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Who do German farmers trust when making decisions about digital technologies? An analysis of the trustworthiness of innovation actors

Increasing scholarly attention is being paid to understanding the roles of different actors involved in digital agriculture. This study contributes to this field of research by exploring farmers' level of trust in digital agricultural actors. Based on a survey of 203 arable farmers from southern Germany, it investigates how adopters and non-adopters of digital technologies perceive the trustworthiness of different actors. The results suggest that farmers have varying levels of trust in innovation actors providing advice and information. Farmers express relatively more trust in other farmers, the agricultural press, and associations and less trust in research institutions, agricultural authorities, private advisory services, agricultural technology, and downstream actors. Significant differences between adopters and non-adopters are observed across the three types of digital technologies examined in the study (disembodied digital, embodied-knowledge and information-intensive technologies). The study highlights the importance of rethinking the roles and practices of innovation actors in the context of digital agriculture. Greater attention to trust can help to better align information and innovation processes between farmers and other innovation actors in the digital agriculture innovation system, enabling farmers to make informed decisions about adopting digital technologies. The results of this study may be of particular interest to those interested in developing strategies to strengthen linkages in the digital agriculture innovation system and to realise the objectives of current policy agendas in Europe.

Keywords: digitalisation, innovation actors, AKIS, information, trust

JEL classifications: Q12, Q13

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Introduction

The emergence of digital, smart, and precision agriculture technologies is associated with economic, environmental, and social benefits at the farm and farming system level (Balafoutis *et al.,* 2020). However, farmers and other innovation actors do not always share the same understanding of the effects of digitalisation (Monteiro Moretti *et al.,* 2023). Within innovation systems, strong collaborations and linkages between different actors are crucial for successful innovation and diffusion, especially to enable on-farm implementation (Eastwood *et al.,* 2017; Landini *et al.,* 2023). Farmers' behaviour, including their innovation decisions, is generally influenced by various actors who support their decision-making with information and advice (Kiraly *et al.,* 2023). Adoption studies show that interactional (Shang *et al.,* 2021), informational (Caffaro *et al.,* 2020; Garcia-Jimenez *et al.,* 2011) and communicative (Colussi *et al.,* 2022; Kutter *et al.,* 2011) factors influence the diffusion of digital technologies in agriculture. For example, the role of vertical (involving upstream and downstream actors) and horizontal (involving peers) exchange of information and advice is reflected in several studies assessing the influence of different actors and organisations (Caffaro *et al.,* 2020; Garcia-Jimenez *et al.,* 2011; Kvam *et al.,* 2022) on the adoption of digital technologies in agriculture.

In recent years, farmers' information behaviour has changed dramatically due to the availability of digital sources of information and an increased scepticism towards traditional sources of information about agriculture (Kiraly *et al.,* 2023; Rust *et al.,* 2022). Recent literature emphasises that different types of trust, such as horizontal trust, vertical trust and trust in sources, are critical for facilitating the adoption and diffusion of agricultural innovations (Leeuwis and Aarts, 2021). In the case of digital agriculture, Lioutas and Charatsari (2022) suggest that there is, to some extent, a trust gap between digital innovation users and innovation providers or brokers. Based on interviews with adopters and non-adopters, they outline that farmers do not fully trust the intentions of commercial actors, as their primary interest lies in selling their products rather than providing unbiased advice on digitalisation. Empirical work on trust in digital agricultural innovation systems is scarce, with most studies addressing the issue only partially or lacking a solid conceptual foundation. Several quantitative studies based on farmer surveys suggest that factors such as credibility (Garcia-Jimenez *et al.,* 2011) and the perceived usefulness of information sources (Toma *et al.,* 2018) positively contribute to the diffusion of digital technologies. Jayashankar *et al.* (2018) conclude that trust is an essential factor in the context of Internet of Things (IoT) adoption in agriculture, as it affects the perceived value and risk of IoT. Bekee *et al.* (2024) show that the extent of farmers' trust varies among actors involved in smart farm networks. Jakku *et al.* (2019) emphasise that a lack of mutual trust is a major issue in digital agriculture innovation processes.

Prior research indicates a potential trust gap between farmers and the broader digital agriculture innovation system, suggesting that vertical and horizontal trust influences the linkages between farmers and other actors in digital agriculture. Given the rapidly increasing level of digitalisation on German farms (Gabriel *et al.,* 2021) and the growing need for trustworthy and reliable advice and information, further research is essential and required. This study therefore explores German farmers' perceptions of the trustworthiness of innovation actors in providing advice and information about digital technologies in crop production. As farm digitalisation is complex and involves various technologies and levels of adoption, it will consider both adoption and non-adoption scenarios for different types of digital technologies in crop production. Based on this, the following two research questions are addressed:

- What is the level of trust that farmers have in different innovation actors as a source of information and advice on digitalisation in crop production?
- What differences in trust can be observed across different types of digital technologies in crop production?

To answer the research questions, the authors analyse the results of a standardised survey of 203 arable farmers in southern Germany.

Conceptual background

Trustworthiness is an important issue that affects the relationship between farmers and other actors in the context of innovation uncertainty and is thus relevant to the process of innovation adoption and diffusion in the broader innovation system. In the following, the authors briefly introduce the Agricultural Knowledge and Innovation System (AKIS) concept as a framework for analysing the dynamics of digital innovation processes, elaborate on the roles that AKIS actors play in them, and explain how they operationalise and study trust in this context.

Agricultural Knowledge and Innovation Systems and digitalisation

The AKIS concept has evolved from and with other concepts revolving around innovation, knowledge, and information systems in agriculture (Blum, 1991; Klerkx *et al.,* 2012; Rivera *et al.,* 2005; Röling, 1988). According to the Standing Committee on Agricultural Research (EU SCAR 2012, p. 8) AKIS is "a useful concept to describe a system of innovation, with emphasis on the organisations involved, the links and interactions between them, the institutional infrastructure with its incentives and the budget mechanisms." The AKIS concept is widely used to study processes of innovation co-development, knowledge and information sharing, and mutual learning around agricultural innovations (Klerkx *et al.,* 2012; Knierim *et al.,* 2015). The concept places farmers at the centre of the innovation system, with other self-organising but rather heterogeneous actors positioned around them (Klerkx *et al.,* 2010). In this regard, it is essential to note that innovation processes in agriculture are driven and affected by various actors, including extension services, educational institutions, research organisations, input suppliers, commercial services, accountants, banks, agricultural media, non-governmental organisations, processors, retailers and consumers (EU SCAR, 2012). The latest implementation of the Common Agricultural Policy (CAP) in Germany outlines that promoting digital agriculture requires increased cooperation among different AKIS actors (BMEL, 2023). This work assumes that digital agriculture is shaped and influenced by the interactions among various actors, in particular the relationship between farmers and the surrounding innovation system.

Actor roles in digital agriculture innovation processes

Digital agriculture can be understood as a socio-technical transition of agriculture affecting the AKIS and its actors (Klerkx *et al.,* 2019), which requires cultural and behavioral changes of all actors in the agricultural value chain to achieve more sustainability (da Silveira *et al.,* 2021). In this context, previous studies ascribe different roles to the actors involved in digitalisation (Lioutas and Charatsari, 2022; Kernecker *et al.,* 2021; Kvam *et al.,* 2022). According to Wittmayer *et al.* (2017), actors are connected with single roles and role constellations in transitions. Single roles refer to an actor's core set of attitudes and activities to cope with a recurring topic or issue. In contrast, role constellations can be understood as an interdependent web of different actors' roles in the context of transitions. Conceptually, single roles and role constellations can be analysed over time or at a specific time. In this context, another critical aspect relates to how actors use and create roles to contribute to transition and how the use and understanding of roles change over time. In the context of innovations and transitions, it is also of analytical importance that certain roles are ascribed to actors both from their perspective and by external actors.

Previous research on digitalisation indicates that actors within the digital agricultural innovation system are associated with roles that reflect specific activities and attitudes related to providing advice and information on digitalisation. This research encompasses quantitative (Caffaro *et al.,* 2020; Giua *et al.,* 2022; Shang *et al.,* 2021) and qualitative studies (Kernecker *et al.,* 2021; Kvam *et al.,* 2022). Scholars have identified other farmers, (farmer) associations and other organisations, private and public advisory services and institutions, research institutions, up- and downstream actors, and media outlets as actors involved in digital agriculture.

A substantial body of research has addressed the role of farmers as impulse providers for digital innovations (Busse *et al.,* 2014; 2015). Similarly, the literature highlights the importance of farmers (Blasch *et al.,* 2022; Kutter *et al.,* 2011; Kvam *et al.,* 2022) and farmer or peer networks (Colussi *et al.,* 2022; Kernecker *et al.,* 2021) as influential sources in the adoption of digital technologies. The literature presents various perspectives on the relevance of public and private advisory services in digital agriculture innovation processes (Kutter *et al.,* 2011). These include issues such as a lack of access to advice (Reichardt and Jürgens, 2009), lack of neutral advice (Kernecker *et al.,* 2020; Kvam *et al.,* 2022), the inclusion and exclusion of advisors at different stages of innovation (Kernecker et al. 2021), negative views of advisors on digitalisation (Lioutas and Charatsari, 2022), and adjustments in farmer-advisor relationships (Charatsari *et al.,* 2022). Shang *et al.* (2021) outline that in 10 out of 16 studies, consultants significantly influence the adoption of digital technologies. Research actors are involved in developing digital innovations but provide little support for their diffusion (Busse *et al.,* 2014; Kernecker *et al.,* 2021).

According to Kutter *et al.* (2011), European research institutions have only a minor to medium degree of influence on the adoption of precision agriculture. In American studies, the impact of universities' outreach activities on the adoption of precision agriculture is also disputed (Asare and Segarra, 2019; Garcia-Jimenez *et al.,* 2011). Studies from Germany and Italy highlight the limited importance of government agencies in terms of providing information on precision agriculture technologies (Blasch *et al.,* 2022; Kutter *et al.,* 2011; Reichardt and Jürgens, 2009) as well as showing that public authorities only marginally support the development of digital technologies (Busse *et al.,* 2014; Kernecker *et al.,* 2021). The mass media play a crucial role in disseminating information about precision agriculture (McBride and Daberkow, 2003), with the agricultural press playing a particularly important role in raising awareness about digitalisation (Kernecker *et al.,* 2021; Kvam *et al.,* 2022; Reichardt and Jürgens, 2009). For example, media coverage of digitalisation in German agricultural magazines has steadily increased in recent years (Gabriel *et al.,* 2021). The relevance of (farmer) associations and organisations in the development (Busse *et al.,* 2014) and diffusion processes of digital technologies (Kutter *et al.,* 2011; Shang *et al.,* 2021) is currently the subject of debate. Kvam *et al.* (2022) report that farmer organisations face challenges in building advisory expertise on digitalisation, while other studies highlight their importance as intermediaries in innovation processes (Busse *et al.,* 2015; Kernecker *et al.,* 2021). Agricultural technology (Agtech) actors play an essential role in diffusion processes as technology providers (Shang *et al.,* 2021) and developers (Busse *et al.,* 2014; Kernecker *et al.,* 2021). Lioutas and Charatsari (2022) critically reflect on Agtech actors' limited interest in co-creating value with farmers through digitalisation, while other studies, such as Kutter *et al.* (2011), raise concerns about the capacity of local dealerships to support farm digitalisation. Empirical studies suggest that downstream actors are rarely involved in digitalisation processes (Busse *et al.,* 2014; 2015). Nevertheless, downstream actors may have increased interest in promoting adoption to improve their environmental footprint (Pedersen *et al.,* 2004) or to gain access to farm data (Birner *et al.,* 2021).

The authors view the results of previous studies on the roles of AKIS actors in digital agricultural innovation processes as a starting point for exploring how farmers perceive the trustworthiness of these actors in providing information and advice. From this, they infer that not all actors involved in digital agriculture are equally significant for the diffusion and adoption of digital technologies.

Trust, trustworthiness, and innovation actors

Trust characterises social interactions and collaborations related to innovation (Leeuwis and Aarts, 2021). Robbins (2016, p.976) defines trust as: "A belief about another person's trustworthiness with respect to a particular matter at hand that emerges under conditions of unknown outcomes." In this sense, trust can be understood as the expectations one person holds about another person's behaviour, reliability, or credibility in situations of uncertainty. Similarly, Bauer (2021) emphasises that trust involves trustor A placing trust in trustee B concerning a specific object of trust. In this context, an object of trust can also be considered a set of expected behaviours. Building on this, trustworthiness refers to the personal judgment of the person giving the trust that the person receiving the trust will behave as expected. In this sense, trustworthiness can be understood as the personal judgement of trustor A that trustee B can be expected to behave in a certain way. In this context, favourable judgements of others' trustworthiness lead to trust, while negative judgments result in distrust.

According to Rijswijk *et al.* (2023), trust also characterises the relationships between actors in the agricultural value chain, such as farmers, suppliers, processors, and service providers. In agricultural innovation processes, trust is of considerable importance in both the vertical and horizontal interactions among the actors who generate, share, and apply innovations (Leeuwis and Aarts, 2021). With regard to diffusion and adoption, Leeuwis and Aarts (2021, p.101) argue that trust plays a vital role in three different ways: "In the context of agriculture, this may relate to whether actors in the agro-support environment or value chain are expected to behave in a conducive manner ('vertical trust') or whether colleagues, household and community members will demonstrate the complementary behaviors on which adoption depends ('horizontal trust'). Another type of trust that may play a role relates to whether the people who are seen to promote the adoption of something are seen to be trustworthy in terms of their expertise, honesty, credibility and legitimacy ('trust in the source')." Thus, in the context of digital agriculture, farmers may trust or distrust other innovation actors, either because they act or fail to act in a supportive manner or because they are (not) considered knowledgeable and credible sources on digitalisation.

Recent studies on farmers' information-seeking behaviour (Kiraly *et al.,* 2023; Lv and Li, 2023; Mesfin *et al.,* 2023; Rust *et al.,* 2022) or collective action involving farmers (Bernard *et al.,* 2021; Koutsou *et al.,* 2014) show that farmers' decision to engage with certain actors depends on their perception of the trustworthiness of these actors. Moreover, given the heterogeneity of farms, farmers cannot be expected to trust all actors who provide advice and information equally (Lv and Li, 2023). In this context, prior adoption or non-adoption of innovations may influence farmers' perceptions of the trustworthiness of innovation actors. For example, the findings of Lioutas and Charatsari (2022) imply that non-adopters of digital technologies have less trust in certain innovation actors than adopters.

In summary, the literature suggests that farmers perceive the trustworthiness of various actors involved in digital agriculture differently. Additionally, the level of perceived trustworthiness can be expected to vary across different non-adoption and adoption scenarios. In line with the research questions, this study addresses these two aspects by examining how different actors are viewed in terms of their trustworthiness as sources of information and advice on digital technologies, considering different technology adoption scenarios in crop production.

Digital technologies in crop production

Digital agriculture in crop production refers to a wide variety of digital technologies. For example, Birner *et al.* (2021) distinguish between embodied and disembodied precision agriculture technologies. They consider farm machinery combining physical and digital components, such as variable rate technologies or robots, to be embodied technologies. In contrast, disembodied technologies are purely software-based solutions, such as platforms or farm management information systems (FMIS). In contrast, Kolady *et al.* (2021) classify precision agriculture technologies in crop production into information-intensive (variable rate (VR) technologies, sensors) and embodied knowledge (steering and section control systems) technologies. Embodied knowledge technologies are expected to be easier to use and do not require additional external data. In contrast, information intensive technologies produce and use different data, necessitating advanced operational skills from their users.

Based on the technology classifications of Birner *et al.* (2021) and Kolady *et al.* (2021), three technology adoption scenarios considering different types of digital technologies have been developed (Table 1).

Technology scenario one considers disembodied digital technologies (DDT), which have no physical components and function solely as software solutions. Consistent with the literature (Birner *et al.,* 2021; Kolady *et al.,* 2021), technology scenario two focuses on physical embodied-knowledge technologies (EKT) that do not require additional data or skills. Scenario three considers physical information-intensive technologies (IIT) that require more complex data processing and increased operational skills. The classification of digital technologies into technology adoption scenarios has informed the empirical analysis of the trustworthiness of various innovation actors.

Table 1: Classification of digital technologies in crop production

Technology adoption scenario 1: Disembodied digital technologies (DDT)
• Forecast models • FMIS (including digital field records)
Technology adoption scenario 2: Embodied-knowledge technologies (EKT)
• Lightbar systems • Automatic steering system • Automatic implement steering (section control and implement alignment)
Technology adoption scenario 3: Information-intensive technologies (IIT)
• Yield mapping • Satellite maps • Georeferenced soil sampling • Soil sensors (e.g., EM38) • Near-infrared spectroscopy (NIR sensor) (harvester and or slurry tank) • Variable rate (VR) nitrogen fertilisation • Variable rate (VR) organic fertilisation • Variable rate (VR) spraying • Variable rate (VR) planting • Precision weeding and robots
• Drones (not considered in the technology adoption scenarios)

Source: own composition based on Birner et al. (2021) and Kolady et al. (2021)

Material and methods

This research was conducted as part of a more extensive study investigating farm digitalisation in the southern German federal state of Baden-Württemberg. The primary purpose of the broader study was to understand the barriers to adoption, as well as farmers' experiences and expectations in the context of digitalising small-scaled farming systems in Germany. The following section briefly introduces the study region and provides information on the study design and data analysis.

Study region and study design

Baden-Württemberg is located in the southwest of Germany. According to the Agricultural Census 2020, the agricultural sector in Baden-Württemberg is relatively small-scaled compared to the rest of Germany (DESTATIS, 2021; STALA, 2021). The average farm size in Germany (63 ha) is twice as large as in Baden-Württemberg (36 ha). Additionally, the share of part-time sole proprietorships is higher in Baden-Württemberg (57%) compared to Germany as a whole (49%).

Due to the lack of research on the use and adoption of digital technologies in Baden-Württemberg, the survey underlying this work was conducted between February and June 2021. The survey was carried out using the survey tool LimeSurvey. It collected information on seven aspects: (i) farm and farmer characteristics, (ii) adoption patterns of different digital technologies in crop and livestock production, (iii) perceived benefits of digitalisation, (iv) usage experiences, (v) data security and sovereignty, (vi) information and technical service needs, and (vii) support needs. The present work is based on the responses to the first part of the survey (farm and farmer characteristics), along with responses related to the adoption of digital technologies in crop production and ratings on the trustworthiness of eight innovation actors in the support needs section of the questionnaire. Under farm and farmer characteristics, survey participants provided information on income type (full- or part-time farm), production type (conventional or organic /mixed), arable land size in hectares, farming experience in years, level of agricultural education (degree, no degree), gender (male or female/diverse) and age (younger than 50 years and 50 years and older).

Furthermore, farmers were asked which of two DDTs, three EKTs, and ten IITs they had adopted or used through contractors or service providers (Table 1). In addition, surveyed farmers were asked to rate on a five-point scale, ranging from strongly disagree (1) to strongly agree (5), whether they consider other farmers, private advisory services, research institutions, agricultural authorities (local agricultural offices, funding agencies, or state institutes), associations, the agricultural press (through farming magazines), Agtech actors (suppliers, dealers, manufacturers), and downstream actors (processors, traders) to be trustworthy sources of information and advice on digital technologies. The actors were selected based on previous research on innovation actors involved in precision and digital farming (Busse *et al.,* 2014; Caffaro *et al.,* 2020; Garcia-Jimenez *et al.,* 2011; Reichardt and Jürgens, 2009).

Data collection and data analysis

Data collection for this study began in February 2021 by informing farmers in the study region about the survey and its goals. To this end, the regional Ministry of Agriculture sent out an information flyer to all 43,600 farms (MLR, 2022) in the study region as part of the information letter on the CAP. For further promotion of the survey, the survey was also shared via social media, newsletters, public mailing lists, agricultural magazines, farmer organisations, and state institutions. 749 people opened the survey link until the end of June 2021. The survey yielded 203 fully completed datasets from arable farmers in the study region. Quantitative data analysis was performed using SPSS 27 and Microsoft Excel. Descriptive statistics were applied to describe the sample, digital technology adoption patterns, and the perceived trustworthiness of innovation actors. Schnell *et al.* (2014) recommend using significance tests to identify differences in central tendencies or distributions between two unrelated samples, such as adopters and non-adopters of digital technologies. Therefore, χ^2-tests were employed to examine significant differences in categorical variables. To examine statistical group differences in metric and interval-scaled variables, either parametric (Student's t-test or Welch's test) or non-parametric (Mann-Whitney U test) two-sample-tests can be used (Gibbons and Chakraborti, 1991). Since farmers in the present study were asked to rate the trustworthiness of different innovation actors on a five-point rating scale, parametric test statistics seemed problematic as they usually require normally distributed data. As this condition was not fully met, statistical differences between adopters and non-adopters in terms of perceived trustworthiness were analysed using the Mann-Whitney U test.

Results

Sample description and adoption of digital technologies in crop production

Table 2 compares the characteristics of the sample with those of all farmers in the study area.

Most surveyed farmers manage full-time (63%) and conventional (86%) farms. On average, the surveyed farms cultivate 83 hectares of arable land. In addition, most farmers managers are younger than 50 years (53%), with an average farming experience of almost 28 years. Additionally, most respondents are male (89%) and have a vocational or academic degree in agriculture (75%). Compared to the study region, noteworthy differences exist in the average size of arable land, the share of full-time farmers, and their level of educational attainment.

Study participants were surveyed on the adoption of DDT, EKT, and IIT. Figure 1 provides an overview of the adoption patterns of 16 digital technologies in crop production. Participants were classified as adopters if they purchased or

Table 2: Description of surveyed farmers (n=203).

Variable	Description	Mean	S.D.	Min	Max	Study region (STALA, 2021)
Income type[1]	1 Full-time, 0 part-time	0.63		0	1	Full-time: 0.35
Production type[1]	1 conventional, 0 organic/mixed	0.86		0	1	Conventional: 0.86
Arable land	In hectares	82.93	79.99	1	689	31.53
Age[1]	1= <50 years, 0= ≥ 50 years	0.53		0	1	Younger than 55 years: 0.52
Experience	In years	27.85	13.33	2	60	At least 20 years of experience: 0.55
Education[1]	1=Agri. degree, 0=No degree	0.75		0	1	With degree: 0.61
Gender[1]	1=male, 0=female/diverse	0.89		0	1	Male: 0.90

[1]Variables are dichotomised.
Source: own composition

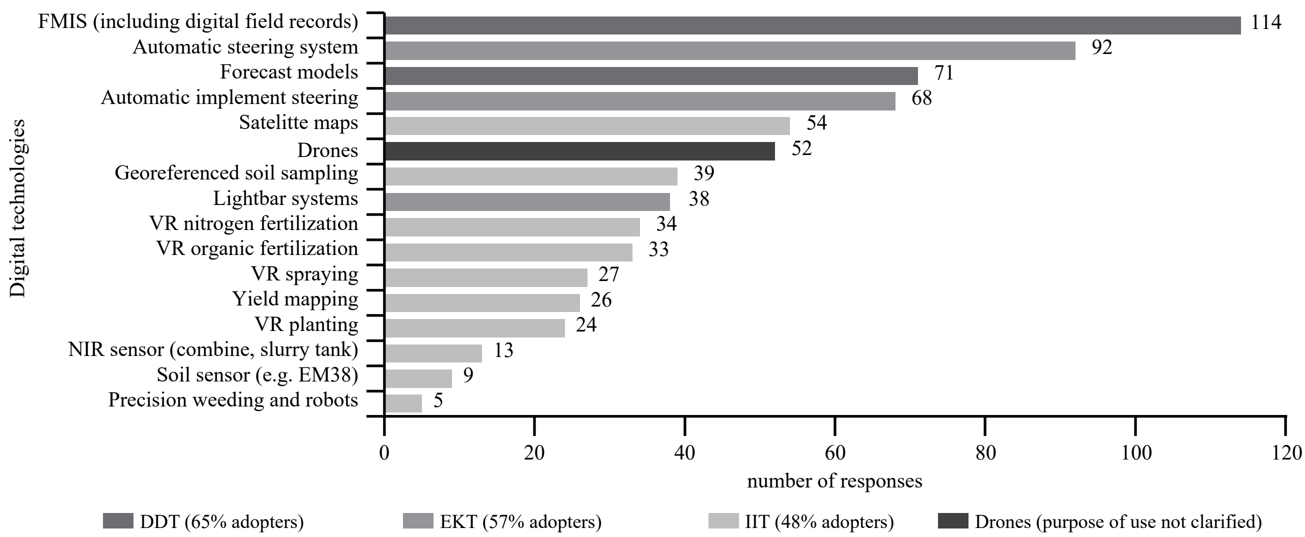

Figure 1: Adoption patterns of digital crop technologies (n=203).
Source: own composition

used one of the proposed technologies through a contractor or service provider. The most commonly used technologies are FMIS (including digital field records, 56%), automatic steering systems (45%), forecast models (35%), and automatic implement control (33%), such as section control or implement alignment. Although 26% of the participants use drones, the specific purpose (spraying, spreading, mapping) of use remained unclear. Therefore, drones were not considered in the technology adoption scenarios. 65% of the surveyed farmers have adopted at least one DDT, such as an FMIS or a forecasting model, and are therefore considered DDT adopters. In the case of EKT, 57% of the farmers have adopted at least one of the proposed technologies, such as automatic steering, implement steering, or lightbar systems. The lowest adoption rates are reported for the IIT scenario, with only 48% of the farmers adopting at least one IIT.

Table 3 summarises the descriptive statistics and significant differences between adopters and non-adopters of DDT, EKT, and IIT. In the DDT scenario, significant differences are evident regarding income type, production type, arable land size, and age. To be more precise, farms adopting DDT are more likely to be conventional full-time operations. Moreover, they cultivate significantly more land and are significantly more likely to have a farm manager under the age of 50. EKT adopters differ significantly from non-adopters in terms of income type, arable land size, age, farming experience, education, and gender. Specifically, the proportion of full-time, larger farms and male, younger, less experienced, but better-educated farm managers is higher in the EKT adopter group than in the non-adopter group. In the IIT scenario, the tests indicate statistically significant differences in arable land size and farming experience. On average, IIT adopters have less farming experience but manage larger farms than non-adopters.

Perceptions of the trustworthiness of digital agriculture innovation actors

Figure 2 shows the ratings for the different sources of advice and information on digital agriculture for the sample as a whole.

Table 3: Descriptive and bivariate differences between adopters and non-adopters (n=203).

Technology adoption scenarios	Disembodied digital technologies[2] scenario			Embodied-knowledge technologies[2] scenario			Information-intensive technologies[2] scenario		
	Adopters	Non-adopters	Sig.	Adopters	Non-adopters	Sig.	Adopters	Non-adopters	Sig.
Variable[1]	n=131	n=72		n=115	n=88		n=97	n=106	
Income type									
Full-time	90	34	*	90	38	***	66	62	n.s.
Part-time	41	38		25	50		31	44	
Production type									
Conventional	120	55	**	101	74	n.s.	84	91	n.s.
Organic/mixed	11	17		14	14		13	15	
Arable land (in hectares)	97.45 (86.79)	56.60 (57.57)	***	115.39 (90.54)	40.50 (30.00)	***	102.59 (94.07)	64.93 (59.46)	***
Age									
<50 years	77	31	*	71	37	**	57	51	n.s.
≥ 50 years	54	41		44	51		40	55	
Experience in years	26.64 (13.14)	30.04 (13.51)	n.s.	25.48 (11.89)	30.94 (14.50)	**	25.96 (13.48)	29.58 (13.02)	*
Education									
Agri. degree	102	50	n.s.	97	55	***	75	77	n.s.
No degree	29	22		18	33		22	29	
Gender									
Male	118	63	n.s.	108	73	*	86	95	n.s.
Female/diverse	13	9		7	15		11	11	

1. Values for arable land size and experience are presented as means (standard deviations); other values are frequencies.
2. χ^2-tests (dichotomous) or Mann-Whitney U tests (continuous) significant at *p≤0.05, Note: **p≤0.01, ***p≤0.001, n.s.=not significant.

Source: own calculations

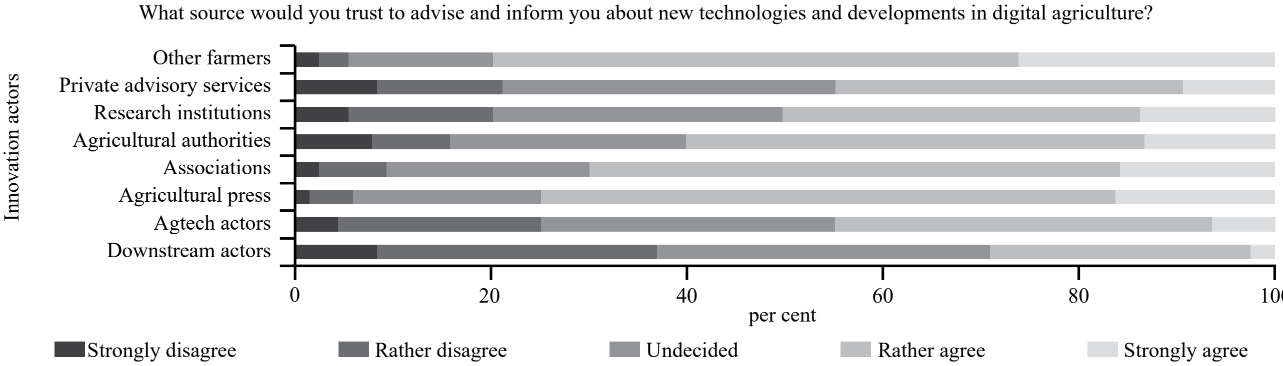

Figure 2: Perceived trustworthiness of innovation actors (n=203).

Source: own composition

Most of the surveyed farmers consider other farmers (80%), the agricultural press (75%), associations (70%), and agricultural authorities (60%) to be relatively trustworthy. Fewer farmers trust research institutions, Agtech actors, downstream actors, and private advisory services.

Table 4 summarises the descriptive findings and the results of the Mann-Whitney U tests, analysing significant differences across the three technology adoption scenarios. Both DDT adopters and non-adopters consider other farmers (mean=4.05; 3.85), the agricultural press (mean=3.95; 3.63), and associations (mean=3.73; 3.77) to be the most trustworthy sources of advice and information on digital technologies. Non-adopters express the least trust in downstream actors (mean=2.60), Agtech actors (mean=2.83), and private advisory services (mean=2.94). In contrast, adopters are neutral towards downstream actors (mean=3.01). Moreover, they positively view Agtech actors (mean=3.43) and private advisory services (mean=3.41). The Mann-Whitney U tests show statistically significant differences for other farmers, private advisory services, research institutions, the agricultural press, Agtech actors, and downstream actors. The mean ranks indicate that adopters perceive these actors more positively than non-adopters. No significant differences are observed for agricultural authorities and associations.

Regarding the EKT scenario, the results show that both adopters and non-adopters perceive other farmers (mean=4.09; 3.84), the agricultural press (mean=3.97; 3.67), and associations (mean=3.70; 3.80) as the most trusted providers of information and advice on digital agriculture. Adopters tend to be neutral about the trustworthiness of downstream actors (mean=3.02). Non-adopters have a rather negative opinion of Agtech actors (mean=2.93) and downstream actors (mean=2.66). Significant differences exist between EKT adopters and non-adopters for other farmers, private advisory services, research institutions, the agricultural press, Agtech actors, and downstream actors. A comparison of the mean ranks shows that adopters rate other farmers, private advisory services, research institutions, the agricultural press, Agtech actors, and downstream actors more positively.

In the case of the IIT scenario, the means indicate that IIT adopters and non-adopters perceive other farmers (mean=3.99; 3.97), the agricultural press (mean=3.92; 3.76), and associations (mean=3.77; 3.71) as the most trustworthy sources of information and advice on digital technologies. Additionally, adopters view research institutions as relatively trustworthy (mean=3.72), whereas downstream actors are viewed more neutrally (mean=3.06). Non-adopters rate downstream actors (mean=2.68) rather negatively, while the means for Agtech actors (mean=3.04) and private advisory services (mean=3.05) are around the neutral value. Significant group differences exist for private advisory services, research institutions, Agtech actors, and downstream actors. According to the mean ranks, IIT adopters perceive private advisory services, research institutions, Agtech actors, and downstream actors significantly more positively.

Discussion

The aim of this study was to examine farmers' trust in actors providing information and advice on digital technologies based on a farmer survey of 203 arable farmers from Germany. Furthermore, the study explored differences in the perceived trustworthiness of actors between adopters and non-adopters across three technology adoption scenarios. This section discusses the main findings in relation to previous studies and highlights results that the authors see as valuable contributions to the literature on digitalisation and AKIS.

Table 4: Perceived trustworthiness of innovation actors across different technology adoption scenarios (n=203)

Technology adoption scenarios	**Disembodied digital technologies scenario**					**Embodied-knowledge technologies scenario**					**Information-intensive technologies scenario**				
	Adopters n=131		**Non-adopters n=72**			**Adopters n=115**		**Non-adopters n=88**			**Adopters n=97**		**Non-adopters n=106**		
Variable	Mean (SD)	Mean rank	Mean (SD)	Mean rank	p	Mean (SD)	Mean rank	Mean (SD)	Mean rank	p	Mean (SD)	Mean rank	Mean (SD)	Mean rank	p
Other farmers	4.05 (0.85)	107.57	3.85 (0.88)	91.86	0.045 *	4.09 (0.86)	109.64	3.84 (0.86)	92.01	0.020 *	3.99 (0.93)	104.72	3.97 (0.81)	99.51	0.487
Private advisory services	3.41 (0.98)	110.92	2.94 (1.16)	85.76	0.002 **	3.37 (1.08)	109.16	3.09 (1.04)	92.65	0.038 *	3.46 (1.02)	114.43	3.05 (1.07)	90.63	0.003 **
Research institutions	3.55 (0.99)	110.37	3.08 (1.14)	86.77	0.004 **	3.57 (1.00)	110.72	3.15 (1.11)	90.60	0.012 *	3.72 (0.91)	119.65	3.08 (1.11)	85.84	0.000 ***
Agricultural authorities	3.46 (1.08)	101.11	3.56 (1.06)	103.61	0.757	3.41 (1.13)	98.14	3.61 (0.99)	107.04	0.254	3.53 (1.13)	104.87	3.47 (1.03)	99.38	0.478
Associations	3.73 (0.89)	101.35	3.77 (0,91)	103.17	0.817	3.70 (0.92)	99.53	3.80 (0.86)	105.22	0.453	3.77 (0.94)	106.68	3.71 (0.85)	97.72	0.233
Agricultural press	3.95 (0.70)	109.09	3.63 (0.93)	89.10	0.009 **	3.97 (0.71)	109.57	3.67 (0.88)	92.11	0.018 *	3.92 (0.77)	107.52	3.76 (0.82)	96.95	0.149
Agtech actors	3.43 (0.92)	113.66	2.83 (1.01)	80.78	0.001 ***	3.43 (0.92)	114.39	2.93 (1.01)	85.81	0.000 ***	3.41 (0.93)	112.49	3.04 (1.01)	92.40	0.011 *
Downstream actors	3.01 (0.95)	109.94	2.60 (1.00)	87.56	0.007 **	3.02 (1.00)	110.50	2.66 (0.93)	90.90	0.014 *	3.06 (0.96)	113.16	2.68 (0.98)	91.78	0.007 **

Note: Items were rated on a scale ranging from 1 (strongly disagree) to 5 (strongly agree). Mann-Whitney U test was significant at *$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$.
Source: own calculations

Adoption of digital technologies in crop production

The study demonstrates that farmers are more inclined to adopt DDT and EKT in crop production than IIT. The reported higher adoption rates for DDT and EKT are not surprising, as these can be considered entry technologies for precision agriculture practices (Gabriel and Gandorfer, 2023). In contrast, most IITs are more complex to use and, in most cases, require the prior adoption of complementary technologies (Barnes *et al.,* 2019; Kolady *et al.,* 2021). The findings on DDT, EKT, and IIT adoption agree well with those from neighbouring small-scale regions and countries, such as Switzerland and Bavaria. For example, Groher *et al.* (2020) show that Swiss farmers are more likely to adopt driver assistance systems than electronic measuring systems, while Gabriel and Gandorfer (2023) provide evidence that adoption rates are higher for FMIS, predictive models and automatic steering systems than for VR or sensor technologies in Bavaria. The fact that DDTs are cheaper to buy is also a major reason for the higher adoption rates of DDT compared to EKT or IIT (Birner *et al.,* 2021; Gabriel *et al.,* 2021).

In all cases, the statistical analysis of the differences between adopters and non-adopters in the three adoption scenarios showed significant results for the variable arable land size. Age (DDT, EKT), farming experience (EKT, IIT), and income type (DDT, EKT) were each statistically significant in two technology adoption scenarios. The findings on farm size are consistent with the results of the literature review conducted by Shang *et al*. (2021), who show that farm size and digital technology adoption are related in 33 out of 43 studies. In this context, the literature argues that economies of scale are a reason for the higher adoption rates of DDT compared to EKT or IIT, as apps and software tend to be scale-neutral or at least more scalable, while embodied digital technologies tend to be more costly, making them more affordable for larger farms (Birner *et al.,* 2021).

Perceptions of the trustworthiness of digital agriculture innovation actors

The results indicate that not all farmers have the same level of trust in all actors providing advice and information on digital technologies. Across the three technology adoption scenarios, the highest levels of trustworthiness are attributed to other farmers, the agricultural press, and associations. From an innovation system perspective, these actors, especially other farmers, can be understood as relatively close to farmers, which is why farmers may have higher levels of trust in them. Leeuwis and Aarts (2021) describe this type of trust as horizontal trust, which is related to the expected behaviour of colleagues, household, and community members. With regard to horizontal trust, previous research shows that farmer-to-farmer exchange is particularly important for making adoption decisions (Blasch *et al.,* 2022; Kvam *et al.,* 2022). Another essential aspect of farmer-to-farmer exchange is that farmers perceive information from other farmers as more credible, honest, and relevant. For example, Kvam *et al.* (2022) report that farmers highly value sharing practical experiences about digital technologies with other dairy farmers.

Associations and the agricultural press are considered highly trusted sources of information and advice on digitalisation by the farmers surveyed. In this context, it is striking that the study by Kernecker *et al.* (2021) implies that agricultural media and associations play a more indirect role in providing information and advice on digitalisation, as they primarily interact as intermediaries between actors in digital agriculture innovation processes. Kvam *et al.* (2022) report that farm magazines and farmer organisations have a limited impact on the actual adoption decision, either because they serve only as an initial source of information in the awareness phase or because they lack the expertise to advise on digital technologies. In the case of associations, it can be assumed that their high level of trust is not necessarily based on being perceived as a leading innovation actor in digital agriculture (Busse *et al.,* 2014; Kernecker *et al.,* 2021). Instead, it can be assumed that they are regarded as trustworthy because they have maintained a connection with farmers for many years. Similarly, the farming press has maintained a long-standing relationship with farmers and has increasingly taken on an important role in providing information about digital technologies in Germany in recent years (Gabriel *et al.,* 2021). This makes the high level of perceived trust unsurprising. In contrast to the findings of this study, Rust *et al.* (2021) show that farmers do not necessarily trust the agricultural press, as some view it as a mouthpiece promoting agricultural innovations on behalf of agribusiness.

DDT, EKT, IIT adopters, and non-adopters express less trust in research institutions, private advisory services, agricultural authorities, Agtech, and downstream actors. The more negative perceptions of these actors may be partly explained by the assumption underlying the idea of vertical trust, which states that farmers expect actors in the agricultural support environment to behave in a manner conducive to trust (Leeuwis and Aarts, 2021). This problem is perhaps best illustrated by the case of Agtech actors and the differences in positive and negative ratings between adopters and non-adopters of DDT and EKT, implying that non-adopters do not necessarily expect Agtech actors to provide information in a manner conducive to trust. In the literature, critical voices point out that farmers have concerns about the intentions behind the advice supplied by Agtech actors, as the information may be biased and influenced by economic interests (Lioutas and Charatsari, 2022).

Research institutions play a crucial role in developing digital technologies and undoubtedly possess advanced expertise in this field (Busse *et al.,* 2014; Eastwood *et al.,* 2017; Kernecker *et al.,* 2021). Interestingly, the results of this study indicate that adopters of DDT, EKT, and IIT perceive the trustworthiness of research actors significantly more positively than non-adopters. This observation may be partly explained by the fact that farmers and researchers are not very well connected (Busse *et al.,* 2014; Landini *et al.,* 2023) and that researchers tend to collaborate with few innovative farmers in the context of precision agriculture (Eastwood *et al.,* 2017). Moreover, Rust *et al.* (2022)

note that researchers often struggle to provide information that aligns with farmers' expectations and needs. This may result in some farmers preferring to consult other innovation actors for information. For example, Toma *et al.* (2018) report that farmers find information on agricultural innovations provided by extension services more valuable than that offered by research institutions.

Downstream actors are perceived as relatively neutral in terms of trustworthiness by the three adopter groups, while non-adopters view them rather negatively. In this context, some studies highlight that downstream actors are barely involved in generating and sharing digital technologies (Busse *et al.,* 2014; Lioutas and Charatsari, 2022). Therefore, it is reasonable to conclude that farmers prefer to seek information on digital technologies from sources other than downstream actors, as they may believe these alternative sources possess greater expertise in this field.

Previous studies showed that farmers in Germany have been struggling for a long time to get access to public or private advisory services on digital technologies (Kutter *et al.,* 2011; Reichardt and Jürgens, 2009). Farmers in this study express higher levels of trust in agricultural authorities than in private advisory services. Interestingly, adopters of DDT, EKT, and IIT tend to rate agricultural authorities and private advisory services quite positively. In contrast, non-adopters view agricultural authorities as more trustworthy than private advisory services across all three adoption scenarios. This finding suggests that non-adopters may be more interested in having access to publicly funded, independent, and neutral advice on digitalisation (Busse *et al.,* 2014) instead of private offerings.

This study has made a substantial contribution to the field of studies that address the role of trust in digital agricultural innovation processes from a quantitative perspective (Bekee *et al.,* 2024; Jayashankar *et al.,* 2018). In this context, the study presents new findings on whom farmers consider to be trusted sources of information and advice on digitalisation. As with any empirical work, this research also has some limitations. One limitation of the study is that the surveyed farmers were asked in general terms whom they trust to provide information on digitalisation without differentiating between their trust in specific actors to behave supportively (horizontal and vertical trust) and their trust in those actors' expertise to advise on digitalisation (trust in sources) (Leeuwis and Aarts, 2021). Moreover, this study did not consider whether the surveyed farmers had previous positive or negative experiences with the included actors, which may have affected how they rated the trustworthiness of these actors. Based on this research, the authors recommend that further studies examine in more detail how perceived trustworthiness, as a moderating factor, affects the strength of influence that certain innovation actors have on farmers' adoption decisions. In addition, qualitative research methods could be used to investigate why farmers trust or distrust certain innovation actors involved in digital agriculture.

Conclusion

The aim of this paper was to disentangle how adopters and non-adopters of DDT, EKT, and IIT perceive the trustworthiness of different innovation actors as sources of information and advice on digital technologies. Based on a survey of 203 German arable farmers, the study has identified actor-related differences in trustworthiness, particularly between adopters and non-adopters. The research indicates that farmers perceive other farmers, the agricultural press, and associations as the most trustworthy sources of information and advice on digitalisation. At the same time, downstream actors are viewed as the least trustworthy source. Across three different technology adoption scenarios, DDT, EKT, and IIT adopters perceive other farmers, private advisory services, research institutions, the agricultural press, Agtech actors, and downstream actors as more trustworthy than non-adopters. A major conclusion of this work is that farmers do not equally trust all actors involved in digital agriculture. In contrast to a portion of the existing literature, the present findings do not suggest that there is a fundamental trust gap between farmers and innovation actors in the context of digital agriculture. However, it becomes clear that farmers, in particular, have a high level of trust in peers, while trusting other actors proves to be more challenging for them.

From an innovation system perspective, the authors conclude that a better understanding of the role of trust in digital agriculture innovation processes can help to strengthen the relationship between potential technology adopters and other innovation actors. In this sense, it is assumed that realising the full potential of digitalisation requires measures and mechanisms to build trust among the different actors involved in digital agriculture. Additionally, it is crucial to consider that certain types of farmers are more difficult to reach and that there is scepticism about the motives of some innovation actors. Moreover, innovation actors need to rethink their individual challenges and roles in providing information and advice on digital agriculture to improve knowledge and information. In this context, considering farmers' perceptions of the trustworthiness of innovation actors in the AKIS can inform and help to design strategies to better align information and innovation processes to the needs of farmers, enabling farmers to make better-informed adoption decisions.

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