



Mapping varieties of farmers' experience in the digital transformation: a new perspective on transformative dynamics

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Abstract

The COVID-19 pandemic has highlighted the vulnerabilities of the global food system, underscoring the need for a sustainable transformation of the food system. With the advent of new digital technologies emerging as critical tools for achieving the agricultural shift, it is important to understand farmers' adoption decisions better. This study aims to systematically uncover and delineate the varied forms of experiences farmers have with new digital technologies and investigate how these experiences impact the organizational adoption decisions on the farm. In this study, twenty interviews with apple growers, wine makers, and intermediaries from a German region encompassing Saxony, Thuringia, and Saxony–Anhalt were conducted and analyzed. Through the lens of the modified adaptive capacity wheel and alongside the interview data, five relevant types of experiences were identified. These types of experiences are closely related to farmers' adaptation motivation (AM) and adaptation belief (AB), potentially influencing their future decisions about the adoption of digital technologies. This study highlights the importance of creating meaningful experiences with technologies to strengthen farmers' AM and AB.

Keywords Digital transformation · New digital technologies · Agriculture · Experience · Smart farming · Adaptive capacity

Introduction

Today's society depends heavily on a global interconnected and compound industrial agriculture network to meet its food demands (Carducci et al., 2021). While the agrifood system is considered robust enough to cope with smaller shocks, it has become increasingly susceptible to major ones (Moersdorf et al., 2024). The COVID-19 pandemic and the war in the Ukraine have exposed its unpreparedness against such events (Ben Hassen

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& El Bilali, 2022; El Bilali et al., 2024; Moersdorf et al., 2024). Within the agricultural domain, small and medium-scale farmers are confronted by a myriad of challenges. These encompass the enduring scarcity of seasonal labour during critical planting and harvesting phases, the amplified costs and accessibility constraints concerning agricultural inputs such as seeds and fertilizers, and the volatile changes inherent in market dynamics (Meixner et al., 2022; Paudel et al., 2023; Stojcheska, 2021). These challenges not only affected individual farming organizations but also disrupted the entirety of the agrifood system, resulting in 122 million more people suffering from hunger than before these events in 2019 (FAO, 2023). Thus, a transformation towards a more resilient agrifood system is needed. New technologies are considered critical to this transformation (FAO, 2022). The term new digital technologies summarizes all recent innovations that potentially transform on farm routines and business procedures, e. g. Precision Agriculture Technologies and Farm Management Information Systems. Anticipated to bolster resilience against the aforementioned challenges, new digital technologies are expected to enhance the production output while offering possibilities to increase the agricultural inputs as well as labour efforts (Moysiadis et al., 2021; Sugandh et al., 2023) and enhance the market access for small and medium-scale farmers by overcoming information barriers (Deichmann et al., 2016). Although new digital technologies continue to evolve and gain acceptance in the market (Osinga et al., 2022), numerous unanswered questions concerning the digital transformation of the agricultural sector remain.

Digital transformation scholars in agriculture have emphasized the need to enhance information access, establish financial support mechanisms, and improve technological services and education (Ammann et al., 2022; Kendall et al., 2022; Mizik, 2023). These suggestions are built upon various studies investigating factors that may either promote or hinder technology adoption among farmers. Typically, these studies employ technology acceptance models, such as the Unified Theory of Technology Acceptance (UTAUT), which have been utilized in numerous research (Li et al., 2020; Otter & Deutsch, 2023; Pathak, 2019; Ronaghi & Forouharfar, 2020; Yatribi, 2020). However, these studies are criticized for their lack of explanatory value (Giua, 2022; Pathak, 2019; Tey & Brindal, 2012; Yatribi, 2020). Additionally, the current literature neglects the organizational context in which such adoption decisions occur, tending to view farmers as isolated decision-makers (Rondan-Cataluña, 2015).

A growing body of research (Engås et al., 2023; Kernecker et al., 2020; Schimmelpfennig & Ebel, 2016) suggests that prior experiences might influence the adoption decision of new digital technologies, however these studies only tangentially address the role of experience. Consequently, there is a noticeable gap in the literature regarding farmers' prior technology experiences in the realm of implementing new digital technologies. Against this backdrop, this study aims to address this gap by exploring the varied forms of experiences farmers have before and with new digital technologies and investigating how these experiences impact the organizational adoption decisions on the farm. To do so, the conceptual framework of the Adaptive Capacity Wheel (ACW), developed by Gupta et al. (2010), in the modified version of Grothmann et al. (2013), is used in this study. The ACW suggests the individual factors *adaptation motivation* (AM) and *adaptation belief* (AB) to explain how an actor's personal attitudes affect the organizational capacities to respond to change. Thus, the concept of *adaptive capacity* (AC) serves as a framework for exploring the relationship between farmer's prior experiences with new digital technologies and the organizational capacity to respond to challenges of the digital transformation. This approach deviates from previous research by recognizing that the experiences made on the individual level affect the capabilities, motivation and beliefs of a farming organization to

make adoption decisions for new digital technologies. Thus, in this study it is assumed that prior experiences with a strong link to AM and AB are most promising to better understand the organizational decision making on the farm.

The primary aim of this research is to systematically uncover and delineate the various types of experiences farmers have had with new digital technologies. Once these experiences are identified, they are juxtaposed with *adaptation motivation* (AM) and *adaptation belief* (AB) to pinpoint the specific types of experiences that hold the most weight in influencing farmers' decisions to adopt digital technologies. This comparative analysis is vital in determining which experiences are most likely to drive or hinder the adoption of digital transformations in agriculture.

Therefore, this study addresses two research questions:

RQ 1: What types of experiences do farmers have when engaging with new digital technologies?

RQ 2: How are these types of experiences relevant to farmers' adaptation motivation and adaptation belief?

These questions are answered by conducting a qualitative study. Twenty German apple growers, wine makers and intermediaries have been interviewed. Pomiculture and viticulture were selected due to their shared technological requirements for cultivation and the challenges they face, such as the need for advanced automated steering systems and image recognition systems for monitoring fruit growth and facilitating robotic harvesting. Additionally, the business conditions for agriculture in Germany merit exploration due to their unique requirements. This study specifically focuses on the 'Dreiländereck' region of Germany, encompassing Saxony, Thuringia, and Saxony-Anhalt.

The paper is organized as follows: Sect. "[Theoretical background](#)" provides an overview of existing literature on the adoption of smart farming technologies, farmers' experiences, and introduces the ACW framework. Sect. "[Material and methods](#)" details the methodology employed for data collection and analysis. Findings and their implications are discussed in Sect. "[Results and discussion](#)". Finally, the paper concludes by discussing the limitations of the study, and delineating its theoretical and practical contributions, as well as its relevance for future research endeavours.

Theoretical background

Experience in the agricultural digital transformation

Experience plays a pivotal role in technology acceptance, shaping the usage intention of new technologies (Eagly & Chaiken, 1993; Fishbein & Ajzen, 1975). Taylor and Todd (1995) distinguished between experienced and inexperienced technology users, laying the groundwork for future studies. However, Varma (2013) argued that researchers must differentiate between types of prior experience, as they can lead to varying levels of acceptance. In the agricultural digital transformation, various factors, including farm size, crop type, financial resources, education, attitude towards risks, age, and gender, have been identified as influential in technology adoption. Authors who tried to synthesize those findings in meta reviews state that many of the factors surveyed are likely to be interrelated, but relationships remain underexplored (Pathak, 2019; Yatribi, 2020). In

the Unified Theory of Acceptance and Use of Technology Model (UTAUT) (Venkatesh and Davies, 2000), experience is considered to impact the facilitating conditions before and after technology introduction. However, in the agricultural transformation research, only Li et al. (2020) have included experience in their study on precision agriculture technology acceptance in the Chinese crop sector, replacing technology experience with general farming experience. Others have either discarded moderating variables (Ronaghi & Forouharfar, 2020) or substituted them with different variables (Giua et al., 2022; Otter & Deutsch, 2023). Whenever studied, experience is defined by the time a user spends with the studied technology.

Outside of the technology acceptance discourse, scholars' interest in experiences with technology seems to increase. However, experience only plays a secondary role in all these studies, which is why there is still no common understanding of the term experience. A mismatch between farmers' expectations and actual experiences with technologies often results in frustration (Kerneck et al., 2020). And, when the expectation in form of a goal for a yield is experienced to be met, this seems to positively influence the adoption decision (Schimmelpennig & Ebel, 2016). But, non-adopters are found to be frustrated even before they decide to adapt a technology, due to frustrating experiences with the availability and accessibility of new technologies (Kerneck et al., 2020). Because past and current experiences have been found to shape individuals' and groups' technological frames and guide their actions during digital transformation (Engås et al., 2023), for this study, it is assumed that not only the expectations towards a technology have an influence on the adoption decision, but that this decision is also significantly influenced by all previous experiences made with (other) technologies.

In the context of this study, experience is defined as the dynamic interplay between an individual, their surroundings and a technology including both conscious and unconscious processing of stimuli, resulting in the acquisition of knowledge, skills, and memories that guide future actions and responses towards new digital technologies. Within this definition and research context, experience is not only a set of mental states of an individual person, experience can also be understood collectively or institutionalized, for example. To improve the informative value, studies on experience should explore their definition of the dynamic interplay depending on the research context (e.g. individual, company and or industry level) and present it more concretely. This is a major reason for exploring and mapping varieties of experience.

The adaptive capacity wheel framework

Adaptive capacities are the “inherent characteristics of institutions that empower social actors to respond to short and long-term impacts either through planned measures or through allowing and encouraging creative responses from society both ex ante and ex post” (Gupta et al., 2010, p. 4). Thus, resilient institutions and organizations are those that allow their actors to navigate both anticipated and unforeseen circumstances with flexibility and creativity, all while preserving a sense of identity (Gupta et al., 2010). The ACW framework was developed by Gupta et al. (2010) for assessing the described adaptation resilience in institutions and organizations. The authors state that institutions that promote adaptive capacity are those that (1) promote diverse perspectives, participants, and approaches; (2) empower actors to perpetually enhance their institutions; (3) empower actors to change their behaviour; (4) harness leadership; (5) mobilize resources to execute adaptation strategies, and (6) strengthen principles

of equitable governance. Built upon these six founding blocks, Gupta et al. (2010) developed a framework with six dimensions to assess adaptive capacities. Grothmann et al. (2013) later incorporated two psychological dimensions to understand adaptation processes better.

Each of the eight dimensions is described by three to four criteria for measuring adaptive capacity (Gupta et al., 2010). The first dimension, *variety*, refers to the (cognitive) room for a diverse framing of problem definitions, the engagement of different actors and stakeholders with different opinions, and a broad range of policy options to tackle a problem (Gupta et al., 2010). The second dimension, *learning capacity*, addresses the presence of trust, the ability of organizations and institutions to learn from their experiences and adjust routines and patterns accordingly, opportunities to discuss doubts, and good monitoring practices to evaluate changes. *Room for autonomous change*, the third dimension, covers access to information, the ability to act according to plans as well as the capacity of organizations and institutions to improvise. The fourth dimension, *leadership*, addresses the importance of shared long-term visions and opportunities for leaders to stimulate change processes and collaboration. Dimension five tackles the availability of necessary *resources*. The sixth dimension, *fair governance*, highlights that organizations and institutions need to be embedded in a system that supports the process of change through legitimacy, equity, responsiveness and accountability. Dimensions seven and eight refer to the role of the individual and play the most pivotal role in this study. *Adaptation motivation* (AM) describes the motivation of an individual to realize, support and promote adaptation. *Adaptation belief* (AB) refers to an individual's belief to be able perform transformative activities. AB is considered in two different ways: First, in the individual's belief that the outcome of a process of change solves their initial problem—the *outcome-efficacy belief*—and second, the feeling of being capable to actually perform a response—the *self-efficacy belief* (Grothmann et al., 2013).

Both, climate adaptation and adaptation to challenges opposed by the digital transformation aim to foster the resilience of organizations. Thus, challenges addressed by the ACW (Prutsch, 2014, Grothmann et al., 2013), such as uncertainty, knowledge gaps, mainstreaming of adaptation, policy integration, equity, and adaptation barriers, are also prevalent in the digital transformation (Cook et al., 2022; Klerkx et al., 2019). Therefore, a horizontal borrowing (Fisher & Aguinis, 2017) of the ACW is performed. The framework has been modified for this study to adequately capture the context of the digital transformation in farming organizations. Those differ from the institutions described by Gupta et al. (2010) and Grothmann et al. (2013) in three ways: First, some of the farming organizations studied are rather small. Therefore, not all of them have the capacity to implement back-up systems (i.e. most of the pomiculture organizations only own one harvester) for creating redundancy. Because of that, the criteria 'Redundancy' has been removed from the Variety dimension. Second, the institutional or organizational knowledge in smaller farming organizations is often implicit and poorly documented or, if documented, sensible. This makes it difficult to compare the changes in the institutional knowledge body over time (institutional memory). Consequently, the criteria 'Institutional Memory' has not been applied in this study. Third, 'Accountability' is described as one criteria of the 'Fair Governance' dimension (Gupta et al., 2010). This refers to the organizational responsibilities transferred to different parties. Although the studied organizations share and transfer accountability to different actors to some degree (i.e. by being a member of a cooperative), none of them had processes in place to evaluate their accountability procedures. For this reason, the criteria 'Accountability'

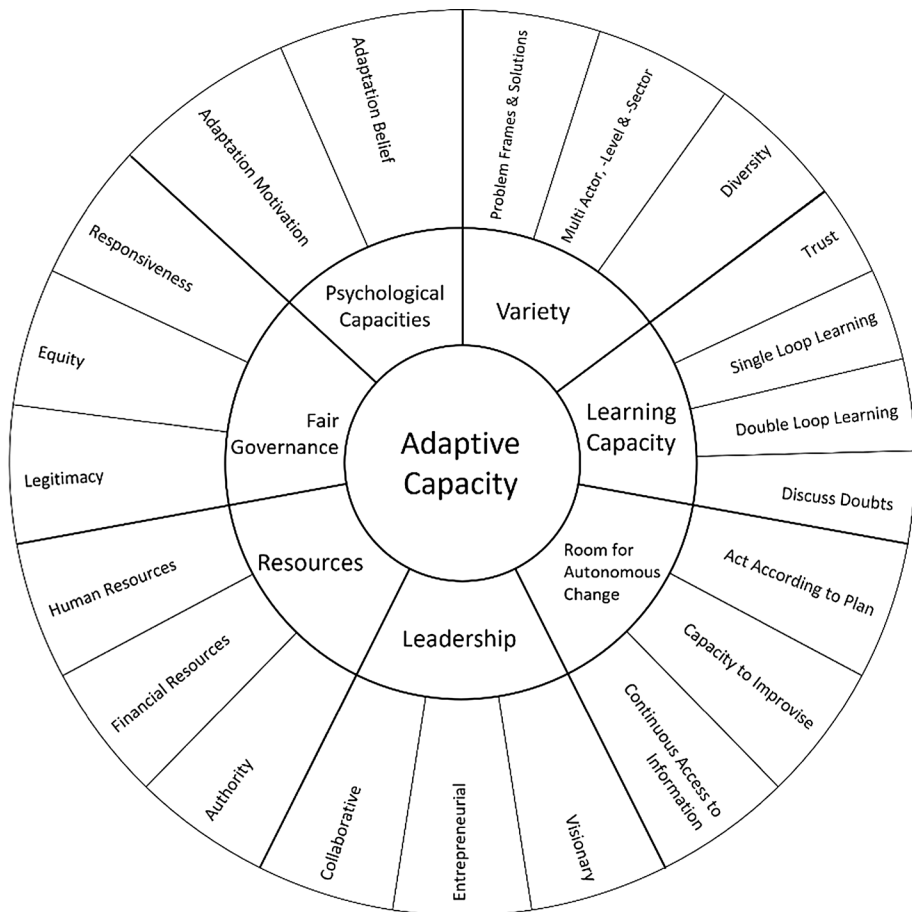


Fig. 1 Overview of the modified adaptive capacity wheel in this study based on Gupta et al. (2010) and Grothmann et al. (2013)

has not been studied. Figure 1 provides an overview of the ACW framework's application in this study.

Material and methods

Data collection

This research was primarily conducted to guide and inform various technology testing within the publicly funded digital experimentation field “EXPRESS” (funded by the German Federal Ministry of Food and Agriculture). The objective of the project is to align the attitudes, factual circumstances, and interests of small and medium-sized wine-making and apple-growing businesses from Saxony, Thuringia, and Saxony-Anhalt with the agendas of applied research and testing. Numerous conversations in different settings took place to

Table 1 Overview of interviews

Title	Type	Profession	Farm size (ha)	Duration (h)
Intermediary_1	Face to face	Agricultural consulting	–	1:15
Intermediary_2	Phone	Agricultural consulting	–	1:22
Intermediary_3	Phone	Agricultural trade	–	1:15
Intermediary_4	Video call	Machine manufacturer	–	1:18
Intermediary_5	Phone	Software provider	–	1:05
Intermediary_6	Video call	Machine manufacturer	–	1:15
Intermediary_7	Face to Face	Pomiculture interest group	–	1:12
Pomiculture_1	Face to Face	Pomiculture	30	0:47
Pomiculture_2	Phone	Pomiculture	300	0:54
Pomiculture_3	Phone	Pomiculture	102	1:15
Pomiculture_4	Phone	Pomiculture	1500	1:13
Pomiculture_5	Video call	Pomiculture	13	1:06
Pomiculture_6	Phone	Pomiculture	500	1:23
Pomiculture_7	Phone	Pomiculture	60	1:00
Pomiculture_8	Face to face	Pomiculture	400	1:10
Viticulture_1	Face to face	Vinery	90	1:15
Viticulture_2	Face to face	Vinery	11	0:58
Viticulture_3	Face to face	Vinery	25	1:27
Viticulture_4	Phone	Vinery	22	1:24
Viticulture_5	Phone	Vinery	5	1:05

achieve this goal. For this study, only conversations that were facilitated using the interview guidelines presented in 3.2.1 have been analyzed.

Thus, the data set consists of twenty interviews with apple growers, wine makers and different intermediaries from the viticulture and pomiculture sector. As depicted in Table 1, the size of the farms and the professions of the intermediaries varied significantly. This variety was intentional, as the goal was to capture a exploratively and qualitatively broad picture of the stakeholders within a particular region. The size of the farms surveyed is typical for the region, ranging from large successor enterprises of the former German Democratic Republic agricultural cooperatives to small-structured, often family-led, orchards and vineyards. Compared to the rest of Germany, this region is important but rather small. In 2020, the German Federal Statistical Office (Destatis) counted 360 of such farms (permanent crops) which means that the studies sample represents roughly 3.6% of all businesses in this region. Germany, in total, counts around 18,000 businesses of this kind with a standard output of 117,500 EUR per business and year (Destatis, 2021). The ‘Dreiländereck’ region represents 4.6% (9,946 ha) of permanent crop land in Germany and has a 2.5 times higher standard output per business (292,600 EUR) compared to Germany in total, mainly due to few very large players (Destatis, 2021). Participants were not chosen at random and there was also no prior segmentation by company size; therefore, not all criteria of representativeness were met. However, this sample can be considered quite typical for a German permanent crop region. Additionally, one third of the total permanent cropland of this region (3058 ha) is represented in this sample. It must be noted that permanent crops are in terms of

standard output comparable to annual crops in Germany (110,000 €). Cost structures, cultivation systems and machinery, however, vary heavily. Despite some interviewed farmers that seemed to be very skeptical towards digital transformation, a slight tendency towards a more technology-optimistic sample should be assumed with respect to participation bias. Participants were identified via web research and complementary official listings in agricultural organizations. They were recruited via email invitations that included a brief description of the “EXPRESS” project. Additionally, most of the farmers were contacted by phone. The intermediaries were chosen based on their area of expertise, following a principle of maximum diversity. A total of 65 stakeholders were formally contacted, most of them farmers. The response rate was 31%.

The interviews were initially scheduled for spring 2021. However, due to the travel restrictions imposed by the COVID-19 pandemic, some interviews were conducted online or via telephone, while others were postponed to spring 2022 to facilitate face-to-face meetings. The average duration of the interviews is 70 min, and all interviews were conducted in German.

Method

According to the theoretical framework of the ACW, a qualitative in-depth interview study was employed, an approach that has been proven suitable for explorative studies in previous research (Gabriel & Gandorfer, 2023; Kendall et al., 2017). In this study, long in-depth interviews proved effective in engaging meaningfully with farmers, providing them with a comfortable platform to share their opinions and past experiences openly. The conducted interviews were semi-structured. This interviewing technique supports the rigorous collection of open-ended data relevant to the topic explored. Moreover, it encourages participants to share their thoughts, feelings, and beliefs, and is thus suitable when addressing more sensitive issues (De Jonckheere & Vaughn, 2019).

Interview guidelines

The semi-structured format allows for flexibility and spontaneity. To ensure all dimensions of the ACW were adequately covered in each interview, a catalog of guiding questions was compiled. The guiding questions are presented with their link to the ACW dimensions below. Notably, in the AB category, a strategic decision was made to refrain from formulating specific inquiries pertaining to the two dimensions—self-efficacy belief and outcome-efficacy belief. This choice was motivated by the recognition that such questions could potentially introduce bias or suggestiveness.

During the interviews, the questions were organized thematically into four different blocks, each building upon the previous one. In adherence to the semi-structured interview approach, situational follow-up questions were utilized to delve deeper into topics of interest. The interviews were conducted and transcribed in German. Below, the guiding questions are presented in their translated version (Table 2).

Coding and analysis

A comprehensive and systematic coding process was conducted using MaxQDA Plus 2022 (Release 22.5.0). The interview transcripts were coded using the Adaptive Capacity Wheel

Table 2 Guiding questions for the interviews based on the ACW dimensions

Variety	
Diversity of problem frames	What significant changes have you noticed in the last few years regarding the digitalization in special crop cultivation [fruit/wine growing]?
Multiple actors, -sectors and -levels	With which other actors (networks) do you regularly cooperate in your daily work?
Diversity of solutions	In your perception, are there enough solutions and approaches to the challenges in the agricultural sector?
Learning capacity	
Trust	Generally speaking, what is your opinion on new digital technologies in agriculture? <i>[Where do you find points of contact with this topic in your everyday work on the farm? To what extent would you describe your farm as 'digitized']?</i> <i>Do you know of concrete examples of digital technologies that you would describe as aberrant for your everyday practice in [viticulture/fruit growing]?</i>
Single loop learning	If you look in general at the machines and technologies used in your company: Can you spontaneously think of specific experiences or examples of what you have learned for yourself in dealing with the technology in everyday use?
Double loop learning	When you take some time away from your daily work, do you think about whether one or the other technology you bought was a good investment? <i>[Alternatively: To what extent do you notice that the use of new technology has changed your everyday work?]</i>
Discuss doubts	Would you say that you like to experiment with digital technologies in your company?
Room for autonomous change	
Act according to plan	What experience do you have in dealing with malfunctions and interruptions of digital devices (e.g., apps, networked machines, sensors in tractors or tanks, cellar technology, farm management system)? How do you regularly cope with malfunctions of machines or digital technology? <i>[How do you prepare for this?]</i>
Capacity to improvise	Have you recently or currently introduced new technologies? How did you approach the topic? Please tell us how you got from idea to implementation <i>[What stumbling blocks did you encounter along the way? To what extent does your example additionally use digital technologies?]</i>
Continuous access to information	How do you find out about new technologies in your company? Do you feel like you have an overview of the most important current developments in your sector?
Leadership	
Visionary	Have you already thought about how you want to develop your business in 5 years or where you want to be in 5 years? Will digital technologies play a role in this?
Entrepreneurial	Do you have concrete plans to introduce (further) new digital technologies in the near future? To what extent do you see opportunities and scope for actively shaping (digital) change in your agricultural business]?

Table 2 (continued)

Variety	
Collaborative	Which networks and associations are you involved in, or which networks have proven to be important/valuable for you? Are there networks where you can inform yourself about new technologies in agriculture / exchange information on the topic? How do you assess the necessity (in the future) to cooperate more with other [winegrowers/fruit growers] more closely? Are there employees in your company with whom you can possibly exchange information on this topic?
Resources	
Human resources	How does the skilled labor situation look in your context?
Financial resources	Do you have enough financial leeway for larger investments (including the purchase of new digital technologies)? Are you familiar with the available subsidies?
Authority	Do you feel that you can make your general challenges or assessments of digitalization sufficiently heard vis-à-vis others (e.g., associations, farmers, administration)?
Fair governance	
Responsiveness	How do you perceive the current agricultural policy? Do you perceive that politics is directed at your needs?
Equity	How do you rate the legal situation and the legal framework for your agricultural production?
Legitimacy	When you think about consumers: How do you see the current relationship of consumers to agricultural production? [What can be done here from your point of view?]
Adaptation motivation	
	From the current perspective, would you (continue to) invest in new technologies? [Under what circumstances would this be interesting for you?] Asked in general terms: What advantages do you see in digitized agriculture? [Do you believe that new technologies will contribute to better economic efficiency or more sustainable management?] [Why?] [In your opinion, what are the obstacles to the digitalization of agriculture? What are the challenges that need to be overcome in order for the development to gain further momentum and for farmers to benefit in the best possible way?]
Adaptation belief	
Outcome-efficacy belief	Do you feel that you can adapt to future challenges with the help of new technologies that will be available in the foreseeable future?
Self-efficacy belief	

framework and a deductive approach, as illustrated in Fig. 2. The aim of this approach was not to evaluate the farmers' adaptive capacity but rather to provide a clear structure to the material and to facilitate the generation of initial heuristics.

Post-coding, there was a deliberate period of reflection and distancing from both the coding process and the hypothesis generation. This distancing was important to facilitate a shift in analytical perspective from a broad consideration of adaptive capacity to a more focused examination of experience.

The analysis was then carried out in two stages. To answer the first research question ("What types of experiences do farmers have when engaging with new digital technologies?") all codes were systematically reviewed to identify any promising references to

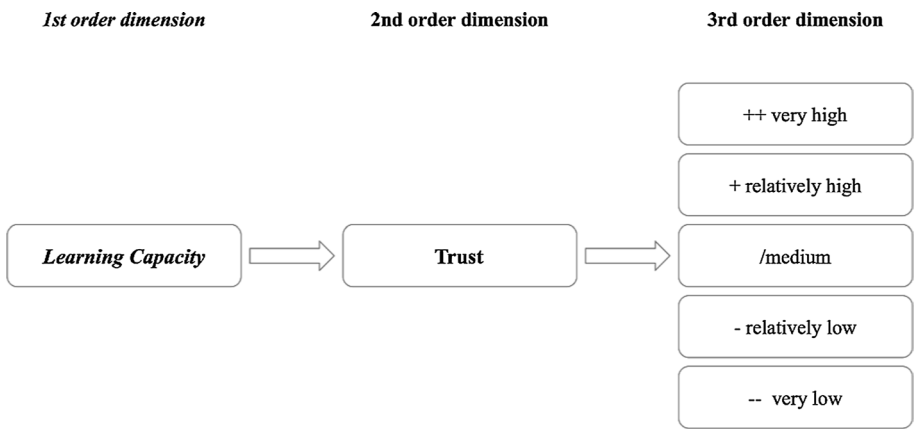


Fig. 2 Example of the coding structure

experience. Once identified, a reflective step was taken to succinctly describe the connection to experience. The identified sections were then grouped into different types of experience, each consisting of one or two specific codes, descriptions, and key quotations.

Second, to address the second research question (“How are these types of experiences relevant to farmers’ adaptation motivation and adaptation belief?”), the MaxQDA code-relations browser was used to investigate the relation of each experience types’ codes and the codes for AM and AB. The code-relations technique aids researchers to draw connections between different statements, so they can identify interrelations and patterns (Kuckartz, 2007; Saldaña, 2015). Thus, in this study it has been used to analyze how the identified types of experience relate to AM und AB. To further analyze the AB dimensions, the codes were divided into coding’s that suggest self-efficacy belief and those that suggest outcome-efficacy belief. Table 3 shows some examples of this allocation to improve comprehensibility.

Due to the explorative research design of this study, the code relations do not imply statistical relevance, nor do they provide an explanation for the observed correlations. However, the systematic analysis of linkages is well suited for theorizing and the development of further research agendas.

Results and discussion

Through the lens of the modified ACW and alongside quotes from the interview study, five types of experience show a close link to AB and AM. In the following section the relevant types of experience and their relation to the ACW factors are introduced (RQ1). Thus, for each type of experience, a table (Tables 4, 5, 6, 7 and 8) with the 2nd order dimension codes, the key quotes and a summary of the quotes is presented. Building up on this, the identified relation to AM and AB is discussed (RQ2).

Table 3 Coding examples for self-efficacy belief and outcome-efficacy belief

1st order dimension	2nd order dimension	Coding examples
Adaptation belief	Self-efficacy belief	· “I studied to be a farmer myself. I was already working with GPS, sensor-controlled fertilization and crop protection and so on in my apprenticeship. And then also with this digital recording, which was included, and I thought that it was a really great thing.” Viticulture_4 · “In this respect, it really is the case that the drive comes more from curiosity and not so much that I say, “if we don’t do this, if we don’t use modern methods, if we don’t think about such things, then the company will go bust”.” Pomiculture_5 · “That’s when it goes digital. That’s when we start taking our nitrogen measurements. That’s when we start measuring our leaf wetness values, our soil wetness values. That’s where it’s going to be very interesting.” Viticulture_1
	Outcome-efficacy belief	· “That is the future. We need this because every year we see how the workforce and availability are declining.” Pomiculture_1 · “Well, I can tell relatively quickly whether or not it takes work off my hands. For example, we bought a digital measuring device for the cellar last year to measure the [grape] must weight during fermentation. And that paid off really well.” Viticulture_5 · “These harvesting robots. That’s a huge topic for me. These harvesting robots also improve quality. The relief of physically hard work through harvesting robots. Monotonous work that can be taken away would certainly help, in my view.” Pomiculture_4

Tech competence and agricultural application

The factors “single loop learning” and “double loop learning” pertain to the general technical competencies required to learn from and reflect upon the usage of (digital) technologies. Also, they reflect on observable changes in farm operating procedures. This code was applied when farmers discussed their learning experiences related to the introduction and utilization of various technologies.

Within these narrations, farmers shared insights into their technical know-how, either by commenting on their technical competence or by reflecting on general limitations for introducing or using a solution. Consequently, throughout the agricultural digital transformation, farmers find themselves experiencing a lack of know-how on the one hand, and a sense of curiosity and willingness to learn about new technologies on the other. Thus, experiencing their tech competence influences farmers’ willingness to engage with new technologies.

Therefore, through the coding’s of single loop learning and double loop learning, the *type (1) of experience*: “*Tech competence and agricultural application*”, can be described.

When examining the relationship between this experience type and the codes for AM and AB, it is unsurprising to find that farmers with technical competence and know-how are likely to exhibit a strong motivation to adapt to new technologies. Furthermore, these farmers typically believe in their ability to manage the challenges associated with adopting new technology. In some instances, these farmers have even developed customized

Table 4 Codes, quotes and summary of type 1

2nd order dimension	Key quote	Summary
Single loop learning	“So the technology must be simple. So, when I see that today, I enter our tractor and I’m not that ignorant. <i>I already know my way around the whole subject. But I enter our tractor and I really have to look at everything first and I have to—I can’t get it started at all. I even can’t get the hoist up?</i> ” — “This and this and this.” Before I’ve started the whole GPS thing there and and and. It’s too complicated. And that’s why it can’t work. <i>That’s why everyone criticises it. Whether it’s at Fendt or a John Deere. It is the same. It is complicated</i> ” (Pomiculture_1)	· Tractors equipped with various new technologies raise the complexity of the machine · Farmer lacks technical know-how to utilize the new functionalities · Lack of knowledge results in frustration
Double loop learning	“So we had an app that was supposed to record [the working hours] GPS-controlled. [...], but that simply didn’t work in practical application. <i>There is not always a GPS signal available, or they have a few more things on in winter and working with a smartphone is not that much of a topic up here.</i> [...] And in the end, I discarded it because, from my point of view, the distributor didn’t go in the direction I wanted and the result wasn’t as feasible or usable for me as I would have liked.” (Pomiculture_6)	· Farmer has enough knowledge to apply the new technology in farm · Farmer can critically evaluate the utility of the app in use · Farmer decides to not stick to a new technology based on technical know-how
Single loop learning	“I: And for concerning that (temperature logging system). Where did you get the knowledge to build it by yourself? [...] B: <i>YouTube.</i> ” (Viticulture_5)	· Based on former experiences, farmer is able to find all relevant information to engage with a new technology · Based on the farmers knowledge, he can even customize existing technologies and implement new functionalities

Table 5 Codes, quotes and summary of type 2

2nd order dimension	Key quote	Summary
Entrepreneurial	“And there, at least that’s what we were told at the university, <i>a usual simple weather station, not one for a five-figure sum, would be sufficient for this</i> , which can measure wind, temperature and precipitation, so to speak. <i>Oh, and by the way, that’s what we’re planning to do</i> . I forgot to tell you that. We are planning to set it up in our vineyard as well.” (Viticulture_4)	· Costs are one important factor in the digital transformation of agriculture · Decision making occurs based on cost efficiency evaluations
Entrepreneurial	“In 2013/2014 we bought a GPS system. [...] It came from John Deere for €20,000. And we integrated it into the Fendt and we got nothing but problems. They also told us: This is compatible. [...] Nothing is compatible together. [...] <i>So we tried that and lost money. I shouldn’t have done it at all. As always, I should have leased it.</i> ” (Pomiculture_1)	· Costs are one important factor in the digital transformation of agriculture · Erroneous decision with investing in new technologies influences upcoming investment decisions

Table 6 Codes, quotes and summary of type 3

2nd order dimension	Key quote	Summary
Discuss doubts	“Our orchards are <i>planted significantly more dense compared to other cultivation systems in other regions</i> , and that’s why we very much like to use these saddle technologies, which of course are then also much more efficient. [...] And that’s where an Italian company came in. We purchased three such [saddle sprayers] – they’re a disaster. It must be said this way. They simply don’t work. It was a ruinous investment. So they run, <i>but it is just not what we had hoped for.</i> ” (Pomiculture_4)	· Farm-specific cultivation system guide farmer’s decision making · Farmers requirements not necessarily match available technology on the market · Experimentation and risk taking is necessary to explore the added value of new technology
Discuss doubts	“Well, I know that my small vineyard on the doorstep, which is not even a hectare in size, has a larger area that slopes steeply. <i>There, the leaves dry relatively early and [...] towards the castle behind, where it goes down a bit, the leaves are much more wet at the same time. And that’s not even one hectare.</i> I know that as a wine maker because I’ve been on the vineyard for a long time and I also know, let’s say, the troublesome areas of the yield. <i>If I only had one sensor somewhere in the middle of a field, it would provide me with results or things that would not be correct.</i> [...] That’s why I’m still very skeptical.” (Viticulture_2)	· Farm-specific considerations seem to impact farmer’s decision making · Local conditions due to the specific terrain are decisive for the consideration of benefits · Experiences with farm specific cultivation conditions guide technology deliberations
Discuss doubts	“[...] but in the end, <i>we have little, very little or no time to deal with things like testing.</i> [...] Because we don’t have the staff or the capacities to do something like that on the side for fun. So, eventually we try out a few things that might work. But we can’t do proper testing for practice or development.” (Pomiculture_6)	· Farm-specific conditions (lack of resources) impact farmer’s willingness to engage in experimenting with new technologies · Limited room for creating firsthand experience

Table 7 Codes, quotes and summary of type 4

2nd order dimension	Key quote	Summary
Human resources	"I'm 34, I have at least ten people leaving in the next five to six years who are going into well-deserved retirement. These are all very good professionals. <i>They are people with a ton of experience that you simply look for and don't find anymore these days. And of course, it is difficult to compensate for them.</i> " (Pomiculture_1)	· Drain of knowledge and on-farm experience because of workers retirement · Potentially missing expertise affects future decision making
Human resources	"We have, for example, an employee who is currently taking his master's course at the research institute in [LVWO] Weinsberg, and he is essentially learning about drone technology for plant protection directly in class. <i>So, we experience more or less live how this is being advancing, and especially the results of thermal measurements, NDRE, and NDVI analyses. I don't think there is anyone in Germany who currently extensively relies on them as much as we do.</i> " (Viticulture_1)	· Specialist knowledge and master course concerned with UAV technology and optics made implementation of new technologies on farm procedures possible · Access to State-of-the-Art research and technology raises motivation for testing
Human resources	"I used to have an old John Deere. [My employees] drove it and anyone could operate it. Anyone, even my near-retirees, I would say. They could handle it. Now I've bought a new Fendt. [...] But when you have to spend ten minutes adjusting the machine software [for your employee] just to make sure everything works correctly, that's a problem. [...] <i>That's my experience. Yes. [laughs] I set it up for my employees. [...] They are simply too old for it, I would say. Or not interested anymore in doing it on their own.</i> " (Pomiculture_3)	· Introduction of new technology accompanies thoughts about experiences of staff capability und expertise · New machine features lead to lower productivity due to staff demographics · Farmer sees a problem in matching new technology with staff capabilities
Human resources	"Exactly, so we are three employees who primarily take care of plant protection here. There's an older employee who is approaching his sixties. Then there's me – I'm in my mid-thirties, and another younger employee who is ten years younger than me. So, you could say there are three generations. We are in constant regular contact, attending trainings together and all that. [...] Theoretical knowledge and knowledge from other companies may be valuable, but it's also invaluable to have someone who knows the company with all its peculiarities and difficult areas [...] That is still very important. <i>Even if we eventually have more accurate forecasting models, we still face the challenge of implementation.</i> " (Viticulture_2)	· Intergenerational knowledge distribution is highlighted in the narration · Match between new technology and staff expertise guides farmers' decision making

Table 8 Codes, quotes and summary of type 5

2nd order dimension	Key quote	Summary
Multi-actor, multi-level, multi-sector; collaborative	“B: No. It’s that easy. You go to your seller when you need a new tractor. Well, I needed one because one of my old ones had broken down—gearbox damage—it wasn’t worth repairing. So, I simply went to a salesman, <i>whom I knew well</i>. I asked him, made him an offer and then I bought it. That was... I: Pragmatic B: Quite pragmatic. I told him that it had to have so and so much horsepower <i>and I didn’t really care about anything else.</i>” (Pomiculture_3)	· Consultants are seen as trustworthy to influence farmers’ investment decisions · Trust in the experience of others is common when making decisions for an investment in a farm
Multi-actor, multi-level, multi-sector; collaborative	“Yes, yes, so [a dialogue] is taking place. There are also pioneer farms that are very active [...] in continuing [...] to run the farm in a future-oriented way, <i>and these are the pioneers with whom we like to cooperate or, of course, then also name them as a showcase farm, so that our customers can of course also go there [...]</i>. So, the farmers among themselves, it’s not that they’re hating each other’s guts, <i>there is a bond by now.</i>” (Intermediary_3)	· Personal networks play a significant role when collaborating to explore new technologies · Farmers mutual trust for deliberating future investments is reported by industry representative

solutions for their farms, what empowers them to further research and explore available technologies. Thus, a high level of technical competence can positively influence a farmers’ capacity to adapt to new digital technologies by relating positively with AM and a self-efficacy belief. However, it is important to note that experiences with new digital technologies can also lead to a decreased AB in some cases.

Thus, farmers with a strong technical competence tend to (a) be motivated to experiment with new technologies, and (b) believe in their capability to do so. While it might be intuitively assumed that these farmers are also best equipped to critically assess the extent to which a new digital technology will meet expectations and whether its implementation will yield the expected benefits, the code relations reveal that these doubts are more prevalent among farmers with a low level of technical competence. This observation may be explained by the effect of frustration when the promises conveyed through professional consultation fail to align with the actual experience once a farmer begins implementing a new solution. This phenomenon of frustration has also been documented by Kernecker et al. (2020).

Reflections on strategic investment

The factor “entrepreneurial” captures the capabilities of leaders to initiate actions. It also represents signs of forward-looking, individual entrepreneurial behavior. This code was applied when farmers discussed the potential of their future technology investments, or the absence thereof. Remarkably, most farmers took this as an opportunity to delve into

cost–benefit considerations, thereby justifying or explaining their previous experiences and business decisions.

Through the interpretation of the identified quotes, it becomes apparent that farmers’ reflections on their investment decisions are indicative of their attitudes towards strategies for implementing new technologies. Therefore, the ability of farmers to learn from their past business decisions, as well as from decisions made in their business network, encapsulates *type (2) of experience: reflections on strategic investment*.

It is likely that the juxtaposition of upcoming investment decisions with past successful or unsuccessful investments plays a role in shaping farmers’ motivation or belief. Farmers who perceive a cost–value benefit in new digital technologies and have had positive experiences with businesses integration tend to show a decent AM. Moreover, successful past strategic investment decisions in new digital technologies appear to contribute to a combination of self-efficacy belief and outcome-efficacy belief, both of which constitute the AB. Consequently, the experience of successful investing in new digital technologies seems to be an important driver overall.

Farm-specific knowledge and capabilities for technology integration

The code “discuss doubts” encapsulates farmers’ openness to embrace risks and uncertainties as they navigate the learning and experimenting with new digital technologies. This code was applied when farmers shared their contemplations and learnings derived from weaving technology into their unique business environment.

When probed about their general attitude towards experimenting with new digital technologies, participants typically brought up their unique business prerequisites. Thus, when farmers evaluate a new technology, they engage in a multi-layered consideration process, often tethered to their company-specific circumstances. All narrations unveil that farmers reflect on their specific current and past business environment and preconditions to properly assess the feasibility of integrating a new digital technology. This results in *type (3) of experience: farm-specific knowledge and capabilities for technology integration*.

A match between the specific features of a technology and the on-farm prerequisites can fuel a farmer’s motivation to experiment with the technology in question. However, a farmer’s outcome-efficacy belief in a solution may deviate. Consequently, AB only aligns positively with this type of experience when previous attempts at incorporating “something new” have been fruitful. This experience is not exclusively limited to new digital technologies; also, the integration of other innovations, such as land-based technologies, equally serve as pertinent precedents for evaluating prospective new digital technology implementation.

On-farm knowledge distribution

The code “human resources” encompasses the availability of expertise, knowledge and manpower as well as professional know-how of skilled workers. This code was utilized for interviewees’ general thoughts on the topic as well as for reflections on their farm specific situation. Farmers and stakeholders addressed not only the overall shortage of (skilled) workforce but also shared their thoughts on the distribution of knowledge within their organizations and how this affects their decision making.

How knowledge is distributed among the staff and how things worked out in the past guide farmers’ decision making. Naturally, farmers also think about substitutional

technology due to shortage of workforce. In this context, various forms of experiences come together, whether it is the actual introduction of new technology or hypothetical considerations based on previous experiences and operational procedures. They address the distribution of know-how among skilled and seasonal workers, as well as the related experience of how technology can complement and replace this knowledge. This is illustrated in *type (4) of experience: on-farm knowledge distribution*.

Overall, there is a strong link between knowledge distribution and the digital transformation capabilities, as nearly all interviewed farmers address this topic in one or the other way. When past experiences indicate that new technologies have complicated farm operations, this results in a lower AM. Conversely, when skilled professionals were available to guide the implementation of new digital technologies, farmers' considerations to adopt it become more serious, and the data shows a neutral or even positive AM and AB. Regarding technologies that are expected to support or replace seasonal labour, AM is higher, although scepticism about the actual implementation prevails and is reflected in a lower outcome-efficacy belief.

Agricultural knowledge networks

The codes “multi-Actor”, “multi-Level”, “multi-Sector” and “collaborative” represent the involvement of different employees and external stakeholders in designing operations, as well as the potential for management staff to initiate cross-company cooperation. These codes were applied when farmers discussed current, past and future business activities, as well as the different information sources, events, and stakeholders they rely on. The coding's in this section highlight the distribution of knowledge throughout a farmer's overall network. While the fourth type of experience was about describing individual-bound competencies, these codes illustrate how farmers draw upon and rely on the experience of third parties to engage with new digital technologies.

Observing the reliance on the experience of others for decision making is challenging, yet it appears to be a pervasive theme in the data. This encompasses knowledge of the expertise level of actors within a farmer's network. Additionally, farmers vary in their openness to specific technologies, depending on the local availability of professionals or experienced colleagues. Consequently, the intersection between farmers and their sources of consultation leads to *type (5) of experience: Agricultural (knowledge) networks*.

Past experiences of collaboration with agricultural trading companies, consultants or similar stakeholders play a crucial role in influencing the decisions of the farmers regarding the acquisition or implementation of new digital technologies.

When relationships of trust, built upon past positive experiences, are in place, some actors are inclined to continue these interactions. However, in the data analyzed, their AM and AB are not distinctly clear. On the other hand, when past experiences were negative, there is a negative impact on both AM and AB. Following Knierim et al. (2018) and Morris et al. (2017), it can be assumed that the absence of trustworthy relationships with advisory stakeholders negatively impacts AM and AB (see also Eastwood et al., 2019, Ayre et al., 2019).

Conclusion

Five types of experience have been identified as highly relevant to the digital transformation in agriculture because it has been demonstrated that these types of experience are closely related to farmers' AM and AB. A profound technical know-how and tech competence (type 1), reflections on strategic investment (type 2), farm-specific knowledge and capabilities for technology integration (type 3), on-farm knowledge distribution (type 4) and agricultural (knowledge) networks (type 5) show the variety of different modes of experience. These findings contribute to the existing literature by establishing the crucial link between the intention to adopt a new digital technology and its actual adoption by introducing the concept of adaptation motivation and adaptation belief. By providing a comprehensive picture on experience, this study sheds light on the paradox of farmers expressing interest in new technologies but often choosing to not adopt them. Consistent with findings from other domains (Giua, 2022; Leonardi, 2011; Selwyn, 2004) this study emphasizes the importance of creating meaningful experiences with technologies to strengthen farmers' AM and AB. While this was demonstrated in an exploratory manner in this study, future research should consider to empirically examine and refine these plausible connections.

This work has several limitations, partly attributable to its exploratory nature. Firstly, the concept of participating "successfully" in the agricultural digital transformation is not systematically defined or measured, and there is no comparison with farmers' own narratives of success, which could influence their AM and AB. Additionally, validating and measuring the outlined experiences needs further exploration due to farm-specific conditions and the diversity of established technologies. While this study has a regional focus and investigates two specific branches, *viti-* and *pomiculture*, also focusing on specific technologies might have enhanced the analysis.

Thus, future research should focus on specific technologies and their required on-site preconditions. Specifically, there is a lack of analytical tools and empirical studies addressing the context of technology matching in the agricultural sector, highlighting this as an important field of research. Beyond validating the five types, further studies must clarify the regional and sectoral transferability. The experience-oriented perspective of this study complements the debate about drivers and barriers for a technological transformation by highlighting the relevance of the subjective—the farmers and their experiences—as key factors to the transformation process. Therefore, future research should emphasize these experiences instead of primarily reflecting on economic conditions of farming businesses.

Practitioners, policy makers and industry representatives can glean from this study the importance of moderating farmers' experiences with new digital technologies before, during and after the implementation. The value of this experience-oriented perspective lies in the connection of experiences and the AM and AB due to their associated potential for a digital transformation. Differentiating dimensions of experience stimulates other reflections from a more theoretical perspective than, for example, thinking about drivers and barriers of the digital transformation. Experiences are subliminal and effective in the long term. Therefore, the paper highlights a nuanced understanding of experiences. This not only makes an analysis of the variations possible, but it also provides starting points for practitioners. They read as follows:

- From Type 1 it can be deduced that a segmentation according to tech competence seems sensible, following the motto: freedom and risk support for 1st movers—support

and step by step advice for late adopters. Differentiating offers or support instruments according to the farmer's own perception of competence level might have a positive impact on AM and AB dynamics. Conversely, this could offer farmers the security to engage in either a simpler or more complex offer or support.

- From Type 2 it can be derived that investment experiences are very influential in change processes, more precisely—that both positive and negative investments seem to have a long-term effect. If practitioners can sensitize both sides more strongly, it may be possible to moderate the effects of negative spirals or positive snowball effects more strongly.
- Type 3 highlights the gap between technology and farm specifics. Matching instruments exist, but apparently, they don't seem to play a role in everyday business. If farmers could match their experiences with a technology offer, experience values would be represented and investment decisions made easier. However, it might be necessary for such matching instruments to be offered independently of manufacturers.
- Type 4 teaches us that the business internal circulation of knowledge is very likely to increase AM and AB. Accordingly, encouraged time resources for farms in the form of specific training formats promise a positive effect on transformation processes in general.
- Type 5 touches on the importance of knowledge networks, whose possible positive effects have already been widely described. As farmers often build trust in technologies through the word-of-mouth within their networks, managing expectations realistically is crucial to protect farmers from poor investments. Specifically, this could mean financing long-term funded, independent, trustworthy, and highly competent consulting offices for individual advice, as farmers seem to be very open to such trustworthy sources. To the best of our knowledge, such dedicated independent technology consultations do not exist in the described region and beyond.

In general, practitioners should facilitate open discussions and share information about the possibilities of integrating new digital technologies into farm systems. From this study, it can be resumed that it is not only very important to empower farmers to experience the effectiveness and meaningful integration of new digital technologies through demonstrations and on-site testing but that there is also a need to address and manage prior bad or good experiences with new digital technologies to stimulate the discussion on the agricultural digital transformation. As explained in the methods section the implications of this study must be limited to permanent crop cultivation in Germany. However, we see great potential for transfer and generalization, not least because the identified varieties of experience are primarily of a general theoretical nature. Additionally, we trust that scholars will find in these results meaningful starting points for testing and elaborating varieties of experience within other regional and agricultural contexts.

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Data availability The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research supporting data is not available. However, anonymised components of the data may be available from the authors upon reasonable request.

Declarations

Competing interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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