Optimising precision agriculture choices for arable farmers in Germany and the UK: the LINKDAPA approach

Optimising Precision Agriculture Choices for Arable Farmers in Germany and the UK: the LINKDAPA Approach

Optimiser les choix des cultivateurs en agriculture de précision en Allemagne et au Royaume-Uni : l'approche LINKDAPA

Präzisionslandwirtschaft in Ackerbauerbetrieben in Deutschland und dem Vereinigten Königreich (UK): Verbesserung der Umsetzung durch den LINKDAPA-Ansatz

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Introduction

Precision Agriculture – beyond the jargon. Farmers' adoption of so-called 'smart technologies' over the past few decades could lead in the future to increased generation of large volumes of data about fields and crops and is one of the main strategies proposed for increased environmental and financial performance for farmers (Foley *et al.*, 2011). Also known as Precision Agriculture (PA), the focus of such technologies has been to make farm processes as profitable as possible by reducing inputs to maximise financial returns. For example, this could include limiting fertiliser use through technological monitoring of crop development and understanding the specific topographical aspects and spatial soil qualities across an individual farm.

However, defining what PA is, is less intuitive than one might think. The International Society for Precision Agriculture defines PA as 'a management strategy that uses electronic information and other technologies to gather, process and analyse spatial and temporal data for the purpose of guiding targeted actions that improve efficiency, productivity and sustainability of agricultural operations' (Lowenberg-DeBoer and Ericson, 2019). This definition places PA specifically within the realm of GNSS-driven and Earth Observation Satellite data, although it does not include PA solutions for livestock or the ability of small-scale, resource-poor farmers to manage crop plants specifically without recourse to technology. Moreover, the term 'smart technologies' includes context-awareness and intelligent analysis of real-time events in applying and managing Information and Communication Technologies (ICT). An example would be utilising a weather monitoring device to adjust irrigation schedules accordingly. Current technology is in place to take weather data and adjust irrigation, fertilising, harvest dates, and then apply these changes to trading indexes and other aspects throughout the entire agri-food supply chain. Either term can be used, but the interchangeability of the various terms can lead to confusion. Here, we will use the term PA but with the smart technology definition included as we use historical, current and future predicted spatial data to inform crop management strategies.

Precision Agriculture on arable farms. Arable farmers have long looked at the sky or felt the soil and made adjustments based upon their specific needs and understanding of the available data. PA simply takes this one step further allowing for the collection and interpretation of not only a farmer's own data, but that of their neighbours and even global competitors. The combination of different technologies, devices, computer systems, protocols and analysis tools allows farmers to make informed precision-targeted decisions that affect all aspects of agriculture. With growing concerns over climate, global trade, subsidies and security, such analysis and resulting precision-targeted decisions offer a simple way to minimise losses and address these concerns.

> "L'agriculture de précision augmente les performances environnementales et financières des agriculteurs."

For arable farmers, PA technologies often take the form of 'smart' combines and tractors, GNSS-linked

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remote sensing by satellites or remotely piloted aircraft (RPAS) systems, variable rate fertiliser and weather monitoring systems which are amongst the most popular. Other systems, such as automated software-based job documentation, camera-based weeding, grain quality mapping etc. are also available for farmers. Several papers have looked at a specific type of PA technology (Department for Environment, Food and Rural Affairs, 2013; Lowenberg-DeBoer *et al.*, 2021) whilst others have focused on the farmer decision-making aspects (Barnes *et al.*, 2019; McBratney *et al.*, 2005; Lieder and Schröter-Schlaack, 2021). Here, we report on the combination of both in a study of 250 arable farmers and their advisers in the UK and Germany, to discuss how PA can be used to support crop management decisions, making farming more financially and environmentally efficient by using PA practices to co-create crop management zones. A programme of fieldwork on case-study farms in Germany, the UK and Italy was also carried out.


Precision inter-row mechanical weeding in a maize crop © John Deere.

Concerns and opportunities over Precision Agriculture adoption by arable farmers.

While not every farmer has access to robust PA or smart systems, the implications for both the agricultural and technological industries need to be evaluated from an adoption viewpoint and the concerns over the new technologies; including validation, relevance to the size and type of enterprise, price and return on up-front investment and re-occurring costs, ease of use, and security, need to be considered (McFadden *et al.*, 2022). The commercial nature of these tools, and in many cases their recent emergence in the marketplace, results in limited validation of the technologies under a diverse range of farming systems and enterprises, increasing the risk and reluctance to adopt such technologies (Pederson *et al.*, 2004). The marketplace for these technologies is also increasingly crowded, with multiple technologies capable of delivering similar outcomes and equipment changing rapidly, adding to the confusion around entry points and adoption of PA. Drewry *et al.* (2019) identified the third strongest concern, amongst farmers in Wisconsin after privacy and security concerns, was the ability to keep up with technological change.

> “Präzisionslandwirtschaft steigert sowohl die ökologische als auch die finanzielle Leistungsfähigkeit der landwirtschaftlichen Betriebe.”

Rettore de Araujo Zanella *et al.* (2020) discuss the various security concerns over PA technologies explaining that ‘data and device integrity, data accuracy, and availability’ are the primary security issues with the new technologies. The use of wireless or GNSS tracking makes data vulnerable to hackers and agroterrorism; power lines are vulnerable to nature, and highly computerised machinery and the diversity of operating systems leaves the integration of technologies beyond most farmers’ managerial capabilities.

Cloud-based data systems, proposed by many as a solution to the above, implies access to large amounts of bandwidth which can be a significant barrier for rural communities where investment in digital infrastructure has been limited (Coble *et al.*, 2019; Tiwasinga *et al.*, 2022). GPS, radio frequency identification tags, cameras, actuators, etc. all require a steady and secure wireless connection, which many rural locations struggle with. Autonomous systems, such as tractors, RPAS, autonomous platforms for sowing or weeding, and combine harvesters all have the potential to be hacked and could suffer from a wide range of safety and security issues such as disruption of services and crop damage. While there are ways around such concerns, they do need to be discussed and considered when looking at adoption of such technologies by farmers (Coble *et al.*, 2019). Similarly, the financial implication of the technologies, i.e. a cost-benefit analysis, needs to be included.

In the remainder of this article, we report on the LINKDAPA project which provided winter wheat farmers with a low-cost, simple way to use big data to help highlight areas of their fields that are likely to give higher yields and/or grain protein content. After presenting the results, we discuss some implications of the approach before drawing some conclusions.

The LINKDAPA project

Project overview and goals. As part of the project, we sought to understand the drivers and barriers to the adoption of PA on arable farms in the UK and Germany. The project was a collaboration between farmers, agricultural agents (including technology firms) and universities and was focussed on the co-creation of solutions to model expected grain yields and protein concentrations during the growing season with farmer-selected levels of confidence according to their risk aversion preferences. These modelled yields and protein concentrations enabled farmers growing bread-making wheat to target nitrogen fertiliser application to areas that will best respond to it, saving them money whilst reducing the environmental impact of their actions. The nature of the project precluded a detailed examination of the farm economics implications of the future adoption of the created approach.

Precision spraying incorporating satellite technology © John Deere.

Methods and materials. To understand the drivers and barriers to the adoption of PA on arable farms, a survey of 250 farmers looking at PA technologies was undertaken in 2020. The respondents were split evenly between the UK and Germany and focused on wheat farmers with holdings at least 300 ha in size. They were selected on the basis that they had been, or would be, responsible for purchasing PA technologies for their farm businesses. These data were subsequently used to guide the development of algorithms to provide PA solutions to enhance wheat yields and quality.

We also worked with case-study farmers and their advisers, using multi-source data to co-create crop management zones to provide PA solutions. These were based on integrating historical and current data from individual fields. Algorithms developed as part of the project since 2020 were used to map wheat crops. These provided information about the potential yield and grain quality variation in fields, as well as probabilities that yield and quality will exceed

Table 1: Precision Agriculture (PA) technology on the survey farms in the UK and Germany

	Farmer Responses				
	I'm using it with my own equipment (%)	I have a contractor that works with it (%)	I don't have it and I am not intending to invest in it (%)	I don't have it but I intend to invest in it (%)	Don't know/ n.a. (%)
Type of technology					
Guidance systems (e.g. AutoTrac, automatic steering)	90	3	3	4	-
Section control	83	3	4	8	2
Yield mapping on combine	58	5	20	16	1
Yield mapping on SPFH	3	6	71	8	12
Automated software-based job documentation	33	1	35	20	11
Fertiliser variable rate application	53	3	19	23	2
Variable rate seeding/planting	35	3	32	28	2
Crop care variable rate application	27	4	38	28	3
Precision mechanical weeding in row crops (e.g. camera based)	6	2	65	23	4
NIR sensor for manure application (Harvest Lab 3000 or other)	3	4	70	14	9
NIR sensor on SPFH to measure constituents	2	4	71	11	12
Drone or satellite imagery for crop monitoring	33	3	38	23	3

farmer-specified thresholds and explore:

- how accuracy increases with the number of data sources;
- farmers' willingness to pay for more data (i.e. higher resolution image capture by RPAS/satellite, soil electrical conductivity/ compaction scans); and
- end-user confidence based on probability maps.

Follow-up focus group meetings in 2021 used results from 50–60 wheat crops in 30 fields on the case-study farms to validate the algorithms and crop management options developed the previous year. These were incorporated into a new software platform which the wider farming community will be invited to access through an area-based subscription charge.

Results. The mean size of the survey farms differed somewhat: in Germany it was 729 ha whereas it was 880 ha in the UK. Over 90 per cent of respondents owned some form of guidance system (i.e. AutoTrac, automatic steering) and over 50 per cent owned some form of section control systems, yield mapping on their combine harvester, and/or a variable rate fertiliser application system (Table 1). However, most technologies discussed were being used by a contracted third-party or respondents had no intent to own or invest in the technologies. This was more likely for respondents in Germany than for those in the UK. These included near-infrared (NIR) sensors, RPAS, mechanical weeding, and yield mapping on self-propelled forage harvesters (SPFH).

There was a country difference in methods of field data recording with survey farmers in Germany being some 35 per cent more likely to use handwritten methods than those in the UK. However, the proportion of farmers who collected a range of different types of field data was equivalent in both countries as was their level of satisfaction with the way they processed this data. Regarding satisfaction and adoption of PA, 41 per cent of the survey respondents were ambivalent about their satisfaction in this, with 10 per cent saying that they felt uncomfortable using the ensuing data, found it difficult to handle, or had issues with compatibility between software applications. The top three reasons for adoption of new PA technologies were financial advantage, compatibility with their current systems, and return on the investment made.

Table 2: Views on what adoption of PA leads to by the survey farmers in the UK and Germany

	Strongly agree/ Agree %	Neither or not sure %	Disagree/ Strongly disagree %
Farmers'views			
Higher presence of other segments in agriculture	50	30	20
Meet the needs of the world's growing population	42	30	18
A reduced number of farms	34	26	40
Inputs' usage reduction (e.g. fertiliser, pest control)	72	17	11
An economic advantage to larger farms	71	21	8
More profitable farm businesses	50	34	16
An increase of farmed hectares per farm	31	27	42
Better product quality (e.g. grain quality)	40	35	25
Human workforce cuts in agriculture	37	25	37
Higher yields	48	33	19
More monitoring over operations	71	20	9
More electrification in the machines	64	25	12
More data share transparency and traceability	65	17	9
More environment protection	64	24	12
The use of robotics and automation	57	22	21
The use of decision-support tools	54	36	10
The use of cloud solutions	46	35	19
More service-based solutions	43	41	16
Specialisation in farming	52	26	22

Most case-study farmers agreed that, in general, adoption of new PA technology leads to input usage reduction, a financial advantage to larger farms, more monitoring, electrification of machinery, transparency and traceability of data and environmental protection (Table 2).

The results were then used to guide the development of an online, cloud-based decision-support tool. The immediate purpose of this was to utilise the various pieces of farm data to support farmers optimising their nitrogen management through the prediction of in-season site-specific crop performance, as well as the

Slurry injection on an arable field using NIR sensors on the slurry tanker © John Deere.

calculation of a site-specific profit map, which would take into account different fertiliser strategies. These were based on novel algorithms using soil, yield and satellite data validated by using historic on-farm data, together with satellite imagery and weather data. The decision-support tool would then enable farmers to identify crop management zones in their fields and apply nitrogen on a site-specific and variable rate basis.

The platform includes data entry points for specific fields including the crop and variety planted, the average Normalised Difference Vegetation Index from Sentinel 2 of the last available date, the average yield (from yield maps uploaded), the average protein content (from protein maps uploaded), and the list of available maps for each field. A colour-coded map of the field is then created by the software, which farmers can use to create personalised prescription maps for variable rate fertiliser applications (see Figure 1).

When asked about the LINKDAPA PA tool, the survey farmers in both study countries were almost identically positive about it and the need for it on their farms. However, it was found that the UK respondents were much more likely to purchase it than those in Germany.

Implications from the LINKDAPA project

In 2012, a voluntary Defra survey of 2,900 farmers in England with at least 20 ha. of arable crops provided information on PA adoption rates (see Table 3).

Defra (2013) asked about GNSS and gave Autosteer and GPS guidance as examples, while VRT refers to variable rate technology for any purpose, including fertiliser, soil amendment, seed, or plant protection chemicals. The Defra (2013) results show a predilection for farmers in England to focus on GPS systems and soil mapping, which the LINKDAPA results for 2020 confirmed. Part of the reason is the integration of GPS into new farm machinery, such as tractors, combines and other harvesters. For example, John Deere has 32 different PA tools alone, including AutoTrac guidance, Fleet management software, HarvestLab 3000 for spatial analysis of quality, and StarFire receivers and signal displays (John Deere, 2022).

Figure 1: Example of a field plot produced by software developed during the project

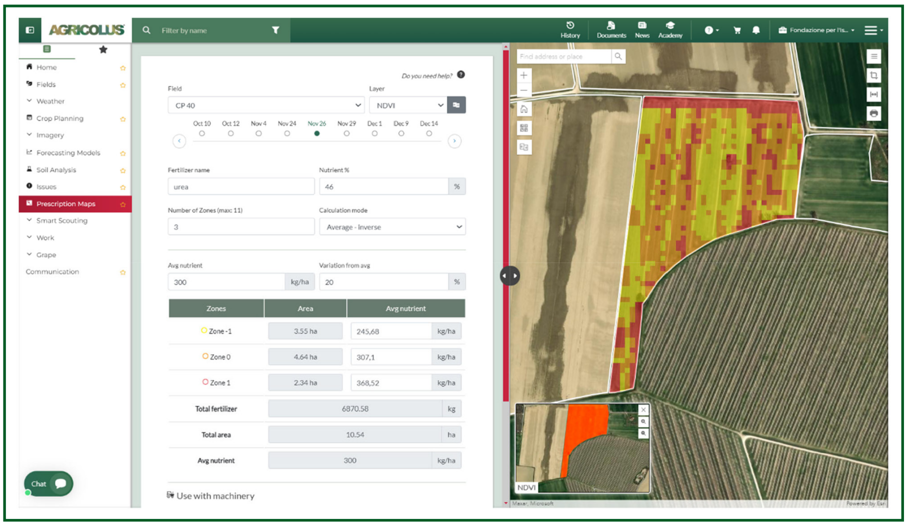

Table 3: Adoption rates of PA in England in 2012 by crop type

Crop type	GNSS Guidance	Yield Map	VRT any	GNSS soil map
Cereal	46%	25%	31%	38%
Other crops	40%	18%	23%	31%

Source: Defra (2013).

> "Precision arable farming increases both the environmental and financial performance of farmers."

GNSS adoption has been relatively fast and holds a large part of the market, becoming the standard practice for 'commercial commodity crop farmers and the most common [of] PA technolog[ies]' (Lowenberg-DeBoer *et al*., 2021). Likewise, VRT's ability to optimise inputs offers farmers the easiest answer to loss ratios, putting it firmly in the number two slot. The LINKDAPA approach offers an opportunity to combine GPS and VRT technologies into one platform where farmers can personalise their field needs. Since one of the major farmer concerns is to minimise VRT costs (soil sampling, map systems, etc.), an integrated VRT/GNSS option would limit external costs. At the same time, the platform offers both visual map imagery and financial analysis, which was the second primary cost concern for farmers. By creating maps each growing season, and comparing the data, farmers can answer the third largest cost issue: comparative financial and nutrient analysis.

Conclusions

Evaluating current PA options and concerns and discussing them with farmers offers the best market analysis for technology co-creation. The approach taken in the project discussed here looked at PA as a toolkit for farmers and technology firms, and then applied these findings toward an integrated management solution that is easy to implement, being a primary driver of technology adoption. The co-creation of this solution utilised a mixed approach working with all actors in the system – random survey analysis, which offered one window into the discussion from the wider farming community in the UK and Germany, directed the focus of the solution to estimating yields and quality at a sub-field level. The farmer focus group meetings provided more nuanced perspectives, and the integration of the views of researchers and technology firms helped fill the farmer-researcher gap in a way that offered co-created practical options for all parties involved.

The focus here on PA in the UK and Germany, however, does limit the scope to mechanised, developed countries that have the financial resources available to implement PA technologies. Therefore, additional farmer discussions in developing countries may open new avenues for the technology to advance through co-creation. Likewise, security issues around PA need to be addressed at the Governmental policy level. These issues are manageable, however, and for the average arable crop farmer, could offer a ready resource to manage on-farm concerns surrounding the environment, and the financial viability of technology adoption.

Finally, a substantial social cost-benefit examination of the benefits (or not) of farmers adopting PA technology would be worthy of investigation soon. This would then assist decisionmaking on whether the public sector should fund further research on designing and developing PA technologies. In addition, it would also aid decisions on the creation of extension and educational activities to encourage the wider roll-out of PA technologies.

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Summary

Optimising Precision Agriculture Choices for Arable Farmers in Germany and the UK: the LINKDAPA Approach

Farmer adoption of so-called Precision Agriculture (PA) or 'smart' technologies in the arable sector has grown in the last few decades with a focus on Global Navigation Satellite Systems (GNSS) and variable rate technologies (VRT). This has led to increased generation of large volumes of data about fields and their crop yields which could be used to increase the environmental and financial performance for farmers. However, survey results show that cost and adaptability have been issues for many farmers in the UK and Germany that have held back such adoption. The LINKDAPA (LINKing multi-source Data for Adoption of Precision Agriculture) project's approach sought to minimise both concerns by creating a customisable web platform that incorporates both GNSS and VRT into one, easy to use, affordable option for farmers. The project developed an online cloud-based decision support tool which takes into account different fertiliser strategies based on novel algorithms using soil, historic yield and satellite data. Co-created by researchers, farmers and agricultural technology firms, the LINKDAPA approach offers both economical and easy to implement solutions for farm management to mitigate resource loss-ratios such as in fertiliser use, provide financial performance analyses, and multi-year graphical imagery for soil mapping.

Optimiser les choix des cultivateurs en agriculture de précision en Allemagne et au Royaume-Uni : l'approche LINKDAPA

L'adoption par les agriculteurs de technologies qualifiées d'agriculture de précision (AP) ou « intelligentes » dans le secteur des grandes cultures s'est développée au cours des dernières décennies, en mettant l'accent sur les systèmes mondiaux de navigation par satellite (GNSS) et les technologies à débit variable (VRT). Cela a généré des quantités importantes et croissantes de données sur les parcelles et leurs rendements, qui pourraient être utilisées pour améliorer les performances environnementales et financières des agriculteurs. Cependant, les résultats d'enquêtes montrent que le coût et l'adaptabilité ont posé des problèmes à de nombreux agriculteurs au Royaume-Uni et en Allemagne qui ont freiné une telle adoption. L'approche du projet LINKDAPA (LINKing multi-source Data for Adoption of Precision Agriculture – relier des données d'origine multiple pour faciliter l'adoption de l'agriculture de précision) visait à minimiser ces deux problèmes en créant une plate-forme Web personnalisable qui intègre à la fois les systèmes GNSS et VRT en une seule option facile d'utilisation et abordable pour les agriculteurs. Le projet a permis le développement d'un outil d'aide à la décision en ligne basé sur le cloud qui prend en compte différentes stratégies de fertilisation fondées sur de nouveaux algorithmes utilisant le sol, les rendements historiques et les données de satellites. Développée conjointement par des chercheurs, des agriculteurs et des entreprises de technologie agricole, l'approche LINKDAPA offre des solutions à la fois économiques et faciles à mettre en œuvre pour la gestion de l'exploitation afin d'atténuer les taux de perte de ressources comme l'utilisation d'engrais, et de fournir des analyses des performances financières et des images graphiques pluriannuelles pour la cartographie des sols.

Präzisionslandwirtschaft in Ackerbauerbetrieben in Deutschland und dem Vereinigten Königreich (UK): Verbesserung der Umsetzung durch den LINKDAPA-Ansatz

In den letzten Jahrzehnten wurden in Ackerbaubetrieben zunehmend sogenannte Präzisionslandwirtschaft oder ‚intelligente'Technologien eingesetzt. Dabei lag der Schwerpunkt auf globalen Satellitennavigationssystemen (GNSS) und variablen Ausbringungstechnologien (variable rate technology - VRT). Dies hat dazu geführt, dass immer größere Datenmengen über Ackerflächen und Ernteerträge erzeugt wurden. Diese Daten könnten genutzt werden, um die ökologische und finanzielle Leistungsfähigkeit der Betriebe zu verbessern. Die Umfrageergebnisse zeigen jedoch, dass im Vereinigten Königreich und in Deutschland die Kosten und die Anpassungsfähigkeit, die Einführung solcher Technologien einschränken. Der Ansatz des LINKDAPA-Projekts (LINKing multi-source Data for Adoption of Precision Agriculture – Verknüpfung verschiedener Datenquellen zur Übernahme der Präzisionslandwirtschaft) zielt darauf ab, diese Bedenken zu minimieren. Hierfür wurde eine anpassbare Webplattform geschaffen, die sowohl GNSS als auch VRT in einer einzigen, einfach zu bedienenden und kostengünstigen Option für landwirtschaftliche Betriebe zusammenfasst. Im Rahmen des Projekts wurde ein cloudbasiertes Online-Entscheidungshilfe-Tool entwickelt, das auf der Grundlage neuartiger Algorithmen und unter Verwendung von Boden-, historischen Ertrags- und Satellitendaten verschiedene Düngestrategien berücksichtigt. Der von Vertretern und Vertreterinnen aus der Wissenschaft, Landwirtschaft und Wirtschaft (Agrartechnologie) gemeinsam entwickelte LINKDAPA-Ansatz bietet sowohl wirtschaftliche als auch einfach umzusetzende Lösungen für die landwirtschaftliche Betriebsführung. Dadurch können Ressourcenverluste, z. B. beim Düngemitteleinsatz, verringert werden, die finanzielle Leistungsfähigkeit analysiert und mehrjährige Abbildungen für die Bodenkartierung bereitgestellt werden.