Rural livelihood diversity and its influence on the ecological intensification potential of smallholder farms in Kenya

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Rural livelihood diversity and its influence on the ecological intensification potential of smallholder farms in Kenya

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Abstract

Smallholder farmers represent the majority of food producers around the world, yet they are often the most at risk of suffering yield gaps and not achieving their production potential. Ecological Intensification (EI) is a knowledge intensive approach to sustainable agricultural intensification which utilizes biodiversity-based ecosystem services to support greater yield and reduce reliance on agrochemical inputs. Despite the potential benefit of EI based practices, uptake by smallholders is not as widespread as it could be. Here we test the hypothesis that application of EI on smallholder farms in Kenya is a viable approach that could be taken in order to enhance food security. Focusing on natural pest control and crop pollination, we used farmer surveys to explore the potential for EI in central Kenya. We identified to what extent farm typology and access to knowledge determine the incentives and barriers facing smallholder producers and how this influences optimal pathways for sharing knowledge and providing extension services. We found considerable potential for EI of smallholder farms in this region; most farmers grew insect pollinated crops and some farmers already employed EI practices, while others relied heavily on chemical pesticides. Based on physical, social, and economic factors, three farm typologies emerged including "semi-commercial," "market orientated," and "subsistence." These typologies influenced the appropriate EI practices available to farmers, as well as routes through which knowledge was shared, and the extent to which extension services were utilized. We propose that to support effective uptake of EI practices, smallholder farm heterogeneity should be acknowledged and characterized in order to target the needs and capabilities of farmers and identify appropriate knowledge sharing and support pathways. The approach we take here has the potential to be employed in other regions globally.

KEYWORDS

agroecology, pest regulation, pollination, socio-economic survey, sustainable intensification

1 | INTRODUCTION

Smallholders account for 84% of all farms worldwide and produce around 30% of the world's food (Lowder et al., 2019), yet smallholder farms are the most vulnerable to extreme climatic events and often suffer significant yield gaps (Tittonell & Giller, 2013). Globally, many smallholder farms did not benefit from the green revolution and/or intensified farming approaches; and it was in such farms in Africa, Asia, and Latin America where some of the earliest iterations of the now established concept of sustainable intensification were first developed (Pretty, 1997). Ecological Intensification (EI) is a knowledge intensive approach to sustainable agricultural intensification, which originated as a concept at a similar time to sustainable intensification (Wezel et al., 2015) and utilizes biodiversity-based ecosystem services to support greater yield and reduce reliance on agrochemicals (Bommarco et al., 2013; Zimmerer et al., 2015). Ecological intensification involves the employment of an array of management practices including the establishment of ecological infrastructure, the modification of farm management practices, such as reduced tillage or intercropping, and the protection or creation of semi-natural habitats (Kovács-Hostyánszki et al., 2017; Garibaldi et al., 2019). Such approaches promote functional biodiversity in and around farms, including natural enemies of pests, pollinators, and biodiverse soil communities, and used in combination with or in place of other conventional approaches such as plant genetic improvements and conventional inputs (Tittonell & Giller, 2013) represents a longer term solution to address yield gaps. Therefore, application of more ecologically intensive approaches has the potential to deliver benefits for smallholder farmers globally (Tittonell & Giller, 2013; Garibaldi et al., 2017).

Despite examples of success (Blaauw & Isaacs, 2014; Pywell et al., 2015; Garibaldi et al., 2019), facilitating a shift to an alternative farming approach or even encouraging the employment of individual farming practices is a fundamental challenge, and as a result, EI is not always adopted to its full potential. Reasons include the fact that research into ecologically intensive practices does not always consider factors relevant to farmers, including crop yield and profit, or they consider the potential benefits at spatio-temporal scales that are less relevant to farmers (Kleijn et al., 2019). Furthermore, promotion of novel practices, including EI, does not always consider the social and economic contexts that guide farmer behavior and result in changes in practice (Caron et al., 2014; Rusere et al., 2019a). Utilization of appropriate knowledge pathways and mechanisms (Wyckhuys et al., 2018) as well as ensuring the right market conditions (Kurgat et al., 2018) are also important for improving uptake and utilization. Falling within the domain of EI, Integrated Pest Management (IPM) provides a case in point, and although effective approaches have existed for some time, a lack of farmer awareness and knowledge, perceptions of low profitability, and risk and uncertainty have been identified as reasons for poor uptake, particularly in smallholder farming systems (Alwang et al., 2019).

A better understanding of the heterogeneous nature of farms and farmers, and consideration of the multiple social and economic contexts in which farmers operate, including their production objectives, labor and technological capability as well as quantifying their level of knowledge and knowledge access pathways, will help target EI initiatives (Tittonell et al., 2010a; Rusere et al., 2019b). Smallholder farming in Kenya is one such heterogeneous farming system where progress to improve the sustainability of production has been limited (Kassie et al., 2015). Like many countries in sub-Saharan Africa, the agricultural sector in Kenya is critical, contributing 34% of total Gross Domestic Product and providing > 70%of informal rural employment; however, production is mainly for subsistence and is therefore vital for both food and nutritional security (KNBS, 2019). Crop pests remain a major challenge for farmers in Kenya and the current mainstay of control is pesticide application, with resulting negative health and environmental consequences (de Bon et al., 2014; Macharia, 2015). Furthermore, pollination of crops is a critical ecosystem service and insect pollinators make a significant contribution to yield and quality of many crops grown by farmers in Kenya (Kasina et al., 2009). Yet little research has been conducted to investigate the potential for improving crop pollination in Kenya (Rodger et al., 2007; Gemmill-Herren et al., 2014). Furthermore, reduced yields, linked to insufficient pollination, are widespread in smallholder farms, including in Africa (Garibaldi et al., 2016). Natural pest regulation and pollination by wild insects are considered pillars of effective EI and through improved management of these services, benefits to smallholder farmers could be delivered. However, the potential for EI in this region is not well understood.

This project used farmer survey approaches to firstly test the hypothesis that application of EI on smallholder farms in Kenya is a viable approach that could be taken in order to enhance food security and secondly to identify appropriate pathways to support the uptake of beneficial EI practices. The aims of the study were to i) quantify the diversity and variability of farming systems within central Kenya, and identify common farm typologies and the implications of these for the uptake of EI, ii) investigate current farmer knowledge of pollination and natural pest control as well as existing farm practices employed to enhance benefits from pollinators and natural enemies, and iii) explore incentives and barriers facing smallholder producers in effectively adopting EI technologies. Findings from this study could be used to direct research to optimize likely candidate EI technologies and help tailor approaches taken by extension services so they can be better utilized by farmers.

2 | MATERIALS AND METHODS

2.1 | Site selection

The study was conducted in central Kenya in Kiambu and Murang'a counties. Both counties are characterized by cash crop farming, mainly tea and coffee, as well as annual subsistence cropping dominated by maize, beans, and vegetables. Although the majority of residents are small-scale farmers, there are several large-scale coffee and tea farms, which are serviced by local industries. Kiambu county is located in the Central highlands of Kenya close to Kenya's capital, Nairobi. The vegetation is diverse, ranging from grassland to forest areas. Murang'a lies approximately 85km northeast of Nairobi, and borders Kiambu in the south, with good access to Nairobi county markets. The vegetation ranges from mosaic forest/shrubland/crop land to more extensive forest areas, with forest areas covering a greater proportion of the county overall (Figure 1 and Table S1). In each county, the research team worked with the County Directors of Agriculture (CDAs) to select three sub-counties as enumeration areas, capturing diversity in terms of intensification gradient, socio-economic variations, biophysical characteristics and the key domains of agricultural development - agricultural potential, market access, and population density (Omamo et al., 2006). By surveying farms in both Kiambu and Murang'a, we were able to capture a broad socio-economic and biophysical demography of farms and farmers within a small geographic area, which can be generalized to many Kenya agro-ecologies.

2.2 | Farmer survey

Within the enumeration areas (sub-counties), we randomly selected three villages from which respondent households were drawn. At the village level, respondent households were selected using systematic random sampling, targeting every 5th household, until between 5 and 10 farmers had been surveyed. After the survey, a total of 118 farmers were surveyed across the two counties. Interviews involving a structured questionnaire were administered by trained enumerators. The farms were surveyed during the long rainy season of 2019 (April 2019) when respondents were more likely to be available and questions were directed to the head of the household

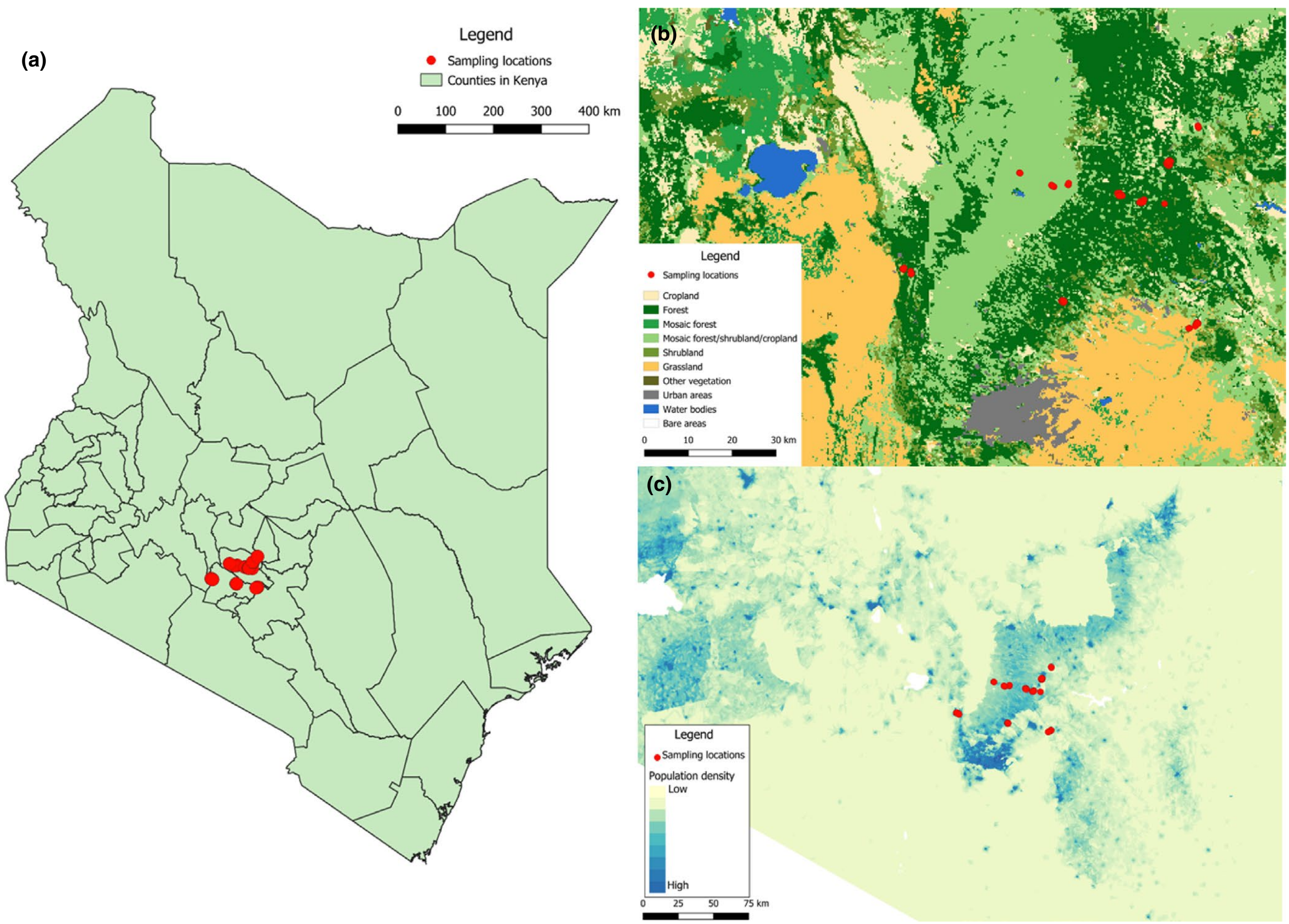

FIGURE 1 The regions and survey locations involved in this study including a) geographical location, b) broad land-use categories, and c) relative population density

TABLE 1 Farm structure and household dynamic components used to characterize and group farms by shared typologies

Dimension	Variable	Description	Units
Farm size	Land farmed	Total area farmed by the household	Ha.
	Land owned	Total area owned by household	Ha.
Farm intensity	External input use	Total cost of purchased inputs used in a growing season	KES
	Input use intensity	Cost of purchased input per farmed area	KES/ha
Land-use types	Annual crops	Percentage of farmland under annual crops	%
	Perennial crop	Percentage of farmland under perennial crops	%
	Vegetables	Percentage of farmland under vegetable crops	%
	Fallow	Percentage of farmland under fallow	%
	Woodlot	Percentage of farmland under woodlot	%
Farm orientation	Market-oriented	Percentage of production for the market	%
	Off-farm income	Households with off-farm income	%
Household dynamics	Family labor	Number of members working full time on the farm	#
	Family size	Number of members living and eating in the household	#
	Extension	Access to formal extension services (yes = 1)	Binary
	Credit	Access to credit (yes = 1)	Binary

or their spouse. Data collection was done using tablet computers employing the Open Data Kit (ODK) collect application and surveys typically took 30–40 mins to complete. The application has an inbuilt Geopoint option which was used to geo-reference all farms where farmers were interviewed. Informed prior consent was sought from the respondents before the questionnaire was completed. The purpose of the study, how data will be handled and stored, and the products that will be generated from the study were explained to the respondents. Providing responses was voluntary and no payments were promised or given to the respondents. Ethical clearance for the survey was granted by the University of Reading School of Agriculture, Policy and Development Ethical Committee in February 2019 (ref: 00911D).

The survey questionnaire was designed to capture three areas of information including i) farm and farmer characteristics and demographic data (Section 1–3), ii) challenges and current practices associated with pest control and pollination (Section 4) and, iii) current knowledge of natural pest control and pollination and knowledge sources used (Section 5–7). Farm size was based on farmer estimates and units were converted to hectares. Information on production practices, crop varieties grown, cropping systems, use of external inputs (fertilizer, manure, chemicals), and conservation practices was plot-based, because farmers may apply different practices on different fields, motivated by crop objective or expected returns. Information on production practices was based on the previous cropping season (short rains 2018), with some questions focusing on an ordinary year to capture any variability that may have confounded results in the previous season, for example, pest outbreaks (See Supplementary material S2 for full questionnaire).

2.3 | Data analysis

To characterize farm typologies, multivariate analysis was used to segment farms according to a range of factors considered important for determining the rates at which farming systems might adapt and change (Kostrowicki, 1977; Tittonell et al., 2005; Oumer & de Neergaard, 2011). These included farm structure defined by farm size, agricultural intensification, land use and orientation, and household dynamics and livelihoods strategies, determined by farm investment decisions, allocation of resources (labor and land), and farming practices (Table 1). Using Principal Component Analysis (PCA), non-correlated socio-economic factors explaining most of the variability between the farms pooled across counties were identified. Factors that had meaningful loadings were included in hierarchical cluster analysis for approximation of cluster households. The resulting clusters were refined to derive farm types that are relatively similar with respect to the principal factors accounting for between-farm variability. Complementary variables such as gender and age of the head of the household were not included in the PCA but were used to refine clusters. Factors of access to credit and extension services were initially included in the analysis but discarded when the original variables had the same or larger loadings with the major principal components.

Descriptive analysis was conducted for quantitative data of socio-economic, land-use, and management practices. Chi-square and *t*-test analyses were used to assess their level of significance across designated farm types, study counties and gender. Data analysis was performed using Stata statistical software version 15.1 (StataCorp. 2017. *Stata Statistical Software: Release 15*. College Station, TX: StataCorp LLC.).

3 | RESULTS

3.1 | Farmer demographic characteristics

Fifty-four percent of respondents across the two counties were men and overall, the average farmed land per household was 0.89ha, of which owned land was on average 0.67ha. The majority of the households (80%) had been in contact with extension staff, and a smaller proportion belonged to farmer groups (48%). At least 76% of the respondents indicated that they had

TABLE 2 Household characteristics in the study region as per the observed clusters derived following Principle Component Analysis

Characteristics	Cluster 1 ($n = 51$) Mean	±SE	Cluster 2 ($n = 49$) Mean	±SE	Cluster 3 ($n = 18$) Mean	±SE	Pearson Chi-square	P-value
Farm size								
Land farmed (ha)	1.0	±0.1	0.8	±0.1	1.0	±0.2	45.45	0.330
Land owned (ha)	0.8	±0.1	0.6	±0.1	0.7	±0.1	34.46	0.634
Input use intensity								
Pesticide costs (KES)	1,220	±114	0.0	±0.0	4,313	±540	219.74	0.000
Pesticide use intensity (KES/ha)	1,484	±127	0.0	±0.0	5,299	±551	227.13	0.000
Land-use types								
Prop. of land under annual crops	44.5	±3.4	42.4	±4.1	42.1	±4.6	83.54	0.432
Prop. of land under perennial crops	23.1	±3.0	20.7	±3.3	32.2	±5.7	103.91	0.150
Prop. of land under fallow	2.5	±1.1	1.5	±0.9	0.9	±0.9	15.13	0.769
Prop. of land under woodlot	3.7	±1.1	6.0	±1.7	0.3	±0.3	32.28	0.552
Household dynamics								
Respondent sex (male = 1)	0.7	±0.1	0.3	±0.1	0.8	±0.1	16.39	0.000
Household size (#)	4.5	±0.3	4.4	±0.3	5.0	±0.4	21.71	0.245
Family labor (#)	1.6	±0.1	1.7	±0.1	2.2	±0.2	15.27	0.123
Access to extension advice (yes = 1)	0.9	±0.1	0.6	±0.1	1.0	±0.0	15.04	0.001
Access to credit services (yes = 1)	0.7	±0.1	0.8	±0.1	0.9	±0.1	6.18	0.045
Farm orientation								
Off-farm income (% of household)	19.6	±5.6	22.4	±6.0	11.1	±7.6	1.08	0.583
Crop commercialization (% marketed)	57.1	±3.8	37.1	±3.6	68.3	±5.3	23.38	0.003

TABLE 3 A description of the household characteristics for each of the three observed clusters identified by PCA analyses

Cluster	Farm type	Resource endowment & production orientation	Main characteristics
1	Semi-commercial	Semi-commercial annual crops-based farming system	About 70% of farm owners are male, with high access to extension services. Access to credit is low compared to other farm types. High investment in annual crops, slightly more than half of farm output is marketed. Input use intensity is medium. More diversified farmers, mainly growing maize, bananas, coffee, cut flowers, kales, and tomatoes.
2	Subsistence	Subsistence oriented farmers, no external input use	Mainly female farm owners (ca. 70%), less access to extension, but high access to credit. High dependence on off-farm income, proportion of farm produce marketed is less than 40%. No external input use. Small land holdings, main crops grown—maize, tea, banana, and potatoes
3	Market-oriented	Market-oriented farmers, high external input use	Mainly male farm owners (ca. 80%), large family size and labor endowment, large proportion of land allocated to cash crop farming, proportion of marketed produce approx. 68%. Access to extension and credit is very good. High expenditure on external inputs and high cost per ha. Main crops grown maize, coffee, cut flowers, & tomatoes.

access to some form of credit facility. Input use intensity (particularly pesticides) was approximately KES1450 (140 USD) per ha. Approximately 20% of sampled households depended to a great extent on off-farm income generated from activities such as trading/business, wage labor, and salaried employment. Significant differences between counties were observed for a number of socio-economic factors (Table S2).

3.2 | Land-use patterns

Crop enterprises on farms surveyed for this study included perennial and annual crops. Perennial crops were the key cash crops and included coffee, tea, banana and cut flowers, and comprised the greatest proportion of land allocation. The main annual crops were maize, green leafy vegetables (kales, nightshade etc), potatoes, beans, and cowpeas. Of the annual crops, maize, and vegetables were the most common food crops in the region (Figure S1). About 20% of respondents had woodlots, and the most common woodlot trees were *Eucalyptus sp*., *Casuarina sp*., and *Pinus sp*. Farmers also grew a diversity of other plants mainly as hedgerows (78% of all respondents) and fruit trees, most commonly avocado (58%), followed by mango (51%) and pawpaw (26%; Table S3). Agro-forestry was widespread with *Grevillea sp*. being the most commonly grown agro-forestry tree. Others included *Moringa oleifera, Croton megalocarpus*, *Leucaena leucocephala*, *Maesopsis eminii*, *Sesbania sesban*, and *Prunus africana*.

TABLE 4 Pest management practices used by farmers overall and disaggregated by farm type and gender

	Percentage of farms employing various pest management methods					
Pest management method	All farms	Semi-commercial farms	Subsistence farms	Market-oriented farms	Female	Male
Pesticides use	47	62	8	67***	31	56***
Biologicals	6	5	9	5	5	7
Cultural practices	41	38	54	30***	41	41
Pesticides + biologicals	79	64	16	67***	35	59***
Pesticides + cultural	77	87	58	82***	65	84***
Cultural + biologicals	50	41	59	33***	45	44
All methods	44	87	63	82***	69	84***

Note: Statistical significance at the 0.01 (***) level of probability

Farmers had more than one plot farmed

TABLE 5 Practices employed by farmers to protect natural enemies and pollinators

Management practices for beneficial insects	Percentage of farmers: Overall	Semi-commercial farms	Subsistence farms	Market-oriented farms	Female	Male
Natural enemies						
Judicious use of chemicals	40	40	23	60	21	47*
Intercropping/ mixed cropping	13	8	8	30	7	15
Crop diversification	13	4	15	30*	7	15
Agro-forestry and windbreaks	13	12	15	10	21	9
Flowering hedges	6	12	0	0	0	9
Pollinators						
Judicious use of chemicals	31	28	29	43	19	37*
Crop diversification	18	19	10	29	14	20
Flowering hedges	15	19	10	14	5	20*
Agro-forestry and windbreaks	10	6	5	29**	10	11
Intercropping/ mixed cropping	4	0	0	21***	0	7
Protection of surrounding bush, woodlands and wetlands	3	6	0	0	5	2
Bee keeping	1	3	0	0	5	0*
Conserving male trees	1	0	5	0	0	2

Note: Statistical significance at the 0.01 (***), 0.05 (**), 0.1 (*) level of probability

3.3 | Farming practices

Soil fertility management using organic inputs was common, especially for tomatoes, bananas, and coffee. A large proportion of tomato farmers (88%) also indicated that they applied inorganic fertilizers. Pest control was carried out by most farmers growing tomatoes, kales, and other vegetables. Significant differences in fertilizer application and pest control practices across key crops were observed (Table S4). Pest control was mainly through the use of insecticides and fungicides with at least 47% of farmers using only pesticides, 41% using cultural practices (e.g. crop rotation, field sanitation, and intercropping), and 6% using only biological controls (Table 4). Farmers also used indigenous technology-based pest control measures such as application of ash/soil, and plant extracts, for example, neem. Apart from tea, tomatoes and coffee, which were most commonly planted in pure stands, crops were intercropped, especially maize with beans or with other preferred legume crops (Tables S5).

3.4 | Emerging farm typologies

Principal component analysis demonstrated that about 78% of the variability between farms was explained by 6 components (Table S6). Component one, explaining 25% of the variation, included the proportion of land under perennial crops and total expenditure on pesticides. The second principal component, explaining 16% of the between-farm variability, was pesticide use intensity (expressed as KES/ha). The third and fourth principal components, explaining 11% and 9% of the variability between farms, respectively, were labor availability and household size. The other two components were the proportion of land under woodlot and the off-farm income (Table 2).

Using the hierarchical cluster analysis, households were then grouped according to those pursuing similar livelihood strategies. At 60% coefficient of similarity, groups of households were identified as falling into three broad typologies. There was no significant association between cluster and county, according to a Pearson Chi-square test. The clusters were interpreted by considering the average and dispersion of the main socio-economic characteristics by the different clusters, and the farm types assigned to each cluster. The characteristics compared across the farm types were; farm size, input use intensity, land-use types, household dynamics, and farm orientation. Each cluster was assigned a descriptive label based upon its key characteristics: semi-commercial (cluster 1), subsistence (cluster 2), and market-oriented (cluster 3) (Table 3).

3.5 | Farmer knowledge and current practices

According to the farmers during the October-December 2018 cropping season, the key pests and pathogens on major crops were; fall armyworm on maize, *Armillaria* root rot on tea, aphids on kales, and coffee berry disease on coffee (Table S7). Regarding pest severity, apart from *Tuta absoluta*, fall armyworm, and blight (tomato), over 50% of farmers rated the other mentioned common pests and pathogens as less severe, that is, affecting a very minor part (<10%) of cultivated area (Figure S2).

Pesticide use intensity was one of the components which explained variation between farm typologies and differences in the application of pest management practices by farm type and by gender were clear (Table 4). Data show that market-oriented farmers were more likely to use pesticides, and a combination of practices compared to other farmers. On the other hand, subsistence farmers were more likely to use cultural practices for pest management. Across gender, men were more likely to apply any pest management practice, and significantly more male than female farmers used pesticides and pesticides in combination with other practices.

Only 37% of farmers indicated knowledge of natural enemies (Table S8). Birds (44%) were the most commonly mentioned natural enemies, followed by ladybird beetles (27%) and ants (19%). Other natural enemies mentioned included termites, wasps, beetles, chameleon, frogs, and spiders. A large proportion of farmers (57%) were aware of pollination and pollinators on farm. Commonly mentioned pollinators were bees, birds, and butterflies.

When asked about the practices they employed to conserve beneficial insects, farmers mentioned various activities (Table 5). For management of natural enemies, farmers mentioned; judicious use of chemicals, intercropping/mixed cropping, crop diversification, agro-forestry, and planting of flowering hedges. Other practices mentioned, albeit by a very minor proportion of respondents were; planting shelter trees, and maintaining an open dam on the farm to provide access to a water source. Practices for conserving pollinators were to a large extent similar to those used for conserving natural enemies. In addition, farmers mentioned protection of surrounding bushlands, bee keeping, and conserving male trees (e.g., papaya). Others included; digging of retention ditches, making water available for the bees on the farm, and planting of sunflower on farm edges.

Crop diversification, agro-forestry and intercropping were mentioned by a larger proportion of market-oriented farmers compared to other farm types. Across gender, significant differences were recorded in the judicious use of chemicals, planting of flowering hedges and bee keeping.

3.6 | Incentives and barriers to adoption of ecological intensification strategies

Farmers identified a number of challenges when trying to effectively maintain beneficial insects/animals on farm (Table 6); however, not all farmers provided examples of barriers to adoption. A lack of knowledge on identification and effective practices required to maintain them was the top-ranking challenge concerning both pollinators and natural enemies. Chemical use was the second ranked challenge, and farmers generally indicated an awareness of their harmful effects but cited a lack of effective alternatives. Farmers also recognized indiscriminate use of chemicals within the community as a related challenge. Weather changes, and often-hot conditions were considered to affect natural enemies and pollinators.

TABLE 6 Challenges identified by farmers in trying to conserve natural enemies and pollinators on their farms

Challenge	Frequency	%
Natural enemies		
Lack of knowledge	15	38
Chemical/pesticide use	8	20
Hot and dry weather	4	10
Small land size to allow for planting various trees/flowers	4	10
Some are a nuisance, for example, safari ants	3	8
They are hard to find thus hard to conserve, for example, ladybirds	2	5
Accidental destruction of nesting area, for example, during pruning	2	5
Lack of time to undertake such activities	1	3
Natural enemies come naturally, no need to conserve them	1	3
Pollinators		
Lack of knowledge	10	24
Some are harmful, for example, honeybees killing animals/children	8	20
Chemical/pesticide use	7	17
Hot and dry weather	7	17
Small land size to allow for planting various trees/flowers	5	12
Expensive to conserve, for example, bees	2	5
Theft of bee hives	2	5

Farmers' sources of agricultural knowledge and information were varied, but our data indicates farmers' reliance on community-based information sources, friends and neighbors (41%), family members (42%), and lead farmers (35%) (Table 7). Mass media, particularly radio and television were also mentioned as important information sources on pest management. Access to formal extension services was generally low (33% overall), and men were more likely than women to access these services. Similarly, market-oriented farmers and semi-commercial farmers were more aware of formal extension services compared to subsistence farmers. Access to information from agro-input dealers was limited, although market-oriented farmers were more likely to access them compared with other farm types. The approach most commonly recommended by extension services was chemical applications, followed by cultural practices including good crop hygiene, crop rotation and intercropping. Biological control options had been recommended to 7% of farmers (Table S9) and similarly training in management of pollinators or pest natural enemies had been received by < 15% of farmers (Table S10).

4 | DISCUSSION

Our data suggest that there is considerable potential for the employment of ecological intensification practices to support natural pest regulation and crop pollination by smallholder farmers in Kenya. The farmers reported a diverse array of pests and pathogens, however, farmers only considered three of these as severe. The predominant control practice was chemical application, being used by 79% of farmers and with 47% reporting this was the only measure employed. Almost all farmers grew some insect pollinated crops to a greater or lesser extent, including important food crops such as beans and cash crops including coffee, avocado and mango (Klein et al., 2007), and with only a few practicing beekeeping, it is likely that there is a reliance on wild pollinators. Therefore, it is predicted that practices to promote the abundance and richness of beneficial arthropods on these farms should deliver enhanced yields (Garibaldi et al., 2016; Dainese et al., 2019). A range of EI practices were already being employed by some farmers including judicious use of chemicals, maintaining flowering hedges, agro-forestry and intercropping or mixed cropping. Although beyond judicious use of chemicals, no more than 20% of farmers employed any one approach. Furthermore, farmers grew a variety of plants/trees on farm. Although not primarily intended for the management of beneficial insects, such crop diversity provides an opportunity (Garibaldi et al., 2019), for example, farmers' knowledge could be enhanced to ensure selection of plants that provide a dual purpose—supporting beneficial insects and providing an additional crop or income. Given that beneficial practices

TABLE 7 Farmers' source of information/advice on pest management

Source of information/ advice	Percentage of farmers receiving information from various sources					
	Semi-commercial farms	Subsistence farms	Market-oriented farms	Female	Male	Overall
Community information sources						
Friends and neighbors	43	33	56	39	42	41
Family	39	49	28	44	39	42
Lead farmer	43	27	33	19	48**	35
Farmers/ community groups	35	16	28**	24	28	26
Village leader	6	12	0	0	14*	8
Broadcast and mass media						
Radio programs	35	39	56	37	42	40
Television	27	27	39	30	28	29
Newspaper	4	4	11	0	9**	5
Internet and other online resources	4	0	6	4	2	3
Formal extension						
Extension officer	47	12	50***	13	50***	33
Plant clinic/PD	2	0	0	0	2	1
Business and other sources						
Agro-input dealer	27	16	39*	24	25	25
Others (e.g., NGOs, private farms)	10	8	28**	2	20 ***	12

Note: Statistical significance at the 0.01 (***), 0.05 (**), 0.1 (*) level of probability known to deliver benefits to pollinators and natural enemies, including reduced pesticide use (Otieno et al., 2011), flowering hedgerows (Mwangi et al., 2012) and agro-forestry (Barrios et al., 2018), have already been employed on some farms, highlights a clear opportunity for increased uptake to deliver benefits to a wider group of farmers.

Farms in our study region were heterogeneous in terms of their social and economic context and the diversity of crops being grown. However, based on the analysis, farms fell into three distinct farm types centered around the livelihood strategies they pursued. These were; "semi-commercial," "subsistence," and "market-oriented" farm types and these typologies differed in a number of aspects. These differences have implications for the potential to employ EI practices to promote pollination and natural pest control, as well as the process by which support to help establish such practices should be appropriately implemented. Firstly, the farm size, the crops being grown, and the market destination of those crops was different between-farm types. Related to this, the access to credit and therefore investment potential in alternate practices also differed significantly between-farm types. "market-oriented" farms were larger, sold most of their crop to market and had high access to credit, investing a greater amount per hectare of crop. Their capacity to invest in EI management practices that are more costly at the outset and may not deliver economic returns in the short-term, such as agro-forestry, would therefore be greater (Jacobi et al., 2017). Furthermore, "market-oriented" farmers are also more likely to have additional available space on their land holdings to maintain and manage non-cropped areas such as field margins, known to be beneficial (Mkenda et al., 2019a, 2019b). In contrast, "subsistence" farms were small and only grew a limited number of crops, many of which are not insect pollinated, and therefore despite high access to credit, investments in EI practices that delivered marginal improvements in yield would be unlikely to be economically justifiable, at least in the short-term (Garibaldi et al., 2019).

A second area where farms diverged considerably was in the use rates of external inputs and this was one of the key components explaining variation between farm types. More than 65% of "market-oriented" and "semi-commercial" farms used pesticides, compared to "subsistence" farms where only 8% employed such approaches. Pesticides are known to be a significant mortality factor for pollinators and natural enemies in smallholder farms (Otieno et al., 2011; de Bon et al., 2014) and moderating these inputs and promoting IPM based approaches involving more targeted application of plant protection products, or use of alternative less harmful products (Stevenson et al., 2017), could be an approach easily integrated into current management practice on these high use farms. For subsistence farms, the challenge would be different, and promoting the use of locally available plant derived products would allow targeted action (Mkenda et al., 2015; Tembo et al., 2018) without needing economic resources. Another option could be the promotion of alternative cultural practices, including intercropping (Rusinamhodzi et al., 2012; Brooker et al., 2015), to provide benefits without the need for direct inputs. Both approaches would incur a cost in time for farmers in the subsistence group which may not be readily available.

Promoting any EI practice amongst farmers who are not currently employing them would require effective knowledge sharing and the provision of support, so that practices are well established and effective. Contrasting farmer knowledge and access to extension services was another key area which characterized the farm typologies. While farmers generally relied on community-based information sources, such as friends and neighbors (41%), family members (42%), and lead farmers (35%), market-oriented and semi-commercial farmers were more likely to access extension services compared to subsistence farmers. Market-oriented farmers also utilized the agro-input industry and NGO's more often. Overall male farmers were also more likely to access formal extension advice than female farmers. A lack of knowledge is a common reason cited for low uptake of more ecologically based farming approaches (Alwang et al., 2019; Mkenda et al., 2020) and this was the primary barrier to conserving natural enemies and pollinators given by farmers in our study. Our study demonstrates that subsistence and women farmers should be targeted by extension services in this region, because currently they are far less likely to utilize these services. Better tailoring of extension and advisory services for groups with specific priorities and needs has been shown to deliver benefits (Mbo'o-Tchouawou & Colverson, 2014). Overall, increasing the knowledge of farmers is identified as a primary opportunity to remove a key barrier to the effective adoption of EI practices although the diverse perceptions and attitudes of farmers toward innovations play a key role in uptake, and knowledge alone will not always bring about change (Meijer et al., 2015).

Many of the on farm EI practices considered by farmers in this study could deliver benefits in terms of pollination and pest regulation but the prominent role of landscape context in which a farm is found on natural enemies of pests, pollinators, and the services they provide is unequivocal (Karp et al., 2018; Dainese et al., 2019). While some of the EI practices employed by farmers in this study, including establishment of flowering hedgerows and planting trees on farms, will help improve the connectivity and configuration of the landscape (Martin et al., 2019), the protection of natural and semi-natural areas beyond the farm boundary is not generally within the control of individual farmers and requires more top-down policy interventions (Garibaldi et al., 2019). Therefore, it is a priority to combine and coordinate local farmer support for on farm activities identified in this study with larger scale landscape interventions such as habitat protection involving multiple actors (Geertsema et al., 2016). Although examples of such landscape scale initiatives exist (Garibaldi et al., 2019) they appear to be currently lacking in Kenya.

Our study focussed on central Kenya; however, our surveys captured a wide spectrum of farmer contexts and included common typologies which are found in other regions of Kenya and sub-Saharan Africa (Tittonell et al., 2010b; Giller et al., 2011). Therefore, conclusions drawn on potential EI practices available to different farmers and how their uptake might be facilitated has wider relevance. Ultimately, any support to help farmers employ EI practices must be adequately resourced and targeted to the needs and capabilities of farmers.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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