractor (Hrs)	4.38	138.21	39.2937	20.91
Irrigation (Hrs)	6.00	316.00	93.48	48.33
Labour (Hrs)	27.75	1830.79	403.21	235.07
Phosphorus (Kg)	50.00	2000.00	635.73	353.16
Nitrogen (Kg)	37.50	2112.50	654.84	349.37
Total yield	720.00	110542.5	24248.66	17467.67
Total income	20880	1226180	342545.1	19452.1

According to the Table 7.1, The average total income generated by the farmers from all crops in mixed farming system is PKR 342545.1 (US$ 3937.3), ranging from minimum of PKR 20880 (US$ 280) to maximum of PKR 1226180 (US$ 14094.2). A number of conclusions can be drawn from a very small total income of US$ 280/Year on some farms, implying that some farmers might have other sources of off farm income and rely less on agriculture for livelihood. Secondly, the farmers might have livestock enterprise as a major source of earning rather than crop enterprise, only grow wheat crop for self-consumption and designate rest of the area to forage crops to feed their livestock. Because, the livestock income is not included in this study, therefore, the total income from crop enterprise appeared low on some farms. A large SD=19452.1 value against total income indicates large variability in income among the sampled farms in mixed farming system. The average aggregated amount of P and N fertilizers applied to all crops is recorded at 635 and 673 Kg, varying from 57 to 2000 Kg and 37 to 2112 Kg, respectively. The standard deviation value of 353 kg and 349 Kg for P and N implies that fertilizers are over or under exploited by the sampled farms and large variation exist in the use of fertilizers. On an average, a total number of 39, 93, 403 hours of tractor, irrigation and labors are used on the sampled farms with standard deviation of 20, 48 and 235, respectively. A wide gap in the use of these resources also exists among the farmers as evident from the minimum and maximum values of these inputs. The use of tractor, irrigation, and labour range from 4.38 - 138 Kg, 6 - 216 Kg and 27 - 1830 Kg, respectively.

Therefore ,in this study one output variable in the form of aggregated total farm income from all crops and six aggregated inputs variables (farm area, tractor hours, irrigation hours, labour hours and N fertilizers) are used in the DEA input orientated model. Similarly, various other studies also employed the output in monetary form in DEA models by aggregating all the output variables (Fandel, 2003; Javed *et al*., 2008; Latruffe *et al*., 2008; Dao, 2013; Bhatt and Shaukat, 2014 and Fatima *et al* 2016). The use of output variables in financial terms provides an easy framework for aggregating the various system outputs. Similar to other studies, the variables of labour, tractor and irrigation is measured in hours (Fraser and Cordina, 1999; Shafiq and Tahir, 2000; Koc *et al*., 2011; Reinhard *et al*., 2000; Lansink *et al*., 2002; Iráizoz *et al*., 2003; Asmild and Hougaard, 2006; Galanapoulos *et al*., 2006; Luik *et al*., 2009, Javed *et al*., 2010; Koc *et al*., 2011). Similar to De Koeijer *et al* (2002), Asmild and Hougaard, (2006) and Umanath & David (2013) the inputs such as nitrogen, phosphorus are measured in Kg in this study.

7.2: OVERALL EFFICIENCY OF MIXED FARMING SYSTEM

Similar to crop wise analysis in pervious chapter, the input orientated framework for DEA is adopted to estimate overall efficiency of the farming system. The overall performance of the mixed farming system is evaluated at aggregated level by combining all the inputs used to produce various crops outputs. The results related each kinds of efficiency derived by using aggregated inputs and outputs in various DEA models are summarized below in Table 7.2.

The results displayed in Table 7.2 reveal no significant difference when CRS and VRS models are considered in analysis and an average TE is computed at .68 and .71, respectively. The narrow difference in TE under CRS and VRS implies that scale of operations has little role in causing technical inefficiency in mixed farming system and substantial input savings potential of 29% is present at aggregated level. From the distribution of farms in relation to the frontier, it can be noted that the farms in case of VRS slightly skewed towards the higher efficiency rankings as compared to CRS distribution that might be due to elimination of scale effect. The difference in minimum and maximum TE values pointed out that the least efficient farm has either not been able to uptake new technologies adopted by the fully efficient farms or inefficient in their managerial operations, or a combination of both factors.

7.2: Summary Statistics of Overall Efficiency Level

RANGE	EFFICIENCY						
	TE (CRS	TE (VRS)	SE	CE	AE	BCTE (CRS)	BCTE (VRS)
Less than .5	27	16	2	58	1	86	78
0.5<= E <0.7	115	113	2	141	19	107	109
0.7<= E <0.8	56	56	3	31	47	31	39
0.8<= E < .9	25	29	17	11	98	19	24
0.9<= E <1	14	13	198	6	82	7	0
TE=1	13	23	28	3	3	0	0
% Farms on frontier	5.2	9.2	11.2	1.2	1.2	0	0
Mean efficiency	.68	.71	.96	.60	.85	.57	.58
Minimum Efficiency	.32	.40	.44	.30	.49		
CI lower bound						.60	.60
CI upper bound						.67	.70

The results obtained in this study are compared with a similar set of other studies that have measured the efficiency of the farming system at aggregated level and the results appeared similar to (Bravo-Ureta & Antonio 1997 (70); Latruffe *et al*., 2004 (73); Javed, 2009 (.70); Simwaka, 2013 (73); Dhehibi *et al*., 2014 (72) and Mwajombe & Malongo, 2015 (.72)). The following studies found higher TE than this study (Wadud and White 2000(86); Henderson & Ross, 2002 (93); Shanmugam and Atheendar, (79); Olson and Vu, 2007 (90), Bozogulo & Vedat 2007 (83); Tchale, 2009 (88); Javed *et al*., 2010 (.83); Dao, 2013 (.83); Javed, 2009 (75); Langemeier, 2010 (86), Bhatt and Shaukat, 2014 (94)). However, A low TE level was estimated by (Fandel 2003 (.62); Davidova & Latruffe, 2003 (67) and Asefa, 2011 (60)).

The above finding is verified as the mean scale efficiency found very high (.96), because the farm size improved to greater extent at aggregated level that reduces the effect of scale on technical efficiency. Bielik and Rajčániová, (2004) also concluded that the inputs like labour and machinery can be better adjusted as farm size increases. The results are consistent with Linh *et al* (2015) that farm size is much less important in changing technical efficiency. The scale efficiency analysis also enables to find whether the farm size is optimal or not optimal (Aldeseit, 2013). The question about optimal farm size has a long history in agricultural economics. When marginal returns equal marginal costs, optimal size is reached (Bielik and Rajčániová, 2004). However, higher marginal returns and lower marginal costs can be found as farm size is increased. However, beyond a certain size, marginal returns will decrease and marginal costs will rise (Bielik and Rajčániová, 2004). These findings suggest that on overall basis the size of the farm is still reasonable in mixed farming system. However, the analysis based on individual crop data reveals technical inefficiency due to farm size.

This is because, in crop wise analysis, the resources may not be better adjusted on some farms due to small farm size. Almost similar SE was found by (Fandel 2003 (.92); Wadud and White 2000 (91) and Dao, 2013 (.95) while low SE level than this study is estimated by (Olson and Vu, 2007 (88); Javed et al., 2011 (0.85) and Bhatt and Shaukat, 2014 (60)).

The average cost and allocative efficiency in the mixed farming system is found at .60 and .85 with minimum of .30 and .49. It means that the 40 percent of the cost is wasted relative to the best practice farm and the overall CE of the mixed farming system is not reasonable and possible reason might be that decision-making is more complicated to run larger operations and selection of inappropriate input mix lead to higher cost inefficiency. A very large number of farms 199 (79%) have attained CE score less than .7. When the results are compared with other studies, Tchale (2009) estimated higher (72), while the following studies found Low CE than this study (Bravo-Ureta & Antonio 1997(31); Javed, 2009, (37) and Javed, 2009 (.40)). Similar level of AE found by (Tchale, 2009 (82)). However, low AE level than this study is estimated by (Bravo-Ureta & Antonio 1997 (44); Olson and Vu, 2007 (77); Javed, 2009, (44); Javed, 2009 (.48); Langemeier, 2010 (72) and Fatima *et al.*, 2017 (75)).

Similar to individual crop analysis, the bootstrap DEA model solved for 2000 iterations and the average bias-corrected TE under CRS and VRS is recorded at .57 and .58, respectively, lower than found in case of standard DEA measure. Melkaw (2014) also found lower biased corrected TE than original TE at farm level because the bootstrap DEA model take into account the losses that are caused by factors beyond farmers' control like diseases, flood, extreme weather while standard DEA models does not consider these factors in calculations. The value of 95 % confidence interval suggests that farms can reduce their inputs level from 33 to 40 percent in case of CRS and 30 to 40 percent if VRS analysis is considered. The percentage bias between original and bias-corrected TE under CRS and VRS assumptions is .11 and .13, respectively. Mugera and Michael, (2011) computed bias corrected TE (.54) that is close to this study. The results are not aligned with the findings of authors who estimated either low or high bias corrected TE in different crop production zone of the world (Olson and Vu, 2007 (77) and Dao, 2013 (.76)).

7.2.1: Overexploited Inputs in Mixed Farming System

A farm can have an efficiency score of one and still be Pareto-Koopmans inefficient (Koopmans, 1951). Koopmans (1951) proposed a formal definition of efficiency, as a producer is technically efficient only if none of its inputs or outputs can be improved without worsening some of its other inputs or outputs. After the proportional change in the inputs or the outputs, excess in inputs and shortfall in outputs that exist is defined in DEA literature as “slack” Padilla-Fernandez & Peter (2009). If there is positive slack, additional saving potential associated with some inputs and/or the opportunity for expansion associated with some outputs exist although the farms appears Farrell efficient. Therefore, in addition to technical efficiency estimate in previous analysis that is based on standard DEA models, a slack-based DEA model is further used to identify specific input reductions and hence, slack values serve as an indication of the level of intensification of the agricultural production in an effort to secure yields and increase profit. Inputs slacks in the model can be used to measure the specific input excess in order to direct farm management towards the improvement of efficiency and sustainable intensification (Gadanakis, 2013). The results pertaining to slack based model are depicted in Table 7.2.1.

7.2.1: Total input Reduction Possible

Inputs	Input used (Mean)	Input saving Potential (ISP)	Inputs slacks (IS)	Total Reduction Possible (ISP+IS)	Total Reduction (%)
P Fertilizer	635.73	196.62	50.65	247.27	38.89
N Fertilizer	654.84	199.01	39.04	238.05	36.35
Labour	403.21	121.25	41.11	162.36	40.26
Irrigation	93.48	28.30	12.02	40.32	43.13
Tractor	39.29	11.74	2.047	13.787	35.08
Farm area	5.87	1.73	.070	1.8	30.66

Table 7.2.1 depict the extent to which use of a particular input can be reduced given that a farm has already reached the frontier of the production set. The results reveal a quite severe problem in the use of phosphorus and nitrogen fertilizers at aggregated level than for individual wheat cotton, maize and sugarcane crops. Without sacrificing efficiency, the farm can further reduce the amount of P and N fertilizers up to 50.65 and 39.04 Kg as suggested by the slack value but a total amount of 247 and 238 Kg can be reduced per farm suggesting overall 38.89 and 36.35 percent reduction, respectively. The next most overexploited input is labour and mean input slack value suggests that 41.11 hours of labors are misused per farm. Based on input saving potential and slack values, 162 hours of labour can be saved for all the crops grown in mixed farming system suggesting a total reduction of 40 %. The water is now becoming scarce input in many crop production zones of the

world and it should be used in careful manner. In mixed farming system of Pakistan, 40 hours of irrigational water are wasted to grow wheat, cotton, maize and sugarcane crops revealing the possibility of total reduction up to 43 percent in irrigational water at aggregated level. These results stress that the farm management practices that ensure balance and uniform utilization of water should be promoted in order to reduce over exploited water consumption at a farm level. The excessive water use reduce crop yield as most of the essential nutrients leaches down from the plant root zone, thus increasing fertilizer costs and reducing grower returns (Dong *et al*., 2015). The unnecessary water losses can be prevented through good irrigation management plan, calculating irrigation runtimes and monitoring soil moisture to set irrigation schedules for efficient use of water resources (Dong *et al*., 2015). A total number of 13.78 hours of tractors are over exploited in mixed farming system, suggesting the possibility of overall 35 percent reduction. The excessive use of machinery hours is dangerous for number of reasons as it put environmental pressure due to emission of unwanted gases and secondly high fuel consumption increase cost of production and this input require highest extra proportional reduction per farm. The values of input saving potential and input slack attached to the variable of farm area reveal that 1.8 acres of land are overly exploited. These results can be interpreted in a manner that the inputs that are required to grow wheat, cotton, maize and sugarcane crops on 1.8 acres of land are wasted by the farmers.

7.3: EFFICIENT PEERS FOR INEFFICIENT FARMS IN MIXED FARMING SYSTEM

DEA produces an efficient frontier consisting of a set of most efficient performers, allowing a direct comparison to the best performers. A unit can become efficient by moving towards the frontier by reducing inputs or increasing outputs produced or a combination of both. Since efficiency is the ratio of output to input, a DMU can become efficient by increasing output or decreasing input. Such measurable and actionable goals satisfy the requirements of step 2 of the benchmarking process. In other words, a DMU becomes efficient by moving towards the frontier. Having identified the reference set and the areas for needed improvement, step 3 of the benchmarking process, implementing benchmarking, can be done. The management can evaluate the operations of the peer group units or reference set to determine what changes in inefficient units can be made (Rayeni and Saljooghi, 2013).

The identification of peer groups should be very useful in practice and can be used to highlight the weak aspects of the performance of the corresponding inefficient unit. The input/output levels of peer units can also sometimes prove useful target levels for the inefficient unit (Martic *et al*., 2009).

Similar to the peer farm analysis at individual crop level, the referent units for least efficient farm are also recognized at aggregated TE measure. This analysis will help to compare overall input level between peer farms and inefficient farm that is used to grow all four crops (aggregated). The data summarized in Table 7.3 present the summary of frequency count of peers. In aggregated analysis of efficiency, a total number of 23 peer farms were identified by DEA, however, the information related to first ten peer farms are presented in Table 7.3 (complete list can be seen in appendix F)

7.3: Frequency Count of Peer Farms

S.NO	FARM NO	Number of Time Appear Peer
1	1	186
2	36	184
3	233	85
4	211	61
5	105	59
6	61	53
7	164	47
8	237	29
9	198	27
10	158	17

Table 7.3 reveals that Farm 1 appears 186 times in the reference group of the inefficient farms and DEA ranked it at first position followed by Farm 36, 233, 211 and 105 that appeared in the peer group of 184, 85, 61 and 59 farms, respectively. The next Table 7.3.1 provides information on input and output level at aggregated level used by least efficient Farm 82 and its respective peers. The results show that the least efficient Farm 82 has allocated 4 acres of land and utilized 26.83 tractor hours, 77 irrigation hours, 255 labour hours, 425 kg of phosphoric and 350 kg of nitrogenous fertilizer to achieve a net income of PKR 115120 (US$ 1223.21) from all crops. Its referent unit Farm 1 has secured a net income of PKR 1226180 (US$ 14094) from 13 acres by consuming 83.33 tractor hours, 180 irrigation hours, 865.03 labour hours, 1400 kg of phosphoric and 1250 kg of nitrogenous fertilizers. Similar to Farm 1, the peer farm 211 also allocated greater land area of 7 acres than Farm 82 and has obtained a net income of PKR 583920 (US$ 6711.71) from all crops by utilizing 67.06 tractor hours, 104.25 irrigation hours, 456.60 labour hours, 675 kg of phosphoric and 500 kg of nitrogenous fertilizers. The referent unit Farm 164 designated less land area than the Farm 82 and applied 18 tractor hours, 44 irrigation hours, 244.01 labour hours, 175 kg of phosphoric and 250 kg of nitrogenous fertilizers to obtain net income of PKR 211704 (US$ 2433.37). Only peer Farm 87 allocated farm area equal to the Farm 82, however this peer farm has obtained a higher net income 329520 (US$ 3787.57) than Farm 82. This peer farm used higher phosphorus and tractor hours and lower level of all other inputs than Farm 82.

It can be seen that the least efficient Farm has used 4 acres of land while its referent units have allocated 13, 3.5, 7, and 4 acres to grow wheat, cotton, maize, and sugarcane crops. Because of different acres, input use level is looking higher on the referent units, therefore to overcome this problem and for easy interpretation of the results, information is converted on per acre basis.

7.3.1: Comparison of Input and output level Between Farm 82 and its Peer Farms

Variables	*Inefficient Farm*	*Referent Units*			
	Farm-82	**Farm-1**	**Farm-164**	**Farm-211**	**Farm 87**
Area	4	13	3.5	7	4
Tractor Hours	26.83	83.33	18.00	67.065	28
Irrigation hrs	77	180	44	104.25	68
Labour hours	255.01	865.03	244.01	456.60	234.28
P Fertilizer	425	1400	275	675	450
N Fertilizer	350	1250	250	500	200
Total Income	165120	1226180	211704	583920	329520
	Inefficient Farm	**Referent Units**			
	Farm-82	**Farm-1**	**Farm-164**	**Farm-211**	**Farm 87**
Tractor Hours	6.7075	6.4	5.14	9.58	7
Irrigation hrs	19.25	13.8	12.57	14.89	17
Labour hours	63.7525	66.5	69.72	65.23	58.57
P Fertilizer	106.25	107.7	78.57	96.43	112.5
N Fertilizer	87.5	96.2	71.43	71.43	50
Net Income	41280	94321.5	60486.86	83417.14	82380

The results summarized in Table 7.3.1 reveal that least efficient Farm 82 has a very low average return from each acre of land 41280 (Us $ 474.78) as compared to its peer farms (Farm 1, Farm 164, Farm 211, and Farm 87). Its peers farms have received an average return of PKR 94321.5 (US $1084.14), 60486.86 (US$ 695.24), PKR 83417.14 (US$ 958.81), PKR 82380 (US$ 946.89). The net lower return on Farm 82 implies that the input mix is not utilized in a proper way that can reduce the cost of production and maximize profit. The net lower return might also be due to lower yield from all crops. It is interesting to note that no wide difference exist in the use of input level between Farm 82 and its peers and most of the peers farms even utilized higher input level than the Farm 82. In the case of tractor hours, Farm 1 (6.4 Hrs) and Farm 164 (5.14 Hrs) slightly used less while Farm 211 (9.58 Hrs) and Farm 87 (7 Hrs) used higher hours of tractors than Farm 82. However, the use of irrigation hours on Farm 82 is higher than all its Peers farms. It can be concluded that increased irrigation hours lead to higher irrigation cost and less net return. The data show that, there is no significant difference in the use of labour hours between Farm 82 and its referent units and these farms almost used similar labour hours with little variations. This implies that labour hours are not contributing significantly towards technical inefficiency on Farm 82. The use of phosphorus fertilizer on Farm 82 is almost similar with peer Farm 1, 211 and 87 with minor variations; however, Peer Farm 164 used quite low phosphorus level than Farm 82. The difference in the use of nitrogen fertilizer is also not substantial between Farm 82 and Peer Farm 1. However, all the other peer Farms used less quantity of nitrogen fertilizer than Farm 82. These findings provide enough information to conclude that the inputs like phosphorus fertilizers and tractor & labour hours are not the major reason of low TE on Farm 82, but irrigation hours, nitrogen fertilizer, and less total income contribute largely towards less TE. Based on these results, it can be suggested for Farm 82 to increase its level of income up to the level that is achieved by its peers by further lowering the irrigation hours and nitrogen fertilizer in order to attain efficiency level equal to its peers. A low total income might be due to low level of yield from all crops as a result of various factors like soil fertility, salty ground water, weed infestation, severe pest attack etc. Thus, this farm can overcome on these yield-limiting factors by following the precautions that are used by its peers in the face of all these problems.

7.4: OVERALL DETERMINANTS OF EFFICIENCY IN MIXED FARMING SYSTEM

In this section, the overall determinants of technical efficiency in the mixed farming systems are identified through the same procedure (double bootstrap truncated regression) as adopted in the previous chapter against each crop. The results pertaining to the determinants, influencing the efficiency of the farmers in mixed farming system are summarized below in Table 7.4. The findings from the truncated bootstrapped second stage regression highlight that the technical efficiency of the farm households at aggregated level significantly related to the variable of tenancy, tractor ownership, extension contact, training, soil quality and with the dummy variable of practicing the extension recommendations, at different level of significance.

However, rests of the variables as shown in Table 7.4 found statistically insignificant. Among the statistically significant variables, tractor ownership, participation in training, soil quality and the dummy variable of practicing the extension recommendations found positive, while contact with extension agent and farm ownership found negatively influencing the TE of the farms in mixed farming system. Among the non-significant variables, age, household size, marital status, tubwell ownership, credit, water quality and land fragmentation have positive impact on TE, while farming experience, education, and farm area found negatively connected with TE.

Table 7.4: Overall Determinants of Technical Efficiency (Truncated Regression)

Variables	Estimate	Std. Error	t-value	Pr(> |t|)
(Intercept)	0.511***	0.067	7.64	2.27E-14***
Age	0.002	0.002	0.75	0.450
Experience	-0.001	0.002	-0.66	0.506
education	-0.020	0.020	-0.99	0.323
Household size	0.0001	0.003	0.04	0.968
Marital status	0.004	0.023	0.18	0.859
Tenancy	-0.037^{o}	0.022	-1.70	0.089^{o}
Farm Area	-0.004	0.004	-1.01	0.313
Tubewell ownership	0.031	0.024	1.29	0.197
Tractor ownership	0.130***	0.024	5.53	3.26E-08***
Extension contact	-0.051^{o}	0.029	-1.77	0.076^{o}
Extension training	0.065*	0.029	2.21	0.026*
Access to credit	0.021	0.032	0.67	0.502
Soil quality	0.050*	0.024	2.05	0.039*
Water quality	0.027	0.025	1.07	0.283
Land fragmentation	0.004	0.020	0.21	0.835
Extension Recommendations	0.086***	0.022	3.87	0.0001***
FYM	-0.013	0.031	-0.42	0.678041
Sigma	0.116***	0.005	21.91	< 2.2e-16***
Log -likelihood	185.64			
DF	19			

("***" if P-value < .001), ("**" if P-value < .01), ("*" if P-value < .05), " ^{0} " if P-value < .1)

The negative sign for farming experience and education is against the expectations that were established early in the previous chapters. This finding is surprisingly different from the extant literature that has elucidated the positive impact of both variables (Bashir and Dilwar, 2005; Kibaara, 2005; Bakhsh 2006; Okoye *et al*., 2008; Solıs *et al*., 2009; Saheen *et al*., 2011; Byma and Tauer 2010; Asogwa *et al*., 2012; Naqvi and Ashfaq 2013 ; Mohapatra, 2013; Ali and Khan, 2014; Kitila, & Alemu 2014; Rajendran 2014; Miraj and Ali , 2014; Khan and Farman., 2013; Saddozai *et al*., 2015; Itam *et al*., 2015; Itam *et al*., 2015; Yang *et al*., 2016 and Fatima *et al*., 2016). However, a highly positive and significant relationship between the variable of practicing according to extension recommendations and TE at .001 level of significance (β= .086***, P-value < .001) providing a strong clue to justify the negative impact of farming experience and education. Specifically, this strong positive and significant relation implies that the farm households largely give priority to extension information over their own experience and knowledge and do practices according to extension recommendations. They prefer extension advice to their own experience and knowledge, because, in the face of continuously changing environment, the production technology also changes rapidly every year. Therefore, the extension provides most accurate and updated information related to the necessary amendments required in the production practices. Against the expectation, contact with extension agent has negative and significant (β= .051°, P-value (.076) >.05) influence on the efficiency of the farms that is surprising. This negative relationship can be justified by assuming that the farmers might not have contact with extension agent for all the crops. For example, the farmers that have contacted extension agent in the case of wheat crop might not have contact for cotton, maize and sugarcane crops. Hence, the aggregation of data for all four crops tends to produce negative impact of extension contact. It can be concluded that the more efforts are required to ensure the availability of extension services for all the crops that are grown in mixed farming system. The unexpected negative sign against FYM (β= -.013) might be due to high reliance on synthetic fertilizers, as also evidently shown in slack based analysis. This implies that despite giving promising results, the use of FYM in combination with high dose of synthetic fertilizers produce negative effect on crop production. In order to utilize the potential of FYM, it is required by the farmers to use less quantity of fertilizer that would also help them in saving unnecessary cost. The positive of sign against tractor ownership, household size, soil and water quality, tubewell ownership and credit is in line with the expectation. Similar to the studies of Tsimpo (2010), Gul *et al* (2009), Okon *et al* (2010) Sarker and Alam (2016); Kitila & Alemu (2014) and Hameed *et al* (2014), the inverse relationship between farm size and efficiency is also sustained from the findings of this study. This implies that the small farmers with greater farm area has little ability to manage the larger farm area that might be due to limited resources specially farm machinery.

7.5: OVERALL SUMMARY

At aggregate level, the properties of the distribution of all the composite indicators would describe how farms are performing as a whole and results could be helpful for developing and evaluating different policies and programs to improve farm sustainability. The second part of the first objective was to measure the efficiency of mixed farming system as a whole and then to find the determinants of TE at aggregated level by employing suitable method. The second part of first objective is covered in this chapter. To evaluate the performance of the mixed farming system as whole, DEA input and bootstrap models were employed by doing aggregation of inputs and outputs. It was evaluated from the overall measure TE that the performance of the mixed farming system at aggregated level is not surprising. A substantial input saving of 29% is possible in mixed farming system and a higher scale efficiency value suggested that the scale of operation has little impact in determining the TE and proper management of inputs is required. The bias corrected TE was found lower than the original TE similar to crop wise analysis, ignoring of noise in the DEA model could produce misleading and biased results. The results pertaining to AE and CE also revealed misallocation of resources and cost wastage and the farms could reduce the production cost by properly allocating the resource and choosing the right input mix. Based on the results of slacks, the current level of all inputs specially N and P fertilizers should be reduced in order to reduce the cost inefficiency. The variable of tenancy, tractor ownership, extension contact, training, soil quality and with the dummy variable of practicing the extension recommendations were found significant determinant of TE at farm level.

CHAPTER 8

EFFICIENCY IMPROVEMENT TROUGH EXTENSION SERVICES

Agricultural information is indispensable for profitable and technical efficient farming (Karimov *et al*., 2014; Illiyaso and Zainal, 2015; Gebrehiwot, 2017). The knowledge of best practice regarding crop production provides a base to the farmers for sound decision making, which ultimately helps farmers to decide what and how to produce, when and in what quantities in order to maximize profit. Agricultural extension acknowledged as an institutional input concerned with communicating and transferring agricultural knowledge originated in research to farmers and this knowledge on conversion translate into productive efficiency (Ofuoku *et al*., 2008).

Efficiency is highly dependent upon efficient and proper management of resources. The exposure of farmers to agricultural knowledge, participation in training and meetings presumably enhance knowledge and decision-making power, allowing farmers to take better decisions that lead to greater productivity and efficiency (Lukuyu *et al*., 2012; Benjamin, 2013 and Baloch & Thapa, 2017). The review of literature evidently elucidates the positive and significant influence of extension services on the performance of decision making units (Chirwa 2007; Croppenstedt 2005; Nyagaka *et al* 2010; Byma and Tauer 2010; Asogwa *et al*., 2012; Naqvi and Ashfaq 2013 and Yang *et al*., 2016). Because access to reliable and effective extension information enhances managerial capability, allowing farmers to clarify their goals and help in the proper allocation of inputs which leads to input minimization and profit maximization (Al-Rimawi *et al* 2004). The poor performance of extension services might be the cause of low efficiency in Pakistan. Therefore, this chapter is designed to explore the possibilities for extension services in the study area for efficiency enhancement.

8.1: CONTACT WITH EXTENSION SERVICES IN THE STUDY AREA

Agricultural extension is an important social innovation and a vital force in agricultural change, which has been created, adapted, and developed over the centuries (Shinn *et al*., 2009). Today, the organizations and staff involved in agricultural extension encompass a wide variety of socially authorized and legitimate activities, which enhance the abilities of farmers to adopt more suitable and often new technologies to adjust to the continuously changing environment (Rasheed, 2012). According to FAO (1990), the farmers who receive non-formal education through extension programs generally increases their productivity and efficiency. Rivera, (1995) stated that the extension services are available to only 1 out of every 5 farmers in the developing regions of the world.

The extension is supposed to have a direct influence on the adoption behavior of farmers (Ahmad *et al*., 2007; Shinn *et al*., 2009; Mahmood *et al*., 2013; Illiyaso and Zainal, 2015; Emmanuel *et al*., 2016 and Wossen *et al*., 2017). The greater is the possibilities of farmers being influenced to adopt agricultural innovations if they contact extension agents (shinn *et al*., 2009 and Adzawla *et al* 2013). The village level worker is one of the most important sources of information on agricultural innovations to farmers (Afzal *et al*., 2016), especially those who are earlier adopters. However, late adopters tend to rely more on relatives, friends, and neighbors for information who have already tried out the innovation and adopted. Therefore, this study assessed the proportion of wheat, cotton, maize, and sugarcane farmers that were received the extension advice from extension agents during production season of 2012/13. The results relating to farmer's contact with the extension services are depicted below in Table 8.1

Table 8.1: Distribution of Respondents based upon their contact with extension Agent

Crops	Contact with Extension Agent				Frequency of Contact		
	YES	%	NO	%	Once	Twice	More than 2
Wheat	112	44.8	138	55.2	56	34	22
Cotton	76	35.18	140	64.82	28	23	25
Maize	90	45.91	106	54.09	47	34	9
Sugarcane	57	25.09	163	74.91	48	7	2

The survey finding depicted in Table 8.1 indicates that the contact with extension agents is more common on wheat and maize farms and 44.80 % and 45.91 % had been receiving whereas 55.2% and 54.09% had never received any advisory services from extension agent during the survey period, respectively. In the case of cotton and sugarcane, only 35.18% and 25.09% of the respondents had contact with the extension agent during this period, indicating that the existing linkage between extension agents and farmers is still very weak in mixed farming system. A similar set of other studies also found that the extension to farmer linkage is not very impressive and most of the farmers remain outside the ambit of extension activities. Hussain *et al* (2012) expressed a weak agricultural extension system in irrigated areas of Punjab as only 22.4% of the wheat farmers have contact with the extension agents. Battese *et al* (2014) found 14% of the sample wheat farmers that had contact with extension services in the irrigated areas of Punjab. The study of Sharazar *et al* (2012) found 53% farmers that were getting extension services in mixed farming system. Abedullah *et al* (2006) mentioned that only 12.5 % of small cotton farmers have contact with extension agents.

It is evident from the study of Ahmad *et al* (2007) that majority (85%) of the farmers did not even know about the extension worker while only 15% had knowledge about the extension worker. In other developing countries, Thabethe *et al*., 2014 claim that majority 64 % of the sugarcane farmers have no access to extension services. The limited extension to farmer's linkage is also reported by (Abedullah, 2007; Chirwa, 2007; Fritz, 2015 and Baloch & Thapa, 2017). However, some studies produced opposites results and found significant contact between extension and farmers (Mekonnen, 2013; Degefa, 2014 and Ndjodhi, 2016)

The frequency of contact refers to the number of contacts per year that the respondent made with extension agents and the results indicate that the 56, 28, 47, and 48 wheat, cotton, maize, and sugarcane farmers had contacted the extension for advice "once in a year" during the cropping year 2012-13. Out of the total, 34, 23, 34, and 7 of the wheat, cotton, maize, and sugarcane farmers expressed that they had contacted the extension agents "twice in a year" respectively. The remaining had "more than two contacts" with the advisory services. Adzawla *et al* (2013) reported higher efficiency level on farms with more frequent contact than those who have less frequent contact.

8.1.1: Difference in Efficiency Level among Contact and Non-Contact Farmers

The extension is a vital policy and institutional variable that has a positive impact on efficiency (Battese *et al*., 2014; Bakhsh *et al*., 2014; Usman *et al*., 2016 and Yang *et al*., 2016) because the improved crop technology is disseminated to the farmers through these services (Ahmad, *et al*., 2007). The availability of extension information about technical aspects of crop production plays a significant role in increasing farm-level efficiency (Abedullah, 2007) and the contact with extension worker and the usefulness of the extension messages (as perceived by the respondents) are major determinants of technical efficiency (Tchale, 2009). The previous studies in Pakistan have shown that contact with the advisory service and information-seeking activities significantly enhance the rate of technical change and efficiency (Hussain *et al*., 2012; Naqvi and Ashfaq 2013 and Usman *et al*., 2016). In this research, the contact between extension agent and farmers is hypothesized to be the leading force that promotes effective dissemination of adequate agricultural information to the farmers, thereby enhancing farmers' efficiency. The performance of the farms that have contact with the advisory service is compared with farms that have no contact and the results are displayed in Table 8.1.1.

Table 8.1.1: Efficiency level of the contact and non-Contact Farmers

CROPS	Technical Efficiency		Allocative Efficiency		Economic efficiency	
	Contact	No contact	Contact	No contact	Contact	No contact
Wheat	0.783	0.652	0.873	0.812	0.632	0.542
Cotton	0.771	0.695	0.942	0.819	0.699	0.585
Maize	0.908	0.799	0.898	0.781	0.754	0.643
Sugarcane	0.6863	0.543	0.914	0.831	0.599	0.472

The estimated results show that the technical, allocative and cost efficiency of the sampled wheat, cotton, maize, and sugarcane farmers who have contact with extension agent is greater than that of non-contact farmers, implying that the mean TE, CE and AE declines from extension to non-extension farmers. The mean TE of the sampled wheat, cotton, maize, and sugarcane farmers who have taken an advice from the extension agent is .78, .77, .90, and 0.65 as compared to the non-contact farmers who have achieved .65, .69, .79, and .54, respectively. The results also reveal that the sampled wheat, cotton, maize, and sugarcane farmers, who have approached the extension agent for an advice are 6.1 %, 13 %, 11 %, and 8 % more efficient in the allocation of their resources as compared non-contact farmers. When the cost efficiency is compared between contact and non-contact farmers, a clear difference can be seen. The average cost efficiency of the sampled wheat, cotton, maize, and sugarcane farmers with regular contact with advisory services is .63, .69, .75, and .59 as compared to non-contact farmers .54, .58, .64 and .47, respectively.

The findings are consistent with Usman *et al* (2016) that farmers having frequent contact with extension agent were less inefficient technically than their counterparts who have less or no contact. Most of the studies conducted in Pakistan also found higher efficiency on farms involved in getting advisory services from extension agent (Hussain *et al*., 2012; Naqvi and Ashfaq 2013; Khan and Farman., 2013; Bakhsh *et al*., 2014 and Battese *et al*., 2014;). Owens *et al* (2001) explored 15% increase in crop production due to impact of agricultural extension. Similar findings were also shown in different studies that extension contact tend to decrease technical inefficiency (Rahman, 2003; Bogale *et al*., 2005; Croppenstedt, 2005; Chirwa 2007; Solıs *et al*., 2009; Byma and Tauer 2010; Asogwa *et al*., 2012; Karimov *et al*., 2014; Chiona *et al*., 2014; Kitila & Alemu 2014; Jirgi *et al*., 2015; Yang *et al*., 2016; Sami, 2016 and Gebrehiwot, 2017).

However, the results are inconsistent with Oladeebo *et al*. (2007), Kiani (2008), Jema (2008), Mekonnen, (2013) and Saddozai *et al* (2013) who found that extension contact decrease technical efficiency. Various authors attributed this negative relationship to low and poor quality information on crop production from extension agents (Abedullah, 2007 and Van & Nguyen, 2014). Mekonnen,

(2013) negatively related extension contact with TE due to involvement of extension agent in non-extension activities like inputs supply, credit disbursement etc. Brodrick & Sanzidur (2014) found that extension contact reduces technical and cost efficiency but significantly improves allocative efficiency. The implication is that farmers who have extension advice are using the inputs in correct combination (i.e., improving allocative efficiency) but perhaps using too much of them and not achieving the expected yield (hence technical efficiency is lower).

The reason of this relationship may be that the farmers having more contacts with extension agents are able to get information about approved agricultural technology and its implementation on farms lead to greater efficiency. Karimov *et al* (2014), Chiona *et al* (2014), Jirgi *et al* (2015) and Sami (2016) also explained the same reason for greater TE in their research. The farmers who have no contact with extension agents mainly rely on other information sources for the solution of their field problems and majority of these information sources are not reliable and can provide wrong information, resulting in low efficiency level. A third issue is that despite focusing on farm production information, the extension agent concentrate more on other tasks, like providing assistance on environmental management or claiming government supports.

8.1.2: Putting Into Practice the Extension Advice

The process by which a new idea spreads among people in an area or famers replace the traditional technology with new is known as diffusion (Rogers, 2003; Hall, 2009 and Simin and Dejan, 2014). The problem of diffusion and implementation of innovations in agriculture should not be considered simplistic and not all farmers will accept a new idea at the same time (Simin and Dejan, 2014). In any rural community, the readiness to accept new ideas and put them into practice varies from farmer to farmer depending on each farmer's previous experience with new ideas, characteristics of adopter and sufficient financial resources available (Simin and Dejan, 2014). The distribution of respondents based on putting into recommendations the extension advice is presented below in Table 8.1.2.

8.1.2: Distribution of Respondents based upon putting into Practice the extension Advice

Crops	Observations	Response		Response	
		YES	%	NO	%
Wheat	112	87	77.68	25	22.32
Cotton	76	62	81.57	14	18.43
Maize	90	82	91.11	8	8.82
Sugarcane	57	42	73.68	15	26.32

The data shown in Table 8.1.2 highlight that out of 112, 76, 90, and 57 farmers that have contact with the extension agent, 87, 62, 82, and 42 of the wheat, cotton, maize, and sugarcane farmers were practicing the extension recommendations, respectively. Whereas, the remaining 25, 14, 8 and 15 wheat, cotton, maize, and sugarcane farmers did not put into practice what they learned from the extension agent, respectively. These respondents were asked to provide reasons for not putting into practice the advice recommended by the extension agent. The major reasons were:

Box 1: Reasons for not putting into practice the extension advice

1. The technical information provided by the extension agent was very complex and they did not clearly understand the provided information.

2. Various inputs that were recommended by the extension agent are not easily accessible from the market.

3. The extension agent recommended various farm operations to carry out at different stages of crop production but they do not have the required tools to perform these operations

4. Some inputs are not cost effective and they are unable to use the dose recommended by the extension agent. Baloch and Thapa (2017) also mentioned that preparing land following extension officials' recommendations required a lot of labor, which was beyond the affordability of farmers

The family farms apply the technical advice more directly to the production activities and try to improve or sustain this production and this technical advice based on agricultural research findings (Taraka *et al*., 2011; Khan & Muhammad, 2012 and Baloch & Thapa, 2017). A new farm practice or crop variety might perform well on a research station, but not do so well in a farmer's field. Trials on farmers' fields are an opportunity to test research recommendations and provide feedback for research staff.

Sometimes farmers discover problems with a recommendation and do not put them into practice and the disseminated knowledge is only converted into higher technical efficiency when farmers actually put recommendations into practice. The efficiency is compared across the farmers who were applying the extension recommendations on their farms and those who were not putting into practice the extension advice. The results are presented in Table 8.1.3.

Table 8.1.3: Efficiency Level of the Respondents Based Upon Putting Into Practice the Advice

Crops	Technical Efficiency		Allocative Efficiency		Economic efficiency	
	Applying	**Not Applying**	**Applying**	**Not Applying**	**Applying**	**Not Applying**
Wheat	0.772	.644	0.942	0.782	0.622	0.524
Cotton	0.813	0.701	0.925	0.842	0.678	0.516
Maize	0.893	0.821	0.864	0.783	0.824	0.674
Sugarcane	0.785	0.578	0.959	0.833	0.667	0.469

It is evident from the data that the farmers who were using the farm practices, according to the recommendations of the extension agent have higher technical, allocative, and cost efficiency. The average TE of the wheat, cotton, maize, and sugarcane farmers who had applied the extension recommendations on their farm is 12.8, 10.9, 7.2 and 20.6 percent greater than those who did not put into practice the extension recommendations.

Similarly, a higher allocative and cost efficiency is observed on the farms practicing extension advice as compared to those who were not using the recommended practices. The wheat, cotton, maize, and sugarcane farmers with recommended agricultural practice are 16, 7.8, 8.1, and 12.6 % more efficient in the allocation of their resources as compared to non-practicing farmers. The results also reveal that the more cost reduction is possible on farms that do not put into practices the extension recommendations. The high level of efficiency appeared on farms that practiced recommendations because extension advice helps farmers to adjust the quantities of inputs more efficiently. Similarly, Otieno *et al* (2014) also expressed that weak extension to farmers' interaction lead to inappropriate input usage that contributes towards low productivity and efficiency.

8.2: LEVEL OF SATISFACTION FROM EXTENSION ADVICE

It is the responsibility of the extension service providers to ensure farmer's satisfaction with the services being delivered (Azikiwe *et al.*, 2013). In enhancing farmers' loyalty and confidence, extension feedback is becoming more and more important (Azikiwe *et al.*, 2013). Farmers' satisfaction, remains is a vital area that must need proper attention and action. Based on the number of farmer satisfaction surveys that have been conducted across the globe, it is evident extension service providers have seen this as an important topic that needs attention (Birner *et al.*, 2009). Farmer satisfaction is the most significant factor in developing and sustaining organizational priorities and practices (Elias, et al., 2016). Thus, farmers' overall satisfaction with agricultural extension services is addressed in this study and the results are presented in Table 8.2.

8.2: Level of Satisfaction from Extension Agent

Crops	Extent of satisfaction		
	Highly satisfied	Moderately satisfied	Not satisfied
Wheat	76	28	8
Cotton	67	6	3
Maize	58	19	13
Sugarcane	36	21	00

The results reported in Table 8.2 display that, 76, 67, 58 and 36 farmers were fully satisfied with the advice given by the extension agent, out of the total 112, 76, 90, and 57 wheat, cotton, maize, and sugarcane farmers that had contact with the extension services. However, 28, 6, 19, and 21 wheat, cotton, maize, and sugarcane farmers were partially satisfied, while 8, 3, and 13 and 0 were dissatisfied from the information given by the extension agents, respectively. The respondents were asked to provide reasons for their dissatisfaction from the extension services and the reasons are mentioned below:

Box 2: Reasons for Dissatisfaction

They are dissatisfied because Agriculture officers are not easily available in their office and much of the time is wasted in searching the extension agent. Most of the time, agriculture officers were busy in their office work and don not pay much attention to the visitors.

Agriculture officers never tried to visit their field, although they promised that they would come to see the current situation of the crops, to suggest some recommendations.

The recommended crop production practices suggested by the agriculture officer are beyond their reach and their resources do not allow them to apply these recommendations on their farms.

8.3: PARTICIPATION IN EXTENSION ACTIVITIES

Participation in extension activities is the other means through which farmers get information about improved farm practices (Illiyaso and Zainal, 2015). Participation in extension programmes enables farmers to identify their farm problems and to set sound solutions for the further measure (Hassan and Ahmad 2001 and Galanopoulos *et al*., 2006). These extension events include arrangements, such as training, demonstration, technical assistance programme, campaign and field visits. Tesso *et al* (2015) and Thabethe *et al* (2014) argued that the resource use inefficiency could be reduced by conducting trainings and informing farmers about the recommended agronomic practices.

According to the survey results, more than 70% of the wheat, cotton, and sugarcane farmers were not aware, but a greater percentage of maize farmers (55.2%) were aware of the training programme conducted in the study area. Only, a small percentage of wheat (24.4), cotton (15.7) and sugarcane (25.4%) farmers indicated that the training was conducted in their area. Concerning farmers' participation in training programs, out of total 61 (wheat), 34 (cotton), 108 (maize), and 56 (sugarcane) farmers that were aware of the training programme, only 55.7 %, 61.7 %, 80.6 % and 28.6 % attended the program. In their study, Brodrick & Sanzidur (2014) found only 10% of the farmers that received any type of training.

Method demonstration is a very vital activity because it practically enables the growers to observe the difference in old and new practice that facilitate the adoption process (Tesfaye *et al*., 2001). In other words, attending demonstration is an important means, which produce solid awareness among the target group on the practice and initiates farmers to try and then adopt best practice on their farm. The results revealed that less than 10 percent of the respondents in the case of all crops were aware of the demonstration conducted in the study area. Among these farmers, 24%, 66.7%, 22.4% and 37.5% of the wheat, cotton, maize, and sugarcane farmers were found attending the demonstration, respectively.

The study revealed that no farmer was found who attended field day and technical assistance programme because no such programs were conducted that indicate weakness of extension services, in the study area. However, Out of 23, 7, 17 and 6 the wheat, cotton, maize, and sugarcane farmers, only 7, 2, 8, and 0 have attended the exhibition, respectively. These results show that the farmer's participation in these extension events is very low that might be due to the reliance on other information sources through which farmers try to get information about improved technologies. The farmers were asked about the reasons for not participating in these extension events and the major reasons are mentioned in Box 3.

8.3: Distribution of Respondents Regarding Awareness about the extension events conducted in the Study Area

Programme	Wheat				Cotton				Maize				Sugarcane			
	Yes	%	No	%	Yes	%	No	%	Yes	%	No	%	Yes	%	No	%
Training	61	24.4	189	75.6	34	15.7	182	84.3	108	55.2	88	44.8	56	25.4	164	74.6
Demonstration	25	10.0	225	90.0	12	5.6	204	94.4	18	9.2	178	90.8	8	3.6	212	96.4
Technical Progremme	00	00	250	100	00	00	216	100	00	00	196	100	00	00	220	100
Field Day	00	00	250	100	00	00	216	100	00	00	196	100	00	00	220	100
Exhibitions	23	9.2	227	90.8	7	3.24	209	96.76	17	8.7	179	91.3	6	2.8	214	97.2

8.3.1: Distribution of Respondents based on Participation in the Extension Events

Programme	Wheat				Cotton				Maize				Sugarcane			
	Yes	%	No	%	Yes	%	No	%	Yes	%	No	%	Yes	%	No	%
Training	34	55.7	27	44.3	21	61.7	13	38.3	87	80.6	21	19.4	16	28.6	40	71.4
Demonstration	6	24	19	76	8	66.7	4	33.3	4	22.2	14	77.8	3	37.5	5	62.5
Technical Progremme																
Field Day																
Exhibitions	7	30.4	16	69.6	2	28.5	5	71.5	8	47.1	9	52.9				

Box 3: *Reasons for non-Participation in Extension Events*

Non-Participation in Training

The topics, mostly discussed in the training are not related to our problems and extension agent only disseminates information that was in his schedule tasks. No attention is given to our information needs.

The information related to farm production as delivered in training is only applicable on rich farms and they are unable to put into practice the recommendations because they are not cost effective.

The Extension agent uses technical language that is not understood by us. Secondly, the timing of the training does not suit us. Tesso *et al* (2015) also mentioned that the extension agent should reconsider the timing.

Non-Participation in Demonstrations

They were not invited by the extension agent to participate in the demonstrations.

They were busy on their farms and were not able to attend the demonstrations.

Non-Participation in Exhibitions

The agriculture exhibitions were conducted far away from the village and the contents of the exhibitions were not of their interest.

8.3.1: Participation in Extension Events and Level Of Efficiency

It is assumed in this research that participation in extension events tends to improve farmers' performance and efficiency because it enhances farmer's knowledge and skill, which help them to allocate their resources properly. If a farmer has no skill and know-how about farm production, he may not be able, to fully convert his inputs into outputs. The skill acquired through training helps to use new technology effectively and efficiently. Hence, the efficiency level is compared across farmers who have participated in these events and those who have not participated. The results pertaining to this analysis are presented in Table 8.1.3:

Table 8.3.1: Efficiency Level of the Respondents Based Upon participation in Training

CROPS	Technical Efficiency		Allocative Efficiency		Economic efficiency	
	Participated	Not Participated	Participated	Not Participated	Participated	Not Participated
Wheat	0.717	0.621	0.891	0.786	0.591	0.512
Cotton	0.784	0.676	0.911	0.849	0.674	0.587
Maize	0.904	0.819	0.876	0.796	0.742	0.654
Sugarcane	0.652	0.569	0.934	0.875	0.567	0.489

The results reveal that the participation in training has improved the efficiency of the wheat, cotton, maize, and sugarcane farmers up to 9.6 %, 10.8 %, 8.5 %, and 8.3 %, compared to non-participants, respectively. The results also indicate the allocative efficiency of the wheat, cotton, maize, and sugarcane participants is .89, .91, .87 and .93, compared to non-participants who have achieved an efficiency score of .78, .84, .79, and .87, respectively.

Similarly, the wheat, cotton, maize, and sugarcane farmers with participation in training are 7.9, 8.7, 8.8, and 7.8 percent more cost efficient as compared to the non-participants, respectively. These results suggest a positive impact of training on technical, allocative, and cost efficiency because it enhance the managerial ability of the farmers regarding the farm decisions that ultimately turned into a high level of efficiency (Daniel, 2010 and Otieno *et al*., 2014). It can also be observed that the difference between participants and non-participants is narrow as compared to the difference in efficiency present between contact and non-contact farmers (see Table 8.1.1). This is because direct contact provides an opportunity to get information of their own choice while in training farmers can get only specific information. In direct contact, the farmer can get information at different stages of crop production, which helps them to correct their farm decisions during the crop production period. While in training, the information is usually delivered once or twice in a year during some specific period. Therefore, the efficiency of the farmers who have direct contact with extension agent is higher as compared to the farmers participating in training. Otieno *et al* (2014) highlighted that the training contents not aligned with farmers' information need often result in inappropriate input usage (low or high). Illiyaso and Zainal (2015) found positive and statistically significant impact on training on technical efficiency. Sami (2016) also stressed that quality training is critical determinant of productivity. Daniel (2010) found training as managerial capacity enhancing input. The results are inconsistent with Tesso *et al* (2015) who found inverse relationship between trainings and TE, because intensive training sessions hinder farmers to give proper time to their routine agricultural practices. Brodrick & Sanzidur (2014) found training negatively and significantly associated with technical and cost efficiency because of irrelevant contents.

8.4: INPUTS AND CREDIT SUPPLY FROM EXTENSION DEPARTMENT

The quality of input delivered by an institution has its own impact on the adoption of agricultural technologies, production and productivity of crops. The formal sources of production inputs and credit in some other countries are the office of agriculture, Service Cooperatives, and Bank. In Ethopia, Abate *et al* (2013) found agriculture Cooperatives as a source of inputs and embedded support services such as training, information, and extension on input application. However, the role of public extension in the provision of inputs and credit in Pakistan is always questioned. With this understanding, data on inputs and credit received from the office of agriculture were collected and summarized as follows.

8.4: Distribution of Farmers based on the supply of Inputs from Extension Agent

Crops	Production inputs				Agriculture credit			
	YES	**%**	**NO**	**%**	**Yes**	**%**	**N0**	**%**
Wheat	24	9.6	226	90.4	--*	--	250	100
Cotton	5	2.31	211	97.7	--	--	216	100
Maize	8	4.0	188	96.0	--	--	196	100
Sugarcane	3	1.40	217	98.7	--	--	220	100

(* the column contains no values because Extension Department is not involved in providing credit)

The results reported in Table 8.4 depicts that only 9.6, 2.31, 4, and 1.40 percent of the wheat, cotton, maize, and sugarcane farmers have been provided with production inputs from the extension department, respectively. More surprisingly, none of the wheat, cotton, maize, and sugarcane farmers has received agricultural credit from the extension department, respectively. The respondents were asked to provide information about the type of inputs received and on what conditions. The farmers replied that the inputs are not provided on regular basis and they only receive production inputs (seed, fertilizers, herbicides, and pesticides), when extension department requires a piece of land to grow some demonstration plots. However, the wheat farmers replied that they had received the seed of new variety from the extension department without any condition. The similar findings were reported by Ahmad, *et al* (2007) that majority of the farmers did not get any benefit from the extension department and only a small number of farmers get some benefits in the form of technical advice and equipments. The farmers also mentioned that the extension department also provides tractor services, but it is very much tedious to avail because the extension department prefers to provide this service to influential farmers. Riaz (2010) and Baloch & Thapa (2017) also reported that small farmers seemed to be the most vulnerable and large farmers have been seen directly benefiting from the extension.

The agriculture officers were also interviewed to get some information about the limited or no supply of production inputs and credit from extension department. When the agriculture officers were asked questions about the provision of inputs and credit to the farmers, they commented that:

Box 4: *Comments of Agriculture officers about Credit and Inputs Supply*

The working of the department revolves round the Government plans and policies. The government usually distributes credit through banks and micro finance institutes.

The effective distribution of inputs depends on the availability of funds. Under current funds availability they are only able to provide inputs to limited number of farmers. Therefore, we distributed these inputs to the farmers that offer their land for demonstration plots.

8.5: OTHER INFORMATION SOURCES

Apart from extension officers, farmers can rely on various other alternative sources of acquiring agricultural knowledge such as input dealers, T.V, radio, extension publications, books and magazines, farmers' associations, friends/neighbors and companies that have direct impact on enhancing knowledge and skills (Ofuoku, 2012, Arshad *et al*., 2012 and Msoffe & Patrick, 2016). The farmers were also questioned about the other information sources they use to get informed in addition to extension agent. These sources were ranked based upon their relative score and data regarding this are presented in Table 8.5.

8.5: Ranking of Information Sources

Sources	Wheat		Cotton		Maize		Sugarcane	
	No	Rank	No	Rank	No	Rank	No	Rank
Farmers, Friend	219	1	189	2	85	3	203	1
Pesticide comp.	178	2	205	1	156	2	114	4
Local Traders	167	3	156	3	189	1	147	2
TV	145	4	118	5	83	4	167	3
Others Sources	118	5	123	4	76	5	84	5
Mobile phone	67	6	34	6	45	6	57	6
Radio	55	7	21	7	18	7	34	7
NGO	21	8	00	8	00	8	00	8

The survey result shows that friends and fellow farmers were the most frequently used sources of information for the wheat and sugarcane farmers; however, this source is ranked 2nd and 3rd by the cotton and maize farmers, respectively. Based upon their relative score, pesticide companies and local traders were ranked 1st by the cotton and maize farmers, respectively. The wheat, cotton, maize, and sugarcane farmers marked NGOs, research stations & radio as the least important sources of information. The fellow farmers, pesticide companies, local trade and TV were the 1st to 4th most valuable sources of information for the wheat, cotton, maize, and sugarcane farmers. In the study area, farmers also rely on some other sources of information and these sources were the newspaper, pamphlets, internet, and agriculture brochures.

The sources of information preferred by farmers in different farming systems are also enlisted in various other studies. Mahmood *et al* (2013) also found that wheat farmers generally get information from fellow farmers. Mahmood *et al* (2006) found that 70 percent of farmers getting information from fellow farmers, followed by extension/ research system (62%) and mass media (about 47 per cent). Kaseem (2014) found farmers associations and neighbors/friends as the main sources of information. Shavgulidze *et al* (2017) reported that the farmers mainly get advice from relatives and fellow farmers and only few prefer local extension service and input supply shops.

8.5.1: RANKING OF INFORMATION SOURCES BASED ON ACCESSIBILITY, TIMELINESS, RELIABILITY AND EFFECTIVENESS

The respondents were asked to rank the information sources in terms of accessibility, timeliness, reliability and effectiveness and the results pertaining to this are presented in Table 8.5.1. The findings show that the fellow farmers, pesticides companies, local traders, extension agent and TV were the leading sources of information in terms of accessibility for all the four crops. The research stations and NGOs were ranked as the least accessible sources. The results further show that in terms of timeliness, reliability, and effectiveness, pesticides companies, local traders, friends, extension agents, TV and mobile phones were the leading sources. Again, the NGOs, research station, and radio were the least important sources in terms of timeliness, reliability, and effectiveness. This may be due to the fact that the farmers in the study area have limited or no contact with these sources.

Table 8.5.1: Ranking Of Information Sources Based On Accessibility, Timeliness, Reliability, and Effectiveness

Source	Wheat				Cotton				Maize				Sugarcane			
	1* Rank	2* Rank	3* Rank	4* Rank	1* Rank	2* Rank	3* Rank	4* Rank	1* Rank	2* Rank	3* Rank	4* Rank	1* Rank	2* Rank	3* Rank	4* Rank
Farmers, Friend	1	1	5	4	4	2	4	3	1	1	5	4	1	1	2	2
Local Trader	2	3	2	2	2	3	1	2	2	3	3	1	3	3	4	4
Pesticide companies	3	2	1	1	1	1	2	1	3	2	1	2	2	2	1	1
Extension Agent	4	5	4	5	3	4	3	4	4	5	4	3	4	5	3	3
TV	5	6	3	3	5	6	5	5	2	6	2	5	5	6	5	5
Radio	6	7	6	6	6	7	6	6	6	7	6	6	6	7	6	8
Mobile phone	7	4	8	7	7	5	7	7	5	4	7	7	7	4	8	7
NGO	8	8	7	9	8	8	8	9	9	9	9	9	8	8	9	9
Research centre	9	9	9	8	9	9	9	8	8	8	8	8	9	9	7	6

1= Accessibility, 2*=Timeliness, 3*=Reliability and 4*=Effectiveness

8.5.2: Preferred information delivery method

Extension methods are procedures implemented to set up situations in which new information and knowledge can move freely between extension workers and their intended audiences (Kassem, 2014 and Afzal *et al*., 2016). For effective dissemination of agricultural technology, extension agent uses a wide variety of activities and methods (Khan and Muhammad, 2012). The choice of improved and innovative extension communication methods used by an extension agent may have serious consequences for program effectiveness. Some fear that using one information delivery method may alienate those who prefer another. Therefore, this research evaluated different extension methods like farm visit, training, field days, demonstration) preferred by the farmers for delivery of information. All the respondents were asked to provide information about the methods that can used by extension agent in future in order to disseminate information suited to local conditions. The results are summarized in Table 8.5.2.

8.5.2: Ranking of Preferred information delivery method

Operation	Wheat		Cotton		Maize		Sugarcane	
	NO	Rank	NO	Rank	No	Rank	No	Rank
Farm visit	223	1	197	1	145	3	176	2
Demonstrations	209	2	151	3	176	1	208	1
Sign boards	182	3	117	5	79	6	118	5
Trainings	179	4	158	2	161	2	154	3
Exhibitions	89	5	24	8	88	4	56	7
campaigns	27	6	33	7	34	8	19	8
Lecture Meetings	18	7	121	4	82	5	134	4
Audio visual Aid	12	8	8	9	17	9	18	9
Others	5	9	97	6	63	7	103	6

Based upon the findings depicted in Table 8.5.2, farm and home visits, training, demonstrations, lecture meetings were the most important information delivery method preferred by the farmers. Exhibitions, campaigns, audio visual aid were the least preferred methods as identified by the farmers. From the results, it can be concluded that the extension agent must try to focus on the information delivery methods as preferred by the farmers. At least one training session and demonstration plot must need to be established every year in order to teach farmers regarding the production technology of these crops.

In order of preference, Khan & Muhammad (2012) found farm/home visit was the leading extension method preferred by the farmers followed by group discussion, demonstration plots, office calls, Workshop/discussion, Farmers’ trainings and by local agriculture fair and exhibitions. Kassem (2014) ranked mixed extension method on 1st position followed by demonstration meeting and finally the Pamphlet.

8.6: EXPRESSED NEED AREAS OF FARMERS FOR AGRICULTURAL ADVICE

Table 8.6 shows the ranking of the area on which information is required by the farmers in the mixed farming system of Punjab, Pakistan. The subject of the extension program is the most important factors influencing farmer's participation. Hence, respondents were asked to identify the interested topics of the extension program activities and results are in Table 8.6.

Table 8.6: Ranking of agricultural extension topics preferred by farmers

Topics	Wheat		Cotton		Maize		Sugarcane	
	N0	Rank	N0	Rank	N0	Rank	N0	Rank
Selection and fertilizers use	235	1	175	4	191	1	176	6
Seed variety	233	2	178	3	154	2	201	1
Soil fertility	228	3	167	5	152	3	142	7
Weed control	196	4	203	2	145	4	192	3
Cultivation techniques	165	5	135	7	67	9	89	8
Irrigation	114	6	98	8	87	8	197	2
Harvesting techniques	98	7	23	9	129	6	32	9
Marketing	67	8	138	6	123	7	174	5
Crop storage	38	9	8	10	52	10	6	10
Pest control	12	10	208	1	134	5	178	4

According to the findings, fertilizer use, seed variety, soil fertility, weed control, and land preparation techniques were ranked as first five most important extension areas on which the information is needed, while the topics like crop storage, marketing, and harvesting techniques were considered less important by the wheat farmers. The cotton crop is heavily attacked by the pests in Pakistan. Therefore, the first preferred area of information is pest control while weed control, soil fertility, and fertilizer use were ranked 2nd, 3rd and 4th by the cotton farmers, respectively. The cotton farmers marked crop storage, harvesting techniques, and irrigation as the least important areas of information. The selection and use of fertilizer, seed variety, and soil fertility were ranked 1st, 2nd and 3rd and furthermore, the subject of weed and pest control was given 4th and 5th preference by the maize farmers. The first three major areas on which the information is required by the sugarcane farmers were the seed variety, irrigation and weed control. The next preferred areas of information for the sugarcane farmers were pest control and marketing. These results imply that the respondents require diverse kind of information on various issues and requirement varies from crop to crop and situation.

8.7: PRACTICES USED BY EFFICIENT PEERS ------- BENCHMARKING FOR INEFFICIENT UNITS

Conceptually, the technical inefficiency in a farming system arises when some farmers unjustifiably use higher quantities of inputs as compared to fully efficient farmers (Rouse *et al*., 2007). The DEA approach has advantage over SFA based on the useful information it provides. The information generated from benchmarking analysis could be used in farm management to suggest some suitable measures for the inefficient farms of how much more productive they might be (Martic *et al*., 2009 and Villano, 2009). As mentioned in Chapter 3 that the DEA identifies set of efficient farms for every inefficient farm that have a similar production mix (Villano, 2009; Huguenin, 2012 and Osamwonyi & Kennedy, 2015) and direct comparison can be made between inefficient and their efficient peers to recognize the specific areas of input inefficiency. The information generated from this analysis would be very constructive, particularly for a extension worker, as it is relatively simple to identify the factors that are preventing inefficient farms from achieving full efficiency. For example, if the inappropriate use of technology is the cause of inefficiency then the extension worker can give technical advice to the farmer in question. If it is simply due to farmer inexperience, then information or training facilities can be provided. These inefficient farmers could improve their efficiency by using the input level as used by the efficient farmers. Keeping in mind the above, the best practice knowledge as practiced by the fully efficient farms is identified in this research. Agricultural extension officers should organize knowledge and experience exchange between successful farmers and other farmers, and can promote the use of production practices as mentioned in Table below in order to improve farm efficiency. The level of input use and production technology that is used by the first five most efficient peer farms for all crops (peers farm identified in Section 6.3 of Chapter 6) are identified and depicted in Table 8.7.

Table 8.7: Practices and level of inputs used by the Efficient Farmers

Operation	Wheat	Cotton	Maize	Sugarcane
Ploughings (no)	2.37	2.15	3.56	2.46
Plankings (no)	1.92	1.04	1.59	1.58
Rotavations (no)	1.09	1.23	2.39	1.84
Seed rate (Kg/acre)	50.43	6.87	10	11.23
P fertilizer (bags/acre)	1.89	1.42	1.81	1.23
N Fertilizer(bags/acre)	1.75	1.83	2.57	1.78
Irrigations (no)	5.14	8.84	13.08	15.69
Herbicides (no)	1.34	.64	1.21	1.28
Pesticides (no)	-----------	5.02	2.44	1.32

The average numbers of ploughing performed by the fully technically efficient wheat, cotton, maize and sugarcane farmers are 2.37, 2.15, 3.56, and 2.46, respectively. The average numbers of rotavation are 1.92, 1.04, 1.57, and 1.58 for wheat, cotton, maize, and sugarcane, respectively.

These results suggest that if the average wheat, cotton, maize, and sugarcane farmer has to achieve the efficiency level of fully efficient farmers then the ploughings and rotavations must be used at these rates. It is evident from the findings that efficient peers tend to use more rotavations in addition to ploughings that implies that more rotavations convert the soil into fine particles and hence promote better germination.

The results suggest that the inefficient wheat, cotton, maize, and sugarcane farmers can use 1.89, 1.42, 1.81, and 1.23 bags of phosphoric fertilizer and 75, 1.83, 2.58, and 1.78 bags of nitrogenous fertilizer to achieve the efficiency level of fully efficient farmers, respectively. These results imply that the inefficient farms should focus on reducing the level of both nitrogen and phosphorous fertilizers in order to attain the efficiency level of the peer farms. The analysis suggests 5.14, 8.84, 13.08 and 15.69 numbers of irrigation for the inefficient wheat, cotton, maize, and sugarcane farmers, respectively. The results show that the use of herbicides and pesticides on peer farms is relatively high as compared to the average farm, which implies that these farms highly focus on weed eradication and pests control at early stages of crop growth. This also implies that weed and pest infestation contributed more towards yield reduction on average farms than any other factor.

8.8: SUGGESTIONS FOR IMPROVING THE EXTENSION SERVICE

In a group discussion, farmers mentioned that the existing extension system could be improved by ensuring regular visits of extension agents to the fields. The information must be according to their current needs and training and demonstration relating to these crops should be conducted at regular intervals. The respondents stressed that the follow-on tours of extension agent must be ensured after the training and demonstrations sessions.

8.9: SUMMARY

In this chapter, the extension activities that were carried out in the mixed farming system were assessed and a weak extension to farmer linkage was observed, as majority of households have no exposure to extension services. One key implication of this study is that it was difficult for many farmers to get benefits from the extension services and consequently, there is a need for permanent and reliable extension services for small-scale wheat, cotton, maize, and sugarcane farmers. Moreover, the farmers' participation in the extension events was also negligible and the contents, timings and complex language were the possible barriers hindering farmers' participation in extension events. Regarding satisfaction from the extension advice, most of them believe that public sector extension is not meeting their needs. The farmers that had regular and strong interaction with the advisory services are more technical, cost and allocative efficient because close farmer to extension link leads to the balance use of inputs at a right time. The use of production practices according to the extension recommendations provides an opportunity to the farmers to achieve higher production. The higher production and balance input use as compared to the other farmers tend to increase the relative efficiency of the contact farmers. The major conclusion that can be drawn from this discussion is that a great opportunity is present for the extension services to improve the efficiency of the farmers by involving more and more farmers in the extension activities and improving contents according to farmers' needs.

In addition to the extension agent, the pesticides companies, local traders, friends, and TV were found most accessible, reliable and effective sources of information and soil fertility, use of fertilizers, seed varieties, insect pest control were the most preferred areas on which information is needed by the farmers. The extension services can improve efficiency in the mixed farming system by involving all the possible sources of information in the communication process and providing timely, reliable and accurate information that is aligned with farmers' needs. In the context of the rural innovation system, the information was collected regarding the input and credit supply from the extension department and other actors providing advisory services in the study area. From the findings, it was observed that the extension department does not provide credit as none of the respondents had received any kind of credit from extension department. The inputs were only received by those respondents who offer their piece of land to the extension department for the establishment of demonstration plots. The major conclusions come out from this finding is that the extension in Pakistan is still traditional, focusing largely on technology transfer rather than performing other diversifying tasks. At the end of this chapter, best practice knowledge that was used by the efficient farmers was identified with the aim to suggest best-input use level for the inefficient farmers. From overall finding, it can be concluded that the role of extension services needs to be defined again. There is a need to bring some revolutionary changing in the system of extension that would be able to perform diversifying tasks by integrating all the actors involved in the innovation process.

CHAPTER 9

SUMMARY, CONCLUSION AND RECOMMENDATIONS

This chapter is divided into three sections. The summary of the study has been presented in the first section. The second and third section elaborates the conclusions, recommendations and policy implications of the study.

9.1: OVERALL FINDINGS

The thesis deals with an important issue that is relevant to the economy of Pakistan and is largely an empirical investigation to measure the efficiency of small-scale farmers in the mixed farming systems of Pakistan's Punjab and to investigate the role of agricultural extension services in improving farmers' production performance. A sustainable growth in agriculture is desirable to guarantee food security in a condition where farmers have meager resources and insufficient support from the Government. It is evaluated from the literature that Pakistan has started facing the immense challenges of declining land and water resources and this condition will be severe in near future. Therefore, under these conditions efficiency measurement is imperative because this is a first step of a process that might lead to substantial savings under current technology. Therefore, the main assumption of this study is that improvement in technical efficiency is not only financially helpful to resource-constrained farmers but can also contribute to environmental sustainability. Therefore, the technical, allocative, scale, economic and biased corrected efficiency of 250 (wheat), 216 (cotton), 196 (maize), 220 (sugarcane) and the overall performance of the small farmers in mixed farming system were estimated. The DEA linear programming approach was applied as it provides an opportunity to recognize the adjustments that could be made in the use of inputs on inefficient farms by comparing them with their peer farms. Second, the factors that can be manipulated to minimize the excessive use of inputs and hence reduce the costs of production can be established. Nonetheless, the DEA has a definite advantage over the standard production function analysis for identifying the sources of inefficiencies on individual farms. The overall findings of this research are briefly summarized below.

The descriptive statistics of the socioeconomic characteristics of the farmers revealed that the mean age, farming experience and household size was 41.74, 24.44 and 8.14 respectively. The analysis of the farm specific characteristics reveled that the average size of the farm was 4.94 acres while an average rent of the land was PKR 28731 (US $ 330.24) per acre. The land fragmentation statistics revealed that the average numbers of parcels of land are 1.80 with mean distance of 3.75 km. The majority of the farms over 70 % were found owner of land and the results pertaining to farm mechanization revealed that a vast majority of the small farmers over 80% lack tractor and related equipments. The small farmers are famous for the use of family labour on their farm and at least one family member was found engaged in full time farming in addition to hired labour. The total available operational area for Rabi, Kharif and Perennial crops (2012-13) was 1283, 1188, 1099 and 1181 acres on wheat, cotton, maize and sugarcane farms, respectively. Out of this area, the wheat, cotton, maize, and sugarcane crops were grown on an area of 658, 360, 250.75, and 197 acres, respectively. The average size of the farm in the case of wheat, cotton, maize, and sugarcane crop was 6.14, 5.30, 5.40 and 4.94 acres, respectively.

This section briefly highlights the main findings related to production technology of the crops under study and the data highlighted that the average number of ploughings and rotavations performed by the wheat, cotton, maize, and sugarcane growers was 2.91, 3.08, 4.45 and 2.63 and .74, 1.14, 1.84, and 1.53, respectively. Only, a very small number of farmers (less than 30%) had done leveling before sowing of all crops. The wheat, cotton, and maize farmers have applied the seed at a rate of 53, 6.43, and 9.45 kg per acre, respectively. Sugarcane farmers have used a space of 11.8 Marlas of sugarcane crop to prepare a seed for growing one acre of sugarcane crop. The results pertaining to sowing of crops showed that 46 percent wheat farmers had sown their crop late and almost 50% of maize and sugarcane farmers preferred to sow their crops on early dates. About 78 percent of cotton farmers had mostly sown their crop in the month of May (mid sowing) and June (late sowing). The broadcast and drill method were most popular for wheat and cotton while ridge planting is most famous for maize and sugarcane crops. The following varieties were found most famous for wheat (Faisalabad 2008 (FSD2008), Lasani 2008, Bhakar 2002, Sehar 2006 and Punjab 11), cotton (BT 121, BT 142, BT703, IR 3701), sugarcane (HSF 240, CPF 237, CPF240, CP90) and maize (Poineer-30-Y- 87, DK-919, P-30R50, P-31R88, and P- 3025). The major sources of seed acquisition were local traders or input dealers for cotton and maize while majority of the wheat and sugarcane farmers used the self-produced seed, held for self-consumption. The phosphoric and nitrogenous fertilizers fertilizer were applied at the rate of 108 Kg, 101 kg, 124 kg, and 83 kg and 82, 97, 128 and 78 kg per acre for wheat, cotton, maize, and sugarcane, respectively. FYM was applied, on an average, at a rate of 2.9 trolleys /acre for wheat, 3.25 trolleys /acre for cotton, 3.54 trolleys /acre for maize and 1.86 trolleys /acre for sugarcane. An average number of 1 herbicide was applied for all crops while Pesticides were intensively used for the cotton crop (4.34 Times/acre). The treatment of seed with fungicide was most common on cotton and maize farms and Imidacalopride was the mostly commonly used fungicide. The average number of irrigations to wheat, cotton, maize, and sugarcane crops was 4.4, 9.65, 14.25, and 18.56, respectively. An average yield of 1381.44 Kg/acre (34.52 Munds), 1457.18 Kg/acre (36.42 Munds), 2920 Kg/acre (73 Munds) and 21840 Kg/ acre (546 Munds) was found on wheat, cotton, maize and sugarcane farms with a yield gap of 86% and 80.48 % was 68% and 56 %, respectively. A net profit of US$ 214.23, US$ 545.18, US$ 377.82, and US$ 596.13 was achieved by investing a cost of US$ 343.50, US$ 455.81, US$ 497.76, and US$ 370.88 on wheat, cotton, maize, and sugarcane crops, respectively. The most common places for the sale of produce were commission agents, fellow farmers and sugar and cotton mills. The informal sources of credits were found more famous in mixed farming system and less than 20 percent farmers in most cases used formal sources (banks). The high input prices, lack of farm machinery, limited access to inputs, water scarcity and small size of the farm were found as the major yield limiting factors.

To fulfill the first objective, the efficiency of the mixed farming system was evaluated by applying the standard and bootstrap DEA models. An average $TE_{crs,}$ TE_{vrs}, SE, CE, AE, $BCTE_{crs}$, and $BCTE_{vrs}$ of the sampled wheat farms were estimated at .59, .89, .66, .73, .82, .41, and .84 in per acre analysis while .59, .66, .88, .54, .81, .42, and .49 in per farm analysis. For cotton crop, an average $TE_{crs,}$ TE_{vrs}, SE, CE, AE, $BCTE_{crs}$, and $BCTE_{vrs}$ was calculated at .53, .82, .76, .63, .77, .46, and .74 in per acre analysis while .64, .71, .92, .60, .86, .49 and .52 in per farm analysis. An average $TE_{crs,}$ TE_{vrs}, SE, CE, AE, $BCTE_{crs}$, and $BCTE_{vrs}$ of the maize farms were quantified at .74, .89, .83, .74, .84, .67, and .84 in per acre analysis while .78, .83, .93, .67, .81, .71, and .75 in per farm analysis. For sugarcane crop, the mean $TE_{crs,}$ TE_{vrs}, SE, CE, AE, $BCTE_{crs}$, and $BCTE_{vrs}$ were estimated at .44, .58, .80, .51, .89, .25, and .39. After the slack analysis, the phosphorus, labour, seed, irrigation, nitrogen, tractor and farm area were found the most excessively used inputs for wheat, while pesticides, irrigation, phosphorus, nitrogen, labour, farm area and tractor were found on cotton farms. For maize crops, phosphorus, irrigation, labour nitrogen, labour, tractor hours and farm area were appeared most excessively used inputs and for sugarcane crop nitrogen, phosphorus, labour, irrigation, tractor hours and farm area were used in excessive quantities. When the overall performance of the mixed farming system is evaluated by aggregating the all inputs and outputs, the mean aggregated $TE_{crs,}$ TE_{vrs}, SE, CE, AE, $BCTE_{crs}$, and $BCTE_{vrs}$ were observed at .68, .71, .96, .60, .85, .57, and .58, respectively. The slack analysis at aggregated level showed that the farm could reduce a total amount of phosphorus, nitrogen, labour, irrigation, tractor hours and farm area up to 39, 36, 40, 43, 35 and 30 percent, respectively. To accomplish the second part of the first objective, a double bootstrap truncated regression model is estimated to find out the possible determinants of TE and to account for the impact of environmental variables. After the analysis, the variables of contact with extension, participation in trainings, FYM, household size, tractor ownership, tubwell ownership and practicing extension recommendation were found positively influencing the technical efficiency of the farmers. These variables were appeared significant in most cases at different confidence level. A very strong and significant inverse relationship between farm area and TE was observed for all crops. A dummy variable of credit was also a found negatively correlated with TE in most cases.

To secure the second objective of the study, the extension activities carried out in the study area were assessed in order to define the future role of the extension services. A small percentage of wheat (44.80%), maize (45.9 %), cotton (35.18%) and (sugarcane (25.09%) farmers had been found receiving advisory services, mostly once in a year. The higher technical, allocative, and economic efficiency was observed on the farms that have contact with extension agent. With regard to use to agricultural practices as recommended by extension agent, a majority of the farmers for all crops were used the practices as recommended by the extension and a higher technical, allocative and cost efficiency was observed on the farms, with practices according to the extension advice. With regard to satisfaction from extension advice, 76, 67, 58 and 36 farmers were fully satisfied with the extension advice out of the total 112, 76, 90, and 57 wheat, cotton, maize, and sugarcane farmers that received advice extension services. A vast majority over 70% was not aware of training programme conducted in the study area and higher technical, allocative and cost efficiency was found on farms that participated in training as compared to non-participants. The extension services in the study area were not engaged in activities like credit disbursement. Among other information sources, friends, local traders, pesticides companies were found to be the most important information sources for the farmers in the study area. The major areas identified by the farmers on which information is required from the extension department were soil fertility, fertilizer information, insect pest control, and seed variety in most cases.

9.2: CONCLUSION

Agricultural productivity in a farming system varies because of differences in production technologies, efficiency of the production processes and the environments in which the production takes place (Lovell *et al*., 1994). A critical analysis of the previous literature exposed a very wider and significant “yield gap” in different farming systems of Pakistan. Therefore, the foundation of this thesis was based on the assumption that if yield gap exists in the mixed farming system of Punjab then to what extent this gap can be closed through better management decisions including more precise choice of agronomic inputs and other crop requirements. In pursuance to this, the analysis of the structure of production technology highlighted a significant extent of resource use inefficiency on the wheat, cotton, maize, and sugarcane farms and the quantities of inputs that would be required to achieve their present levels of crop output were found unjustifiably higher on some farms. Some farmers irrationally used 2 to 3 times higher quantities of fertilizers, pesticides, labour, machinery, irrigation water as compared to others. Similar to input use inefficiency, a substantial yield gap is assessed between the farmers that were obtaining maximum and the lowest yield of wheat cotton, maize and sugarcane crops.

A substantial difference in yield might be due to failure of some producer to operate on a technical efficient frontier or the failure of some farmers to use that level of inputs that maximize output and profit. The analysis of the performance of the farms at individual crop and aggregated level helped to conclude that the resource use inefficiency is quite high in both kind of analysis. It is concluded that the wheat, cotton, maize and sugarcane farms can achieve the efficiency level of most efficient farms by making adjustments in 34, 29, 17 and 42 percent overused input resources, respectively. The analysis carried out at per acre and per farm level, revealed a considerable difference in all kinds of efficiency estimate (TE, SE, AE, CE and BCTE). This analysis helped to conclude that the use of only per acre data (as used in various studies) is not sufficient, as the results do not give valid estimate to draw any conclusions about the performance of farms. It is further concluded that the analysis is largely confounded with scale efficiency effect and overall less TE was mainly due to scale inefficiency rather than management, in per acre analysis. However, the results in per farm analysis were found devoid of scale efficiency effect and are considered more valid in this thesis and further used in performing the benchmarking and slack analysis. For inefficient farms two options emerge, they can either reduce the misused inputs with no change in current level of output or expand their output by effectively utilizing these over-utilized inputs. The overall performance of the mixed farming system at aggregated level also indicates the need for input adjustment in the short run in order to improve control over the production process. The economic and allocative efficiency analysis revealed that the wheat, cotton, maize, and sugarcane farmers have unjustifiably used 46, 40, 33, and 49 percent higher cost on their farms and the results of AE reveal that the CE can be improved by allocating 19, 14, 19, and 11 percent of misallocated resources more properly. These findings help to conclude that the allocative efficiency has major contribution in overall gain in economic efficiency than TE. The values of input slacks at crop and aggregated level have shown that all factors of production are excessively used and farms are quite inefficient especially in the management of phosphorus fertilizer, labour hours, irrigation hours and nitrogen fertilizer. DEA also provides an opportunity for inefficient farms to recognize the adjustments that could be made in the use of inputs and the benchmark analysis revealed a higher inputs use and very low farm production on least efficient farm as compared to peer farms at both crop and aggregated level. In conclusion, it is identified that the inefficient farms has main problem with output level rather than input and more attention is required to increase the output level rather focusing more on decreasing the inputs in order to achieve the efficiency level of its peers. The overall performance of the mixed farming system at aggregated level also revealed a possibility of considerable resource and cost saving through managing the existing resources specially phosphorus and nitrogen fertilizers, labour, and irrigation.

The standard DEA models do not take into consideration the statistical properties of the dataset and results can be misleading. The DEA approach is preferred in this study because since the introduction of bootstrap DEA models, none of studies has applied this approach in the context of Pakistan’s agriculture in order to correct the efficiency from bias and to establish confidence interval. After solving the bootstrap DEA model for 2000 bootstrap iterations, a substantial difference in the original and biased-corrected efficiency was seen with a very sharp downward movement in TE at both crop and aggregated level, indicating that the original efficiency scores have upward bias. The confidence intervals established from bootstrap analysis, although wide enough to suggest cautious interpretation of the efficiency measures. These results help to conclude that the previous measures of efficiency in Pakistan contain considerable bias and are not providing the exact picture of the situation.

This thesis also provided one of the first applications of the double bootstrap procedure In Pakistan to account for the impact of environmental variables on the level of TE. It is evaluated and concluded from the results of double bootstrap truncated regression model that age, household size, ownership of land, extension contact, participation in training, practicing the extension recommendations, tractor and tubwell ownership, FYM, early sowing of crops have very strong positive significant relationship with the technical efficiency for majority of cases. A very strong negative relation has seen between farm area and TE for all crops and the Schultz hypothesis “poor but efficient” is sustained in this research. At aggregated level, the variable of tenancy, tractor ownership, extension contact, training, soil quality and the dummy variable of practicing the extension recommendations were found significant.

At the end, various kinds of extension activities and their impact on farmer's efficiency is evaluated in addition to including the variables of extension services in second step contextual analysis. The purpose of this analysis was to get an understanding about the farmers and extension relationship that exist in the mixed farming system and to identify the possibilities by which extension services can play its role in efficiency improvement. This analysis helped to establish that the extension services are poor in mixed farming system with a weak extension to farmer's linkage as majority of the households were relying mostly on other information sources. However, the positive impact of extension contact and extension activities on technical, allocative, and cost efficiency provided strong evidence to conclude that the extension services can help to improve the efficiency of the mixed farming system by targeting more farmers, disseminating relevant and specific information, diversification in tasks and involving all the actors in the innovation process.

9.3: RECOMMENDATIONS AND POLICY IMPLICATIONS

The agricultural policies are designed in most countries based on the quantitative analysis of the production system. The present study was designed to estimate the technical, allocative, economic and biased corrected efficiency and to identify the factors causing inefficiency. Secondly, this study also aims to correct the efficiency from bias through the application of bootstrap procedure. Third, the possibilities for extension services were identified to increase the efficiency of the production system. On the basis of findings, the following recommendations and policy implications can be made for the selected crops, in the mixed farming system of Pakistan' Punjab.

The small farms found quite irrational in the use of resources for all crops and the input use level found unreasonably higher than the level that would be required to achieve present crop output level. It is a misconception among the farmers that higher input use increase farm production but an overdose of inputs such as fertilizers, pesticides can have negative impact on environment in addition to increasing production cost. The most apparent implication of this finding is that there is a need for sound policies to educate the farmers on how and when to use these scarce inputs in right quantities. For this reason, the input level that is used by the fully efficient wheat, cotton, maize, and sugarcane farmers was identified and in a short run, this information could be disseminated to the inefficient farmers through extension in order to enable them to make better technical decisions in the adjustment of inputs.

The application of potash fertilizer is negligible on all crops that might be due to its high price or lack of awareness about its importance in crop Production. Therefore, the government should promote programmes that highlight the importance and utilization of potash in crop production in addition to ensuring its provision on subsidized rates. There is a need to establish soil-testing laboratories on a location that can easily be accessible to rural population, in order to ensure optimal use of fertilizers.

A considerable yield gap between the least and best productive farm for all crops highlighted a substantial opportunity for production enhancement within the available resource. Such colossal difference in yield might be due to deviation from the recommended practices, lack of resources or environmental factors. A important implication of this finding is that there is need to devise some strategies in collaboration with extension that would capacitate farmers to effectively deal with the natural disasters like droughts, heavy insect pest attack etc. The credit might not use properly on farms as evident from a negative relationship between TE and credit against three crops. To ensure that credit is not being diverted to other non-farm operations, government and other financial institutions should give credit in the form of complete inputs package (facility to higher in tractor, fertilizers, herbicides, Pesticides) against every crop.

Pakistan is expected to face severe land and water challenges in the upcoming years because most of the farming systems are operating at a very high level of cropping intensity (159%), promoting land degradation due to lack of proper sustainable crop intensification strategies. Pakistan is also in transition from water stressed to water scarce country, further threatening land resources. Therefore, the government should devise some strategies to ensure future high production through sustainable intensification of farming systems by putting less pressure on environment, land and water resources. To cope with the challenges of water scarcity, government should put serious efforts to construct new dams in addition to increasing the storage capacity of the existing dams. The long lasting dispute between India and Pakistan over water issue need special attention and should be resolved on some international forum for economic, social, and political stability of the continent.

The results of truncated regression analysis revealed that the tractor and tube well ownership has a positive effect and the policies ensuring the provision of tractors to the small farms on subsidized rate could be helpful for improving TE. On the provision of tractors, the tractor driven tube wells should also be promoted to fulfill the deficiency of canal water in the study area. The government can also achieve this objective by providing tractors to the extension department that can supply these services to poor and needy farmers at low rates.

Farm area was found negatively and significantly associated with the technical efficiency at crop and farm level, providing strong evidence that the government policies in the favor of small farms could be beneficial for achieving the objective of self-sufficiency in food. The small farms have allocated a very small portion of their land to sugarcane crop and it is required to promote the production on commercial basis. The government can encourage farmers to bring more area under sugarcane by announcing a reasonable support price. The average farm size is very small in mixed farming system and can be sub-optimal in near future, the policies ensuring the allocation of culturable wasteland to small farmers on lease for a specific period are direly need to sustain the optimal farm size for crop production.

The variable of early sowing is found positive and significant determinant of TE for wheat and cotton crops, implying that in order to harvest optimal yield, the early crop establishment factor should be considered. The early sowing would be helpful in improving CE of the farmers by saving the seed cost wasted on higher seed rate in a condition of late sowing. Therefore, there is need to educate the farmers about the advantages of early sowing and this could be done by establishing a demonstration plots and then showing the difference in yield and production on early and late growing plots.

The impact of all type of extension variables was found positive and significant on TE in spite of a weak extension to farmer linkage. It is therefore, recommended that the policy makers should concentrate on enhancing farmers' access to information via the provision of better extension services. The government could achieve this objective by allocating more resources to extension department, reinforcing and expanding the net of extension services in the mixed farming system. By setting up new institutional arrangements, an effective extension to farmer link can be established through the deployment of more trained and skilled extension workers that provide relevant technical messages, and bring farmers' problems to the attention of researchers. There is a need to set up mechanism that ensures frequent and regular contact between extension agents and farmers.

The participation of the wheat, cotton, maize, and sugarcane farmers in various extension programmes was very low and the farmers that were participating and putting into practice the recommendations found more efficient. The policy implication of the foregoing finding is that the technical expertise of the farmers related to crop production should be enhanced by organizing specialized need-based and skill-oriented training, demonstrations and technical assistance programmes and ensuring their participation. Secondly, it is recommended that the contents of these programmes should be aligned to the farmers' need, and these events must be organized and conducted in a manner that farmer are encouraged to attend, taking into consideration timing, duration, location, and language.

The participatory extension approaches can still be used in the study area as the farmers largely rely on informal sources (fellow farmers and friends, local traders) sometimes regarded as ‘beneficiaries’ or ‘target groups’, and become vital in the information exchange of the extension system for information delivery. Therefore, it is recommended that extension department, experts, administrative bodies, planners and related organizations first should think the impact and influence of informal agricultural information sources.

The low efficiency on some farms might be due to deviation from recommended crop production practices and for this reason, the best practices used by the efficient farmers were identified through benchmark analysis. It is therefore; recommended for the extension department to recommend this input use level to the inefficient farmers and this information can be disseminated through the establishment of demonstration plots, training, and farm visits because farmers preferred these methods for effective delivery of information.

The innovation system of Pakistan has evolved over time and In order to make innovation process more effective, there is a need to diversify the policy formulation process. The development of an effective and interactive system will not be possible until unless all the stakeholders are taken into consideration while formulating policy. The finding suggests that the government should reconsider the role of extension and there is need to diversify the activities and tasks of the extension department. The multiple tasks can be performed by working in close collaboration with other actors like pesticide companies, local traders, leading farmers, credit supply companies and NGOs, etc. According to my opinion, it is recommended that to build an office in each city preferably in “Mandi”. “Mandi” is present in every city of Pakistan where almost every farmer comes from the surrounding villages in order to sell their produce and to buy inputs. This place contains shops of local traders, pesticides franchises, brokers, etc. The next step will be to select one competent representative from each organization and the duties of these representatives will be to guide and help the farmers related to their area of expertise. The duties of these representatives are listed in Table 9.1:

Table 9.1: Role and Duties of the Representatives

Office functionaries	Role and duties
Representative from Bank	Credit information to the farmers, provision of credit, informing bank about farmer's problems and preferences
Research Representative	Informing farmers and other functionaries about new research and recommendations, getting suggestions from all the stakeholders and guiding the researchers about these suggestions
local trader Representative	Ensuring fast sale of farmers product, guiding farmers about the expected future sale price of crops, provision of good quality seed
Pesticide Representative	Ensuring good quality pesticides and herbicides, informing pesticides companies about field situation and farmers 'need,
Farmers representative	Informing these functionaries about the farmers' problems and preferences, providing information to the other farmers as guided by these functionaries
Extension representative	Collecting information from all these sources and transferring to the vast majority of farmers, providing information back to all these functionaries about farmers' needs and problems.
Government role	Evaluating the working of office, ensuring regular training of all the functionaries relating to their expertise, providing incentive to these functionaries based on performance, ensuring provision of inputs on subsidies rate.

The close collaboration of these actors would help the farmers to get all the information at one place and this will ensure timely availability of farm inputs and credit to the farmers. Secondly, the new policies and technologies will be designed at all tiers keeping in mind the farmers' need and preferences. The proper and timely supply of inputs, credit, and information aligned with farmers' needs would increase the efficiency and productivity of small farmers.

9.4: LIMITATIONS OF STUDY

Several limitations are attributed to the data set used and assumptions made while estimating technical, scale cost, allocative and bias-corrected of the farmers in the mixed farming system and the results have to be interpreted with great care. One of the major limitations of this study is that the results are only applicable to the mixed farming system of Punjab and may not be generalized to other cropping systems and countries due to different socioeconomic and agro-climatic environment. The second limitation relates to the reliability of the data used in this research that is based on respondent's memory recall and therefore, it is not as precise as observed facts, or information generated through experimentation. Secondly, the objectivity of the findings would be limited to the extent the farmers provide information honestly and sincerely. In this study, the efficiency of only small farmers was estimated and it provides no information about the performance of medium and large farms. The comparison of efficiency results across different farm sizes would produce results that are more comprehensive. Due to the length of the questionnaire, time scarcity, and funds availability, the analysis is based on cross-sectional data collected during 2012-13 and provides no information how productivity changes over time and the use of panel data would be more comprehensive to understand the pattern in productivity change over time. The missing variables are also a data limitation and failure to take into account the market attributes in the second stage analysis can produce biased results. This study could not include marketing risks in the analysis due to data scarcity and remains a potential area for further research subject to availability of appropriate data. Failure to accommodate risk can lead to biased results and the efficiency estimates through state-contingent techniques can be helpful in the presence of uncertainty (Chambers and Quiggin, 2010).

9.5: SUGGESTIONS FOR FURTHER RESEARCH

The results of this study suggest a number of directions in which this study can be extended. This study relied on cross-sectional data, directing that the future research must look at the technical, scale cost, allocative and biased corrected efficiency using time series data that would help to evaluate technical efficiency over different periods. The results derived from the application of bootstrap DEA revealed a considerable bias with a downward movement in efficiency This study also stresses that the application of bootstrap DEA in future efficiency studies should not be neglected. It is therefore, recommended for the researchers to conduct research in the other farming systems of Punjab by applying the bootstrap technique. This study used per acre and per data in the analysis and a considerable difference in efficiency was seen in both estimations, suggesting that the use of only per acre data can produce biased results. Therefore, the farm level data must be included in future research in addition to using per acre data. To extend this work, further research should be conducted to understand the influence of environmental factors, risks and crop diversification on efficiency in order to have greater understanding about farm-specific effects and benefits of diversified cropping. In future research, the parametric technique (SFA) can also be used in addition to DEA and Bootstrapping for more reliable estimation and it will provide an opportunity to compare the results across three different approaches.

REFERENCES

1. **Abatania, L. N. (2013). "**Identifying Performance Benchmarks in Ghanaian Agriculture through Efficiency Analysis". Ph.D. Theses, The University of Western Australia, Australia.

2. **Abbasi, Z. F. (2012). "**Corporate Agriculture Farming: The Role Of Corporate Sector". Report, Impact Consulting, Islamabad, Pakistan.

3. **Abatania, L. N., Atakelty, H. & Amin W. M. (2012).** "Analysis of Farm Household Technical Efficiency in Northern Ghana Using Bootstrap DEA". Paper presented at the 56th annual conference of the Australian Agricultural and Resource Economics Society. The Esplanade Hotel, Fremantle WA, Australia.

4. **Abate, G. T., Francesconi, G. N. & Getnet, K. (2013).** "Impact Of Agricultural Cooperatives On Smallholders' Technical Efficiency: Evidence From Ethiopia", Euricse Working Paper, 50(13).

5. **Abdullah, Hassan, G., Khan, I. A., Khan, S. A. & Ali, H. (2008).** "Impact Of Planting Methods And Herbicides On Weed Biomass And Some Agronomic Traits Of Maize". *Pak. J. Weed Sci. Res*., 14: 121-130.

6. Abebayehu, G. (2011). "Technical Efficiency of Haricot Bean Seed Production in Boricha District of Sidama Zone, Southern Ethiopia". M.Sc. Thesis Presented to School of Graduate Studies of Haramaya University.

7. **Abedullah, S. K. & Mushtaq, K. (2007).** "Analysis Of The Technical Efficiency of Rice Production in Punjab (Pakistan)". *Pakistan Economic and Social Review*, 45, 231-244.

8. **Abedullah., Khuda B. & Bashir, A. (2006)**. "Technical Efficiency and its Determinants in Potato Production, Evidence from Punjab, Pakistan". The Lahore Journal of Economics, 11(2), 1-22.

9. **Abedullah., Shahzad, K., Khalid, M. & Muhammad, M. (2006).** "Role of Credit to Enhance Cotton Production in Punjab, Pakistan". *Pakistan Journal Agriculture Sciences*, 43, 3-4.

10. **Abid, M., Faisal, M., & Shakeel, A. A. (2016).** "Supplemental Irrigation - A Key Strategy to Unravel the Potential of Rainfed Agriculture In Pakistan". Journal of Agriculture Research, 54(4), 657-675.

11. **Adachi, K., Carlo D, N. and Donald J. L. (2010).** "Technical Efficiency In Bangladesh Rice Production Are There Threshold Effects In Farm Size? Poster prepared for presentation at the Agricultural & Applied Economics Association, CAES, & WAEA Joint Annual Meeting, Denver, Colorado.

12. **Adamopoulos, T. & Diego, R. (2011).** "The Size Distribution of Farms and International Productivity Differences". Working Paper 441. Department of Economics, University of Toronto, Canada.

13. **Adegbite, O. & Adeoye, I. B. (2015).** "Technical Efficiency of Pineapple Production in Osun State, Nigeria". *Agris on-line Papers in Economics and Informatics*, 7(1).

14. **Adeleke, S., Abdul, B. K. & Zuzana, B. (2010).** "Smallholder Agriculture in East Africa: Trends, Constraints and Opportunities". Working Paper, African Development Bank.

15. **Adem, M. & Kidanemariam, G. (2014).** "The Effect Of Agricultural Extension Program On Technical Efficiency Of Rural Farm Households Evidence From Northern Ethiopia: Stochastic Frontier Approach". *International Reseachers* 3(3), 13-31

16. **Adhikari, C. B. & Bjorndal, T. (2012)**. "Analyses Of TE Using SFA And DEA Models: Evidence From Nepalese Agriculture". *Applied Economics*, 44, 3297-3308.

17. **Adzawla, W., Fuseini, J. & Donkoh, S. A. (2013).** “Estimating Technical Efficiency of Cotton Production in Yendi Municipality Northern Ghana”. *Journal of Agriculture and Sustainability*, 4 (1), 115-140.

18. **Adzawla, W., Fuseini, J. and Donkoh, S. A. (2013)**. “Estimating Technical Efficiency of Cotton Production in Yendi Municipality, Northern Ghana”. Journal of Agriculture and Sustainability, 4(1), 115-140.

19. **Afzal, A., Faisal, S. A. & Abdulrahman A. M. (2016).** “The Attitudes of Agricultural Extension Workers towards the Use of E-Extension for Ensuring Sustainability in the Kingdom of Saudi Arabia". Sustainability, 8 (980), 1-10.

20. **Afzal, N. & Shahid, A. (2009).** “Agricultural Input Use Efficiency in Pakistan: Key Issues and Reform Areas”. Research Briefings, 1(3), 1-12.

21. **Ahmad, M. & Qureshi, S. K. (1999)**. “Recent Evidence on Farm Size and Land Productivity”. *Pakistan Development Review*, 38, 1135-1153.

22. **Ahmad, M. (2001).** “Agricultural Productivity Growth Differential in Punjab, Pakistan: A District-Level Analysis”. *Pakistan Development Review*, 40, 1-26.

23. **Ahmad, M. (2003).** “Agricultural Productivity, Efficiency, and Rural Poverty in Irrigated Pakistan: A Stochastic Production FrontiermAnalysis”. *The Pakistan Development Review*, 42(3), 219–248

24. **Ahmad, M., Chaudhry, G. M. & Muhammad, I. (2002).** “Wheat Productivity, Efficiency, and Sustainability: A Stochastic Production Frontier Analysis”. *Pakistan Development Review*, 41, 643-663.

25. **Ahmad, R. (1997).** “Deterioration in cane yield and quality characteristics due to lodging in sugarcane”. Proc. 59th Ann. Conv. Sug. Tech. Assoc. India. A 7-A 12 [Field Crops Absts. 5 (10):1038, 1998

26. **Ahmad, S. (2007).** “Land and Water Resources of Pakistan— A Critical Assessment”. *The Pakistan Development Review 46*, 4(II), 911–937.

27. **Ahmad, M. & Farooq, U. (2010).** “The State of Food Security in Pakistan: Future Challenges and Coping Strategies”. The Pakistan Development Review, 49(4), 903-923.

28. **Ahmad, S., Muhammad, A., Robina, R. & Urooba, P. (2007).** “Interaction Of Extension Worker With Farmers And Role Of Radio And Television As Sources Of Information In Technology Transfer: A Case Study Of Four Villages Of District Peshawar And Charsadda”. *Sarhad Journal of Agriculture*, 23(2), 515-518.

29. **Ahmad, U. I., Yang, L., Bashir, M. K. & Iqbal, M. A. (2016).** “Access To Output Market By Small Farmers: The Case Of Punjab, Pakistan”. *The Journal of Animal & Plant Sciences*, 26(3), 787-793.

30. **Ahmed, M. A., Zainalabidin, M & Golnaz, R. (2017).** “Impact of Microfinance on the Efficiency of Maize Producers in Nigeria”. *American Journal of Applied Sciences*, 14 (5), 569.577.

31. **Ahmed, M. H., Lemma Z. & Endrias G. (2015).** “Measuring Technical, Economic and Allocative Efficiency of Maize Production in Subsistence Farming: Evidence from the Central Rift Valley of Ethiopia”. Applied Studies in Agribusiness and Commerce. DOI: 10.19041/APSTRACT/2015/3/9

32. **Aigner, D., C. A. K. & Schmidt, P. (1977).** “Formulation and Estimation of Stochastic frontier production function models”. Journal of econometrics, 6(1), 21-37.

33. **Ajibefun, I. A. (2008).** “An Evaluation Of Parametric and Non-Parametric Methods of Technical Efficiency Measurement: Application To Small Scale Food Crop Production in Nigeria”. *Journal of Agriculture & Social science*, 4(3), 95-100.

34. **Akhtar, M., Ali, F. G., Muhammad, S. & Afghan, S. (2000).** “Effect of Moisture Regimes and Fertilizer Levels on Yield and Yield Parameters Of Spring Planted Sugarcane”. Pakistan Sugarcane Journal, 15(5), 2-6.

35. **Alam, M. (2006).** "Factors affecting Yield Gap and Efficiency in Rice Productions in Some Selected Areas of Bangladesh". Ph.D. Thesis, Department of Economics, Jahangir Nagar University, Bangladesh.

36. **Alao, J. S. & Kuje, E. D. (2010).** "Determination of Technical Efficiency And Production Function For Small Scale Furniture Industry In Lafia Metropolis, Nasarawa State, Nigeria". *Journal of Agricultural Social Sciences*, 6, 64-66.

37. **Aldaz, N., Millian, J.A. (2003).** "Regional Productivity of Spanish Agriculture in a Panel DEA Framework". *Applied Economics Letters*, 10, 87–90.

38. **Aldeseit, B. (2013)**. "Measurement of Scale Efficiency in Dairy Farms: Data Envelopment Analysis (DEA) Approach". *Journal of Agricultural Science*, 5(9), 37-43.

39. **Alemdar, T & Oren, M. N. (2006).** "Determinants of technical efficiency of wheat farming in Southeastern Anatolia, Turkey". *Journal Of Applied Sciences*, 6 (4), 827-830.

40. **Alemdar. T., Bahidar, B. & Oren, M. N. (2010).** "Cost and Return Analysis and Technical Efficiency of Small Scale Milk Production: A Case Study for Cukurova Region, Turkey". *Journal of Animal and Veterinary Advances*, 9(4), 844-847.

41. **AL-HASSAN, S. (2008).** "Technical Efficiency of Rice Farmers in Northern Ghana". African Economic Research Consortium.

42. **ALI, A., Mushtaq, K., Ashfaq, M. & Muhammad, A. R. (2009).** "An Analysis of Productivity Growth of Agriculture in Pakistan". *Journal of Agricultural Research*, 47(4), 439-450.

43. **ALI, M. S. (2009).** "Farm Sizes And Agricultural Productivity".Dailay Times newspaper . http://www.dailytimes.com.pk/default.asp?page=2009%5C11%5C17%5Cstory_17-11-2009_pg3_3.

44. **Ali, A. & Abbas, J. (2017).** "Analysis of Technical Efficiency of Sugarcane Crop in Khyber Pakhtunkhwa: A Stochastic Frontier Approach". *Sarhad Journal of Agriculture*, 33(1): 69-79

45. **Ali, A. A., Imad E. E. & Abdel, K. Y. (2012).** "Economic Efficiency of Wheat and Faba Bean Production for Small Scale Farmers In Northern State Sudan". *The Journal of Animal & Plant Sciences*, 22(1), 215-223.

46. **Ali, F. G., Iqbal, M. A., Chattha, A. A. & Afghan, S. (2000).** "Effect of Fertilizer and Seed Rate towards Stripped-Cane Yield of Spring-Planted Sugarcane". *Pakistan Sugarcane Journal*, 15(4), 12-16.

47. **Ali, G., Syed, M. A. S., Dawood, J., Abbasullah, J., Mohammad, F., Irfan, U. & Muhammad Z. K. (2013).** "Technical Efficiency of Sugarcane Production in District Dera Ismail Khan". *Sarhad Journal of Agriculture*, 29 (4), 585-590.

48. **Ali, M., & Flinn J. C. (1989).** "Profit Efficiency Among Basmati Rice Producers In Pakistan Punjab. American Journal of Agricultural Economics, 71(2), 303-310.

49. **Ali, S. & Khan, M. (2014).** "Technical Efficiency of Wheat Production in District Peshawar, Khyber Pakhtunkhwa, Pakistan". *Sarhad Journal of Agriculture*, 30(4): 433-441.

50. **Ali, S., & Khan, M. (2014).** "Technical Efficiency of Wheat Production in District Peshawar, Khyber Pakhtunkhwa, Pakistan". *Sarhad Journal of Agriculture*, 30(4), 433-441.

51. **Al-Rimawi, A. S., Karablieh, E. K. & Al-Kadi, A. S. (2004).** "An Investigation into the Perceived Farm Management and Marketing Educational Needs of Farm Operators in Jordan". *Journal of Agricultural Education*, 45, 34-43.

52. **Amin, A. & Awung, W. J. (2005).** “Economic Analysis of Private Returns to Investment in Education in Cameroon”. Regional Conference on Education in West Africa: Constraints and Opportunities”. African Institute for Economic Development and Planning (IDEP), Dakar, Senegal.

53. **Amos, T. T. (2007).** “An Analysis of Productivity and Technical Efficiency of Smallholder Cocoa Farmers in Nigeria”. *Journal of Social Sciences,* 15(2), 127-133.

54. **Anang, B. T., Bäckman, S. and Antonios, R. (2016).** “Does Farm Size Matter? Investigating Scale Efficiency of Peasant Rice Farmers in Northern Ghana”. *Economics Bulletin*, 36(4), 2275-2290.

55. **Anderson, J. & Feder, G. (2003).** “Rural Extension Services”. Working Paper No. 2976, World Bank Policy Research.

56. **Andersson, A. (2014).** “Computer Shopping: A study in understanding commuting in the context of shopping”. BSc Thesis, Jönköping International Business School, Jonkoping University

57. **Anjum, A. S., Roshan, Z. & Waqarul H. T. (2016).** “Organic Farming: Hope For The Sustainable Livelihoods Of Future Generations In Pakistan”. *Journal of Rural Development and Agriculture*, 1(1), 20-29.

58. **Antholt, C. H. (1994).** “Getting Ready for the Twenty-First Century: Technical Change and Institutional Modernization in Agriculture”. World Bank Tech. Paper No. 217

59. **Anwar, M. A., & Supaat, H. I. (1998).** “Information Needs of Rural Malaysians: An Exploratory Study of a Cluster of Three Villages with no Library Service”. *International Information & Library Review*, 30, 23–36.

60. **APO. (2001).** “Strengthening Agricultural Support Services For Small Farmers”. Seminar Report (SEM-28-01), Asian Productivity Organization, Japan.

61. **APO, (2003).** “Impact of Land Utilization Systems on Agricultural Productivity”. Report of the APO Seminar on Impact of Land Utilization Systems on Agricultural Productivity Islamic Republic of Iran.

62. **Arain, G. N. (2013).** “Maize (corn) cultivation in Pakistan”. Valley irrigation Pakistan (private), limited.

63. **Arain, G. N. (2013).** “Sugarcane Cultivation in Pakistan”. Valley irrigation Pakistan (private), limited

64. **Armagan, G., Ozden, A., & Bekcioglu, S. (2010).** Efficiency And Total Factor Productivity Of Crop Production At Nuts1 Level In Turkey: Malmquist index approach.” *Qualilty & Quantity*, 44, 573-581

65. **Arshed, A., Mahmood, K., Iqbal, M. & Hussain A. (2012)**. “Effectiveness Of Extension Education Methods Used By Rafhan Maize Products For Information Dissemination To Maize Growers Of Central Punjab, Pakistan”. *Pakistan Journal of Food Sciences*, 22(1), 36-39.

66. **Arysta. (2016).** “Technical Note of Vitavax”. Arysta Crop Sciences.

67. **Artukoglu, M. M., Olgun, A., & Adanacioglu, H. (2010)**. “The Efficiency Analysis Of Organic And Conventional Olive Farms: Case Of Turkey”. *Agricultural Economics* – Czech, 56(2), 89–96

68. **Asefa, S. (2011).** “Analysis Of Technical Efficiency Of Crop Producing Smallholder Farmers In Tigray,Ethiopia”. *Munich Personal RePEc Archive*, Paper No. 40461.

69. **Asekenye, C. (2012).** "An Analysis of Productivity Gaps among Smallholder Groundnut Farmers in Uganda and Kenya" Master's Theses, University of Connecticut, USA.

70. **Asghar, S. (2014).** “Farming System Analysis of Irrigated Farms in Faisalabad, Pakistan”. Msc Thesis, Asian Institute of Technology School of Environment, Resources and Development Thailand.

71. **Asim, S. M. (2010).** “Significance of Family Farming in the Asian Region – Perspective of Small Farmers in Pakistan”. Asian NGO Coalition, Rural Development Foundation, Diliman Quezon City, Philippines.

72. **Aslam, M. (2016).** “Agricultural productivity current scenario, constraints and future prospects in Pakistan”. *Sarhad Journal of Agriculture*, 32(4): 289-303

73. **Aslam, M., Abdul, H., Chattha, A. A. & Chattha, M. U. (2005).** “Effect of Sowing Depth and Earthing Up on Lodging in Sugarcane”. Pakistan Sugarcane *Journal*, 20(1), 6-8.

74. **Asmild, M., Hougaard, J.L. (2006).** “Economic Versus Environmental Improvement Potentials of Danish pig Farms”. *Agricultural Economics*, 35, 171–181.

75. **Asogwa, B. C., Ihemeje, J. C. & Ezihe, J. A. C. (2011).** “Technical and Allocative Efficiency Analysis of Nigeria Rural Farmers Implication: for Poverty Reduction”. *Agricultural Journal*, 6(5), 243-251.

76. **Asogwa, B. C., Joseph C. U. and Simon T. P. (2012).** “Technical Efficiency Analysis of Small-holder Farmers in Rural and Peri-urban Areas of Nigeria”. J Humanity Ecology, 37(1): 57-66.

77. **Asogwa, B. C., Umeh, J. C. & Ater, I. (2006).** “Technical Efficiency Analysis of Nigerian Cassava Farmers: A Guide for Food Security Policy”. Poster paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia.

78. **Assuncao, J. J. & Ghatak, M. (2003).** "Can Unobserved Heterogeneity in Farmer Ability Explain the Inverse Relationship Between Farm Size and Productivity". *Economics letters*, 80(2), 189-194.

79. **Aujla, K. M., Sajida, T., Khalid, M. & Nadeem, A. (2010).** “Wheat Management Practices and Factors of Yield Decline in the Punjab Province of Pakistan”. *Journal of Agricultural Research*, 23 (1-2), 17-24.

80. **Aung, N. Y. (2012).** “Production and Economic Efficiency of Farmers and Millers in Maynmar Rice Industry.V.R.F. Series. No 471, Institute of Developing Economies, Japan.

81. **Aurangzeb, M. (2007).** “Irrigation Cost of Major Crops: A Comparison Of Electric And Diesel Tubewells Irrigation In District Charsadda (NWFP- Pakistan)”. *Sarhad Journal of Agriculture*, 23(1), 217-222.

82. **Avkiran, N. K. (2001).** “Investigating Technical and Scale Efficiencies of Australian Universities through Data Envelopment Analysis”. *Socio-Economic Planning Sciences*, 35, 57–80.

83. **Awan, S. A., Muhammad, A., Syed, A. L. N. & Makhdum, A. H. (2015).** “Profitability Analysis of Sustainable Cotton Production: A Case Study of Cotton – Wheat Farming System in Bahawalpur District of Punjab”. *Bulgarian Journal of Agricultural Sciences*, 21(2), 251–256

84. **Ayaz, S., Zakir, H., H. & Maqbool, H. S. (2010).** “Role of Credit on Production Efficiency of Farming Sector in Pakistan (A Data Envelopment Analysis)”. *International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering*, 4(6), 1075-1080.

85. **Azam, S., Murad, A., Mohammad, A., Shahida, B. & Muhammad, A. (2007).** “Effect Of Plant Population On Maize Hybrids”. *Journal of Agricultural and Biological Science*, 2(1), 13-20.

86. **Azam, A. & Muhammad S. (2017).** “Agriculture In Pakistan And Its Impact On Economy—A Review”. *International Journal of Advanced Science and Technology* , 103 (2017), 47-60.

87. **Azikiwe, A. I., Monde, N., Obi, A. & Sunday, O. (2013).** “Quality of Extension Services: A Case Study of Farmers in Amathole”. *Journal of Agricultural Science*, 5(2), 204.

88. **Aziz, N. (2011).** “Sustainable Agriculture. linking Practice to Policy”. Policy, Advocacy & Research Unit, ActionAid, Pakistan.

89. **Badar, H. & Qamar, D. (2005).** "Wheat Production and Marketing: A Comparative Study of Traditional and Progressive Farmers in Faisalabad (Pakistan)". *Journal of Agriculture & Social Sciences*, 1(1), 16–19.

90. **Bagchi,, M. & Zhuang, L. (2016).** "Analysis of Farm Household Technical Eefficiency in Chinese litchi farm using Bootstrap DEA". *Gronegócio*, 12(4),378-394.

91. **Bakh, M. E. & Serajul, I. (2005).** "Technical and Allocative Efficiency of Growing Wheat in Northwest Districts Of Bangladesh". *Bangladesh Journal of Agricultural Economics*, 28(1&2), 73-83.

92. **Bakhsh, K, & Ahmad B. (2006)**. "Technical Efficiency And Its Determinants In Potato Production, Evidence From Punjab, Pakistan".

93. **Bakhsh, K. (2007).** "An Analysis of Technical Efficiency and Profitability of Growing Potato, Carrot, Radish and Bitter Gourd: A Case Study of Pakistani Punjab". Ph.D. Thesis, Department of Environmental and Resource Economics, University of Agriculture, Faisalabad.

94. **Bakhsh, K., Hassan, I. & Maqbool, A. (2005).** "Factors Affecting Cotton Yield: A Case Study of Sargodha (Pakistan). *Journal of Agriculture & Social Sciences*, 1(4), 332-334.

95. **Bakhsh, K., Sarfraz, H., Muhammad, A. K. and Rashed, S. (2014).** Determinants of Environmental Efficiency in Bitter Gourd Production in Pakistani Punjab". *Pakistan Journal of Social Sciences (PJSS)*, 34(1), 167-176.

96. **Bakhshoodeh, M. & Thomson, J. (2001).** "Input and Output Technical Efficiencies of Wheat Production In Kerman, Iran". *Agricultural Economics,* 24 (2001), 307–313.

97. **Balcombe, K., Davidova, S., Latruffe, L. (2005). "**Application of Double Bootstrap to Investigation of Determinants of Technical Efficiency of Farms in Central Europe". Working Paper, 5-3.

98. **Balcombe, K., Davidova, S., Latruffe, L. (2008a)** "The use of bootstrapped Malmquist indices to reassess productivity change findings: an application to a sample of Polish farms", Applied Economics, 40(16), 2055–2061.

99. **Balcombe, K., Fraser, I., Kim, J.H. (2006)** "Estimating technical efficiency of Australian dairy farms using alternative frontier methodologies", Applied Economics, 38(19), 2221– 2236.

100. **Balcombe, K., Fraser, I., Latruffe, L., Rahman, M. & Smith, L. (2008b)** "An application of the DEA double bootstrap to examine sources of efficiency in Bangladesh rice farming", Applied Economics, 40(15), 1919–1925.

101. **Baležentis, T. & Irena, K. (2012).** "Application Of The Bootstrapped DEA For The analysis Of Lithuanian Family Farm Efficiency". *Management Theory And Studies For Rural Business And Infrastructure Development*, 34(5), 35-45.

102. **Baloch, M. A. & Thapa, G. B. (2017).** "Review of the agricultural extension modes and services with the focus to Balochistan". *Pakistan Journal of the Saudi Society of Agricultural Sciences*, 1-7.

103. **Banaeian, N., Morteza, Z., & Mahmoud, O. (2010).** "Energy Use Efficiency For Walnut Producers Using Data Envelopment Analysis (DEA)". *Australian Journal of crop Science*, 4(5), 359-362.

104. **Banga, R. S., Yadav, A. & Malik, R. K. (2003).** "Bio Efficacy of Flufecacet and Sulfo-Sulfuron Alone and In Combination against Weed Flora in Wheat". *Indian Journal off Weed Science*, 35(3/4), 179–182.

105. **Banker, R. D., Charnes, A. & Cooper, W. W. (1984).**"Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. *Management Science*, 30(9), 1078-1092.

106.**Banker, R. D., Cooper, W. W., Seiford, M., Thrall, R. M. & Zhu, J. (2004).** "Returns to Scale in Different DEA Models". *European journal of operational research,* 154 (2004), 345–362.

107.**Banker, R. D., & Natarajan, R., (2008).** "Evaluating Contextual Variables Affecting Productivity Using Data Envelopment Analysis". *Operations Research*, 56, 48-58.

108.**Banmeke, T. O. A. & Olowu, T. A. (2005).** "Agricultural Information Need of Women Farmers in South Western States of Nigeria". *Journal of Agricultural Extension*, 8, 32–40.

109.**Barghouti. S., Kane, S., Sorby, K. & Mubrak, A. (2004).** "Agricultural Diversification for the Poor Guidelines for Practitioners". Agriculture and Rural Development discussion paper no. 1, Washington, DC, World Bank.

110.**Briscoe, J. & Usman, Q. (2008).**"Pakistan's Water Economy: Running Dry". Water, P-Notes, Issue 17. Oxford University Press.

111.**Barreiro, P. L. & Justo, P. (2001).** "Population and Sample. Sampling Techniques". Management Mathematics for European Schools, 94342 - CP - 1 - 2001 - 1 - DE - COMENIUS - C21, University of Seville, Spain.

112.**Barrett, C. B., Carter, M. R. & Timmer, C. P. (2010).** "A Century–Long Perspective on Agricultural Development". *American Journal of Agricultural Economics*, 92 (2), 447 – 468

113.**Bashir, M. & Dilawar, K. (2005).** "An Analysis of Allocative Efficiency of Wheat Growers in Northern Pakistan". *The Pakistan Development Review* 44, 4(2), 643–657.

114.**Battese, G. E., Hina N. & Melinda S. (2014). "**Productivity and Efficiency of Farmers Growing Four Popular Wheat Varieties in Punjab, Pakistan". Harvest Plus Working Paper | December 2014

115.**Bautista, F. (2016).** "The Basics of land Preparation". Philippine Rice Research Institute.

116.**Belachew, T. & Abera, Y. (2010).** "Response of maize (Zea mays L.) to Tied Ridges and Planting Methods at Goro, Southeastern Ethiopia". *Am. Euroasian J. Agron*., 3: 21-24.

117.**Belen, Iraizoz, Manuel, R. & Idoia, Z.. (2003).** "Assessing the Technical Efficiency of Horticultural Production in Navarra, Spain." Agricultural Systems, 78:387-403.

118.**Bempomaa, B & Henry, D. G. A. (2014).** "Technical Efficiency Analysis of Maize Production: Evidence from Ghana". *Applied Studies in Agribusiness and Commerce* , 8(2-3), 73-79.

119.**Benjamin, A. M. N. (2013).** "Farmers' Perception Of Effectiveness Of Agricultural Extension Devlivery In Cross-River State, Nigeria". IOSR Journal of Agriculture Vetnary Sciences. 2 (6), 01–07.

120.**Berry, J. K., Delgado, J. A., Khosla, R. & Pierce, F. (2003).** "Precision Conservation for Environmental Sustainability". *Journal Soil Water Conservation*., 58(6), 332-339.

121.**Bhatt, M. S and Showkat, A. B. (2014).** "Technical Efficiency and Farm Size Productivity— Micro Level Evidence from Jammu & Kashmir". *International Journal of Food and Agricultural Economics*, 2(4), (2014), 27-49.

122.**Bhatti, M. N. & Muhammad, F. (2014).** "Politics of Water in Pakistan". *Pakistan Journal of Social Sciences,* 34(1), 205-216.

123.**Bhushan, S. (2005).** "Total Factor Productivity Growth of Wheat in India: A Malmquist Approach". *Indian Journal of Agricultural Economics*, 60(1), 32-48.

124.**Bhutto, A. W. & Aqeel, A. B. (2007**). "Sustainable Agriculture and Eradication of Rural Poverty in Pakistan". *Natural Resources Forum*, 31 (2007), 253–262.

125.**Bielik, P. & Rajčániová, M. (2004).** "Scale Efficiency Of Agricultural Enterprises In Slovakia". *Agriculture Economics – Czech*, 50(8), 331–335.

126.**Bifarin, J., Alimi, T., Baruwa, O. & Ajewole, O. (2008).** Determinant of Technical, Allocative and Economic Efficiencies in the Plantain (Musa spp.) Production industry, Ondo State, Nigeria". IV International Symposium on Banana, Mombasa, Kenya.

127.**Binam, J. N., Tonye, J. & Wandji, N. (2005).** "Source Of Technical Efficiency among Small Holder Maize and Penut Farmers in the Slash and Burn Agriculture Zone of Cameroon". *Journal of economic cooperation*, 26(1), 193-210.

128.**Binam, J., Sylla, K., Diarra, I. and Nyambi, G. (2003).** "Factors Affecting Technical Efficiency Among Coffee Farmers In CoˆTe D'ivoire: Evidence From The Centre West Region". *African Development Review*, 15, 66–76.

129.**Binuyo, G., Abdulrahman, S., Yusuf, O. & Timothy, A. J. (2016).** "Technical Efficiency of Rain-fed Lowland Rice Production in Niger State, Nigeria". *Asian Journal of Agricultural Extension, Economics & Sociology,* 9(4), 2-12.

130.**Birner, R., Davis, K., Pender, J., Nkonya, E., Anandajayasekeram, P., Ekboir, J. & Cohen, M. (2009).** "From Best Practice To Best Fit: A Framework For Designing And Analyzing Pluralistic Agricultural Advisory Services Worldwide". *Journal of Agricultural Education and Extension*, 15(4), 341-355.

131.**Bizimana. C., Nieuwoudt, W. L. & Ferrer, S. R. D. (2004).** "Farm Size, Land Fragmentation and Economic Efficiency in Southern Rawanda". *Agrekon*, 43(2), 244-262.

132.**Błażejczyk-Majka, L., Radosław, K., & Krzysztof, M. (2011).** "Productivity and Efficiency of Large and Small Field Crop Farms and Mixed Farms of the Old and New EU Regions". *Agric. Econ. – Czech*, 58(2), 61–71

133.**Bogale, T. & Ayalneh, B. (2005).** "Technical Efficiency of Resource Use in the Production of Irrigated Potato: A Study of Farmers Using Modern and Traditional Irrigation Schemes in Awi Zone,Ethiopia". Journal of Agriculture and Rural Development in the Tropics and Subtropics, 106(1), 2005, 59-70.

134.**Bojnec, S. & Latruffe, L. (2009).** "Determinants of Technical Efficiency of Slovenian Farms". *Post-communist economies*, 21 (1), 117-124.

135.**Bolandnazar, E., Keyhani, A., & Omid, M. (2014).** "Determination Of Efficient And Inefficient Greenhouse Cucumber Producers Using Data Envelopment Analysis Approach, A Case Study: Jiroft city in Iran." *Journal of Cleaner Production*, 79, 108-115

136.**Boundeth, S., Teruaki N. & Shigeyoshi, T. (2012).** "Analysis On Technical Efficiency Of Maize Farmers In The Northern Province Of Laos". *African Journal of Agricultural Research*, 7(49), 6579-6587.

137.**Bozogulo, M. & Vedat, C. (2007).** "Measuring The Technical Efficiency And Exploring The Inefficiency Determinants Of Vegetable Farms In Samsun Province, Turkey". *Agricultural Systems,* 94(3), 649-656.

138.**Bravo-Ureta , B. E. & Antonio E. P. (1997).** "Technical, Economic, and Allocative Efficiency in Peasant Farming: Evidence from the Dominican Republic". *The Developing Economies*, 35(1), 48-67.

139.**Brázdik, F & EI, C. (2006).** "Non-Parametric Analysis Of Technical Efficiency: Factors Affecting Efficiency Of West Java Rice Farms". *Working Paper Series*, (ISSN 1211-3298)

140.**Brink, P. J. & Wood, M. J. (1998).** " Design in Nursing Research". 2nd Edition. Sage publications, London.

141.**Brock, G., Grazhdaninova, M., Lerman, Z. & Uzun, V. (2007).**” Technical Efficiency in Russian Agriculture. AgEcon Discussion Paper No. 13.06, Department of Agricultural Economics and Management, Hebrew University of Jerusalem.

142.**Brodrick O. A. & Sanzidur, R. (2014).** “Profitability and Efficiency of Cassava Production at the Farm-Level In Delta State, Nigeria”. School of Geography, Earth and Environmental Sciences, University of Plymouth, UK.

143.**Brümmer, B. (2001).** “Estimating Confidence Intervals for Technical Efficiency: The Case of Private Farms in Slovenia.” *European Review of Agricultural Economics* 28(3), 285- 306.

144.**Brunner, E. & Hsin P. Y. E. (1949).** “Rural America and the Extension Service”, Columbia University.

145.**Buriro, R. A., Khooharo, A. A., Talpur, G. H. & Rajput, M. I. (2013).** “Technical Efficiency of Wheat Farming In Sindh Province of Pakistan*”. Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Sciences*, 2013, 29 (1), 77-87.

146.**Burja, C. & Vasile, B. (2016).** “Farms Size and Efficiency of the Production Factors in Romanian Agriculture”. *Economics Of Agriculture*, 63(2), 361-374.

147.**Burki, A. A. & Shah, N. H. (1998).** “Stochastic Frontier and Technical Efficiency of Farms in Irrigated Areas of Pakistan's Punjab”. *Pakistan Development Review*, 37, 275-292.

148.**Burns, N. & Grove, S. K. (1997).** “The Practice of Nursing Research Conduct, Critique, & Utilization”. 5th Edition

149.**Byma, J. P. & Tauer, L. W. (2010).** “Exploring the Role of Managerial Ability in Influencing Dairy Farm Efficiency”. *Agricultural and Resource Economics Review*, 39(3), 505-516

150.**Cabrere,V.E., Solis, D. and Corral, J.D. (2009).** “Studying the Impact of Managerial Activities on the Technical Efficiency of Wisconsin Dairy Farm”. Efficiency Series Papers, Department of Dairy Science, University of Wisconsin, Madison 53706.

151.**Campbell, J. & Holland, J. (2005).** “Methods in Development Research: Combining Qualitative and Quantitative Approaches”. Intermediate Technology Development Group, Warwickshire, UK.

152.**Candemir, M. & Ertugrul, D. (2007).** “Production Efficiency and Total Factor Productivity Growth in Turkish State Agricultural Enterprises”. *Agricultural Economics Review*, 8(2), 29-41.

153.**Casley, D. J. & Kumar, K. (1988).** “The Collection and Use of Monitoring and Evaluation Data”. Baltimore, MD ,The John Hopkins University Press.

154.**Caves, D., Christensen, L. and Diewert, E. (1982)**. “The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity”, Econometrica, 50, 1393–1414.

155.**Cesaro, L., Sonia, M. & Maria, G. C. (2009).** “Methodology For Analysing Competitiveness, Efficiency And Economy Of Scale”. Use and applications of DEA FACEPA Deliverable No. D5.1.3

156.**Chamber, R. G. (1988).** “Applied Production Analysis, A Dual Approach”. Cambridge University Press.

157.**Chand, R., Prasanna, P. A. L. & Aruna, S. (2011).** "Farm size and productivity: understanding the strengths of smallholders and improving their livelihoods." *Economic & Political Weekly Supplement*, 46(26-27), 5-11.

158.**Charnes, A., Cooper, W. W. & Rhodes, E. (1978).** Measuring the Efficiency of Decision-Making Units,” *European journal of operational research*, 2(6), 429-44.

159.**Charnes, A., Cooper W. W. Golany, Seiford, & Stutz. (1985).** "Foundations of data envelopment analysis for pareto-koopmans efficient empirical production functions. *Journal of Econometrics*, 30(1–2), 91-107.

160.**Chattha, M. B., Muhammad, M., Arshad, A. C. & Muhammad, K. M. (2010).** "Effect Of Earthing Up And Fertilizer Levels on Growth and Yield of Spring Planted Sugarcane (Saccharum Officinarum L.)". *Journal of Agricultural Research*, 48(3), 327-334.

161.**Chaudhry, A. U. & CHATTHA, F. A. (2000)**. "Determination of Optimum Level of Phosphorus and Its Effect on the Growth, Yield and Quality of Ratoon Sugarcane". *Pakistan Journal Biological Sciences*, 3(3), 483-484.

162.**Chaudhry, M. A. (2001).** "Impact of the Changing Economy on Small Farmers in Asia and the Pacific". Country Paper, Asian Productivity Organizations, Tokyo, Japan.

163.**Chebil, A., , Abdelaziz A. H.,** Alawia**, O. H., Ishtiag, A., Izzat , T., Solomon, A. & Ouambi, Y. (2016).** "Metafrontier Analysis of Technical Efficiency of Wheat Farms in Sudan". *Journal of Agricultural Science*, 8(2), 179-186.

164.**Cheema, M. S., Muhammad, N., Muhammad, A. & Liaquat, A. (2008).** "Comparative Efficacy of Different Planting Methods and Weed Management Practices on Seed Cotton Yield". *Pakistan Journal of Weed Science Research*, 14(3-4), 153-159.

165.**Cheema, Z. A., Muhammad, F. & Abdul, W. (2013).** " Allelopathy: Current Trends and Future Applications".Springer, Verlag Berlin Heidelberg.

166.**Chemak, F. (2011).** "Technical Change Performance and Water Use Efficiency in the Irrigated Areas: Data Envelopment Analysis Approach". European Association of Agricultural Economists (EAAE), 2011 International Congress,, Zurich, Switzerland.

167.**Chen, Z., Huffman, W. E, & Rozelle, S. (2003).** "The Relationship between Farm Size and Productivity in Chinese Agriculture." Unpublished manuscript, Department of Economics, Iowa state university, USA.

168.**Chiona, S., Thomson, K. & Gelson, T. (2014)**. "Stochastic Frontier Analysis of the Technical Efficiency of Smallholder Maize Farmers in Central Province, Zambia". *Journal of Agricultural Science*, 6(10),108-118.

169.**Chirwa, E. W. (2007).** "Sources of Technical Efficiency among Smallholder Maize Farmers in Southern Malawi". AERC Research Paper 172, African Economic Research Consortium, Nairobi, Africa.

170.**Clemente, F., Viviani, S. L., & Marília F. M. G. (2015**). "Technical Efficiency in Brazilian Citrus Production". *Bio-based and Applied Economics*, 4(2), 165-178.

171.**Cobanoglu, F. (2013). "**Measuring the Technical Efficiency of Cotton Farms in Turkey Using Stochastic Frontier and Data Envelopment Analysis". *Sage Journals*, 42(2), 2013.

172.**Coelli, T. (2005).** An introduction to efficiency and productivity analysis, springer Verlag.

173.**Coelli, T. (1996).** "A Guide to DEAP Version 2.1: A Data Envelopment Analysis (Computer) Program". Centre for Efficiency and Productivity Analysis Working Paper 96/08, University of New England, Armidale, Australia.

174.**Cooper, W. W., Seiford, L. M. & Zhu, J. (2004).** "Data Envelopment Analysis". Handbook on data envelopment analysis, 1-39.

175.**Cooper, W.W., Seiford, L.M., & Tone, K. (2000).** "Data Envelopment Analysis: A Comprehensive Text With Models, Applications, References And DEA-Solver Software". Boston, MA: Kluwer Academic Publishers.

176.**Creswell, J. W. (2013).** "Steps in Conducting a Scholarly Mixed Methods Study". DBER Speaker Series. 48

177.**Croppenstedt, A. (2005).** “Measuring Technical Efficiency of Wheat Farmers in Egypt”. ESA Working Paper No. 05-06.

178.**Currivan, D. B. (2004).** “The SAGE Encyclopedia of Social Science Research Methods”. Print ISBN: 9780761923633 | Online ISBN: 978141295058

179.**Dağistan, E. (2010).** “Determination Of Technical Efficiency In Wheat (Triticum aestivum l.) Production of Turkey: A Case Study of Cukurova Region”. *Journal of Food, Agriculture & Environment*, 8 (2): 354-358.

180.**Dang, H. X. H. (2011).** “Evaluation of Input Efficiency For Catfish Farming Mekong River Delta, Vietnam. United Nations University Fisheries Training Programme, Iceland.

181.**Daniel, O., Gideon, A., John, M. & Wilson, N. (2010).** “Technical Efficiency In Resources Uses: Evidence From Smallholder Irish Potato Farmers In Nyandarua North District Kenya”. *African Journal of Agricultural Research*, 5: 1179-1186.

182.**Danso-Abbeam, G, Abubakari M. D. and Gbanha A. B. (2015).** “Resource-Use-Efficiency among Smallholder Groundnut Farmers in Northern Region, Ghana”. *American Journal of Experimental Agriculture, 6(5*), 290-304

183.**Dao, G. T. N. (2013).** “An Analysis Of Technical Efficiency Of Crop Farms In The Northern Region Of Vietnam”.Ph.D Thesis, University of Canberra, Australia.

184.**Davidova, S., & Latruffe, L. (2003).** “Technical Efficiency and Financial Management in Countries in Transition”. INRA, Working Paper, 3(10).

185.**Davidova, S., & Latruffe, L. (2007)**. “Relationships between Technical Efficiency and Financial Management for Czech Republic Farms”, Journal of Agricultural Economics, 58(2), 269– 288.

186.**Davidson, A. P. (2001).** “Dilemmas of agricultural extension in Pakistan: Food for thought”. Citeseer.

187.**Davis, K. E. (2009). “**Agriculture and Climate Change: An Agenda for Negotiation in Copenhagen For Food, Agriculture,and the Environment The Important Role of Extension Systems”. International Food Policy Research Institute.

188.**De Haan, C, Van V., Brandenberg, B. & Simeon, M. (2001).** “Livestock Development: Implications For Rural Poverty, The Environment And Global Food security”. The World Bank, Washington DC

189.**DEBERTIN, D. L. (1986)**. Agricultural production economics, Macmillan.

190.**Debois, S. (2016).** “Advantages and Disadvantages of Questionnaires”. Surveyanyplace

191.**Debreu, G. (1951).** “The Coefficient of Resource Utilization”. *Econometrica*, 19(3):273–292

192.**Degefa, K. (2014).** “Economic Efficiency Of Smallholder Farmers In Maize Production In Bako Tibe District, Oromia National Regional State, Ethiopia”. M. SC. Thesis, Haramaya University.

193.**Demetriou, D. (2014).** “The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation”. Springer International Publishing, Switzerland.

194.**Demircan, V., Turan, B. & Carl R. Z. (2010).** “Assessing Pure Technical Efficiency of Dairy Farms in Turkey”. *Agricultural economics-Czech*, 56(3), 141-148.

195.**Dethier, J. & Alexandra, E. (2012).** “Agriculture and Development: A Brief Review of the Literature”. Economic Systems,1-31.

196. **Dietrich, J. P., Christoph, S. & Marianela, F. (2012).** "Measuring Agricultural Land-Use Intensity – A Global Analysis Using A Model-Assisted Approach". *Ecological Modelling*, 232 (2012),109–118.

197. **Deininger, K., Castagnini, R. and Gonza´lez, M. (2004).** "Comparing Land Reform and Land Markets in Colombia: Impacts on Equity and Efficiency". World Bank Working Papers No. 3258, Washington, DC, 2004).

198. **Dev, M. S. (2014).** "Small Farmers in India: Challenges and Opportunities". Working Paper, Indira Gandhi Institute of Development Research, Mumbai.

199. **Dhanuka. (2017).** "Vitavax Power". Dhanuka Agritech Limited, India.

200. **Dhehibi, B., Alimari, A., Haddad, N. & Aw-Hassan, A. (2014).** "Technical Efficiency and Its Determinants in Food Crop Production: A Case Study of Farms in West Bank, Palestine". *Journal of Agricultural Science and Technology*, (16), 717-730.

201. **Dhungana, B.R., Nuthall, P. L. & Nartea, G. V. (2000).** "Explaining Economic Inefficiency Of Nepalese Rice Farms: An Empirical Investigation". 44th Annual Conference of the Australian Agricultural and Resource Economics Society, Sydney.

202. **Dhungana, B.R., Nuthall, P.L., Nartca, G.V. (2004)** "Measuring the Economic Inefficiency of Nepalese Rice Farms Using Data Envelopment Analysis". *The Australian Journal of Agricultural and Resource Economics*, 48(2), 347–369.

203. **Dilshad, A. & Afzal, M. (2012).** "The Determinants of Technical Efficiency of cotton farmers in the Southern Punjab (Pakistan)". *International Journal of Physical and Social Sciences*, 2 (12),

204. **Dinarvand, E. & Sabbaghi, M. A. (2015)**. "Calculating the Technical Efficiency of Wheat Farmers Regarding To the Farm Size In Dehloran". *Research Journal of Fisheries and Hydrobiology*, 10(10), 137-139.

205. **Dirro, G. M & Abdoul, G. S. (2015).** "Agricultural Technology Adoption and Non Farm Earnings in Uganda, A Semiparametric Analysis".*The Journal of Developing Areas,* 49(2), 145-162.

206. **Dlamini, S., Rugambisa, J., Masuku, M. & Belete, A. (2010).** "Technical Efficiency Of The Small Scale Sugarcane Farmers In Swaziland: A Case Study Of Vuvulane And Big Bend Farmers". *African Journal Of Agricultural Research*, 5 (9), 935-940.

207. **Dogar, M.H., Akhtar, S. & Muhammad, H. (2016).** "Factors Affecting Yield Gap In Different Wheat Varieties In Punjab". *Journal of Environmental & Agricultural Sciences*, 7, 42-47

208. **Dong, F., Paul D. M. & Jed, C. (2015).** "Measuring farm sustainability using data envelope analysis with principal components: The case of Wisconsin cranberry". *Journal of Environmental Management*, 147 (2015) 175-183.

209. **Dossah, B. O. & Ibrahim, U. M. (2016).** "Evaluation of Gender Differences in Resource Utilization And Technical Efficiency Of Irrigated Vegetable Farming In Plateau State, Nigeria". *European Journal of Basic and Applied Sciences*, 3(2),2059-3058.

210. **Druilhe, Z. and Barreiro-Hurlé, J. (2012).** "Fertilizer Subsidies in Sub-Saharan Africa". ESA Working paper No. 12-04. Rome, FAO.

211. **Dyson, R. G., Allen, R., Camanho, A. S., Podinovski, V. V., Sarrico, C. S AND Shale, E.A. (2001).** "Pitfalls and protocols in DEA". *European Journal of Operational Research*, 132(2), 245-259.

212. **Eastwood, R, Lipton, M. & Andrew, N. (2010).** "Farm Size". *Handbook of Agricultural Economics*, 4. Burlington: Academic Press, 3323-3397.

213.**Efron, B. (1979).** “Bootstrap Methods: Another Look at the Jackknife”, *Annals of Statistics*, 7, 1–16.

214.**Elahi, E. Liqin Z., Muhammad A, & Han, X. (2015).** “Impact of Balance Use of Fertilizers on Wheat Efficiency in Cotton Wheat Cropping System of Pakistan”. *International Journal of Agriculture Innovations and Research*, 3 (5), 2319-1473

215.**Elepaño A. R., Suministrado, D. C. & Rodulfo, V. A. (2009).** "Agricultural Mechanization Development In Philippines." country report.

216.**Elias, A, Makoto N, & AREGA, D. A. (2014).** “The Effect Of Agricultural Extension Service On The Technicalefficiency Of Teff (Eragrostistef) Producers In Ethiopia”. *American Journal of Applied Sciences* 11 (2): 223-239.

217.**Elias, A., Nohmi, M., Yasunobu, K. And Ishida, A. (2016).** “Farmers’ Satisfaction with Agricultural Extension Service and Its Influencing Factors: A Case Study in North West Ethiopia”. *Journal of Agriculture Science and Technology*, 18 (1), 39-53.

218.**Emmanuel, D., Enoch, O. S. & Henry, J. (2016).** “Impact Of Agricultural Extension Service On Adoption Of Chemical Fertilizer: Implications For Rice Productivity And Development In Ghana”. *NJAS - Wageningen Journal of Life Sciences,* 79, 41-49.

219.**Enwerem, V. A. & Ohajianya, D. O. (2013)**. “Farm Size and Technical Efficiency of Rice Farmers in Imo State, Nigeria”. *Greener Journal of Agricultural Sciences*, 3 (2), 128-136.

220.**Edirisinghe, N. C. P and Zhang, X. (2007).** Generalized DEA Model of Fundamental Analysis and Its Application to Portfolio Optimization, Journal of Banking and Finance, 31, 311-335, 2007.

221.**Ewert, F., Rounsevell, M. D. A., Reginster, I., Metzger, M.J., & Leemans, R., (2005).** Future scenarios of european agricultural land use: Estimating changes in crop productivity. *Agriculture, Ecosystems & Environment*, 107, 101–116.

222.**Fandel, P. (2003).** “Technical and Scale Efficiency of Corporate Farms in Slovakia”. *Agriculture Economy Czech*, 49(8), 375-383.

223.**FAO (2004).** “Fertilizer use by Crop in Pakistan”. Land and Plant Nutrition Management Service, Land and Water Development Division, FAO, Rome.

224.**FAO. (2011).** “The State Of The World’s Land And Water Resources For Food And Agriculture”. http://www.fao.org/docrep/017/i1688e/i1688e.pdf.

225.**FAO. (2010).** “Policies and Institutions To Support Smallholder Agriculture”. Committee on Agriculture, 22nd Session. http://www.fao.org/docrep/meeting/018/K7999E.pdf

226.**FAO.(2012).** “Small Holders and Family Farms”.

227.**FAO. (2015).** “Yield gap analysis of field crops: Methods and case studies”. Food And Agriculture Organization Of The United Nations Rome, Italy.

228.**Färe, R., Grosskopf, S., Lindgren, B. and Roos, P. (1992)**. “Productivity Changes in Swedish Pharmacies 1980– 1989: a Nonparametric Approach”, *Journal of Productivity Analysis*, 3(1-2), 85–101.

229.**Fare R, Grosskopf S, Lovell C. A. K & Pasurka, C. (1989)**. “Multilateral Productivity Comparisons When Some Outputs Are Undesirable: A Nonparametric Approach”. *Review of Economic and Statistics*, 71, 90-98.

230.**Fare R, Grosskopf S, Lovell C. A. K & Yaisawarng, S. (1993).** “Derivation of Shadow Prices for Undesirable Outputs: a Distance Function Approach”. *Review of Economics and Statistics*,75, 374-380.

231.**Färe, R.; Grosskopf, S. & Lovell, C. A. K. (1994). "**Production Frontiers."Cambridge University Press, Cambridge.

232.**Färe, R. Grosskopf, S. & Lovell, C. A. K. (1985).** "The Measurement of Efficiency of Production."Kluwer Academic Pub.

233.**Farrell, M. J. (1957).** "The Measurement of Productive Efficiency". *Journal of the Royal Statistical Society*, 120, 253-290.

234.**Fatima, H.(2015).** "An Analysis on Farm Size and Nonparametric Efficiency Measurement for Food Crops in Pakistan". *International Journal of Research in Agriculture and Forestry*, 2(5), 34-41.

235.**Fatima, H., Khan M.A., Zaid-Ullah M., Abdul, J. & Khurrum, N. S. (2016).** "Technical Efficiency of Cotton Production in Pakistan: A Comparative Study on Non BT and BT-Cotton Farms*". Sarhad Journal of Agriculture,* 32(4), 267-274.

236.**Fatima, H., Lal, A. & Bushra, Y. (2017).** "Allocative Efficiency and Profitability Analysis of High-Tech Cotton-Melon Multiple Cropping System In Punjab, Pakistan". *Sarhad Journal of Agriculture*, 33(1), 117-126.

237.**Feel, M. A. & Basheer, A. (2012).** "Economic Efficiency of Wheat Production In Gezira Scheme, Sudan". *Journal of the Saudi Society of Agricultural Sciences*, 11, 1–5.

238.**Fekadu, G. & Bezabih E. (2009).** "Analysis Of Technical Efficiency Of Wheat Production: A Study In Machakel Woreda Ethiopia". *Journal of Agricultural Economics*, 7(2):1-34.

239.**Felipe, J. (1999).** "Total Factor Productivity Growth in East Asia: A Critical Survey." *Journal of Development Studies*, 35(4): 1-41.

240.**Finn R. F., Sverre, A. C. K. & Frode, L. (2005).** "Efficiency and Productivity of Norwegian tax Offices". Mmorandum No 29/2005, Department of Economics University of Oslo

241.**Flubacher, M. (2015).**"Comparison of the Economic Performance between Organic and Conventional Dairy Farms in the Swiss Maountain Region Using Matching and Stochastic Frontier Analysis". *Journal of Socio-Economics in Agriculture*, 8, 76-84.

242.**Fogarasi, J. (2006).** "Efficiency and total factor productivity in post-EU accession Hungarian sugar beet production". *Studies in Agricultural Economics*, 105, 87-100.

243.**Fox, N., Ammenda, H & Nigel, M. (2009).** "Sampling and Sample Size Calculation". NIHR.

244.**Fraser , I & Cordina, D. (1999).** "An Application of Data Envelopment Analysis to Irrigated Dairy Farms in Northern Victoria, Australia". *Agricultural Systems*, 59, 267-282.

245.**Freeman, C. (1987).** "Technology Policy and Economic Performance: Lessons from Japan". London: Pinter.

246.**Frija, A., Chebil, A., Speelman, S., Buysse, J., & Van Huylenbroeck, G. (2009).** "Water use and technical efficiencies in horticultural greenhouses in Tunisia". *Agricultural Water Management,* 96(11), 1509-1516.

247.**Frija, A., Wossink A., Buysse, J., Speelman, S., Van Huylenbroeck, G. (2011)** "Irrigation pricing policies and its impact on agricultural inputs demand in Tunisia: A DEA-based methodology", *Journal of Environmental Management*, 92, 2109–2118.

248.**Fritz, S. (2015).** "Improving Food Security Through Smallholder Adoption Of Sustainable Agricultural Intensification (SAI)".Graduate Diploma in Science, University of Sydney, Australia

249.**Furi, T. & Getachew, B. (2016).** "Analysis of Technical Efficiency of Coffee Production on Small Holder Farmers in Case of Sasiga & Limu Districts of East Wollega Zone". *Journal of Economics and Sustainable Development*, 7(15), 34- 43.

250.**Gabdo, B. H., Mansoor, M. I., Kamal, H. A. & Ilmas, A. M. (2017).** "Regional Simulation of Bootstrap Efficiency of Broiler Production in Peninsular Malaysia". Journal of Agriculture Science and Technology, 19, 279-291.

251.**Gabdo, B. H.; Ismail, A., Zainal A., & Mad, N. (2014).** "Homogenous Smoothed DEA-Bootstrap Optimization Of Robust Technical Efficiency In Livestock-Oilpalm Integration In Johor, Malaysia". Agricultural Journal , 9(1),22-31.

252.**Gadanakis, Y. (2013).** "Sustainable Intensification of Farming Systems". Ph.D Thesis, University of Reading Uk.

253.**Garnett, & Godfray. (2012).** "Sustainable intensification in agriculture. Navigating a course through competing food system priorities"Food Climate Research Network and the Oxford Martin Programme on the Future of Food, University of Oxford, UK.

254.**Galagedera, D. U. A. & Silvapulle, P. (2003).** "Experimental Evidence on Robustness of Data Envelopment Analysis". *Journal of the Operational Research Society*, 54, 654-660.

255.**Galanopoulos, K., Aggelopoulos, S., Kamenidou, I. & Mattas, K. (2006).** "Assessing the Effects of Managerial And Production Practices On The Efficiency Of Commercial Pig Farming." *Agricultural Systems*, 88, 125-141.

256.**Galanopoulos, K., Zaphiris, A., Vassiliki, L., Ioannis, H. & Jean, B. (201**1). "The Technical Efficiency Of Transhumance Sheep And Goat Farms And The Effect Of EU Subsidies: Do Small Farms Benefit More Than Large Farms"? *Small Ruminant Research*, 100(1), 1-7.

257.**Gautam, M., Nagarajan, H. K. & Pradhan, K. C. (2012).** "Technical, Economic And Allocative Efficiency And Its Determinants Of Indian Agricultural Farmers Using ARIS/REDS Panel Data". NCAER Working Papers on Decentralisation and Rural Governance in India. National Council of Applied Economic Research, New Delhi, India.

258.**Gebrehiwot, K. G. (2017).** "The Impact Of Agricultural Extension On Farmers' Technical Efficiencies In Ethiopia: A Stochastic Production Frontier Approach". *South African Journal of Economics and Management Sciences*, 20(1)

259.**Gebreslassie, H. B. (2016).** "Effect of Potasium Fertilizer on Crop Production". *Journal of Natural Sciences Research*, 6(7), 81-86.

260.**Ghosh, B. K. (2010).** "Determinants of Farm Mechanization in Modern Agriculture: A Case Study of Burdwan Districts of West Bengal". 5, 1107-1115.

261.**Gill, J. (2015).** "Assessing Technical Efficiency Of Wheat Farmers In Pakistan: A Comparison To Prior Productivity Analyses Of Pakistani Agriculture". M.Sc Thesis, Michigan State University, USA.

262.**Giroh, D. Y. & Adebayo, E. F. (2009).** "Analysis of the Technical Inefficiency of Rubber Tapping in Rubber Research Institute of Nigeria, Benin City, Nigeria". Journal of Human Ecology, 27(3), 171-174.

263.**Gollin, D. (2014).** "Smallholder Agriculture In Africa An Overview And Implications For Policy". Institute Of Development Studies, Working Paper.

264.**Gómez-Limón, J. A., Picazo-Tadeo, A .J., & Reig-Martínez, E., (2012).** "Eco-Efficiency Assessment Of Olive Farms In Andalusia." *Land Use Policy*, 29, 395-406.

265.**Gorton, M. & Davidova, S. (2004).** "Farm Productivity and Efficiency in the CEE ApplicantCountries: a Synthesis of Results". *Agricultural economics*, 30, 1-16.

266.**Goud, V. V. (2016).** "Evaluation of Pre and Post Emergence Herbicides on Weed Flora and Yield of Greengram". *PKV Research Journal*, 40(1), 27-30.

267.**Government of India. (2013).** "Status Paper on Sugarcane". Directorate Of Sugarcane Development. Ministry of Agriculture.

268.**Government of India. (2016). "**Manual for Drought Management". Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, India.

269.**Government of Pakistan (GOP). (2000).** "Agricultural Census".Government of Pakistan, Finance Division, Islamabad.

270.**Government of Pakistan. (2005). "**Agriculture Statistics of Pakistan". Ministry of Food, Agriculture And Livestock, Islamabad.

271.**Government of Pakistan. (2010).** "Economic Survey of Pakistan". Government of Pakistan, Finance Division, Islamabad.

272.**Government of Pakistan. (2013).** "Economic Survey of Pakistan". Government of Pakistan, Finance Division, Islamabad.

273.**Government of Pakistan. (2014).** "Economic Survey of Pakistan". Government of Pakistan, Finance Division, Islamabad.

Government of Pakistan. (2016). "Economic Survey of Pakistan". Government of Pakistan, Finance Division, Islamabad.

274.**Government of Punjab. (2016).** Faisalabad, Punjab Portal. www.Punjab.gov.Pk/faisalabad.

275.**Government of Pakistan (2017).** "National Food Security Policy". Ministry of National Food Security and Research Islamabad.

276.**Government of USA. (2014).** "Corporate Consolidation in Agriculture Fact Sheet. (http://www.taxpayer.net/library/article/corporate-consolidation-in-agriculture-fact-sheet.

277.**Goyal, S. K. & Suhag, K. S. (2003).** "Estimation of Technical Efficiency on Wheat Farms In Northern India – A Panel Data Analysis". International Farm Management Congress 2003.

278.**Grain. (2014).** "Hungry for Land: Small Farmers Feed The World With Less Than A Quarter Of All Farmland". Report.

279.**Garcia, A. F., & Shively, G. E. (2011)**. "How Might Shadow Price Restrictions Reduce Technical Efficiency? Evidence from a Restricted DEA Analysis of Coffee Farms in Vietnam", *Journal of Agricultural Economics*, 62(1), 47–58.

280.**Greene, W. H. (2008)**. "The Econometric Approach to Efficiency Analysis. In the Measurement of productive Efficiency and Productivity Growth". 92-250.

281.**Guesmi, B., Serra, T. & GIL, J. M. (2014).** "Efficiency Of Egyptian Organic Agriculture: A Local Maximum Likelihood Approach". Paper presented at the Conference of the European Association of Agricultural Economists (EAAE), Ljubljana, Slovenia, August 26 - 29.

282.**Guesmi, B., Serra, T., & Featherstone, A. (2015).** "Technical Efficiency Of Kansas Arable Crop Farms: A Local Maximum Likelihood Approach." *Agricultural Economics*, 46, 6, 703-713.

283.**Gul, M., Demeircan , V., Hassan , Y. & Hilal, Y. (2016).** “Technical Efficiency of Goat Farming in Turkey: A Case Study of Isparta Province”. *Revista Brasileira de Zootecnia*, 45(6), 328-335.

284.**Gul, M., Koc, B., Dagistan, E., Akpinar, M. G. & Parlakay, O. (2009).** “Determination of technical efficiency in cotton growing farms in Turkey: A case study of Cukurova region”. *African Journal of Agricultural Research*, 4(10), 944-949.

285.**Gupta, S. P. & Gupta, M.P. (2002).** Business statistics. Suttan Chand and Sons, New Dehli.

286.**Haji, J. (2007).** “Production Efficiency of Smallholders' Vegetable-Dominated Mixed Farming System In Eastern Ethiopia: A Non-Parametric Approach”. *Journal of African Economies*, 16, 1- 27.

287.**Hall, B, H. (2009).** “Innovation and Diffusion”. Scholarly Research Reviews, Oxford Handbooks Online.

288.**Hameed, A., Ihtsham, H., P , Abdul S. (2014).** “Estimation of Productivity and Efficiency of Cotton Farmers: A Case Study of District Dera Ghazi Khan”. *Business & Economic Review*, 6(2), 63-82

289.**Hamid, S., Habibi, R. M. & khorasani, N. A. (2016).** “Measuring Water Use Efficiency and Productivity of Tehran Using Data Envelopment Analysis”. *Iranian Journal of Natural Resources*, 68(4), 595-608.

290.**Hammad, B., Abdul, G & Sultan, A. A. (2007)**. “Factors Affecting Agricultural Production Of Punjab (Pakistan)”. *Pakistan Journal of Agriculture Sciences*, 44(3), 506-510.

291.**Hanh, B. L. T. (2009).** “Impact of Financial variables on the production efficiency of Pangasius farms in An Giang province, Vietnam”. Maters Thesis, University of Tromso, Norway

292.**Hasanov, S. and Ahmed. M. N. (2011).** "Agricultural Efficiency under Resources Scarcity In Uzbekistan: A Data Envelopment Analysis". *Business and Economic Horizons*, 4(1), 81-87.

293.**Hashmi, M. S., Muhammad, A. K., Khuda, B. & Muhammad, A. B. (2016).** “Role Of Socio-Economic Factors On Scale Efficiency Of Cotton Farms”. *Bulgarian Journal of Agricultural Science*, 22 (3) , 358–367.

294.**Hashmi, M. S., Muhammad, A. K., Khuda, B., Muhammad, A. B. & Muhammad, I. (2015).** “Technical Efficiency of Cotton Farms and Its Determinants”. *Science International*, 27(4), 3561-3568.

295.**Hassan, S. & Ahmad, B. (2001).** “Technical Efficiency of Wheat Farmers in Mixed Farming System of the Punjab, Pakistan”. *International Journal of Agriculture and Biology*, 7, 431-435

296.**Hassan, S. & Ahmad, B. (2005).** “Technical Efficiency of Wheat Farmers in Mixed Farming System of the Punjab, Pakistan”. *International Journal of Agriculture and Biology*, 7(3), 431–435.

297.**Hassan. S., Nazia, T. & Javaid, I. (2005).** “An Economic Analysis of Wheat Farming in the Mixed Farming Zone of Punjab Province, Pakistan”. *Journal of Agriculture & Social Sciences*, 1(2), 167–171.

298.**Hazell, P., Poulton, C. Wiggins, S. & Dorward, A. (2007).** “The Future Of Small Farms For Poverty Reduction And Growth”. Washington, DC: International Food Policy Research Institute

299.**Hazneci, E. & Vedat, C. (2015).** “Measuring the Productive Efficiency and Identifying the Inefficiency Determinants of Dairy Farms in Amasya Province, Turkey”. *Journal of Agriculture and Environmental Sciences*, 4(1), 10-107.

300.**Headey, D., Alauddin, M., & Rao, D. S. P. (2010).** “Explaining Agricultural Productivity Growth: An International Perspective.”Agricultural Economics, 41, 1-14.

301.**Heidari, M. D., Omid M. & Akram A. (2011).** “Using Nonparametric Analysis (DEA) for Measuring Technical Effi ciency in Poultry Farms”. *Brazilian Journal of Poultry Science*, 13(4), 271-277.

302. **Hetemaki L (1996).** “Essays On The Impact Of Pollution Control On A Firm: A Distance Function Approach”. Finnish Forest Research Institute Research Papers 609, Helsinki, Finland

303. **Heltberg, R. (1998).** "Rural Market Imperfections and the Farm Size--Productivity Relationship: Evidence from Pakistan." *World Development*, 26(10), 1807-1826.

304. **Hendersonm, B. & Ross, K.(2002).** An Investigation of the Technical and Allocative Efficiency of Broadacre Farmers. Contributed Paper to the 46th Annual Conference of the Australian Agricultural and Resource Economics Society, Canberra.

305. **Henderson, B., Godde, C., Medina-Hidalgo, D. and Herrero, M. (2016).** “Closing System-Wide Yield Gaps To Increase Food Production And Mitigate Ghgs Among Mixed Crop–Livestock Smallholders In Sub-Saharan Africa”. Agricultural Systems, 143, 106-113.

306. **Hoppe, R. A., James M. M. & Penni, K. (2010).** Small Farms in the United States: Persistence under Pressure”. Economic Research Service, U.S. Department of Agriculture.

307. **Hossain, M. K, Kamil, A. A, & Mustafa, A. (2012).** “Stochastic Frontier Approach and Data Envelopment Analysis to Total Factor Productivity and Efficiency Measurement of Bangladeshi Rice”. PLOS ONE, 7(10).

308. **Hossain, M. M. (2015).** “Recent Perspective Of Herbicide: Review Of Demand And Adoption In World Agriculture”. *Journal of Bangladesh Agril. University*, 13(1), 19–30,

309. **Houshyar, E., Sheikh D. & Nassiri, S. M. (2010).** “Energy Efficiency for Wheat Production Using Data Envelopment Analysis (DEA) Technique”. *Journal of Agricultural Technology*, 6(4), 663-672.

310. **Huguenin, J. (2012).** “Data Envelopment Analysis (DEA) A pedagogical guide for decision makers in the public sector”. IDHEAP, Lausanne.

311. **Hussain, A. (2014).** “An Analysis Of Technical Efficiency Of Wheat Farmers In Punjab”. Ph.D. Thesis. Department of Economics and Agric. Econ. PMAS Arid Agriculture University, Rawalpindi, Pakistan.

312. **Hussain, A., Arsahd, B., Muhammad, Zubair, A. & Irfan, M. (2011).** “Agricultural Productivity and Rural Poverty in the Rice-Wheat and Mixed Cropping Zones of the Punjab”. *Pakistan Journal of Life and Social Sciences*, 9(2), 172-178.

313. **Hussain, A., Aujla, K. M. & Badar, N. (2014).** “Yield Gap Determinants For Wheat Production In Major Irrigated Cropping Zones Of Punjab, Pakistan”. *Pakistan Journal of Agricultural Research*, 23(3), 188.

314. **Hussain, A., Saboor, A. & Anwar, M. Z. (2012).** “Technical Efficiency of Wheat Production in Punjab (Pakistan): A Cropping Zone Wise Analysis”. *Pakistan Journal of Life and Social Sciences,* 10(2), 130-138.

315. **Hussain, I., Marikar, F & Jehangir, W. A. (2000).** “Productivity and Performance of Irrigated Wheat Farms across Canal Commands In The Lower Indus Basin”. International Water Management Institute, Report.

316. **Hussain, S. S. (1995).** "Analysis of Allocative Efficiency in Northern Pakistan: Estimation, Causes, and Policy Implications". The Pakistan Development Review, 34(4), 1167-1180.

317. **Ibrahim, A. S. S. (1984).** “Weed competition and control in sugarcane”. *Weed Research*, 2: 227-271.

318. **Idiong, I. (2007).** "Estimation of farm level technical efficiency in small scale swamp rice production in Cross River State of Nigeria: A Stochastic Frontier Approach." *World Journal of Agricultural Sciences*, 3(5), 653-658.

319. **IFAD (2013)**: Smallholders, Food Security, and the Environment.4

320.I**FAD. (2012)**. food prices: smallholder farmers can be part of the solution.https://www.ifad.org/what/operating_model/tags/1963528

321.**Iftikhar, L. K., Babar, S. & Zahoor, N. G. (2010).** "Best Irrigation Management Practices in Cotton". *Pakistan Journal of Botany*, 42(5), 3023- 3028.

322.**Ignatius, T. (2011).** "Effect Of Tillage Practices On Soil Fertility: A Case Study Of The West Mamprusi District Of Northern Region". Master's Thesis, Department Of Theoretical And Applied Biology, Kwame Nkrumah University Of Science And Technology

323.**Iliyaso, A. & Zainal, A. M. (2015).** "Evaluating contextual factors affecting the technical efficiency of freshwater pond culture systems in Peninsular Malaysia: A two-stage DEA approach". *Aquaculture Report,* 3, 12-17.

324.**Imtiaz, H., Hassnain S, M. & Yaqub, M. (2012).** "Productivity in Rice-Wheat Crop Rotation Of Punjab: An Application Of Typical Farm Methodology". *Pakistan Journal of Agricultural Research*, 25 (1), 1-11.

325.**IMF, (2015).** "Issues In Managing Water Challenges And Policy Instruments: Regional Perspectives And Case Studies". International Monetary Fund.

326.**Inoni, O. E. (2007).** "Allocative Efficiency in Pond Fish Production in Delta State, Nigeria: A Production Function Approach". *Agricultura Tropica Et Subtropica* , 40 (4), 127-134.

327.**International Fertilizer Association, (2014).** "African Leaders and Farmers Need To Launch an Agricultural Revolution to Eradicate Hunger and Malnutrition on the Continent within a Lifetime".FAO.

328.**Iqbal, M. & Ahmad, M. (2005).** "Science & Technology Based Agriculture Vision of Pakistan and Prospects of Growth". Proc. PSDE 20th AGM, 10-12.

329.**Iqbal, M., Ahmad, M. & Abbas, K. (2003).** "The Impact of Institutional Credit on Agricultural Production In Pakistan". *The Pakistan Development Review*, 42 (4), 469-485.

330.Iqbal, S., Maqbool, H. S. & Zakir, H. (2009)."Technical Efficiency of Citrus Production in Sargodha District, Punjab".*International Journal of Agriculture and Applied Sciences*, 1(2), 68-75.

331.Iqbal, A. R. (2010). "Shortage In Pakistan – A Crisis Around The Corner". ISSRA Papers.

332.**Iráizoz, B., Rapún, M., & Zabaleta, I. (2003)**."Assessing the Technical Efficiency Of Horticultural Production In Navarra, Spain". Agricultural Systems, 78, 387–403.

333.**Islam, K. M., Stefan, B. & John, S. (2011). "**Technical, Economic and Allocative Efficiency of Microfinance Borrowers and Non-Borrowers: Evidence from Peasant Farming in Bangladesh". *European Journal of Social Sciences*, 18(3), 361-377.

334.**IUCN (1992).**"The National Conservation Strategy Of Pakistan". Karachi, Pakistan: Author

335.**Khan, F. U. (2001).** "Tragic Failure Of Two Mega Drainage Projects". The Dawn, Karachi, Pakistan., p. B1.

336.**Jahanshahloo, G. R., Lotfi, H. F. & Balf, F. R. (2007).** "Finding Strong-Defining Hyper planes Of Production Possibility Set". *European Journal of Operational Research*, 177(1), 42-54.

337.**Jaime, M. M. & César, A. S. (2011).** "Participation in Organizations, Technical Efficiency And Territorial Differences: A Study Of Small Wheat Farmers In Chile". *Chilean journal of agricultural research,* 71(1), 104-113.

338.**Jarzębowski, S. (2013).** "Parametric And Non-Parametric Efficiency Measurement – The Comparison Of Results"**.** *Quantitative Methods in Economics*, 14(1), 170 – 179.

339.**Javed, M. I. & Khursheed, W. (2011).** "Analysis Of Technical And Scale Efficiency Of Smallholder Farms Of Rice-Wheat System In Punjab, Pakistan." *Journal of Agricultural Research*, 49(1).

340.**Javed, M. I. & Sultan, A. D. (2008).** "Efficiency Analysis of Rice-Wheat System In Punjab, Pakistan." *Pakistan Journal Agricultural Sciences*, 45(3).

341.**Javed, M. I. (2009).** "Efficiency Analysis of Cotton-Wheat and Rice-Wheat Systems in Punjab, Pakistan". Doctoral thesis, University of Agriculture Faisalabad

342.**Javed, M. I., & Sultan, A. D. (2010).** "Measurement Of Technical Efficiency Of Rice-Wheat System In Punjab, Pakistan Using DEA Technique." *Journal of Agricultural Research*, 48(2), 227-238.

343.**Javed, M. I., Sultan, A. D., & Asghar, A. (2009).** "An Efficiency Analysis of Punjab's Cotton-Wheat System". *The Lahore Journal of Economics*, 14(2), 97-124.

344.**Jema H. (2008).** "Economic Efficiency and Marketing Performance of Vegetable Production in Eastern and Central Parts of Ethiopia". Doctorial Thesis. Acta Universitatis Agriculture Sueciae (SLU)Uppsala, Sweden.

345.**Jenkins, L. & Anderson, M. (2003).** "A Multivariate Statistical Approach to Reducing the Number of Variables in Data Envelopment Analysis". *European Journal of Operational Research*, 147(1), 51- 61.

346.**Jha R. K. (2007).** Impacts Of Participatory Extension Program On Technical Efficiency Of Farmers In Nepal. South Asian Network of Economic Institutes (SANEI

347.**Jha, R. , Chitkara, Puneet and Gupta, S. (2000)** 'Productivity, technical and allocative efficiency and farm size in wheat farming in India: a DEA approach', Applied Economics Letters, 7,1, 1-5.

348.**Jirgi, A. J., Jordaan, H., Grové, B., &. Nmadu, J. N. (2015).** "Technical Efficiency of Millet/Cowpea Farmers in Kebbi State Nigeria: A Double Bootstrapping Approach". *British Journal of Economics, Management & Trade,* 5(3), 366-373.

349.**Judith, C.S., Lemley, A. T. & Hornsby, A. G. (2001).** "Health Effects Of Drinking Water Contamination". Florida Cooperative Extension Service, Institute of food and agriculture Sciences, University of Florida.

350.**Kalaitzandonakes, N. G. & Dunn, E. G. (1995).** "Technical Efficiency, Managerial Ability and Farmer Education in Guatemalan Corn Production: A Latent Variable Analysis". *Agricultural and Resource Economics Review*, 24.

351.**Kamruzzaman, M., Basil, M. & Moss, A. B. (2006).** "Evaluation of Economic Efficiency of Wheat Farms in a Region of Bangladesh under the Input Orientation Model". *Journal of the Asia Pacific Economy*, 11(1).

352.**Kamur, R. (2010).** "Research Methodology: A Step-by-Step Guide for Beginners". SAGE Publications.

353.**kaneva, K. (2016).** "Efficiency and Productivity of Bulgarian Farms". *Bulgarian Journal of Agricultural Science*, 22 (2), 176–181

354.**Karimov, A. (2013).** "Productive Efficiency of Potato and Melon Growing Farms in Uzbekistan: A Two Stage Double Bootstrap Data Envelopment Analysis". *Agriculture*, 3(3), 503-515.

355.**Karimov, A., Bola, M. A. & Amos, T. T. (2014).** "Production and scale efficiency of maize farming households in South-Western Nigeria". I*nternational Journal of Social Economics*, 41(11), 1087-1100.

356.**Karimov, A. & Miguel, N. (2017).** "Assessing Efficiency of input Utilization in Wheat Production in Uzbekistan".Restructuring land allocation, water use and agricultural value chains, Chapter: 4.3, Publisher: Bonn University Press, Editors: John P. A. Lamers, Asia Khamzina, Inna Rudenko, Paul L. G. Vlek,231-252.

357.**Kashiwagi, K., Atsushi K., Sami S. & Hiroko I. (2012).** "Technical Efficiency of Olive Growing Farms in Tunisia and Potential Demand for Olive Oil in Japan". *Journal of Arid Land Studies*, 22(1), 45-48.

358.**Kashiwagi, K., Mohamed, K., Mohamed, K., Monem, K., Atsushi, K., & Hiroko, I. (2013).** "Effect of Introduction of Irrigation on Technical Efficiency of Olive-Growing Farms in Tunisia". *Journal of Agricultural Science and Technology*, A (3), 667-676.

359.**Kasssem, H. S. (2014).** "Effectiveness Of Different Agricultural Extension Methods In Providing Knowledge And Skills In Disease Prevention: A Case Of Smallholder Poultry Production Systems In Dakhalia Governorate Of Egypt". *Asian Journal of Agricultural Extension, Economics & Sociology*, 3(2), 91-107.

360.**Kea, S., Hua, L., & Linvolak, P. (2016).** "Technical Efficiency and Its Determinants of Rice Production in Cambodia". Economies, 4(22), 1-17.

361.**Kelemu, K. & Negatu, W. (2016).** "Analysis Of Levels And Determinants Of Technical Efficiency Of Wheat Producing Farmers In Ethiopia". *African Journal of Agricultural Research*, 11(36), 3391-3403

362.**Kelly, E., Shalloo, L., Geary, U., Kinsella , A. & Wallace, M. (2012).** "Application of Data Envelopment Analysis to Measure Technical Efficiency on A Sample Of Irish Dairy Farms". *Irish Journal of Agricultural and Food Research*, 51, 63–77.

363.**Kerssen, T. M. (2014).** "Five Global Threats to the Survival of Family Farms in the International Year of Family Farming". Food First Backgrounder (Special Issue), 19(4).

364.**Khan, F. A. (2014).** Water-stressed crop economy. Dawn, Retrieved from http://www.dawn.com/news/1086093

365.**Khan S. A. M., Nawawi, C. & Rusdi, B. (2016).** "Determining Technical, Allocative and Cost Efficiencies Of Rice Farmers In Kedah, Malaysia Using Data Envelopment Analysis". AIP Conference Proceedings, 1782:1.

366.**Khan, A. & Muhammad, A. (2012).** "Farmers Perception Of Extension Methods Used By Extension Personnel For Dissemination Of New Agricultural Technologies In Khyber Pakhtunkhwa: Pakistan". *Sarhad Journal of Agriculture,* 28(3), 511-520.

367.**Khan, M. A., Munir, A. & Hasnain , S. H. (2012).** "Review of Available Knowledge on Land Degradation in Pakistan". Oasis Country Report, International Centre for Agriculture Research in Dry Area(ICARDA).

368.**Khan, H. & Farman, A. (2013).** "Measurement of Productive Efficiency of Tomato Growers in Peshawar, Pakistan". *Agric. Econ. Czech*, 59 (8), 381–388.

369.**Khan, H. & Imranullah, S. (2011).** "Measurement of Technical, Allocative and Economic Efficiency of Tomato Farms in Northern Pakistan." International Conference on Management, Economics and Social Sciences (ICMESS'2011) Bangkok Dec., 2011/

370.**Khan, F. U. (2001).** "Tragic Failure Of Two Mega Drainage Projects". The Dawn, Karachi, Pakistan., p. B1.

371.**Khan, I., Abbas, U. J. & Muhammad, N. K. (2102).** "Wheat and Berseem Cultivation: A Comparison of Profitability in District Peshawar". *Sarhad Journal of Agriculture*, 28(1), 83-88.

372.**Khan, M. A. (2003).** "Wheat Crop Management for Yield Maximization." Agricultural Department, Punjab, Pakistan.

373.**Khan, M. A., Ejaz, A. K. & Kaleem, U. (2015).** "Irrigated Wheat Response to Different Tillage Systems, Crop Residue Management Practices and Sowing Dates in Rice-Wheat Cropping System". *Pakistan Journal of Life & Social Sciences*, 13 (3), 162-169.

374.**Khan, M. A., Yaqoob, M., Ahtasham, G. & Saeed, A. (2005).** "Impact of Professional Factors on the Working Efficiency Of Agriculture Extension Field Staff In Punjab". *Journal of Agriculture and Social Sciences*, 1, 25-28.

375.**Khan, M. F., Jianhua, Z. & Muhammad, S. H. (2011).** "Land Distribution, Technological Changes and Productivity in Pakistan's Agriculture: Some Explanations and Policy Options". *International Journal of Economics and Management Sciences,* 1(1), 51-74.

376.**Khan, M. J, Shahid, A. & Khurrum N, S. (2008).** "Economic Analysis of Wheat Profitability in Peshawar Valley, NWFP". *Pakistan journal of life, sociology and science*, 6(2): 112-117.

377.**Khan, M. Z., Shah, T., Nawaz, A. & Rahman, A. (2017).** "Farmers' Empowerment Under Fsc Approach Regarding Selected Agricultural Inputs In Khyber Pakhtunkhwa, Pakistan". *International Journal of Agriculture and Enviornmental Research*., 3(2), 250 – 259.

378.**Khan, N., Idrees, S. M. & Muhammad, N. (2009).** "The Tractor Impact in the Rural Area of District Peshawar". *Sarhad Journal of Agriculture*, 25(3), 509-516.

379.**Khan, R. E. A. & Ghafar, S. (2103).** "Technical Efficiency of Tomato Production: A Case Study of District Peshawar (Pakistan)". *World Applied Sciences Journal*, 28 (10): 1389-1392.

380.**Khan, S. A. B., Azizul, B. & Razamin, B. (2016).** "Technical, Allocative, Cost, Profit and Scale Efficiencies in Kedah, Malaysia Rice Production: A Data Envelopment Analysis". *Journal of Agricultural and Biological Science*, 11(8), 322-335.

381.**Khan. (1990).** "Institutional Constraints In Lending Credit To Small Farmers The ADBP Case". A Seminar Report. Organized by Faculty of Agri. Economics and Rural Sociology, University Of Agriculture Faisalabad and Punjab agri. Research Coordination Board.

382.**Khoshnevisan, B., Bolandnazar, E., Barak, S., Shamshirband, S., Maghsoudlou, H., Altameem, T. A., & Gani, A., (2015).** "A Clustering Model Based On An Evolutionary Algorithm For Better Energy Use In Crop Production." *Stochastic Environmental Research and Risk Assessment,* 29,1921-1935

383.**Kiani, A. K. (2008).** "Farm Size and Productivity in Pakistan". *European Journal of Social Sciences*, 7(2), 42-52.

384.**Kiani, K. (2010).** "Drastic Decline In Chenab Water Flows", The Dawn, 21 January 2010.

385.**Kiatpathomchai, S. (2008).** "Assessing Economic and Environmental Efficiency of Rice Production Systems in Southern Thailand: An Application of Data Envelopment Analysis". PhD Thesis, Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management, Justus-Liebig University Giessen.

386.**Kleinhanß, W., Murillo, C., San Juan, C., & Sperlich, S. (2007).** "Efficiency, Subsidies And Environmental Adaptation Of Animal Farming Under CAP", *Agricultural Economics*, 36, 49– 64

387.**Kibaara, B. W. (2005).** Technical Efficiency in Kenyan's Maize Production: An Application of the Stochastic Frontier Approach.Msc theses. Department of Agricultural and Resource Economics. Colorado State University,USA.

388.**Kitila, G. & Alemu, B. (2014).** "Analysis of Technical Efficiency of Small Holder Maize Growing Farmers of Horo Guduru Wollega Zone, Ethiopia: A Stochastic Frontier Approach". Science, *Technology and Arts Research Journal*, 3(3), 204.

389.**Klerkx, L. & Leeuwis, C. (2009).** "The Emergence and Embedding Of Innovation Brokers at Different Innovation System Levels: Insights from The Dutch Agricultural Sector". *Technological Forecasting and Social Change*, 76, 849-860.

390.**Koc, B., Gull, M. & Parlakay, O. (2011).** "Determination of Technical Efficiency in Second Crop Maize Growing Farms in Turkey: A Case Study for the East Mediterranean in Turkey." *Asian Journal of Animal and Veterinary Advances*, 6(5), 488-498.

391.**Koondhar, M. A., Lingling Q. B., Habibullah, M. & Abbas, A. (2016).** "Comparing Economic Efficiency Of Wheat Productivity In Different Cropping Systems Of Sindh Province, Pakistan". *Journal of the Saudi Society of Agricultural Sciences*, 1-10

392.**Koopmans, T. C. (1951).** "An Analysis of Production as an Efficient Combination of Activities. Activity Analysis of Production and Allocation". Jhon Wiley and Sons, Inc

393.**Krasachat, W. (2003).** "Technical Efficiencies of Rice Farms In Thailand: A Nonparametric Approach". Proc. Hawaii International Conference on Business, Honolulu.

394.**Krasachat, W. (2004).** "Technical Efficiencies of Rice Farms in Thailand: A Non-Parametric Approach." The Journal of American Academy of Business, 4(1), 64-69.

395.**Kristo, I., Gyapjas, J. & Szekeres, A. (2006).** "Effect Of Sowing Date And Seeding Rate On Different Winter Wheat Cultivars". Available online at http://agricultura.usab-tm.ro/ Simpo 2007 pdf/

396.**Kuo, H. F, Hsiang, L. C. & Ku-wan, T. (2014). "**Analysis of Farming Environmental Efficiency Using a DEA Model with Undesirable Outputs".*APCBEE Procedia*, 10, 154-58.

397.**Kusz, D. (2014).** "Modernization Of Agriculture Vs Sustainable Agriculture". Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, 14(1), 171-178.

398.**Kugelman, M. & Hathaway, R. M. (2010)**. " Hunger Pains: Pakistan's Food Insecurity". Woodrow Wilson International Center for Scholars, Washington, D.C.

399.**Labarthe, P. & Laurent, C (2013).** Privatization of agricultural extension services in the EU: Towards a lack of adequate knowledge for small-scale farms? Food Policy 38, 240-252 .

400.**Ladvenicová, J. & Silvia Miklovičová. (2015).** The Relationship Between Farm Size And Productivity In Slovakia. Visegrad Journal on Bioeconomy and Sustainable Development. DOI: 10.1515/vjbsd-2015-0011.

401.**Lambarraa, F., Teresa, S. & José, M. G. (2006).**"Technical Efficiency Analysis And Decomposition Of Productivity Growth Of Spanish Olive Farms". European Association of Agricultural Economists) Seminar, Chania, Greece.

402.**Lambarraa, F., Teresa, S. & José, M. G. (2011).** "Technical efficiency and productivity analysis of Spanish citrus farms". *New Medit*, 10(4), 35-39.

403.**Lambin, E. F., & Meyfroidt, P., (2011).** "Global Land Use Change, Economic Globalization, And The Looming Land Scarcity". Proceedings of the National Academy of Sciences 108, 3465.

404.**Langemeier, M. (2010).** "Relative Technical and Cost Efficiency of No-Till Farms. *Journal of International Farm Management*, 5(2), 1-11.

405.**Lansink, A.O., Pietola, K., & Bäckman, S. (2002)**. "Efficiency And Productivity Of Conventional And Organic Farms In Finland 1994-1997". *European Review of Agricultural Economics*, 29(1), 51–65.

406.**Lanker, S. & Gunnar, B. (2015).** "Productivity and technical efficiency of organic farming – A literature survey". *Acta fytotechn. zootechn*, 18(Special Issue), 74-77

407.**Lanker, S. & Gunner, B. (2017).** "Efficiency Analysis Of Organic Farming Systems – A Review Of Concepts, Topics, Results And Conclusions". German Journal of Agricultural Economics, Accepted.

408. **Latif, M., Syed S, H. , & Muhammad, U. R . (2016).** “Adoption of High Efficiency Irrigation Systems to Overcome Scarcity of Irrigation Water in Pakistan”. *Journal of Life and Environmental Sciences*, 53(4): 243–252 (2016).

409. **Latruffe, L. (2010).** “Competitiveness, Productivity and Efficiency in the Agricultural and Agri-Food Sectors”, OECD Food, Agriculture and Fisheries Working Papers, No. 30, OECD Publishing.

410. **Latruffe, L., Balcombe, K., Davidova, S., Zawalinska, K. (2004)** “Determinants of technical efficiency of crop and livestock farms in Poland”. *Applied Economics,* 36(12), 1255–1263.

411. **Latruffe, L., Davidova, S. & Balcombe, K. (2008a).** “Application of a Double Bootstrap to the Investigation of Determinants of Technical Efficiency of Farms In Central Europe”. *Journal of Productivity Analysis*, 29, 183-191.

412. **Latruffe, L., Fogarasi, J., Desjeux, Y. (2012)** Efficiency, productivity and technology comparison for farms in Central and Western Europe: The case of field crop and dairy farming in Hungary and France, Economic Systems, 36, 264–278

413. **Latruffe, L., Guyomard, H., Le Mouël, C. (2008b)**. “Impact of CAP Direct Payments on French Farms’ Managerial Efficiency”, 12th Congress of the European Association of Agricultural Economists – EAAE.

414. **Laure, S. & Latruffe, L. (2008).** “Agglomeration Externalities and Technical Efficiency in Pig Production”. 12th Congress of the European Association of Agricultural Economists.

415. **Leech, N & Onwuegbuzie, A. (2008).** “A Typology Of Mixed Methods Research Designs”. *Quality and Quantity*, 43(2), 265-275.

416. **Lema, T. Z., Solomon, A. T. & Fentahun, A. A. (2017).** “Analysis of Technical Efficiency Of Rice Production In Fogera District Of Ethiopia: A Stochastic Frontier Approach”. MPRA Paper No. 77774, posted 21 March 2017

417. **LI, D., Teruaki, N. & Shigeyoshi T. (2011).** “Measurement of Corn Production Efficiency in Different Counties of Hebei Province, China: A Model Based on Data Envelopment Analysis”. *Journal of Faculty of Agriculture., Kyushu Univ*., 56 (2), 409–415

418. **Lilienfeld, A., & Asmild, M. (2007).** “Estimation of Excess Water Use in Irrigated Agriculture: A Data Envelopment Analysis Approach*”. Agricultural Water Management*, 94, 73-82.

419. **Linh, T. T., Teruaki N. & Yosuke C. (2015).** “Productive Efficiency of Crop Farms in Viet Nam: A DEA with a Smooth Bootstrap Application”. *Journal of Agricultural Science*, 7(5), 37-46.

420. **Linh, V. H. (2012).** “Efficiency of Rice Farming Households in Vietnam*”. International Journal of Development Issues*, 11(1), 60-73.

421. **Lipton, M. (2005).** The Family Farm in a Globalizing World . The Role of Crop Science in Alleviating Poverty. IFPRI

422. **Liu, M. X. & Yong, Q. G. (2008).** “Effects Of Ridge-Furrow Tillage On Soil Water And Crop Yield In Semiarid Region”. The 2nd International Conference on 16-18 May.

423. **Llewelyn, R. V. & Williams, J. R. (1996).** “Nonparametric Analysis of Technical, Pure Technical, And Scale Efficiencies for Food Crop Production In East Java, Indonesia”. *Agricultural Economics*, 15, 113-126.

424. **Lovell, C. A. K, & Sickles, R. K. (1983).** "Testing Efficiency Hypothesis in Joint Production: A Parametric Approach", *Review of Economics and Statistics*, 65.

425.**Lovell C. A. K., Richardson S., Travers P. & Wood L. L. (1994).** “Resources and Functionings: a New View of Inequality in Australia, in Models and Measurement of Welfare and Inequality”. Eichhorn W., editor. Springer-Verlag; Berlin.

426.**Lowder, S. K., Skoet, J. & Singh, S. (2014).** What Do We Really Know About The Number And Distribution Of Farms And Family Farms Worldwide”? Background paper for The State of Food and Agriculture, ESA Working Paper No. 14-02. Rome, Italy.

427.**Lowder, S. K., Jakob, S. & Terri, R. (2016).** “The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide”. *World Development*, 87,16–29

428.**Lu, H. (2012).** “Chinese Energy Efficiency Analysis Based on DEA Model and the Influencing Factors---from a Regional Approach”. Master thesis, School of Economics and Management, Lund University, Sweden.

429.**Luik, H., Seinlenthal, J. & Värnik, R. (2009)**. “Measuring the input-orientated technical efficiency of Estonian grain farms in 2005–2007”, *Food Economics - Acta Agriculturae Scandinavica*, Section C, 6, 204–210

430.**Lukuyu, B., Place F., Franzel S., Kiptot, E. (2012).** “Disseminating Improved Practices: Are Volunteer Farmer Trainers Effective”. *Journal of Agriculture Education and Extension*, 18 (5), 525–540

431.**Lundvall, B. Å. (1992).** “National Systems of Innovation: Towards a Theory of Innovation and Interactive learning, London: Pinter.

432.**Luqman, M., Javed, A. & Asghar, N. (2005).** “Impact of Administrative Changes on the Working Efficiency of Extension Field Staff after Decentralization in the Punjab, Pakistan”. *Journal of Agriculture and Social Sciences Pakistan,* 1(3), 223-226.

433.**McDonald, J. (2008).** “Allowing For Different Frontier And Sub-Frontier Relationships In Second Stage Dea Efficiency Analyses”. Flinders Business School, 19, Flinders University.

434.**Madau, F. A. (2015).** “Technical and Scale Efficiency in the Italian Citrus Farming: A Comparison between SFA and DEA Approaches”. *Agricultural Economics Review,* 16(2), 15-27.

435.**Mądry W. , Roszkowska-Mądra B. , Gozdowski D. , Hryniewski R. (2016).** “Some Aspects Of The Concept, Methodology And Application Of Farming System Typology”. *Electronic Journal of Polish Agricultural Universities*, 19(1), 12.

436.**MAF. (2007).** “The State of Food and Agriculture in Lao PDR”. Report to the 34th Session of the FAO Conference, Rome, Italy, 17-24.

437.**Mahdi N., Sghaier M. & Bachta M.S. (2008)**. “Efficiency Of Water Use In The Irrigated Private Schemes In Smar Watershed, South-Eastern Tunisia. Options Méditerranéennes”. *Série A. Séminaires Méditerranéens*, 88, 289-300.

438.**Mahesh, R. (2000).** Farm Size-Productivity Relationship: Some Evidence from Kerala, KIED Working Paper, Kerala Institute for Environment and Development, India.

439.**Mahmood, H. Z., Muhammad, Q., Khan, M. & Husnain, M. I. U. (2014).** “Re-Examining the Inverse Relationship between Farm Size and Productivity in Pakistan”. *The Journal of Animal & Plant Sciences*, 24(5), 2014, 1537-1546.

440.**Mahmood, M. A., Sheikh, A. D., Hussain, A. & Abbas, M. (2006).** “Recommended Technologies and Production Practices at Farm Level: Wheat Scenario”. *Pakistan Journal of life social science*, 4(1-2), 52-57.

441.**Mahmood, N., Ali, T., Bajwa, M.S., ShahbaZ, M. & Chattha, M. B. (2013).** "Analysis Of The Adoption Of Wheat Sowing Recommendations Among Small Farmers Using Water Saving Interventions". *The Journal of Animal & Plant Sciences,* 23(1), 309-312.

442.**Malik, S. J. (1999).** "Poverty and Rural Credit: The Case of Pakistan". Pakistan Institute of Development Economics, Islamabad, Pakistan.

443.**Malmquist, S. (1953)**. "Index Numbers and Indifference Surfaces", *Trabajos de Estatistica*, 4, 209–242.

444.**Manevska-Tasevska, G. (2012).** "Efficiency Analysis of Commercial Grape-Producing Family Farms in the Republic of Macedonia". Doctoral Thesis, Swedish University of Agricultural Sciences, Uppsala.

445.**Manjunatha, A. V., Speelman, S., Chandrakanth, B. & Van H. G. (2011).** "Impact of Groundwater Markets in India on Water Use Efficiency: A Data Envelopment Analysis Approach". *Journal of Environmental Management* 92, 2924- 2929.

446.**Marchand, S. (2010).** "Technical Efficiency, Farm Size and Tropical Deforestation in the Brazilian Amazonian Forest". CERDI, Etudes et Documents, E 2010.12.

447.**Mari, F, M. (2009).** "Structure And Efficiency Analysis Of Vegetable Production And Marketing In Sindh, Pakistan." Ph.D Thesis, Department Of Agricultural Economics Faculty Of Agricultural Social Sciences Sindh Agriculture University, Pakistan.

448.**Mari, F. M. & Heman D. L. (2007).** "Measuring Production Function and Technical Efficiency of Onion, Tomato, and Chillies Farms in Sindh, Pakistan". *The Pakistan Development Review 46*, 4(2), 1053–1064.

449.**Mari, J., Shahzadi, A. & Chachar, Q. (2011).** "Perception of the Problems in Farming Community at Hyderabad Pakistan". *Journal of Agricultural Technology*, 7, 9-17.

450.**Martey, E., Alexander N. W. and Prince M. E. (2015).** "Impact of Credit on Technical Efficiency of Maize Producing Households in Northern Ghana". Selected Paper Prepared for Presentation at the Centre for the Study of African Economies (CSAE) Conference 2015, University of Oxford,

451.**Martic, M. M., Marina S. N., & Alenka B. (2009).** "Data Envelopment Analysis - Basic Models and their Utilization". *Organizacija*, 2, 37-43.

452.**Martinez, E. R. & Tadeo, A. J. P. (2004).** "Analysing Farming System with Data Envelopment Analysis. Citrus Farming in Spain". *Agriculture Systems*, 82(1), 17-30.

453.**Masterson, T. (2007).** "Productivity, Technical Efficiency, and Farm Size in Paraguayan Agriculture". Working Paper No. 490

454.**Matchaya, G. (2007)**. "Does size of operated area matter? Evidence from Malawi's Agricultural Production". *International Journal of Agriculture and Rural Development*, 10, 114-125.

455.**Mburu, S., Chris, A. O. & Richard, M. (2014). "**Analysis of Economic Efficiency and Farm Size: A Case Study of Wheat Farmers in Nakuru District, Kenya". *Economics Research International*. 14, Article ID 802706, 10 pages

456.**Meeusen, W. & Van Den Broeck, J. (1977).** "Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error". *International Economic Review*, 18, 435-444.

457.**Mekonnen, D., Afreen, S. & Claudia, R. (2016).** "Drivers Of Groundwater Use And Technical Efficiency Of Groundwater, Canal Water, And Conjunctive Use In Pakistan's Indus Basin Irrigation System". *International Journal of Water Resources Development*, 32(3), 459–476.

458.**Mekonnen, E. (2013).** “Economic Efficiency Of Sesame Production In Selamago District Of South Omo Zone, Southern Ethiopia”. M. Sc Thesis, Haramaya University.

459.**Melkaw, A. B. (2014).** “Farm Household Production Efficiency Analysis in Ethiopia: The Case of Dessie Zuria District”. MSc Thesis, University of Wageningen, Neatherland.

460.**Memon, I. N., Sanaullah, N. & Abdul, W. (2016).** “Analysis on Technical Efficiency of Hybrid Maize Production in District Mirpurkhas, Sindh”. *Management and Organizational Studies*, 3(2), 31-38.

461.**Mendola. (2007).** Farm Household Production Theories: A Review of “Institutional and “Behavioral” Responses. *Asian Development Review*, 24(1), 49-68.

462.**Mian, N. I. & Khan, M. A. (1981).** “A Study of Cropping Pattern in Peshawar District”. IDS NWFP Agric. Univ. Peshawar, 8, 76.

463.**MINFAL (2004).** “Agricultural Perspective and Policy”. Ministry of Food, Agriculture and Livestock, Islamabad, Pakistan.

464.**Miraj, N. & Shahid, A. (2014).** “Estimation of Technical Efficiency of Garlic Farms in District Peshawar, Pakistan: A Stochastic Frontier Analysis”. *International Journal of Innovation and Scientific Research*, 9(1), 140-149.

465.**Mirza, F. M., Noshaba, N., Mubashir, M. & Burhan, A. (2015).** “Determinants of Technical Efficiency Of Wheat Farms In Pakistan”. *Pakistan Journal of Agriculture Sciences*, 52(2), 565-570.

466.**Mkhabela, T. (2005).** “Technical Efficiency in a Vegetable based Mixed-Cropping Sector In Tugela Ferry, Msinga District, Kwazulu-Natal”. Agrekon, 44(2), 187-204.

467.**Mohapatra, R. (2013).** “Farm Level Technical Efficiency in Paddy Production: A Translog Frontier Production Function Approach”. International Journal of Advanced Research, 1(3), 300-307.

468.**Mojid, M. A., Mia, M. S., Saham A. K. & Tabriz, S. S. (2013).** “Growth Stage Sensitivity of Wheat to Irrigation Water Salinity”. *J. Bangladesh Agril. Univ*. 11(1), 147–152.

469.**Mokgalabone, M. S. (2015).** “Analyzing the Technical and Allocative Efficiency of Small-scale Maize Farmers In Tzaneen Municipality Of Mopani District: A Cobb-Douglas And Logistic Regression Approach”. Master’s thesis, Department of Agricultural Economics and Animal Production, University Of Limpopo, SA.

470.**Mondal, B., Alka S. & Girish K. J. (2012).** “Impact of Watershed Development Programmes on Farm-specificTechnical Efficiency. A Study in Bundelkhand Region of Madhya Pradesh”. *Agricultural Economics Research Review*, 25(2), 299-308.

471.**Mondal, M. (2011).** “Causes of Yield Gaps and Strategies for Minimizing the Gaps in Different Crops of Bangladesh”. *Bangladesh Journal of Agricultural Research*, 36(3), 469-476.

472.**Moock, P. R. (1981).** “Education and Technical Efficiency in Small-Farm Production”. *Economic Development and Cultural Change*, 29, 723-739.

473.**Morri, M., Kell,y V., Kopicki R. J. & Byerlee, D. (2007).** “*Fertilizer Use In African Agriculture: Lessons Learned And Good Practice Guidelines*. The World Bank, Washington

474.**Msoffe, G. & Patrick, N. (2016).** “Farmers' Access to Poultry Management Information in Selected Rural Areas of Tanzania”. *Library & Information Science Research*, 38(3), 265-271.

475.**Mugera, A. W. & Michael, R. L. (2011).** “Does Farm Size and Specialization Matter for Productive Efficiency? Results from Kansas”.*Journal of Agriculture and Applied Economics*, 43(4), 515-528.

476.**Mughal, F. H. (2002).** "Irrigation-Induced Salinity: Environmental Impacts". The Dawn, Karachi, Pakistan.

477.**Muller, N. D., James, S. G. & Jonathan., F. A. (2012)**. "Closing Yield Gaps through Nutrient And Water Management". Research Letter, Macmillan Publisher.

478.**Mulwa, M. R., Emrouznejad, A. & Murithi, F. M. (2009).** "Impact of liberalization on efficiency and productivity of sugar industry in Kenya". *Journal of Economic Studies*, 36 (3), 2009, 250-264.

479.**Murgai, R., Ali, M. & Byerlee, D. (2001).** "Productivity Growth And Sustainability In Post–Green Revolution Agriculture: The Case Of The Indian And Pakistan Punjabs". The World Bank Research Observer, 16, 199.

480.**Murthy, D. S., Sudha, M., Hegde, M. R. & Dakshinamoorthy, V. (2009).** "Technical Efficiency and Its Determinants in Tomato Production in Karnataka, India: Data Envelopment Analysis (DEA) Approach". *Agricultural Economics Research Review*, 22, 215-224.

481.**Mustafa, D., Akhter, M. & Nasrallah. (2013).** "Understanding Pakistan's Water-Security Nexus". United States Institute of Peace, Washington DC, USA .

482.**Mwajombe, K. K. & Malongo R. S. (2015).** "Measuring Farm-level Technical Efficiency of Urban Agriculture in Tanzanian Towns: The Policy Implications". *World Journal of Social Science*, 2(1), 62-72.

483.**Naceur, M. & Sghaier, M (2013).** "The Technical Efficiency of Collective Irrigation Schemes in South-Eastern Of Tunisia". International Journal of Sustainable Development & World Policy, 2(7), 87-103.

484.**Nadeem, M. A., Muhammad, I. & Khuram, M. (2013).** "Effect of Different Weed Control Practices and Sowing Methods on Weeds and Yield of Cotton". *Pakistan Journal of Botany*, 45(4), 1321-1328.

485.**Naeem, M. K., Bashir, M. K., Hussain, B. & Abbas, M. (2007).** "Assessment of Profitability of Sugarcane Crop in Faisalabad District". *Pakistan Journal of Social Sciences*, 5(1-2), 30-33.

486.**Nagayets, O. (2005).** "Small Farms: Current Status and Key trends." The Future of Small Farms".

487.**Naheed, A. & Ghulam, G. (2010).** "Projections of Crop Water Requirement in Pakistan under Global Warming". *Pakistan Journal of Meteorology*, 7(13), 45-51.

488.**Najjuma, E., Kavoi, M. M. & Mbeche, R. (2016).** "Assessment of Technical Efficiency of Open Field Production in Kiambu County, Kenya (Stochastic Frontier Approach)". *Journal of Agriculture, Science and Technology*, 17(2), 21-39.

489.**Naqvi, S. A. & Ashfaq M. (2013). "**Technical Efficiency Analysis Of Hybrid Maize Production Using Translog Model Case Study In District Chiniot, Punjab (Pakistan)". *Agricultural Sciences,* 4(10), 536-540

490.**Nargis, F. & Lee, S. H. (2013).** "Efficiency Analysis Of Boro Rice Production In North-Central Of Bangladesh." *The Journal of Animal & Plant Sciences*, 23(2), 527-533.

491.**Naseer, A., Muhammad, A. & Sarfaraz, H. (2016).** "Current Status and Key Trends in Agricultural Land Holding and Distribution in Punjab, Pakistan: Implications for Food Security". *Journal of Agricultural Studies,* 4(4), 14-27.

492.**Natarja, N. R & Johnson, A. J. (2002).** "Guidelines for Using Variable Selection Technique in Data Envelopment Analysis". *European Journal of Operation Research*, 215, 662-669.

493.**Nazir, A., Ghulam, A. J. & Mumtaz, A. J. (2013).** "Factors Affecting Sugarcane Production in Pakistan". *Pakistan Journal of Commerce and Social Sciences*, 7 (1), 128-140.

494.**Nchare, A. (2007).** "Analysis of Factors Affecting the Technical Efficiency of Arabica Coffee Producers in Cameroon". AERC Research Paper 163, African Economic Research Consortium, Nairobi.

495. **Ndjodhi, M. N. (2016).** "Sources of Technical Efficiency of The Smallholder Maize Farmers At Etunda Irrigation Project In Omusati Region, Namibia". Master's Thesis, Department of Agricultural Economics, University of the Free State, Bloemfontein.

496. **Negash, R. (2007).** "Determinants Of Adoption Of Improved Haricot Bean Production Package In Alaba Special Woreda, Southern Ethiopia, Haramaya University, Ethiopia.

497. **Nelson, R. R. (1993).** "National Innovation Systems: A Comparative Study". Oxford: Oxford University Press.

498. **Neumann, K., Verburg, P. H., Stehfest, E. & Müller, C. (2010).** "The Yield Gap Of Global Grain Production: A Spatial Analysis". Agricultural Systems, 103, 316–326.

499. **Ngenoh, E., Mutai, B. K. Chelang, P. K. & Koech, W. (2015).** "Evaluation of Technical Efficiency of Sweet Corn Production among Smallholder Farmers in Njoro District, Kenya". Journal of Economics and Sustainable Development, 6(17), 183-192.

500. **Nizami, M. (2008).** "The water bomb", The Nation, 27 May 2008.

501. **Niazi, T. (2003).** "Land Tenure, Land Use, and Land Degradation: A Case for Sustainable Development in Pakistan". *Journal of Environment & Development*, 12(3), 275-293.

502. **Nishimizu, M. & Page, J. (1982).** "Total Factor Productivity Growth, Technological Progress And Technical Efficiency Change: Dimensions Of Productivity Change In Yugoslavia 1967-1978", Economic Journal, Vol. 92, pp. 920-936

503. **Nin-Pratt, A., Johnson, M., Magalhaes, E., You, L., Diao X., & Chamberlin J. (2011).** "Yield Gaps and Potential Agricultural Growth in West and Central Africa". International Food Policy Research Institute (IFPRI); Washington, D.C

504. **Noonari, S., Irfana, N. M., Muhammad, M. & Maria, P. (2015).** "Estimating Productivity Gap and Contribution of Wheat Production in Sindh Pakistan". *Journal of Resources Development and Management*, 10, 104-116.

505. **Nurwahidah, S., Dwidjono, H.D. & Lestarmi, R. W. (2015).** "Technical Efficiency of Corn Farming in Sumbawa Regency". *International Journal of Computer Applications*, 126(7), 36-40.

506. **Nyagaka, D. O., Obare, G. A., Omiti, J. M. & Nguyo, W. (2010).** "Technical Efficiency in Resource Use: Evidence from Smallholder Irish Potato Farmers in Nyandarua North District, Kenya". *African Journal of Agricultural Research*, 5, 1179-1186.

507. **Nyanjong, O. J. & Lagat, A. K. (2012).** "Analysis Of Efficiency In Sugarcane Production: The Case Of Men And Women Headed Households In Sony Sugar Out -Grower Zone, Rongo And Trans-Mara Districts, Kenya". MPRA Paper No. 40796.

508. **Obasi, P. (2007).** "Farm size-productivity relationships among arable crops farmers\'in Imo State, Nigeria." *International Journal of Agriculture and Rural Development*, 9(0), 91-99.

509. **Odeck, J. (2007).** "Measuring Technical Efficiency and Productivity Growth: A Comparison of SFA And DEA On Norwegian Grain Production Data". *Applied Economics,* 39(20), 2617-2630.

510. **Odeck, J. (2009).** "Statistical Precision of DEA and Malmquist Indices: A Bootstrap Application to Norwegian Grain Producers", *Omega*, 37, 1007–1017.

511. **Odetola, T. & Chinonso, E. (2013).** "Contribution of Agriculture to Economic Growth in Nigeria". The 18th Annual Conference of the African Econometric Society (AES) Accra, Ghana

512.**Oduol, J. B. A., Hotta, K., Shinkai, S. & Tsuji, M. (2006).** “Farm size and Productive Efficiency: Lessons from Smallholder Farms in Embu District, Kenya”. *Journal of the Faculty of Agriculture*, 51, 449-458.

513.**OECD. (2012).** “Agricultural Policies for Poverty Reduction”. Paris, France.

*514.***Oerke, E. C. (2006).** “Crop Losses to Pests”*. Journal of Agricultural Science, 144, 31–43.*

515.**Ofuoku A. U. (2012)**. “Influence Of Extension Agents’ And Farmers’ Communications Factors On The Effectiveness Poultry Technology Messages”. *Tropical Agricultural Research & Extension*, 15(1), 14-23.

516.**Ogundari, K. (2013).** "Crop Diversification and Technical Efficiency in Food Crop Production: A Study of Peasant Farmers in Nigeria". *International Journal of Social Economics*, 40(3), 267-287.

517.**Ogundari, K. & Ojo, S. O. (2006).** “An Examination of Technical, Economic and Allocative Efficiency of Small Farms: The Case Study of Cassava Farmers In Osun State Of Nigeria”. *Journal Central Europe Agriculture*, 7(3) 423-432.

518.**Ogundari, K. & Ojo, S. O. (2007).** “An Examination of Technical, Economic and Allocative Efficiency of Small Farms: The Case Study of Cassava Farmers in Osun State of Nigeria”. *Bulgarian Journal of Agricultural Science,* 13, 185-195.

519.**Ogundari, K. (2006).** “Determinants of Profit Efficiency among Small Scale Rice Farmers In Nigeria: A Profit Function Approach”. Poster paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia.

520.**Ogundari, K. (2008).** “Resource-Productivity, Allocative Efficiency and Determinants of Technical Efficiency of Rainfed Rice Farmers: A Guide for Food Security Policy in Nigeria”. *Journal of Sustainable Development in Agriculture & Environment*, 3(2), 20-33.

521.**Ogundari, K., Ojo, S. O. & Ajibefun, I. A. (2006).** “Economies of Scale and Cost Efficiency in Small Scale Maize Production: Empirical Evidence from Nigeria”. *Journal of Social Sciences*, 13(2), 131-136.

522.**Ogunniyi, L. T., Komolafe, O. D., Fanifosi, G. E. & Rasaki W. A. (2015).** “Production Efficiency of Rice Production in Kwara State, Nigeria”. *International Journal of Agriculture and Crop Sciences*, 8(3), 339-345.

523.**OKON U. E. , ENETE, A. A., (2010).** "Technical efficiency and its determinants in garden egg (solanum spp) production in uyo metropolis, akwa ibom state." field actions science reports. *The journal of field actions*, (special issue 1).

524.**Okoye, B. C., Onyenweaku, C. E. & Agwu, A. E. (2008).** Technical Efficiency of Small-Holder Cocoyam Farmers in Anambra State Nigeria: Implications for Agricultural Extension Policy. *Journal of Agricultural Extension*, 12(1), 107-116.

525.**Okoye, B. C., Onyenweaku, C. E. and Asumugha, G. N. (2006).** Allocative Efficiency of Small-Holder Cocoyam Farmers in Anambra State, Nigeria. MPRA Paper No. 17362, Online at http://mpra.ub.uni muenchen.de/17362/

526.**Oladele, O. I. (2006).** “Multilinguality of Farm Broadcast and Agricultural Information Access in Nigeria”. *Nordic Journal of African Studies*, 15 (2), 199-205.

527.**Olapade, O. F., Adedeji, I. A. & Ogunniyi, L. T. (2013).** “Effects Of The Adoption Of Extension Technologies On The Technical Efficiency Of Maize Farmers In Oyo State”. *International Journal of Advancements in Research & Technology*, 2(12), 58-74.

528.**Olarinde, L. O. (2011).** “Analysis of Technical Efficiency Differentials among Maize Farmers in Nigeria”. AERC Research Paper 232, African Economic Research Consortium, Nairobi.

529.**Olasup, M. A. & Carolyn, A. F. (2013).** “Technical Efficiency Of Microfinance Banks In Southwest, Nigeria: Input And Output Oriented Measures”. *Net Journal of Business Management*, 1(1), 7-13.

530.**Olson, K. & Vu, L. (2007).** “Economic Efficiency and Factors Explaining Differences between Minnesota Farm Households”. Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Portland.

531.**Omonona, B. T., Egbetokun, O. A. & Akanbi, A. T. (2010).** “Farmers Resource – Use and Technical Efficiency in Cowpea Production in Nigeria*”. Economic Analysis & Policy*, 40(1), 87-95.

532.**Ortner, K. M., Hambrusch, J. & Kirner, L. (2006).** “The Efficiency of Dairy Farms in Austria: Do Natural Conditions Matter?.” Federal Institute of Agricultural Economics, Vienna.

533.**Osamwonyi, I. O. & Kennedy, I. (2015).** “Benchmarking and Ranking of Quoted Manufacturing Companies in Nigeria: A Data Envelopment Analysis Approach”. *International Journal of Financial Research,* 6(4), 90-98.

534.**Otchia, C. S. (2014).** “Agricultural Modernization, Structural Change and Pro-poor Growth: Policy Options for the Democratic Republic of Congo”.*The Official Journal of the Pan-Pacific Association of Input-Output Studies (PAPAIOS),* 3(8).

535.**Otieno, D. J., Lionel, H. & Eric, R. (2012).** “Determinants of Technical Efficiency In Beef Cattle Production In Kenya”. Paper Presented at International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguacu, Brazil.

536.**Otieno, D. J., Lionel, H. & Eric, R. (2014).** “Assessment of Technical Efficiency and its Determinants in Beef Cattle Production In Kenya”. *Journal of Development and Agricultural Economics,* 6(6), 267-278.

537.**Owens, T., J. Hoddinott & B. Kinsey. (2001).** “The Impact Of Agricultural Extension On Farm Production In Resettlement Areas Of Zimbabwe”. Working Paper CSAE WPS/2001-6. Centre for the Study of African Economies, University of Oxford, UK

538.**Padilla-Fernandez, M. D & Peter, L. N. (2012).** “Farm Size And Its Effect On The Productive Efficiency Of Sugar Cane Farms In Central Negros, The Philippines”. *J. ISSAAS*, 18(1), 49-61.

539.**Padilla-Fernandez, M. D. & Peter, L. N. (2009).** “Technical Efficiency In The Production Of Sugar Cane In Central Negros Area, Philippines: An Application Of Data Envelopment Analysis”. *J. ISSAAS*, 15(1), 77-90

540.**Paller, E. C., Ramirez, A. H. M. and Malenab, E. T. (2001).** “Weed Management In Grain Corn: Comparing Calendared Treatments And Use Of Weed Control Action Indicators (WCAI)”. *Philippine Journal of Crop Sciences*, 27(1), 9–12.

541.**Papke, L.E., & Wooldridge, J.M. (1996).** Econometric Methods For Fractional Response Variables With An Application To 401(K) Plan Participation Rates”Journal of Applied Econometrics. 11 (6), 619–632.

542.**PARC, (2012).** National Coordinated Wheat Programme. http://www.parc.gov.pk/

543.**Parikh A, Ali F., Shah, M. K. (1995).** “Measurement of Economic Efficiency in Pakistani Agriculture”. *American Journal of Agricultural Economics*., 675_685.

544.**Parikh, A., Farman A. & Mir K. S. (1995).** “Measurement of Economic Efficiency in Pakistan Agriculture”. *American Journal of Agricultural Economics*, 77(3): 675–685.

545.**Park, J. & Sung, S. (2016).** “Integrated Approach to Construction of Benchmarking Network in DEA-Based Stepwise Benchmark Target Selection”. *Sustainability* , 8, 2-15.

546.**Patton, M Q. (2002).** “Qualitative Research & Evaluation Methods”. 3rd Edition. Sage Publications: Thousand Oaks, USA.

547.**Petrovska, M., Aleksandra M. S., Bo Ö. & Ana K. (2013).** “Technical Efficiency of Macedonian Pig Farms”. *Agroeconomia Croatica*, 3(1), 18-25.

548.**Photakoun, V. (2010)**. “The Role of Capacity Building For Livestock Extension And Development In Lao PDR”. Master’s Thesis. Charles Sturt University, Australia.

549.**Picazo-Tadeo, A. J, Gomez-Limon J.A. & Reig-Martinez, E. (2011). “**Assessing Farming Eco-Efficiency: A Data Envelopment Analysis Approach”. *Journal of Environmental Management*, 92(4), 1154-1164.

550.**Pittman, R. (1983).** “Multilateral Productivity Comparisons With Undesirable Outputs”. *The Economic Journal*, 93, 883-891.f

551.**Piesse, M. (2015).** “The Indus River and Agriculture in Pakistan”. Stratagic Analysis Paper.

552.**Plaas, E. (2014).** “Differences between Family Farming and Other Types of Farming in the EU. International Year of Family Farming(IYFF)”.

553.**Poudel, K. L., Johnson, T. G. & Mishra, B. (2015).** Comparing Technical Efficiency Of Organic And Conventional Coffee Farms In Rural Hill Region Of Nepal Using Data Envelopment Analysis (DEA) Approach, *Organic Agriculture*, 5: 263–275.

554. **Pradhan, P., Günther, F. & Juergen P. K. (2015).** “Closing Yield Gaps: How Sustainable Can We Be? *PLoS One*, 10(6).

555.**Prasad, A., Singh, G. & Upadhyay, R. K. (2008).** “Integrated Weed Management in Maize (Zea mays l.) and Maize + Blackgram”. *Indian Journal of Weed Science*, 40(3/4), 191-192.

556.**Pyburn, R & Jim, W. (2014). “**Dynamics of Rural Innovation. Royal Tropical Institute Development Policy and Practice”. ISBN: 978-9460221491

557.**Qazi, A. R. (1996).** “Village Organizations and Extension: A Case Study of Baluchistan Rural Support Programme (Pakistan)”. Department of Agriculture Extension and Rural Development, The University of Reading, UK.

558.**Qayyum, A. & Khalid, R. (2012).** “Technical Efficiency of Pakistani Banks: An Application of Bootstrapped Data Envelopment Analysis Approach”. *World Applied Sciences Journal*, 16 (12), 1837-1845.

559.**Quiggin, J. & Chambers, R. G. (2006).** “The State-Contingent Approach to Production under Uncertainty”. *Australian Journal of Agricultural and Resource Economics,* 50(2), 153-169.

560.**Raab. R., & Lichty, R. (2002).** “Identifying Sub-Areas That Comprise A Greater Metropolitan Area: The Criterion Of Country Relative Efficiency”. *Journal of Regional Science*, 42, 579-594.

561.**Rahman, K. M. M, Mia M. I. A & Bhuiyan M. K. J (2012). “**A Stochastic Frontier Approach to Model Technical Efficiency of Rice Farmers in Bangladesh: An Empirical Analysis”. *Scientific Journal of Krishi Foundation*, 10(2),9-19.

562.**Rahman, S. & Brodrick, O. A. (2015).** “Technical and Scale Efficiency of Cassava Production System in Delta State, Nigeria: An Application of Two-Stage DEA Approach”. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 116(1), 59–69.

563.**Rahman, S. (2003).** “Profit Efficiency among Bangladeshi Rice Farmers. Proceedings of the 25th International Conference of Agricultural Economists (IAAE). ISBN Number: 0-958-46098-1. Durban, South Africa.

564.**Rehman, A., Luan, J., Babar, S. & Muhammad, S. I. (2015).** "Economic perspectives of major field crops of Pakistan: An empirical study". *Pacific Science Review B: Humanities and Social Sciences*, 1(2015) 145-158.

565.**Rajendran, S. (2014).** "Technical Efficiency of Fruit and Vegetable Producers in Tamil Nadu, India: A Stochastic Frontier Approach". *Asian Journal of Agriculture and Development*, 11(1), 77-92.

566.**Rajendran, S., Victor, A., Daniel, K. K & Radegunda, F. K. (2015).** "Technical Efficiency of Traditional African Vegetable Production: A Case Study of Smallholders in Tanzania". *Journal of Development and Agricultural Economics,* 7(3), 92-99.

567.**Randhawa, H. A. (2002).** "Water development for irrigated agriculture in pakistan: past trends, returns and future requirements In investments in land and water". Proceedings of the Regional Consultation. Bangkok, Thailand: Food and Agricultural Organization, 65-81.

568.**Rangaswamy, R., (1995).** A textbook of Agricultural Statistics. Weley Eastern Lmited, New Delhi.

569.**Rasheed, S. V. (2012).** Agricultural Extension In India: Current Status And Ways Forward. Background Paper prepared for the Roundtable Consultation on Agricultural Extension, Beijing, China.

570.**Rashid, G. M., Almas H. & Esmail, P. (2016).** "A Comparison of Panel Data Models in Estimating Technical Efficiency". IZA Discussion Paper No. 9807.

571.**Rauf, A. A. (1991).** "Education and Technical Efficiency during the Green Revolution in Pakistan". *Economic Development and Cultural Change*, 39:651-665.

572.**Rauf, H. A., Khalid, M., Abedullah. & Abdul, G. (2014).** "The Effect of Adoption of Better Farm Management Practices in the Technical Efficiency of Dairy Farms in Punjab, Pakistan". *Pakistan Journal of Life and Social Sciences*, 12(3), 144-149.

573.**Rayeni, M. M. and Saljooghi, F. H. (2013).** "The Measurement Of Productivity Growth And Benchmarking In The Academic Departments". *African Journal of Business Management*, 7(38), 3953-3962.

574.**Raza, A. (2016).** "Grain and Feed Annual Pakistan". GAIN Report Number:1605, Global Agriculture Information Network.

575.**Raza, S. A. and Yasir, A. & Farhan, M. (2012).** "Role of Agriculture in Economic Growth of Pakistan". MPRA Paper No. 32273.

576.**Reardon, T., Barrett, C., Berdegue, J., (2009).** "Agrifood Industry Transformation And Small Farmers In Developing Countries". *World Development*, 37, 1717–1727.

577.**Reddy, A. A. & Bantilan, M. C. (2012)**. "Competitiveness and Technical Efficiency: Determinants in the Groundnut Oil Sector of India". *Food Policy,* 37 (3), 255-263.

578.**Reetz, H. F. (2016).** "Fertilizers and their Efficient Use". International Fertilizer Industry Association (IFA) Paris, France.

579.**Reig-Martinez, E. & Picazo-Tadeo, A. J. (2004).** "Analysing Farming Systems with Data Envelopment Analysis: Citrus Farming In Spain". *Agricultural systems,* 82, 17-30.

580.**Reinhard, S., Lovell, C. A. & Thijssen, G. J. (1999).** "Econometric Estimation of Technical and Environmental Efficiency: An Application to Dutch Dairy Farms". *American Journal of Agricultural Economics,* 81(1), 44-60.

581.**Reinhard, S., Lovell, C. A., & Thijssen, G .J. (2000)**. "Environmental Efficiency With Multiple Environmentally Detrimental Variables; Estimated With SFA And DEA". *European Journal of Operational Research*, 121, 287–303.

582.**Riaz, M. (2010).** "The Role Of The Private Sector In Agricultural Extension In Pakistan". *Rural Development News*, 1, 15–22

583.**Rios, A. & Shively, G. (2005).** "Farm Size and Nonparametric Efficiency Measurements for Coffee Farms in Vietnam". Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Providence, Rhode Island.

584.**Roberts, T. L. (2009).** "The Role of Fertilizer in Growing the World's Food". *Better Crop*, 39(2), 12-15.

585.**Robinson, S. (2014).** "New Census Data Shows Decrease In the Number of Farms, Growth in the Average Farm". Size.http://investigatemidwest.org/2014/02/20/new-census-data-shows-decrease-in-the-number-of-farms-growth-in-the-average-farm-size/

586.**Rodríguez, X. A. & Elasraag, Y. H. (2014).** "Technical Efficiency and Productivity Growth in Egypt's Cotton Production". *African Journal of Agricultural Research*, 9(40), 3032-3038.

587.**Rodríguez-Díaz, J.A., Camacho-Poyato, E., & López-Luque, R. (2004)** "Application of Data Envelopment Analysis to Studies of Irrigation Efficiency in Andalusia", Journal of Irrigation and Drainage Engineering, 130(3), 175–183.

588.**Rose, T.J., Rengel, Z., Ma, Q.F., & Bowden, J.W., (2009).** "Crop Species Differ In Root Plasticity Response To Localised P Supply". *Journal of Plant Nutrient and Soil Science*, 172, 360–368

589.**Rosset, P. (2000).** "The Multiple Functions and Benefits of Small Farm Agriculture in the Context of Global Trade Negotiations". *Development,* 43, 77-82.

590.**Rouse, P., Chen, L. & Harrison, J. A. (2007).** "Benchmarking the Performance of Dairy Farms Using Data Envelopment Analysis". The University of Auckland, New Zealand.

591.**Ruggiero, J. (2005).** "Impact Assessment of Input Omission on DEA". *International Journal of Information Technology and Decision Making*, 4(3), 359-368.

592.**Ruiz, J. L.; Pastor, J. & Sirvent, I. (2002).** "A statistical test for radial DEA models". *Operations Research,* 50(4), 728-735.

593.**Sabouhi, M., Sabouni, R. & Esfanjar K. (2014).** "Measuring Technological Gap Ratio OF Wheat Production Using StoNED Approach To Metafrontier". *International Journal of Applied Operational Research*, 4 (2), 33 -42.

594.**Saddozai K. N., Azeem, K., Jan, D. & Ali, G. (2013)**. "Analyzing the Impact of Farmer Field School on Technical Efficiency of Cotton Growers in Southern Districts of Punjab-Pakistan: Stochastic Production Frontier Approach". Sarhad Journal of Agriculture, 29(2), 291-298.

595.**Saddozai K. N., Muhammad, N. & Noor P. K. (2015).** "Stochastic Frontier Production Analysis of Tobacco Growers in District Mardan, Pakistan". *Pakistan Journal of Agricultural Research*, 28(4), 346-353.

596.**Sami, U. (2016).** "Efficiency Measurement of Dairy Farmers under Integrated Cropping Systems in Pakistan". PhD Thesis, Georg-August-University Göttingen, Germany.

597.**Sarantakos, S., (1998).** "Social Science Research". 2nd edition, Macmillan Press Ltd, London.

598.**Sarker, A. R. (2012).** "A Study On Economic Efficiency And Sustainability Of Wheat Production In Selected Areas Of Dinajpur District". Master's Thesis, Department Of Agricultural Economics, Bangladesh Agricultural University, Mymensingh.

599.**Sarker, J. R & Alam, F. (2016).** "Efficiency and Economics in Cotton Production Of Bangladesh". *Journal of Agriculture and Environment for International Development*, 110 (2), 325-348.

600.**Sattar, M., Muneeb, Z., Laila, K. & Mushtaq , A. (2017).** "Trend Of Crop Area Shifting And Profitability Analysis Of Cotton And Maize In Agro-Ecological Zone Of Vehari". *International Journal of Advanced Multidisciplinary Research*, 4(3), 23-29.

601.**Schultz, T. W. (1953).** "The Economic Organization of Agriculture". McGraw Hill Book Co, New York:

602.**Schultz, T. W. (1964).** "Transforming Traditional Agriculture". New Haven, Yale University Press, London,

603.**Schwerzel, P. J. & Thomas, P .E. L. (1971).** "Weed Competition in Cotton". *PANS*, 17 (1) : 30-34.

604.**Seale, C., Gobo, G.J., Gubrium, F., & Silverman, D. (2007).** "Qualitative Research Practice". London Sage.

605.**Seth, T. (2016).** "Land: Meaning, Importance and Other Details". Economics Discussion.

606.**Sexton, T. R., Silkman, R. H & Hogan A. J. (1986).** "Data Envelopment Analysis: Critique and Extensions".*New Directions for Program Evaluation*, 32, 73-105.

607.**Seyouma, E. T., Battese, G. E. & Flemingc E. M. (1998).** "Technical Efficiency And Productivity Of Maize Producers In Eastern Ethiopia: A Study Of Farmers Within And Outside The Sasakawa-Global 2000 Project". *Agricultural Economics*, (19), 341-348.

608.**Shafiq, M. & Tahir, R. (2000).** "The Extent of Resource Use Inefficiencies in Cotton Production In Pakistan's Punjab: An Application of Data Envelopment Analysis". *Agricultural Economics*, 22(3), 321-330.

609.**Shafiq, M. (1998).** "Relative Efficiency of Crop Production in the Irrigated Area of Cotton Wheat Zone, Punjab, Pakistan". Ph.D Theses, University of Reading, UK.

610.**Shah, T., Tao, J., Shah, F. & Khan, S. B. (2016).** "A Comparative Study Of The Agricultural Practices Of Members And Non-Member Farming Community Of Model Farm Services Center In Khyber Pakhtunkhwa Pakistan". *The Journal of Animal & Plant Sciences*, 26(6), 1787-1796.

611.**Shaheen, S., Maqbool H. S., Ghulam, S. & Rahila, M. (2011).** "Nexus between Human Capital and Technical Efficiency of Cauliflower Growers in Soon Valley, Punjab: A Panel Data Analysis". *International Journal of Humanities and Social Science,* 1(14), 129-135.

612.**Shaikh, S. (2016).** "Averting Impending Water Crisis Through Climate-Smart Management In Pakistan". Pamir Times. http://pamirtimes.net/2016/03/22/averting-impending-water-crisis-through-climate-smart-management-in-pakistan.

613.**Salleh, M. I. (2012).** "An Empirical Analysis of Efficiency and Productivity changes in Malaysian Public Higher Education Institutions". PhD Thesis, University of Wollongong,

614.**Shams, S. (2016). "**Why Water Scarcity Is A Bigger Threat To Pakistan's Security Than Militancy". http://www.dw.com/en/why-water-scarcity-is-a-bigger-threat-to-pakistans-security-than-militancy/a-19293470

615.**Shanmugam, K. R. & Atheendar, V. (2006).** “Technical Efficiency in Agricultural Production and Its Determinants: An Exploratory Study at the District Level.” *Indian Journal of Agricultural Economics*, 61(2), 169-184.

616.**Sharazar, W., Sabir, M., Mehmood, Y. & Anwar, N. (2012).** “Estimating Productivity Differential and Constraints in Wheat Production: A Case Study of District Faisalabad, Pakistan”. *Journal of Agriculture & Social Sciences* , 8(4), 139-142.

617.**Shavgulidze, R., Bedoshvili, D, & Aurbacher, J. (2017).** “Technical Efficiency Of Potato And Dairy Farming In Mountainous Kazbegi District, Georgia”. *Annals of Agrarian Science*, 15 (1), 55-60.

618.**Sheikh, B., Sheikh, S. & Soomro, G. (2005).** “Pakistan Agriculture in Global Perspective”. *Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Science*, 21, 53-59.

619.**Shim, W. (2003).** “Applying DEA Technique To Library Evaluation In Academic Research Libraries”. Library Trends 51:312-332

620.**Shinn, G. C., Wingenbach, G. J. & Baker, M. (2009).** “Redefining Agricultural and Extension Education as a Field of Study: Consensus of Fifteen Engaged International Scholars”. *Journal of International Agricultural and Extension Education*, 16(1), 73-88.

621.**Shuhao, T. (2005).** “Land Fragmentation and Rice Production: A Case Study of Small Farms in Jiangxi Province, P. R. China”. Ph.D. Thesis, Wageningen University, Neatherland.

622.**Saunders, M., Lewis, P., & Thornhill, A. (2012)**. Research methods for business students (6th edition). Essex: Pearson Education Limited.

623.**Sustainable Development Solutions Network. (2015).** “Solutions for Sustainable Agriculture and Food Systems”. Technical Report For The Post-2015 Development Agenda

624.**Sial, M. H., Shahid, I. & Sheikh, A. D. (2012).** “Farm Size – Productivity’ Relationship Recent Evidence from Central Punjab”. *Pakistan Economic and Social Review*, 50(2), 139-162.

625.**Sikandar, F. (2015).** “Globalization and Environmental Degradation: Sustainable Growth in Pakistan”. *Academy of Contemporary Research Journal,* VIV (I), 18-24.

626.**Simar, L. & Wilson, P. W. (1998).** “Sensitivity Analysis of Efficiency Scores: How to Bootstrap In Nonparametric Frontier Models”. Management Science, 44(1), 49-61.

627.**Simar, L. & Wilson, P. W. (2000)**. “Statistical Inference in Nonparametric Frontier Models., the State of the Art”. *Journal of Productivity Analysis*, 13, 49-78.

628.**Simar, L. & Wilson, P. W. (2007)**. “Estimation and Inference in Two-Stage, Semi-Parametric Models of Production Processes”. *Journal of Econometrics*, 136(1), 31-64.

629.**Simin, M. T. & Dejan, J. (2014).** “Applicability of Diffusion of Innovation Theory in Organic Agriculture”. Economics of Agriculture, 61(2), 517-529.

630.**Sims, B. J. & Josef, K. (2006).** “Farm Power and Mechanization for Small Farms in Sub-Saharan Africa”. Agricultural And Food Engineering Technical Report Technical Report.

631.**Simwaka, K. Stuart, F. & Geoff H. (2013).** “Analysis Of Factors Affecting Technical Efficiency Of Smallholder Farmers: Comparing Time-Varying And Time Invariant Inefficiency Models”. *African Journal of Agricultural Research*, 8(29), 3983-3993.

632.**Singh, B. G., Saran, S. & Singh, T. (2015).** “Measuring the Technical Efficiency of Cotton Production, SFA Approach”. *Indian Journal of Economics and Development,* 11(1), 53-60.

633.**Singh, S., Kang, J. S. & Jagroop, K.(2017).** "Tillage And Residue Management For Sustaining Rice-wheat Cropping System In Indo-Gangetic Plains- A Review". *The Pharma Innovation Journal*, 6(8), 89-99.

634.**Siraj, M. (2011).** "A model for ICT based services for agricultural extension in Pakistan".

635.**Skevas, T., Stefanou, S. E., Lansik, A. O. (2014).** "Pesticide Use, Environmental Spillovers And Efficiency: A Dea Risk-Adjusted Efficiency Approach Applied To Dutch Arable Farming". *European Journal of Operational Research*, 237 (2), 658-664.

636.**Smith, P. (1997).** "Model Misspecification in Data Envelopment Analysis". *Annals of Operations Research*, 73, 233-252.

637.**Solakoglu, M. N. (2013)**. "Technical Efficiency in Cotton Production: The Role of Premium Payments in Turkey". *Transit Stud Rev*, 20, 285–294.

638.**Solís, D. & Corral, J. D. (2009).** "Studying the Impact of Managerial Activities on the Technical Efficiency of Wisconsin Dairy Farm". Efficiency Series Papers 01/2009.

639.**Solís, D., B. Bravo-Ureta, & Quiroga, R. (2009).** "Technical Efficiency among Peasant Farmers Participating in Natural Resource Management Programmes in Central America" Journal of Agricultural Economics, 60 (1), 202 -219.

640.**Soomro, U. A., Rahman, M. U., Odhano, E. A., Gul, S. & Tareen, A. (2009).** Effects of Sowing Method and Seed Rate on Growth and Yield of Wheat (Triticumaestivum). *World Journal of Agricultural Science*, 5, 159-162.

641.**Soteriades, A. D., Philippe, F., Margaret, M. & Alistair, W. S. (2015).** "Improving Efficiency Assessments Using Additive Data Envelopment Analysis Models: An Application to Contrasting Dairy Farming Systems". *Agricultural and Food Science*, 24(3), 235-248.

642.**Speelman, S., Frija, D'Haese. & Luc, D. (2009).** "Estimating the Impacts of Water Pricing On Smallholder Irrigators In North West Province, South Africa". *Agricultural Water Management*, 96(11), 1560-1566

643.**Speelman, S., Marijke D., Jeroen, B. & Luc D. (2007).** "Technical efficiency of water use and its determinants, study at smallscale irrigation schemes in North-West Province, South Africa". Paper Prepared For Presentation At The 106 Th Seminars Of The Eaae Pro-Poor Development In Low Income Countries, Montpellier, France.

644.**Speelman, S., Marijke D., Jeroen, B. & Luc D. (2008).** "A Measure for the Efficiency of Water Use and Its Determinants, A Case Study Of Small-Scale Irrigation Schemes In North-West Province, South Africa". Agricultural Systems, 98(1), 31-39.

645.**Spicka, J. & Lubos, S. (2014).** "The Technical Efficiency of Specialised Milk Farms: A Regional View". *The Scientific World Journal*, 14, Article ID 985149.

646.**Spross, J. (2013).** "Pakistan Now 'One Of The Most Water-Stressed Countries In The World' As 'Demand Exceeds Supply".https://thinkprogress.org/pakistan-now-one-of-the-most-water-stressed-countries-in-the-world-as-demand-exceeds-supply-6cdf3d163ae9/

647.**Steckel, L .E., Sprague, C. L., Stoller, E. W. & Simmons, F. W. (2007).** "Tillage, Cropping System, And Soil Depth Effects On Common Waterhemp (Amaranthus rudis) Seed-bank Persistence". *Weed Science*, 55, 235-239

648.**Sudaryanto, T., Sri, H. S. & Umaryanto. (2009).** "Increasing Number of Small Farms in Indonesia: Causes and Consequences". 111 EAAE-IAAE Seminar 'Small Farms: decline or persistence'. University of Kent, Canterbury, UK.

649.**Sukhera, N. (2016).** “Diversifying Pakistan’s Water Resources. MIT Technology Review Pakistan”. http://www.technologyreview.pk/diversifying-pakistans-water-resources/

650.**Sulieman, S. A. (2010).** “The Influence Of Triticum Asetivum Seeding Rates And Sowing Patterns On The Vegetative Characteristics In Shambat Soil Under Irrigation”. *Journal Agriculture and Biological Science*, 6(2), 93-102.

651.**Supaporn, P. (2015).** “Determinants of Technical Efficiency of Sugarcane Production among Small Holder Farmers in Lao PDR”. *American Journal of Applied Sciences*, 2015, 12 (9), 644.649.

652.**Tan, S., Heerink, N., Kuyvenhovenb, A. & Qu, F. (2010).** “Impact Of Land Fragmentation On Rice Producers’ Technical Efficiency In South-East China”. *Wageningen Journal of Life Sciences,* 57(2), 117-123.

653.**Tanveer, S. K., Imtiaz, H. & Abbas, S. G. (2003).** “Effect of Different Planting Methods on Yield and Yield Components of Wheat”. *Asian Journal of Plant Sciences,* 2(10), 811-813.

654.**Taphe, B. G., Agbo, F. U. & Okorji, E.C. (2015).** “Resource Productivity and Technical Efficiency of Small Scale Groundnut Farmers in Taraba State, Nigeria”. *Journal of Biology, Agriculture and Healthcare*, 5(17), 25-35.

655.**Taraka, K., Latif, I. A., & Shamsudin, M. N. (2010)** “A Nonparametric Approach To Evaluate Technical Efficiency Of Rice Farms In Central Thailand”. *Chulalongkorn Journal of Economics*, 22, 1 – 14.

656.**Taraka, K., Latif, I. A., & Shamsudin, M. N. (2011).** “Estimation of Technical Efficiency for Rice Farms in Central Thailand Using Stochastic Frontier Approach”. *Asian Journal of Agriculture and Development,* 9(2), 1-11.

657.**Tavva, S., Aden, A. H. & Javed , R. (2017).** “Technical Efficiency Of Wheat Farmers And Options For Minimizing Yield Gaps In Afghanistan”. Sage Publications, 46(1), 13-19.

658.**Tchale, H. (2009).** “The Efficiency of Smallholder Agriculture in Malawi”. *AFJARE*, 3(2), 101-121

659.**Tesfaye, Z., Bedassa, T. & Shiferaw, T. (2001).** “Determinants of high yielding maize technology adoption. Empirical evidence from Southwestern Oromia”. Research Report No. 38. Ethiopia Agricultural Research Organization (EARO).

660.**Tesso, A., Workneh, N. & Sisay, A. (2015).** Does Farmer Field School Training Improve Technical Efficiency? Evidence from Smallholder Maize Farmers in Oromia, Ethiopia. *International Journal of African Development,* 3(3), 23-50.

661.**Thabethe, L., Eric, M. & Marlene L. (2014).** “Estimation of Technical, Economic and Allocative Efficiencies in Sugarcane Production in South Africa: A Case of Mpumalanga Growers”. *Journal of Economics and Sustainable Development*, 5(16), 86-95.

662.**Thabethe, L. (2013). “**Estimation of Technical, Economic and Allocative Efficiencies in Sugarcane Production in South Africa: A Case of Mpumalanga Growers”. Msc Thesis, University of Preetoria.

663.**Than, K. M. (2011). “**A Study of Literature Reviews on Farmer Education and Farm Efficiency.” *Distance Education Research Journal,* 3(1),

664.**Thapa, G. (2009).** “Smallholder Farming in Transforming Economies of Asia and the Pacific: Challenges and Opportunities”. Discussion Paper, IFAD.

665.**Thapa, G. and Raghav, G. (2011).** "Smallholder Farming in Asia and the Pacific: Challenges and Opportunities". Paper presented at the IFAD Conference on New Directions for Smallholder Agriculture, Rome, Italy.

666.**Theodoridis, A. M. & Anwar, M. M.(2011). "**A Comparison of DEA and SFA Methods: A Case Study Of Farm Households In Bangladesh". *The Journal of Developing Areas*, 45 (1), 95-110.

667.**Thiam, A., Bravo-Ureta, B. & Rivas, T. E. (2001)**. "Technical Efficiency In Developing Country Agriculture: A Meta-Analysis", Agricultural Economics, 25, 235–243.

668.**Tijani, A. A. (2006).** "Analysis of the Technical Efficiency of Rice Farms in Ijesha Land of Osun State, Nigeria". *Agrekon*, 45(2), 126-135.

669.**Tipi, T., & Rehber, E. (2006).** "Measuring Technical Efficiency And Total Factor Productivity In Agriculture: The Case Of The South Marmara Region Of Turkey." *New Zealand Journal of Agricultural Research*, 49, 137-145

670.**Tipi, T., Nural Y., Mehmet N. & Bahattin Ç. (2009).** "Measuring The Technical Efficiency And Determinants Of Efficiency Of Rice (Oryza Sativa) Farms In Marmara Region, Turkey, New Zealand". *Journal of Crop and Horticultural Science,* 37(2), 121-129.

671.**Tiruneh, W. G. and Endrias, G. (2015).** "Technical efficiency of smallholder wheat farmers: The case of Welmera district, Central Oromia, Ethiopia". *Journal of Development and Agricultural Economics*, 8(2), 39-51.

672.**Tone, K. (2001).** "A Slacks-Based Measure Of Efficiency In Data Envelopment Analysis". *European Journal of Operational Research*, 130, 498–509.

673.**Trujillo, J. C. & Wilman J. I. (2013).** "Measurement of the Technical Efficiency of Small Pineapple Farmers in Santander, Colombia: A Stochastic Frontier Approach". *Revista de Economia e Sociologia Rural,* 51(1),

674.**Tshuma, M. C. (2014).** "Understanding the Small-Scale Agricultural Sector as a Precondition for Promoting Rural Development in South Africa". *African Journal of Agricultural Research,* 9(31), 2409-2418.

675.**Tsimpo, C. N. (2010)**. "Technical Efficiency and Optimal Farm Size in the Jajik‟S Cotton Sector". MPRA Paper, No. 35192.

676.**Tsutsui, M & Mika, G. (2009).** "A Multi-division Efficiency Evaluation of U.S. Electric Power Companies Using A Weighted Slacks-Based Measure". *Socio-Economic Planning Sciences,* 43(3), 201-208.

677.**Tung, D, T. (2013).** "Changes In The Technical And Scale Efficiency Of Rice Production Activities In The Mekong Delta, Vietnam". *Agricultural and Food Economics*, 1(16).

678.**Tunio, S. D. (2000).** "Significance of Cultural Weed Control In Cotton". Economics and business review. "The Daily Dawn" Karachi, August 28 and September 3, 2000.

679.**Tyteca,D. (1996)**. "On the Measurement of the Environmental Performance of Firms - A Literature Review and a Productive Efficiency Perspective". *Journal of Environmental Management*,46, 281-308

680.**Udayanganie, A. D. D., Prasada, D. V. P. & Little, D. C. (2006).** "Efficiency of the Agrochemical Input Usage in The Paddy Farming Systems In The Dry Zone Of Sri Lanka". Prepared for the Annual Meeting of the Canadian Agricultural Economics Society in Montreal, Quebec.

681.**Umanath, M. & David, R. (2013).** "Data Envelopment Analysis to Estimate Technical and Scale Efficiency of Farms in Periyar-Vaigai Irrigation System of Tamil Nadu, India". *Indian Journal of Science and Technology*, 6(10), 5331-5336.

682.**Umanath, M. & David, R. (2013).** "Estimation of Technical, Scale and Economic Efficiency of Paddy Farms: A Data Envelopment Analysis Approach". *Journal of Agricultural Science,* 5(8), 243-251.

683.**UNDP. (2015).** "Sustainable Land Management Programme to Combat Desertification in Pakistan". United Nations Development Programme, Pakistan Project Document.

684.**United Nations. (2014).** "The Role Of Smallholder Farmers In Sustainable Commodities Production And Trade". United Nations Conference on Trade and Development

685.**Uri, N. D. (2001).** "Technical Efficiency, Allocative Efficiency, and the Implementation of a Price Cap Planin Telecommunications in the United States". *Journal of Applied Economics*, 4(1) (may 2001), 163-186.

686.**USDA. (2007).** "Census of Agriculture". Government of United States, USA

687.**Usman, M., (2016).** "Contribution Of Agriculture Sector In The GDP Growth Rate Of Pakistan". *Journal of Global Economy*, 4 (184). http://dx.doi.org/ 10.4172/2375-4389.1000184.

688.**Usman, M., Waheed, A., Ihsan J. & Muhammad, W. (2016).** "Efficiency Analysis of Wheat Farmers of District Layyah of Pakistan". *American Journal of Experimental Agriculture*, 11(2), 1-11.

689.**Uzmay , A., Koyubenbe, N. & Armagan, G. (2009). "**Measurement of Efficiency Using Data Envelopment Analysis (DEA) and Social Factors Affecting the Technical Efficiency in Dairy Cattle Farms within the Province Of Izmir, Turkey". *Journal of Animal and Veterinary Advances*, 8(6), 1110-1115.

690.**Van, P, N. & Nguyen, T. T. (2014).** "Agricultural Extension And Technical Efficiency Of Tea Production In Northeastern Vietnam". Universit´e de Strasbourg, Veitnam.

691.**Van, T., Rennie, A. M., Hundley, V., & Graham, W. (2001).** "The Importance of Conducting and Reporting Pilot Studies: The Example of the Scottish Births Survey". Journal of Advanced Nursing 34(3), 289-295.

692.**Viengpasith, V , Mitsuyasu, Y. & Goshi, S. (2012).** "Analysis of Technical Efficiency of Smallholder Maize Farmers in Northern Lao PDR: Case Study of Paklay District, Sayaboury Province". J. Fac. Agr., Kyushu Univ., 57 (1), 309–315

693.**Villano, R. (2009)**. "Benchmarking Sheep Performance". *ANPR*, 350/450, 3-19.

694.**Virat, J. (2016).** "Role of Technology in Rural Development in Agriculture". W.B. Saunders and Co., Philadelphia, USA.

695.**Walden, J. B. & Kirkley, J. E. (2000)**. "Measuring Technical Efficiency And Capacity In Fisheries By Data Envelopment Analysis Using The General Algebraic Modeling System (GAMS): A workbook". Report of NOAA Technical Memorandum NMFS-NE-160. 15p.

696.**Wambani, H. (2011).** "Improving Scientific Research At Kenya Agricultural Research Institute (Kari) – Kakamega Research Centre: A Research Methods Approach". Ph.D Thesis. Jomo kenyatta University of Agriculture and Technology, kenya.

697.**Wang, N., Jin, X., Ye, S. T., Gao, Y. & Li, X. F. (2016). "**Optimization Of Agricultural Input Efficiency For Wheat Production In China Applying Data Envelopment Analysis Method". *Applied Ecology And Environmental Research*, 15(3), 293-305.

698.**Watkins, K. B., Tatjana, H., Ralph, M. & Charles, E. W. (2013).** "Measuring Technical, Allocative, and Economic Efficiency of Rice Production in Arkansas using Data Envelopment Analysis". Selected Paper prepared for presentation at the Southern Agricultural Economics Association (SAEA) Annual Meeting, Orlando, Florida, 3-5.

699. **Watto, M. A. & Mugera A. (2014).** "Measuring Efficiency of Cotton Cultivation in Pakistan: A Restricted Production Frontier Study". *Journal of Science Food Agriculture,* 94(14), 3038-3045.

700. **Watto, M. A. (2013).** "Measuring Groundwater Irrigation Efficiency in Pakistan: A DEA Approach Using the Sub-vector and Slack-based Models". 57th AARES Annual Conference at The Sydney Convention and Exhibition Centre in Darling Harbour, Sydney, New South Wales.

701. **Wen, W. (2015)**. "Uncertain Data Envelopment Analysis, Uncertainty and Operations Research". Springer, 11, 45-59.

702. **Wiggins, S. (2011).** "Supporting Small-Scale Farming: Messages for the G20". World Vision Australia, Burwood East, VIC, Australia.

703. **Wilson, P., David H. & Carol A. (2001).** "The Influence of Management Characteristics on the Technical Efficiency of Wheat Farmers in Eastern England". *Agricultural Economics*, 24 (2001), 329-338.

704. **Wolfenson, K. D. M. (2013).** "Coping With The Food And Agriculture Challenge: Smallholders' Agenda". Preparations and outcomes of the 2012 United Nations Conference on Sustainable Development, Rome, Italy.

705. **World Bank. (2003).** "Reaching the Rural Poor: A Renewed Strategy for Rural Development". Washington, DC.

706. **World Bank. (2012).** "Agricultural innovation Systems". A source Book. An investment Source Book. Washington, DC.

707. **World Bank. (1997).** "World Bank Approves Us $285 Million For Pakistan's National Drainage Program". News Release No. 98/1528/SAS.

708. **Wossen, T., Tahirou, A & Victor, M. (2017).** "Impacts Of Extension Access And Cooperative Membership On Technology Adoption And Household Welfare". *Journal of Rural Studies*, 54, 223-233.

709. **Wu, Y. (2008).** "Productivity, Efficiency and Economic Growth in China". 1st edition, Macmillan Publisher, UK.

710. **Wu, Z. I. (2011).** "Research on Harmony between Agricultural Modernization and regional Economy Development in China". *Asian Agricultural Research*, 3(3), 6 – 10.

711. **Yan, C. P., Zhang, Y. Q. & Dang, J. Y. (2008).** "Effects Of Sowing Date And Planting Density On The Grain's Protein Component and Quality of Strong and Medium Gluten Winter Wheat Cultivars". The Journal of Applied Ecology, 19 (8), 1733-40.

712. **Yang, J. B., Wong, B. Y. H., Xu D., & Stewart, T. J. (2009).** "Integrating DEA-oriented performance assessment and target setting using interactive MOLP methods". *European Journal of Operational Researc*h, 195, 205-222.

713. **Yang, Z. Z., Amin W. M. & Fan, Z. (2016).** "Investigating Yield Variability and Inefficiency in Rice Production: A Case Study in Central China". *Sustainability*, 8, 1-11.

714. **Yercan, M. & Engindeniz, S. (2002).**"Profitability of Dried Fig Production: A Case Study of Turkey". *Poljoprivreda*, 9(1).

715. **Yusuf, S. A. and Malomo, A. (2007).** "Technical Efficiency of Poultry Egg Production in Ogun State: A Data Envelopment Analysis (DEA) Approach". *International Journal of Poultry Science*, 6(9), 622-629.

716. **Yaqub, M, Beytullah E., Emrah, D.(2015).** "Flood Causes, Consequences and Protection Measures in Pakistan". *Disaster Science And Engineering*, 1(1), 8-16.

717. **Zhang, Liu, Bressers, & Buchanan. (2011).** "Productivity Growth And Environmental Regulations - Accounting For Undesirable Outputs: Analysis Of China's Thirty Provincial Regions Using The Malmquist–Luenberger Index". *Ecological Economics*, 70(12), 2369-2379.

718. **Zia, M. S., Tariq, M., Mirza B. B. & Muhammad A. (2004).** Land and Environmental Degradation and Its Amelioration for Sustainable Agriculture in Pakistan. *Quarterly Science Vision*, 9(1-2), 1-5.

719. **Zschille, M., Jörn G., Barnabas, K., Robert M., Matthias W. (2009).** "The Performance of German Water Utilities: A Semi-Parametric Analysis". Efficiency Analysis Working Papers, WP-EA-20, Dresden University of Technology.

720. **Zulfiqar, F., & Thapa, B. (2016).** "Is 'Better Cotton' Better Than Conventional Cotton In Terms Of Input Use Efficiency And Financial Performance?" *Land Use Policy*, 52 (2016), 136-143.

Appendix A

UNION COUNCILS AND VILLAGES IN TEHSIL SAMUNDRI

Total No of Union councils: 24
Total No of Villages: 128
Source of Data: Department of Agricultural Extension and Adaptive Research

Sr.NO	U.C	Village	No of villages in union council
1	468/GB	1. 472/GB 2. 469/GB 3. 468/GB 4. 470/GB	4
2	467/GB	1. 389/GB 2. 465/GB 3. 464/GB 4. 466/GB 5. 390/GB 6. 467/GB	6
3	225/GB	1. 222/GB 2. 49/GB 3. 45/GB 4. 224/G B 5. 225/GB 6. 48/GB	6
4	527/GB	1. 530/GB 2. 527/GB 3. 531/GB 4. 529/GB 5. 528/GB	5
5	228/GB	1. 52/GB 2. 51/GB 3. 41/GB 4. 42/GB 5. 228/GB	5
6	463/GB	1. 461/GB 2. 169/GB 3. 438/GB 4. 463/GB 5. 168/GB 6. 462/GB 7. 385/GB	7
7	198/GB	1. 197/GB 2. 198/GB 3. 199/GB 4. 196/GB	4
8	475/GB	1. 477/GB 2. 218/GB 3. 476/GB 4. 217/GB 5. 475/GB	5

9	175/GB	1. 165/GB 2. 175/GB 3. 174/GB 4. 166/GB 5. 176/GB 6. 177/GB 7. 167/GB	7
10	441/GB	1. 444/GB 2. 442/GB 3. 445/GB 4. 471/GB 5. 443/GB 6. 441/GB 7. 447/GB 8. 446/GB 9. 448/GB	9
11	170/GB	1. 171/GB 2. 172/GB 3. 230/GB 4. 173/GB 5. 170/GB 6. 232/GB 7. 229/GB	7
12	437/GB	1. 437/GB 2. 390/GB 3. 439/GB 4. 417/GB 5. 414/GB 6. 440/GB 7. 413/GB	7
13	47/GB	1. 46/GB 2. 44/GB 3. 43/GB 4. 47/GB	4
14	226/GB	1. 226/GB 2. 227/GB 3. 220/GB 4. 219/GB 5. 221/GB 6. 223/GB	6
15	388/GB	1. 386/GB 2. 373/GB 3. 136/GB 4. 388/GB 5. 387/GB 6. 372/GB	6
16	214/GB	1. 214/GB 2. 213/GB 3. 215/GB 4. 216/GB	4
17	193/GB	1. 193/GB 2. 192/GB 3. 195/GB	3

18	205/GB	1. 207/GB 2. 206/GB 3. 209/GB 4. 208/GB	4
19	479/GB	1. 479/GB 2. 473/GB 3. 474/GB 4. 480/GB 5. 481/GB	5
20	201/GB	1. 200/GB 2. 495/GB 3. 487/GB 4. 202/GB 5. 204/GB 6. 201/GB	6
21	203/GB	1. 211/GB 2. 488/GB 3. 210/GB 4. 203/GB 5. 212/GB	5
22	484/GB	1. 484/GB 2. 485/GB 3. 483/GB 4. 486/GB 5. 482/GB	5
23	138/GB	1. 138/GB 2. 137/GB 3. 135/GB 4. 134/GB 5. 50/GB	5
24	142/GB	1. 141/GB 2. 142/GB 3. 139/GB 4. 140/GB 5. 143/GB	5

APPENDIX B

UNION COUNCILS AND VILLAGES IN TEHSIL JARANWALA

Total No of Union councils: 42
Total No of Villages: 202
Source of Data: Department of Agricultural Extension and Adaptive Research

S.No	Union Council	Villages	No of villages in union council
1.	235/GB	1. 236/GB 2. 234/GB 3. 235/GB 4. 124/GB 5. 233/GB	5
2.	55/GB	1. 56/GB 2. 57/GB 3. 54/GB 4. 25/GB 5. 53/GB	5
3.	353/GB	1. 357/GB 2. 353/GB 3. 356/GB 4. 354/GB 5. 355/GB	5
4.	96/GB	1. 93/GB 2. 97/GB 3. 94/GB 4. 96/G 5. 95/GB	5
5.	93/RB	1. 92/RB 2. 95/RB 3. 93/RB 4. 94/RB 5. 90/RB 6. 91/RB	6
6.	648/GB	1. 649/GB 2. 648/GB 3. 625/GB 4. 534/GB	4
7.	23/GB	1. 128/GB 2. 24/GB 3. 21/GB 4. 23/GB 5. 22/GB	5
8.	239/GB	1. 237/GB 2. 239/GB 3. 240/GB 4. 238/GB 5. 126/GB	5

9.	58/GB	1. 125/GB 2. 60/GB 3. 59/GB 4. 58/GB	4
10.	283/GB	1. 278/GB 2. 277/GB 3. 283/GB 4. 279/GB	4
11.	363/GB	1. 377/GB 2. 363/GB 3. 585/GB 4. 367/GB	4
12.	383/GB	1. 383/GB 2. 382/GB 3. 381/GB 4. 384/GB 5. 379/GB 6. 380/GB	6
13.	581/GB	1. 580/GB 2. 581/GB 3. 376/GB 4. 584/GB 5. 375/GB	5
14.	378/GB	1. Dana Abad 2. Kannel 3. Pindi essa 4. Herchokey 5. Harian 6. Thatha 7. 582/GB 8. 583/GB 9. 633/GB 10. 378/GB	10
15.	273/GB	1. 273/GB 2. 276/GB 3. 5274/GB 4. 275 /GB	4
16.	282/GB	1. 281/GB 2. 282/GB 3. 272/GB 4. 280/GB 5. 374/GB	5
17.	364/GB	1. 362/GB 2. 364/GB 3. 366/GB 4. 435/GB 5. 365/GB	5
18.	39 G.B	1. 39 G.B 2. 38 G.B 3. 40 G.B 4. 232 G.B	4
19.	28 G.B	1. 26 G.B 2. 29 G.B 3. 27 G.B	4

		4. 28 G.B	
20.	115 G.B	1. 114 G.B 2. 118 G.B 3. 115 G.B 4. 116 G.B 5. 117 G.B	5
21.	37 G.B	1. 34 G.B 2. 37 G.B 3. 35 G.B 4. 36 G.B	4
22.	32 G.B	1. 30 G.B 2. 89 G.B 3. 31 G.B 4. 32 G.B 5. 33 G.B **6.** 77 G.B	6
23.	434 G.B	1. 432 G.B 2. 434 G.B **3.** 433 G.B	3
24.	72 G.B	1. 70 G.B 2. 71 G.B 3. 72 G.B 4. 73 G.B 5. 74 G.B	5
25.	68 RB	1. 69 /RB 2. 71 /RB 3. 66 /RB 4. 68 /RB 5. 70 /RB	5
26.	266 RB	1. 194/ RB 2. 193/ RB 3. 266/ RB	3
27.	76 RB	1. 76 /RB 2. 74 /RB 3. 73/ RB 4. 77/RB	4
28.	200 RB	1. 211 /RB 2. 206/ RB 3. 200 /RB 4. 205/ RB	4
29.	151 RB	1. 151/ RB 2. 149 /RB 3. 150 /RB 4. 72 /RB 5. 65/R B	5
30.	61 RB	1. 60 /RB 2. 61 /RB 3. 62 /RB	3
31.	58 RB	1. 63 /RB 2. 52 /RB 3. 58/RB 4. 59 /RB 5. 64 /RB	5

32.	54 RB	1. 54 /RB 2. 55 /RB 3. 57 /RB 4. 53 /RB 5. 56 /RB	5
33.	97/RB	1. 99/RB 2. 98 /RB 3. 97 /RB 4. 96 /RB	4
34.	569/GB	1. Lundianwala 2. 569/GB 3. 568/GB 4. 587/GB	4
35.	147/GB	1. 144/GB 2. 145/GB 3. 459/GB 4. 352/GB 5. 147/GB	5
36.	657/GB	1. 658/GB 2. 624/GB 3. 635/GB 4. 656/GB 5. 657/GB 6. 655/GB	6
37.	562/GB	1. 571/GB 2. 588/GB 3. 562/GB 4. 563/GB 5. 565/GB	5
38.	644/GB	1. Jodhkay 2. 644/GB 3. 570/GB 4. 642/GB 5. 643/GB	5
39.	654/GB	1. 631/GB 2. 632/GB 3. 626/GB 4. 650/GB 5. 654/GB 6. 627/GB 7. 651/GB 8. 652/GB 9. 653/GB	6
40.	628/GB	1. 646/GB 2. 647/GB 3. 628/GB 4. 629/GB 5. 630/GB 6. Rangpur 7. 645/GB	7
41.	591/GB	1. 591/GB 2. 560/GB 3. 559/GB 4. 586/GB	4

42.	566/GB	1. 564/GB 2. 561/GB 3. 566/GB 4. 567/GB	4

Appendix C: Detailed procedure for computation of input and output variables

CROP	COMPUTATION OF TOTAL PRODUCTION
wheat	• Total yield (kg) = yield per acre * No of acre grown
sugarcane	• Total yield (kg) = yield per acre * No of acre grown
Maize	• Total yield (kg) = yield per acre * No of acre grown
cotton	• Total yield (kg) = yield per acre * No of acre grown

CROP	TRACTOR HOURS	DETAILED PROCEDURE FOR COMPUTATION
Wheat	Tractor hours= tractor ploughing (hrs) + tractor planking (hrs) + tractor levelling (hrs) + + tractor Rotavations (hrs) + tractor (hrs) drilling	(no of ploughings * no of acres * Time spent (hours) to plough one acre) + (no of planking * no of acres * time spent (hours) to plank one acre) +(no of Rotavations * no of acres * time spent (hours) to rotavate one acre) +(no of acres levelled * time spent (hours) to level one acre) + (no of acres drilled * time spent to drill)
Cotton	Tractor hours= tractor ploughing (hrs) + tractor planking (hrs) + tractor levelling (hrs) + tractor Rotavations (hrs) + tractor interculturing	(no of ploughings * no of acres * Time spent (hours) to plough one acre) + (no of planking * no of acres * time spent (hours) to plank one acre) +(no of Rotavations * no of acres * time spent (hours) to rotavate one acre) +(no of acres levelled * time spent (hours) to level one acre) + (no of acres drilled * time spent to drill)
sugarcane	Tractor hours= tractor ploughing (hrs) + tractor planking (hrs) + tractor levelling (hrs) + tractor furrow (hrs) + tractor earthing up (hrs) + tractor rotavations (hrs)	(no of ploughings * no of acres * Time spent (hours) to plough one acre) + (no of planking * no of acres * time spent (hours) to plank one acre) +(no of Rotavations * no of acres * time spent (hours) to rotavate one acre) +(no of acres levelled * time spent (hours) to level one acre) + (earthing up done on number of acres * time spent to done earthing up one acre) + (furrow making(no of acres*time spent
Maize	Tractor hours= tractor ploughing (hrs) + tractor planking (hrs) + tractor levelling (hrs) + tractor ridging (hrs) + tractor drilling (hrs) + + tractor rotavations (hrs)	(no of ploughings * no of acres * Time spent (hours) to plough one acre) + (no of planking * no of acres * time spent (hours) to plank one acre) +(no of Rotavations * no of acres * time spent (hours) to rotavate one acre) +(no of acres levelled * time spent (hours) to level one acre) + (no of acres drilled * time spent to drill)+ (no of acre ridged*time spent to done ridging one acre)

CROP	COMPUTATION OF FERTILIZER
Wheat	Nitrogen fertilizer(kg)= No of kg of fertilizer applied per acre (top and basal dose) * no of acre Phosphoric fertilizer (kg)= No of kg of fertilizer applied per acre (top and basal dose) * no of acre Potash fertilizer(kg)= No of kg of fertilizer applied per acre (top and basal dose) * no of acre
Cotton	Nitrogen fertilizer(kg)= No of kg of fertilizer applied per acre (top and basal dose) * no of acre Phosphoric fertilizer (kg)= No of kg of fertilizer applied per acre (top and basal dose) * no of acre Potash fertilizer(kg)= No of kg of fertilizer applied per acre (top and basal dose) * no of acre
sugarcane	Nitrogen fertilizer(kg)= No of kg of fertilizer applied per acre (top and basal dose) * no of acre Phosphoric fertilizer (kg)= No of kg of fertilizer applied per acre (top and basal dose) * no of acre Potash fertilizer(kg)= No of kg of fertilizer applied per acre (top and basal dose) * no of acre
Maize	Nitrogen fertilizer(kg)= No of kg of fertilizer applied per acre (top and basal dose) * no of acre Phosphoric fertilizer (kg)= No of kg of fertilizer applied per acre (top and basal dose) * no of acre Potash fertilizer(kg)= No of kg of fertilizer applied per acre (top and basal dose) * no of acre

VARIABLES	COMPUTATION OF IRRIGATION HOURS
Irrigation (hours)	Irrigation (hours) = irrigational hour(canal) +irrigation hour(tube well)+ irrigational hour(canal +tube well)
	Irrigations (hrs)= (No of canal irrigations including rauni)*(no of acres irrigated with canal)*(time required to irrigate one acre) + ((No of tubwell irrigations including rauni)*(no of acres irrigated with tubewell)*(time required to irrigate one acre) + (No of canal +tubewell irrigations including rauni)*(no of acres irrigated with canal+tubewell)*(time required to irrigate one acre)

CROP	COMPUTATION OF PESTICIDES
Wheat	Total cost rupees=No of litres applied/acre* price of one litre* no of acres
Cotton	Total cost rupees=No of litres applied/acre* price of one litre* no of acres
sugarcane	Total cost rupees=No of litres applied/acre* price of one litre* no of acres
Maize	Total cost rupees=No of litres applied/acre* price of one litre* no of acres

CROPS	Computation of Labour hours	Detailed Procedure
Wheat	Labours hours = labour ploughing (hrs) + labour planking (hrs) + labour levelling (hrs) + labour (hrs) drilling +labour harvesting (hrs) + labour threshing (hrs)	(no of ploughings/acre * no of labour involved * time required (hours) to plough one acre * wheat area) + (no of planking * no of labour involved * no of acres * time required (hours) to plank one acre) + (no of rotavations * no of acres * no of labour involved * time required (hours) to rotavate one acre) + (no of acres drilled * time spent to drill* no of labour involved)+ (no of acre harvested Mechanically * time spent) + No of acre threshed* time spent to threshed*)
Cotton	Labours hours = labour ploughing (hrs) + labour planking (hrs) + labour levelling (hrs) + labour (hrs) drilling +labour harvesting (hrs) + labour threshing (hrs	(no of ploughings * no of acres * time spent (hours) to plough one acre) + (no of planking * no of acres * time spent (hours) to plank one acre) +(no of Rotavations * no of acres * time spent (hours) to rotavate one acre) +(no of ploughings * no of acres * time spent (hours) to plough one acre) + (no of ploughings * no of acres * time spent (hours) to plough one acre) + (no of acres drilled * time spent to drill)+ (no of acre harvested Mechanically * time spent) + No of acre threshed* time spent to threshed)
sugarcane	Labours hours = labour ploughing (hrs) + labour planking (hrs) + labour levelling (hrs) + labour (hrs) drilling +labour harvesting (hrs) + labour threshing (hrs	(no of ploughings * no of acres * time spent (hours) to plough one acre) + (no of planking * no of acres * time spent (hours) to plank one acre) + (no of Rotavations * no of acres * time spent (hours) to rotavate one acre) +(no of ploughings * no of acres * time spent (hours) to plough one acre) + (no of ploughings * no of acres * time spent (hours) to plough one acre) + (no of acres drilled * time spent to drill)+ (no of acre harvested Mechanically * time spent) + No of acre threshed* time spent to threshed)
Maize	Labours hours = labour ploughing (hrs) + labour planking (hrs) + labour levelling (hrs) + labour (hrs) drilling +labour harvesting (hrs) + labour threshing (hrs)	(no of ploughings * no of acres * time spent (hours) to plough one acre) + (no of planking * no of acres * time spent (hours) to plank one acre) +(no of Rotavations * no of acres * time spent (hours) to rotavate one acre) +(no of ploughings * no of acres * time spent (hours) to plough one acre) + (no of ploughings * no of acres * time spent (hours) to plough one acre) + (no of acres drilled * time spent to drill)+ (no of acre harvested Mechanically * time spent) + No of acre threshed* time spent to threshed)

Appendix D: Village Rates for Different Operations

S.NO	Operation	Village rate (Hired)	Own tractor
Village rate Land Preparation			
1	Ploughing per Acre	Rs.811.46/Acre	Rs.361.66
2	Planking	Rs.408/Acre	Rs.170.24
3	Rotavations	Rs.1682.68/Acre	Rs.964.54
4	Levelling	1800/hour	Rs.865/hour
5	Drilling	Rs.886/Acre	Rs.400.78
6	Ridge making	Rs.914/Acre	Rs.482
7	Bed making	Rs.856/Acre	Rs.433
Village Rate Harvesting			
1	Harvesting wheat	3.5 Munds wheat/acre Approx. (3000PKR)	
2	Shelling Maize	2 Kg Maize/ Mund	2000/Acre
3	Cotton picking	5 to 7 Rupees/kg	
4	interculturing	20 Rupees/ridge	
5	Earthing up	2000/acre Manual, 700/acre tractor	400/Acre tractor
Village Rate Irrigation			
1	Tube well irrigation	650/Hour	300/Hour
2	Canal irrigation	200/acre annually	
Price of Fertilizer			
	Name of Fertilzer	**Price /50 Kg bag**	
1	DAP	3236	
2	UREA	1145	
3	Nitrophos	2108	
4	SSP	896	
5	TSP	2418	
6	SOP	2807	
Price/40 Kg			
1	Wheat	1123.35	
2	Cotton	2273.5	
3	Maize	975.00	
4	Sugarcane	146.760	

Appendix E: Questionnaire

NAME OF ENUMERATOR:		DISTRICT:	
VILLAGE NAME:		TEHSIL:	
VILLAGE NO:		DATE:	

1- FARMER'S CHARACTERISTICS	
1.1- Farmer's name	
1.2- Head of the household (Tick in relevant Box)	1-Yes ☐ 2- No ☐
1.3- Age	(Years)
1.4- Sex (Tick in the relevant Box)	1- Male ☐ 2- Female ☐
1.5- Education	1- No formal Education ☐ 2- Primary ☐ 3- Secondary ☐ 4- College ☐ 5- University ☐ 6- Other (Specify)______ ☐
1.6- Farming Experience	(Years in Farming)
1.7- Marital Status (Tick in relevant Box)	1-Single ☐ 2-Married ☐ 3-Divorced ☐
1.8- Size of Household (No)	1-Adults ☐ 2- Children ☐ 3-Total ☐
1.9- Tenure status	1-Owner ☐ 2-Tenant ☐ 3-Owner cum tenant ☐

2-CHARACTERISTICS RELATED TO FARM	
2.1- Total farm area including renting in and renting out land	(Acres)
2.2- How much area of land you are renting in at present?	(Acres)
2.3- How much area of land you are renting out at present?	(Acres)
2.4- Total farm area currently under crop production	(Acres)
2.5- Own land	(Acres)
2.6- Fallow land	(Acres)
*Land Temporarily out of cultivation for a period of not less than one year and not more than five years and will be included in the total farm area	
2.6.1- What are the reasons for not cultivating the fallow land? Please state	1-____________________ 2-____________________
2.7- Culture able waste	(Acres)
2.8- How much area of your land is under shed and building?	(Acres)
2.9- Please mention the rent/acre of tenanted land	(PKR)
2.10- Is all of your land present at a single location?	1-yes ☐ 2-No ☐ If No answer the question below
2.11- What is number of parcels of land that you control?	(No) What is the average distance between each parcel? (approximately)______________Km
2.12- What is the effect of fragmentation on crop production	1- Increase transportation cost ☐ 2-Time Consuming ☐ 3- increased use of labour ☐ 4- Other (specify) ☐ 5-Other (specify) ☐
2.13-Type of soil	1-Sandy ☐ 2- Clayey ☐ 3-Sandy loam ☐ 4-Clayey loam ☐
2.14- What is your perception about the quality* of soil?	1-Good ☐ 2- Medium ☐ 3-Bad ☐
Quality * Good= Highly productive, medium=Less productive, Bad= Not productive	
2.15- Do you have problem of water logging?	1-Yes ☐ 2- No ☐
2.16- What is the major source of Irrigation?	1-Canal water ☐ 2- Tube well water ☐ 3-canal+ tube well ☐
2.17-Type of canal	1-Prennial* ☐ 2- Non perennial ☐

2.18- Do you have your own tubewell?	1-Yes ☐ 2- No ☐
2.19-Type of tube well	1-Diseal ☐ 2- Electric ☐ 3-Tractor driven ☐ 4- peter ☐
2.20- What is your perception about the quality of your tube well water?	1-Fit for irrigation ☐ 2- Not fit for irrigation ☐ 2- Moderately fit for irrigation ☐
2.21- Does tube well water cause salinity?	1-Yes ☐ 2- No ☐
2.22- Extent of salinity according to your opinion	1-High ☐ 2-Medium ☐ 3-Low ☐
2.23- What is the share of each type of irrigation source in total irrigation water?	1- Canal water ______% 2- Tube well water ______%
2.24- If you are not satisfied with the availability of irrigation water what are the reasons? Please state	1- ________________ 2- ________________ 3- ________________
3-LABOUR INFORMATION	
3.1-Please provide the details on family members engaged in full time farming.	1-Males ☐ No 2-Females ☐ No 3-Childern ☐ No 4-Total ☐ No
3.2- Please provide the details on family members engaged in part time farming.	1-Males ☐ No 2-Females ☐ No 3-Childern ☐ No 4-Total ☐ No
3.3- Permanent hired Labour.	(No)
3.4- Wages paid to permanent hired labour.	(PKR/year) Other incentives 1-Clothes/shoes ______________ 2-Food items ______________ 3- Other(specify) ______________

Perennial canal* : Canals which supply water almost throughout the year

4- INFORMATION ABOUT CROPPING PATTERN DURING RABI AND KHARIF SEASON (2010-11)

AREA UNDER DIFFERENT CROPS DURING RABI SEASON		
S.NO	CROPS	AREA UNDER PARTICULAR CROP (ACRES)
1	Wheat	
2	Barley	
3	Mustard	
4	Peas	
5	Rabi fodder	
6	Rabi pluses	
7	Rabi vegetables	
8	Other (specify)	
9	Other (specify)	
10	Other (specify)	
11	Other (specify)	
12	Other (specify)	
AREA UNDER DIFFERENT CROPS DURING KHARIF SEASON		
S.NO	CROPS	AREA UNDER PARTICULAR CROP (ACRES)
1	Cotton	
2	Rice	
3	Maize	
4	Sugarcane	
5	Kharif fodder	
6	Kharif vegetables	
7	Kharif pluses	
8	Other (specify)	
9	Other (specify)	
10	Other (specify)	
11	Other (specify)	
12	Other (specify)	

PLEASE PROVIDE INFORMATION ABOUT THE WHEAT PRODUCTION PRACTICES

WHEAT PRODUCTION PRACTICES	
1.1) Land Preparation	**(No/acre)**
• Ploughing	
• Planking	
• Rotavation	
• Deep Ploughing	
1.2) Levelling of field (please tick in the box)	1-yes ☐ 2- No ☐ (if "No" go to Q 1.4)
1.3) Time spent on levelling	(Hrs /acre)
1.4) No of rauni applied	(No)
1.5) Sowing date	1- Early (before 15 Nov) ☐ 2- Late (16 Nov to 15 Dec) ☐
1.6) If crop is grown late, please state reasons for late sowing?	1. ______ 2. ______ 3. ______
1.7) Please provide the details of planting method used to sow crop and area grown using particular planting method	Planting Method / Area (acres) 1-Drill ☐ 2-Broadcast ☐ 3- Kera ☐
1.8) Bund making	1- yes ☐ 2- No ☐
1.9) Source of cultivation	1- Own tactor ☐ 2- Hired tractor ☐ 3-Bullock ☐
1.10) Please provide the detail about village rate for hiring in tractor services/ operation and the number of hours of tractor spent to carry out particular farm operation	Operation / Rate /acre PKR/operation / Hr spent/acre (own tractor) / Hr spent/acre (hired tractor) 1-Ploghing ☐ ☐ ☐ 2-Planking ☐ ☐ ☐ 3-Rotavation ☐ ☐ ☐ 4-Levelling ☐ ☐ ☐ 5-Drilling ☐ ☐ ☐
1.11) In case of own tractor, cost to prepare one acre of land	(PKR/acre)

2-SEED INFORMATION	
2.1) Source of seed	1. Punjab seed corporation ☐ 2. Research institute ☐ 3. Fellow farmers ☐ 4. Arti ☐ 5. Self produced ☐ 6. Other (please specify) ☐
2.2) Area under wheat crop	(Acres)
2.3) please provide detail about the area under different crop varieties	Variety / Area grown 1. Faisalabd 2008 ☐ 2. Lasani 2008 ☐ 3. Sehar 2006 ☐ 4. Shafaq 2006 ☐ 5. Inqlab 91 ☐ 6. Pasban 90 ☐ 7. Bhakar 2002 ☐ 8. Punjab 11 ☐ 9. Millat 11 ☐

	10. Other (specify______ ☐
2.4) Seed rate	Amount Kg/acre 1. Early sowing ☐ 2. Late sowing ☐
2.5) Quality of seed	1- Improved ☐ 2- Unimproved ☐
2.6) Did you grade the seed before sowing?	1-Yes ☐ 2- No ☐
2.7) Germination (approximately)	%
2.8) Seed cost	(PKR/kg)
2.9) Seed treatment with fungicide (please tick in the box)	1-Yes ☐ 2- No ☐
2.10) Name of fungicide	1- __________
3-PLANT PROTECTION MEASURE	
3.1) Weedcide	1- Yes ☐ 2- No ☐
3.2) If yes name of weedcides sprayed	1_________ 2 _______ 3 ________
3.3) No of litres of each weedcide sprayed (Litres/acre)	1_________ 2 _______ 3 ________
3.4) Cost of each weedcide (PKR/litre)	1_________ 2 _______ 3 ________
3.5) Weed intensity	1- Low ☐ 2- Medium ☐ 3-High ☐

4-FERTILIZER APPLICATION			
4.1) Basal dose of fertilizer applied	**Fertilizer**	**Amount(bag/acre)**	**Price/bag**
	• Diaammonium phosphate		
	• Single super phosphate		
	• Nitrophosphate		
	• NPK		
	• Anyother(specify)____		
	• Anyother(specify)____		
	• Anyother(specify)____		
4.2)Top dose of fertilizer used	• Urea		
	• Ammonium Nitrate		
	• Nitrophose		
	• Anyother(specify)____		
	• Anyother(specify)____		
	• Anyother(specify)____		
	• Anyother(specify)____		
4.3) Amount of farm yard manure applied/acre	(Trolly/acre)		
4.4) Area treated with farm yard manure	(Acres)		
4.4) Cost/trolley	(PKR)		
4.5) Green manuring	1- Yes ☐ 2- No ☐		
5-IRRIGATION INFORMATION			
5.1) Time of first irrigation (day after planting)			
5.2) Did you apply the irrigations on time?	1- Yes ☐ 2- No ☐		
5.3) if no, did the crop yield is effected?	1- Yes ☐ 2- No ☐		

5.4) Total number of irrigation to wheat crop	(No/acre)
5.5) No of irrigation by different sources	Source / own /hired / No/acre / Amount(Acre-inch) 1-Canal 2-Tubewell 3-Canal + tubwell
5.6) Share of tube well and canal water	1- canal ______% 2- tubwell______%
5.7) Village rate for tubwell water	(PKR/Hr)
5.8) No of hours of tubwell water bought	(Hrs)
5.9) Time taken by tubwell water to irrigate one acre	(Hrs)
5.10) Effect of ground water on production of crop	1- Positive 2- Negative
5.11) Were all the irrigation on time	1- Yes 2- No
5.12) Amount paid for canal water	PKR/acre
6-HARVESTING	
6.1) Harvesting date	
6.2) Harvesting method and area harvested using particular harvesting method	Method / Acres 1- Manual 2- Combine harvestor 3- Reaper
6.3) Harvesting cost	Paid in kind (kg/acre) / Paid in cash (PKR/acre) 1. Manual harvesting 2. Reaper 3. Combine harvester
6.4) Threshing cost	• Thresher cost ________ (PKR/40kg)
7-LABOUR INVOLVED	
7.1) Labour involved in carrying out different farm operations	No / Time Spent (Hr/acre) / Rate/Hr PKR 1. Land preparation 2. Weeding 3. Water channel cleaning 4. Harvesting 5. Threshing 6. Irrigation 7. Spraying
8-PRODUCTION	
8.1) Total wheat production	(Maund (40kg)/acre)
8.2) Wheat production in good field	(Maund (40kg)/acre)
8.3) Wheat production in poor field	(Maund (40kg)/acre)
8.4) Wheat price	(PKR/40 kg)
8.5) Wheat straw produced	1. Amount ________ (kg/acre) 2. Price ________ (PKR/kg)
***9-* WHAT ARE THE MAJOR YIELD LIMITING FACTOR (SPECIFY)**	

1- ____

2- ____

3- ____

4- ____

5- ____

COTTON PRODUCTION PRACTICES	
1) Land Preparation	(No/acre)
• Ploughing	
• Planking	
• Rotavations	
• Deep ploughing	
• Cultivator	
1.2) Levelling of field (please tick in the box)	1-yes ☐ 2- No ☐
1.3) Time spent on levelling	1- Own tractor______ (hrs /acre) 2- Hired tractor ______ (hr/acre)
1.4) Sowing Date	1- Early sowing (March) ☐ 2- Mid sowing (April) ☐ 3- Late (1st May to 15 May) ☐
1.5) Reasons for late sowing	1. ______________ 2. ______________ 3. ______________
1.6) Please provide the details of planting method used to sow crop and area grown using particular planting method	**Planting Method** / **Area (acres)** 1-Drill ☐ 2-Broadcast ☐ 3- Kera ☐ 4-Manual ☐
1.7) Source of cultivation	1- Own tactor ☐ 2- Hired tractor ☐ 3-Bullock ☐
1.8) Please provide the detail about village rate for hiring in tractor services/ operation and the number of hour of tractor spent to carry out particular farm operation	see table below
1.9) In case of own tractor, cost to prepare one acre of land	(PKR/acre)

Operation	Rate(PKR)	Hr spent/acre (own tractor)	Hr spent/acre (hired tractor)
1-Ploghing			
2-Planking			
3-Rotavation			
4-Levelling			
5-Drilling			

2-SEED INFORMATION	
2.1) Source of seed	1. Punjab seed corporation ☐ 2. Research institute ☐ 3. Fellow farmers ☐ 4. Arthi ☐ 5. Self produced ☐ 6. Other (please specify ☐
2.2) Area under cotton crop	(Acres)
2.3) Areas under different crop varieties	**Variety** / **Area grown** 1. IR-3701 ☐ 2. Ali akbar-703 ☐ 3. MG-6 ☐ 4. FH-113 ☐ 5. Neelam-121 ☐ 6. Ali akbar- 802 ☐ 7. IR-1524 ☐ 8. MNH 886 ☐ 9. Other (specif) ☐

2.4) Seed rate	Amount Kg/acre 3. Early sowing ☐ 4. Late sowing ☐
2.5) Seed treatment with fungicide and virus (please tick in the box)	1-Yes ☐ 2- No ☐
2.6) Name of fungicide	1-__________ 2.__________
2.7) Quality of seed	1- Improved ☐ 2- Unimproved ☐
2.8) Seed grading for sowing	1-Yes ☐ 2- No ☐
2.9) Germination rate (approximately)	%
2.10) Seed cost	(PKR/kg)
2.11) Row to row distance	(Inches)
2.12) Plant to plant distance	(inches)
2.13) Thinning	1-Yes ☐ 2- No ☐
2.14) Plant Population	(no/acre)
3-PLANT PROTECTION MEASURE	
3.1) Weedcide	1- Yes ☐ 2- No ☐
3.2) Method of weed control	1- Manual ☐ 2- Chemical ☐ 3- Both ☐
3.3) if manual no of hoeing/acre	(no/acre)
3.4) If chemical, name of weedcides sprayed	1________ 2 ________ 3 ________
3.5) No of litres of each weedcide sprayed (Litres/acre)	1________ 2 ________ 3 ________
3.6) Cost of each weedcide (PKR/litre)	1________ 2 ________ 3 ________
3.7) Weed intensity	1- Low ☐ 2- Medium ☐ 3-High ☐
3.8) Pesticides sprayed	(no/acre)
3.9) Name of each pesticide sprayed	1. _______ 2. _______ 3._______
3.10) No of litres of each pesticide sprayed	1. _______ 2. _______ 3._______
3.11)Cost of each pesticide	1. _______ 2. _______ 3._______
3.12) Did you apply the pesticide before the economic threshold level of pests?	1- Yes ☐ 2- No ☐
3.13) Method of spraying	1- Hand Sprayer ☐ 2- Boom sprayer ☐ 2- tractor mounted sprayer ☐

4-FERTILIZER APPLICATION			
4.1) Basal dose of fertilizer applied	Fertilizer	Amount(bag/acre)	Price/bag
	• Diaammonium phosphate		
	• Single super phosphate		
	• Nitrophosphate		
	• NPK		
	• Anyother(sp)________		
	• Anyother(sp)________		
	• Anyother(sp)________		
4.2)Top dose of fertilizer used	• Urea		
	• Ammonium Nitrate		
	• Nitrophose		
	• Anyother(sp)________		
	• Anyother(sp)________		
	• Anyother(sp)________		
4.3) Amount of farm yard manure applied/acre		(Trolly/acre)	
4.4) Area treated with farm yard manure		(acres)	
4.4) Cost/trolley		(PKR)	
4.5) Green manuring		1- Yes ☐ 2- No ☐	

5-IRRIGATION INFORMATION	
5.1) Time of first irrigation (day after planting)	
5.2) Total number of irrigation to cotton crop	(No/acre)
5.3) No of irrigation by different sources	Source / own /hired / No/acre / Amount(Acre-inch) 1-Canal ☐ ☐ ☐ 2-Tubewell ☐ ☐ ☐ 3-Canal + tubwell ☐ ☐ ☐
5.4) Share of tube well and canal water	1- canal ______% 2- Tubwell______%
5.5) Village rate for tubwell water	(PKR/hr)
5.6) No of hours of tubwell water bought	(Hrs)
5.7) Time taken by tubwell water to irrigate one acre	(Hrs)
5.8) Effect of ground water on production	1- Positive ☐ 2- Negative ☐

6-HARVESTING						
6.1) Date of first picking						
6.2) Total number of pickings	(No)					
6.3) cost of picking and labour		1st	2nd	3rd	4th	5th
	Labour (no)	☐	☐	☐	☐	☐
	Wages (knid)	☐	☐	☐	☐	☐
	Wages(PKR)	☐	☐	☐	☐	☐

6.4) Harvesting cost	Paid in kind (kg/acre) / paid in cash (PKR/acre) 1. Picking cost 2. Cutting of crop

7-LABOUR INVOLVED

7.1) Labour involved in carrying out different farm operations	No	Time Spent (Hr/acre)	Rate/Hr PKR
1. Land preparation			
2. Weeding			
3. Water channel cleaning			
4. Picking			
5. seed treatment			
6. Irrigation			
7. Spraying			

8-PRODUCTION

8.1) Total Cotton production	(Maund 40kg)/acre)
8.2) Cotton production in good field	(Maund 40kg)/acre)
8.3) Cotton production in poor field	(Maund 40kg)/acre)
8.4) Cotton price	(PKR/40 kg)
8.5) By- product of cotton	1. Price __________ (PKR/kg)
	2.

9- WHAT ARE THE MAJOR YIELD LIMITING FACTOR (SPECIFY)

1-____

2-____

3-____

4-____

5-____

6-____

SUGARCANE PRODUCTION PRACTICES	
Type of Crop	1- Main crop ☐ 2- Ratoon crop ☐
1) Land Preparation	(No/acre)
• Ploughing	
• Planking	
• Rotavations	
• Deep ploughing	
1.2) Levelling of field (please tick in the box)	1-yes ☐ 2- No ☐
1.3) Time spent on levelling	1- Own tractor_______ (hrs /acre) 2- Hired tractor _______ (hr/acre)
1.4) Sowing Date	1- Feb to mid March ☐ 2- September ☐
1.5) Please provide the details of planting method used to sow crop and area grown using particular planting method	Planting Method / Area (acres) 1-Ridge sowing ☐ 2-Furrow sowing ☐ 3- Stripe sowing ☐ 4-Double stripe sowing ☐
1.6) Source of cultivation	1- Own tactor ☐ 2- Hired tractor ☐ 3-Bullock ☐
1.7) Please provide the detail about village rate for hiring in tractor services/ operation and the number of hour of tractor spent to carry out particular farm operation	Operation / Rate(PKR) / Hr spent/acre (own tractor) / Hr spent/acre (hired tractor) 1-Ploghing ☐ ☐ ☐ 2-Planking ☐ ☐ ☐ 3-Rotavation ☐ ☐ ☐ 4-Levelling ☐ ☐ ☐ 5-Furrow making ☐ ☐ ☐ 6-Eathing up ☐ ☐ ☐
1.8) In case of own tractor, cost to prepare one acre of land	(PKR/acre)
2-SEED INFORMATION	
2.1) Source of seed	2- Punjab seed corporation ☐ 3- Research institute ☐ 4- Fellow farmers ☐ 5- Arthi ☐ 6- Self produced ☐ 7- Other (please specify) ☐
2.2) Area under Sugarcane crop	(Acres)
2.3) Areas under different crop varieties	`Early maturing Vareities / Area / Late varieties 1. CPF-243 ☐ SPF-213 ☐ 2. HSF-243 ☐ SPF-234 ☐ 3. CPF-237 ☐ SPF-245 ☐ 4. CPF-33-44 ☐ 5. CP 40-77 ☐ 6. Other(specify) ☐ 7. Other (specify) ☐

2.4) Seed rate	Varaiety Amount Kg/acre Sets/acre (no) 1. Early Maturing ☐ 2. Late sowing ☐
2.5) Seed treatment with fungicide (please tick in the box)	1-Yes ☐ 2- No ☐
2.6) Name of fungicide	1-_____________ 2._____________
2.7) No of buds on setts	1- One ☐ 2- Two ☐ 3- Three ☐
2.8) Seeding depth below soil	(cm)
2.9) Germination rate (approximately)	%
2.10) Earthling up	1- First Earthing up day after planting ________ 2- Second earthing up day afetr planting ________
2.11) Seed cost	(PKR/40Kg)
2.12) Row to row distance	(Inches)
2.13) Plant to plant distance	(inches)
2.14) Distance between setts	(cm)
2.15) Plant Population	(no/acre)
2.16) Did you cover the setts with soil?	1-Yes ☐ 2- No ☐
3-PLANT PROTECTION MEASURE	
3.1) Weedcide	1- Yes ☐ 2- No ☐
3.2) Method of weed control	1- Manual ☐ 2- Chemical ☐ 3-Both ☐
3.3) if manual no of hoeing/acre	(no/acre)
3.4) How many days after, the first hoeing was done?	(days)
3.4) If chemical, name of weedcides sprayed	1________ 2 _______ 3 ________
3.5) No of litres of each weedcide sprayed (Litres/acre)	1________ 2 _______ 3 ________
3.6) Cost of each weedcide (PKR/litre)	1________ 2 _______ 3 ________
3.7) Weed intensity	1- Low ☐ 2- Medium ☐ 3-High ☐
3.8) Pesticides sprayed or applied	(no/acre)
3.9) Name of each pesticide sprayed or applied	1. _______ 2. ______ 3._______
3.10) No of litres or Kg of each pesticide sprayed or applied	1. _______ 2. ______ 3._______
3.11 Cost of each pesticide	1. _______ 2. ______ 3._______
3.12) Did you apply the pesticide before the economic threshold level of pests?	1- Yes ☐ 2- No ☐
3.13) Method of spraying or applying	1- Hand Sprayer ☐ 2- Manual ☐

4-FERTILIZER APPLICATION			
4.1) Basal dose of fertilizer applied	Fertilizer	Amount(bag/acre)	Price/bag
	• Diaammonium phosphate		
	• Single super phosphate		
	• Nitrophosphate		
	• NPK		
	• Anyother(sp)________		
	• Anyother(sp)________		

	• Anyother(sp)________		
	•		
4.2)Top dose of fertilizer used	• Urea		
	• Ammonium Nitrate		
	• Nitrophose		
	• Anyother(sp)________		
	• Anyother(sp)________		

4.3) Amount of farm yard manure applied/acre	(Trolly/acre)
4.4) Area treated with farm yard manure	(acres)
4.5) Cost/trolley	(PKR)
4.6) Green manuring	1- Yes ☐ 2- No ☐

5- IRRIGATION INFORMATION

5.1) Time of first irrigation (day after planting)	
5.2) Total number of irrigation applied	(No/acre)
5.3) No of irrigation by different sources	**Source** **own /hired** **No/acre** **Amount(Acre-inch)** 1-Canal ☐ ☐ ☐ 2-Tubewell ☐ ☐ ☐ 3-Canal + tubwell ☐ ☐ ☐
5.4) Share of tube well and canal water	1- canal ______% 2- Tubwell______%
5.5) Village rate for tubwell water	(PKR/hr)
5.6) No of hours of tubwell water bought	(Hrs)
5.7) Time taken by tubwell water to irrigate one acre	(hr)

6-HARVESTING

6.1) Date of Harvesting	
6.2) Cost of harvesting	(PKR)

7-LABOUR INVOLVED

7.1) Labour involved in carrying out different farm operations

	No	Total time (hr)	Rate/hr
1-Land preparation	☐	☐	☐
2-Weedcide	☐	☐	☐
3-Water channel cleaning	☐	☐	☐
4-Seed cutting	☐	☐	☐
5-Seed treatment	☐	☐	☐
6-Irrigation	☐	☐	☐
7-Hoeing	☐	☐	☐
8- Spraying	☐	☐	☐
9-Seed sowing	☐	☐	☐

8-PRODUCTION

8.1) Total Sugar cane production (main crop)	(Maund 40kg/acre)
8.2) Total sugarcane production (ratoon)	(Maund 40kg/acre)
8.3) Sugarcane production in good field	(Maund 40kg/acre)
8.4) production in poor field	(Maund 40kg)/acre)
8.5) where did u sale your produce?	1- Mill ☐ 2- Fellow farmers☐

8.6) Sale price	(PKR/40 kg)
8.7) By- product of Sugarcane	3. Amount ________ (kg/acre) 4. Price ________ (PKR/kg)

9- WHAT ARE THE MAJOR YIELD LIMITING FACTOR (SPECIFY)

1-______________________________
2-______________________________
3-______________________________
4-______________________________
5-______________________________
6-______________________________
7-______________________________

MAIZE PRODUCTION PRACTICES	
1) Land Preparation	(No/acre)
• Ploughing	
• Planking	
• Rotavations	
• Deep ploughing	
• Cultivator	
1.2) Levelling of field (please tick in the box)	1-yes ☐ 2- No ☐
1.3) Time spent on levelling	1- Own tractor______ (hrs /acre) 2- Hired tractor ______ (hr/acre)
1.4) Sowing Date	
1.5) Planting method	1- Ridge sowing ☐ 2- Broadcast ☐
1.6) Source of cultivation	- 1- Own tactor ☐ 2- Hired tracto ☐ 3-Bullock ☐
1.7) please provide the detail about village rate for hiring in tractor services/ operation and the number of hour of tractor spent to carry out particular farm operation	see below
1.8) In case of own tractor, cost to prepare one acre of land	(PKR/acre)

Operation	Rate(PKR)	Hr spent/acre (own tractor)	Hr spent/acre (hired tractor)
1-Ploghing	☐	☐	☐
2-Planking	☐	☐	☐
3-Rotavation	☐	☐	☐
4-Levelling	☐	☐	☐
5-Ridging	☐	☐	☐

2-SEED INFORMATION	
2.1) Source of seed	1. Punjab seed corporation ☐ 2. Research institute ☐ 3. Fellow farmers ☐ 4. Self produced ☐ 5. Other (please Specify) ☐ 6. Other (please specify) ☐
2.2) Area under Maize crop	(Acres)
2.3) Areas under different crop varieties	see below
2.4.) Seed rate (kg/acre)	see below

varieties	Area
1. Hybrid(FH-810)	☐
2. Ageti - 2002	☐
3. Sahiwal-2002	☐
4. Synthetic seed	☐
5. White 3025	☐
6. Dk 6789	☐
7. Poineer 30y87	☐
8. Other (specify)	☐

Operation	Ridge	Broadcast
1. Hybrid(FH-810)	☐	☐

	2. Ageti - 2002 ☐ ☐ ☐ 3. Sahiwal-2002 ☐ ☐ ☐ 4. Synthetic seed ☐ ☐ ☐ 5. White 3025 ☐ ☐ ☐ 6. Poineer 30y87 ☐ ☐ ☐ 7. Dk 6789 ☐ ☐ ☐
2.5) Seeding depth below soil	(cm)
2.6) Germination rate (approximately)	%
2.7) Seed cost	1- Hybrid seed _______ (PKR/Kg) 2- Synthetic seed _____ _ (PKR/Kg)
2.8) Distance between ridges	(Inches)
2.9) Plant to plant distance	(inches)
2.10) Thinning	1-Yes ☐ 2- No ☐
2.11) Plant Population	(no/acre)

3-PLANT PROTECTION MEASURE	
3.1) Weedcide	1- Yes ☐ 2- No ☐
3.2) Method of weed control	
3.3) if manual no of hoeing/acre	(no/acre)
3.4) If chemical, name of weedcides sprayed	1_________ 2 _______ 3 ________
3.5) No of litres of each weedcide sprayed (Litres/acre)	1_________ 2 _______ 3 ________
3.6) Cost of each weedcide (PKR/litre)	1_________ 2 _______ 3 ________
3.7) Weed intensity	1- Low ☐ 2- Medium ☐ 3-High ☐
3.8) Pesticides sprayed or applied	(no/acre)
3.9) Name of each pesticide sprayed or applied	1. _______ 2. _______ 3._______
3.10) No of litres or Kg of each pesticide sprayed or applied	1. _______ 2. _______ 3._______
3.11) Cost of each pesticide	1. _______ 2. _______ 3._______
3.12) Did you apply the pesticide before the economic threshold level of pests?	1- Yes ☐ 2- No ☐
3.13) Method of spraying or applying	1- Hand Sprayer ☐ 2- Manual ☐

4-FERTILIZER APPLICATION			
4.1) Basal dose of fertilizer applied	**Fertilizer**	**Amount(bag/acre)**	**Price/bag**
	• Diaammonium phosphate		
	• Single super phosphate		
	• Nitrophosphate		
	• NPK		
	• Anyother(sp)________		
	• Anyother(sp)________		
	• Anyother(sp)________		
4.2)Top dose of fertilizer used	• Urea		
	• Ammonium Nitrate		
	• Nitrophose		
	• Anyother(sp)________		
	• Anyother(sp)________		
4.3) Amount of farm yard manure applied/acre		(Trolly/acre)	
4.4) Area treated with farm yard manure		(acres)	

4.5) Cost/trolley	(PKR)
4.6) Green manuring	1- Yes ☐ 2- No ☐
5-IRRIGATION INFORMATION	
5.1) Time of first irrigation (day after planting)	
5.2) Total number of irrigation applied	(No/acre)
5.3) No of irrigation by different sources	Source / own /hired / No/acre 1-Canal ☐ ☐ 2-Tubewell ☐ ☐ 3-Canal + tubwe ☐ ☐
5.4) Share of tube well and canal water	1- canal ______% 2- Tubwell______%
5.5) Village rate for tubwell water	(PKR/hr)
5.6) No of hours of tubwell water bought	(Hrs)
5.7) Time taken by tubwell water to irrigate one acre	(hr)
5.8) Effect of ground water on production	1- Positive ☐ 2- Negative ☐
6-HARVESTING	

6.1) Harvesting date	
6.2) Threshing Method	1- Manual ☐ 2- Mechanical ☐
6.3) if manual, which method is followed	1- Removing grains from cobs bare hande ☐ 2- Removing grains froms cobs by beating ☐
6.4) Harvesting cost	(PKR)
7-LABOUR INVOLVED	
7.1) Labour involved in carrying out different farm operations	

Operation	No	Total time (hr)	Rate/hr
1-Land preparation	☐	☐	☐
2-Weedcide	☐	☐	☐
3-Water channel cleaning	☐	☐	☐
4- Sowing	☐	☐	☐
5-Seed treatment	☐	☐	☐
6-Irrigation	☐	☐	☐
7-Hoeing	☐	☐	☐
8- Spraying	☐	☐	☐
9-Seed sowing	☐	☐	☐
10- Threshing	☐	☐	☐

8-PRODUCTION	
8.1) Total Maize production	Maund (40kg/acre)
8.2) Maize production in good field	Maund (40kg/acre)
8.3) Maize production in poor field	Maund (40kg/acre)
8.4) Maize sale price	(PKR/40 kg)
8.5) By- product of Maize	2- Amount _________ (kg/acre) 3- Price _________ (PKR/kg)

7-Farm Inventory

Type	Ownership 1-Yes 2-No
Tractor	
Trolley	
Cultivator	
Rotavator	
Ridger	
leveller	
Thresher	
Hand Sprayer	
Tractor Sprayer	
Combine Harvester	
Wheat seed drill	
Cotton seed drill	
Chisel plough	
Scraper/Blade	
Electric tubewell	
Tractor tubewell	
Peter tubewell	
Disc plough	
Other (Specify)	
Other (Specify)	

8-SOURCE OF AGRICULTURAL CREDIT	
8.1- Did you borrow the money from any source? if no go to question 8.6	1- Yes ☐ 2- No ☐ (if yes answer the Q below ,
8.2- Please mention the source from where you borrowed the loan?	1-Formal ☐ 2-Non Formal ☐ 3- Both ☐
8.3- if non formal then tick in the relevant box	1- Friends ☐ 2- Relatives ☐ 3-Money lenders ☐ 3- Any other(Specify)________ ☐
8.4- What are the reasons of preference to a particular source ?(Please state)	1 2- 3-
8.5- If formal please mention the institution from where you borrowed the loan?	1-UBL ☐ 2-ZTBL ☐ 3- ABL ☐ 4-HBL ☐ 5- NBP ☐ 6-Punjab Bank ☐ 7- Any other (Please Specify)---------------- ☐ ***
8.6- What are the Reasons of Preference for a particular institution? (Please state)	1- 2- 3- 4-
8.7- If you are not borrowing loan from any source what are the reasons? Please State	1- 2- 3- 4-
9-STORAGE INFORMATION	
9.1- Do you store your produce before sale?	1-Yes ☐ 2- No ☐ (if no go to question 10.1)
9.2- Where do you store your produce?	1-Own store ☐ 2- Private ☐ 3- Any other ☐
9.3- Storage cost	PKR/year
10-MARKETING INFORMATION	
10.1-Where do you usually sell your produce?	1-Friend ☐ 2- Market ☐ 3- Middle man ☐ 4- Govt.Institution ☐ 5-Other(specify) ________ ☐
10.2-Did you receive the same price as announced by the Govt. for your produce?	1-Yes ☐ 2-No ☐ if No what are the reasons? Please State 1- 2- 3-
10.3- Do you have easy access* to agricultural inputs?	1-Yes ☐ 2- No ☐ (if no answer the question below)
10.4- What are the reasons if you have no or little access to agricultural inputs? Please state	1- 2- 3- 4-

11-PERCEPTION OF RESPONDENTS ABOUT THE PROBLEMS EXISTING IN STUDY AREA					
11.1 To what extent the following problems influence your crop yield?		To much extent	To an average extent	To some extent	Not at all
	1-Water scarcity				
	2- Low soil Fertility				
	3 –Water Lodging				
	4-Limited resources				
	5-Salinity				
	6-Poor quality Seed				
	7-High input Pricing				
	8-Size of holding				
	9- Improper Management				
	10-Weed infestation				
	11-Labour shortage				
	12-Insufficienct Machinery				
	13- Low Rainfall				
	14-Insect pest attack				
	15-No access to information				
	16- Lack of Modern knowledge				
11.2 To what extent the production can be increased by improving these factors?	Increased water availability				
	Lower input Prices				
	Providing sufficient Machinery				
	Weed control				
	Easy access to inputs				
	Better extension services				
	-Increased size of holding				
	Providing Funds				
	Better access to Market				
	Subsidy on inputs				
	Improving infra structure				
	Providing high quality seed				
	Increasing technical how know				

PART 2
SOURCE OF AGRICULTURAL INFORNMATION

1.1: Do you have contact with extension agent in your area? (1) Yes___ 2) No ___
1.2: If yes, did you get advisory service from extension agents? (1) Yes___ 2) No___
1.3: If no, why? Please state

____
____

1.4: If yes, did you get an advice from extension agent relating to wheat, cotton, sugarcane and maize?

S.No	Crop	Response	
		Yes	No
1	Cotton		
2	Maize		
3	Sugarcane		
4	Wheat		

1.5: How frequently do you visit extension agents to get information?

S.No	Crop	Once in year	Twice in Year	More than 2
1	Cotton			
2	Maize			
3	Sugarcane			
4	Wheat			

1.6: Did you put into practices, what you hear/learn from extension agent?

S.No	Crop	Response		If no, why? Please state
		Yes	No	
1	Cotton			
2	Maize			
3	Sugarcane			
4	Wheat			

1.7: Are you satisfied with the advice given?

S.No	Crop	Response		If yes, to what extent you are satisfied? 1-Highly satisfied 2-moderatly satisfied 3-Satisfied
		Yes	No	
1	Cotton			
2	Maize			
3	Sugarcane			
4	Wheat			

1.8: If no, why ? Please state

____
____
____

1.9- Did extension department provide any inputs? (1) yes___ (2) No_____
1.10: if yes? Did you get the inputs? (1) yes___ (2) No_____
1.11: what types of inputs you received?
1-_____________
2-_____________
3-_____________
4-_____________
5-_____________
1.12: If no, why didn't you get the inputs? please state
____
____

1.13- Did extension department provide any credit facility? (1) yes___ (2) No_____
1.14: if yes, Did you get the credit? (1) yes___ (2) No_____
1.15:if no, why you didn't get the credit from extension department? Please state
____
____

2.1: Did any training session relating to cotton, maize, rice, wheat, and cotton was conducted in your area and did you participate?

S.No	Crop	Response		Participation	
		Yes	No	Yes	No
1	Cotton				
2	Maize				
3	Sugarcane				
4	Wheat				
5	other ____				

2.2: Are you satisfied with the performance of the extension agent in conducting that training?

S.No	Crop	Response		If no, why? Please state
		Yes	No	
1	Cotton			
2	Maize			
3	Sugarcane			
4	Wheat			

3: Have you ever participated in the following extension events (Field days, Demonstration and Visits) over the last two years? (1) yes___ (2) No_____

S.No	event	Response		Participation	
		Yes	No	Yes	No
1	Field day				
2	Demonstration				
3	visits				
4	campaigns				
5	others				

.3.1: If not participated what were the reasons?
3.2Are there extension, technical assistance programs or educational opportunities regarding cotton, wheat sugarcane and maize crop are available on a regular basis?

S.No	Crop	Response		Participation		If you have not participated what are the reasons? please put the code
		Yes	No	Yes	No	
1	Cotton					
2	Maize					
3	Sugarcane					
4	Wheat					
5	other _____					

3.3. please rank the preferred communication method?

Method	Rank
Audio visual aid	
Farm and home visit	
Field day	
Result demonstration	
Trainings	
Signboard	
Lecture Meeting	
Method demonstration	
Others	
Campaigns	
Exhibitions	

.3.4: please rank information sources

Sources	Please tick in the box
Fellow farmers	
Local Traders	
NGO	
Friends	

Mobile phone	
Telephone	
Radio	
Other ________	

3.5 Rank your sources of information based on Accessibility, timeliness, reliability of their information

Sources	Response			
	Accessibility	Timeliness	Reliability	Effectiveness
Research centre				
Extension Agent				
Fellow farmers/friends				
Local Traders				
NGO				
Mobile phone				
Telephone				
Radio				
Other ________				

3.6: According to you perception what are the weakness in the current extension system and how it can be improved? suggest

____
____
____

Appendix F: A Complete List of Peer Farms

S.No	Wheat		Cotton		Maize		Sugarcane		Aggregated	
	Farm	No of Times	Farm	No of Times	Farm	No of Times	Farm	No of Times	Farm	No of Times
[1,]	24	143	13	89	165	141	156	118	1	186
[2,]	36	137	213	80	196	95	9	82	36	184
[3,]	13	113	1	74	58	81	66	71	233	85
[4,]	123	101	175	70	184	44	28	65	211	61
[5,]	190	54	173	62	187	35	16	47	105	59
[6,]	77	43	26	58	80	27	209	45	61	53
[7,]	53	38	150	57	31	18	169	31	164	47
[8,]	6	26	28	35	73	16	214	25	237	29
[9,]	68	16	71	26	150	8	68	17	198	27
[10,]	230	15	196	25	1	8	70	13	158	17
[11,]	135	14	75	23	87	7	197	11	87	16
[12,]	35	11	216	20	30	6	44	11	78	15
[13,]	1	9	179	17	134	6	205	10	225	13
[14,]	181	8	23	15	93	5	186	4	68	9
[15,]	71	5	193	14	54	5			109	9
[16,]	182	3	83	13	190	4			89	7
[17,]	26	2	98	13	96	4			113	6
[18,]	130	2	36	10	128	4			102	5
[19,]	39	1	166	9	146	3			180	5
[20,]			6	6	88	2			118	4
[21,]			159	5	45	1			162	4
[22,]			134	5	186	1			95	2
[23,]			19	5	172	1			130	1
[24,]			190	4						
[25,]			58	2						
[26,]			149	2						
[27,]			157	1						