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From the attitude towards digitalisation in agriculture to the acceptance of future agricultural technologies

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ABSTRACT

As agriculture undergoes a transformative phase propelled by technological innovations, the integration of digital farming tools is becoming increasingly prevalent in animal husbandry and arable farming. In animal husbandry, virtual fences, as a precision livestock farming technology, have emerged as a promising solution for managing livestock. Similarly, the rapid evolution of technology in arable farming continues to redefine the landscape of agricultural practices, with autonomous systems such as fully autonomous hacking robots playing a pivotal role. However, a limited understanding of the social and psychological factors and perceptions of risks and benefits influence farmers' acceptance of these novel digital farming technologies in Switzerland. This study aimed to provide insights into farmers' attitudes towards digital agriculture and to help understand the acceptance of digital farming technologies in the future. It sought to explore the drivers of and barriers to the acceptance of digital farming tools among family farm managers. A survey was conducted among 939 Swiss arable and animal farmers, and multiple linear regression models were used to determine robust predictors of attitude and acceptance of virtual fence technology and fully autonomous hacking robots. The results indicate that attitudes towards digital farming technologies depend on farmers' characteristics, such as age, technology interaction affinity, education level, and digital competence, alongside their financial situation. Acceptance of virtual fences was influenced by farm characteristics (size, workforce), farmers' perceptions (attitudes towards digital farming), digital competence, and risk–benefit perceptions. In contrast, the acceptance of fully autonomous hacking robots was influenced by farmers' perceptions, education level, and risk–benefit perceptions. The results emphasise that the acceptance of specific technologies is driven by application-specific reasons and depends on risk–benefit assessments. The findings shed light on decision-making in digital agriculture for small-scale farms, highlighting the need for digital skill development and support for farmers in risk–benefit assessment. Recommendations include peer networks and research settings, such as model farms, to support farmers in adopting digital farming technologies.

1. Introduction

The starting point of the rapid worldwide development of digitalisation in agriculture is mainly intelligent robot, sensor, and satellite technologies in combination with modern application software in smartphones, tablets, and apps [1,2-4]). While placing emphasis on the general digitalisation in society [5] "digitisation in agriculture" has become a promising megatrend (DBV, 2016, p. 1; [6]; Schweizer [7]). As agriculture undergoes this transformative phase, propelled by technological innovations, the integration of digital farming tools is becoming increasingly prevalent in animal husbandry and arable farming.

In animal husbandry, virtual fences as precision livestock farming technologies have emerged as a promising solution for managing livestock and delineating grazing areas without the need for physical barriers [8]. In the Swiss agricultural landscape, where sustainable and efficient farming practices are paramount, understanding the factors influencing farmers' acceptance of virtual fences is crucial for successful adoption and implementation. Groher, Heitkämper and Umstätter [9] analysed the degree of digital technologies used in the agricultural practice of Swiss life stock farms. Virtual fences are not yet used and permitted in Switzerland [10]; however, often powered by advanced technologies such as GPS and sensors, they offer a dynamic and flexible

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alternative to traditional fencing methods.

In arable farming, the rapid evolution of technology (precision farming) continues to redefine the landscape of agricultural practices, with autonomous systems increasingly playing a pivotal role in enhancing efficiency, precision, and sustainability. In this era of innovation, the emergence of fully autonomous hacking robots is at the forefront and represents a paradigm shift in the way Swiss farmers work [11].

The acceptance of these novel technologies, however, is a complex process influenced by a multitude of factors rooted in technological, social, economic, and environmental dimensions (see references in detail in the following chapters). This paper aims to shed light on the key determinants shaping the acceptance of Swiss farmers towards the adoption of the cutting-edge technologies of virtual fences in animal husbandry and of fully autonomous hacking robots in arable farming, shedding light on the intricate interplay of factors that either facilitate or hinder their integration into contemporary agricultural practices by Swiss farmers. These technologies confront farmers with complex decisions [12]. The decision process—how and why farmers decide on these digital farm technologies—is influenced by many interacting factors [13] and is extremely complex and dynamic. Knowledge about the factors that influence farmer decisions is important [14-17], especially in understanding how farmers adapt to changes in the development of new farm technologies. In this paper, we shed light on the acceptance of future technologies for fully autonomous hacking robots and virtual fences. Virtual fencing systems are now widespread in places where grazing plays a major role, for example, in Norway, the UK, and Australia. In Switzerland, collars are still prohibited under the Animal Protection Act [18].

There is some broad and general literature on the acceptance of digital agricultural technologies. For example, Pierpaoli et al. [19] review identified three classes of drivers that affect the intention to adopt precision agriculture: competitive and contingent factors, socio-demographic factors, and financial resources. Other studies have examined individual technologies with largely diverging characteristics, with a few considering farmers' characteristics (social and psychological influencing factors). Tey and Brindal [20] pointed out the necessity of understanding the acceptance of new technologies. The following is a literature review of the factors mentioned in relation to the use of digital technologies.

1.1. Farmers' characteristics

The influence of prior digital knowledge as a predictor of acceptance of digital farm technologies has been rarely analysed [21,19,22], although it was shown to influence the acceptance of different technologies according to adoption studies outside of agriculture [23,24]. Building on these results, we assume that the existence of digital competences is essential to accepting new digital technologies on farms. The affinity for technology interaction (ATI, [25]) is connected to digital competences. Pierpaoli et al. [19] referred to the importance of individual computer confidence. The influence of technology affinity on the acceptance of digital farming technologies has yet to be analysed. Based on the connection between digital skills and the concept of affinity for technology interaction, we assume an influence on acceptance.

1.2. Farmers' perceptions

The attitude of farmers towards digital farming technologies has been suggested as an important factor that influences general decision making on information technologies ([1,4,13,46,51,52,57]; Odintsov [26,27,19]). We refer to the original meaning of attitude [28] — that is, the positive or negative evaluation of an object. Farmers' attitudes regarding digital farming technologies play a role not only in their own acceptance of the technologies but also in that of their family members [21]. Based on these findings, we assume that farmers with a positive attitude towards digital farming technologies are more likely to accept them.

The influence of the perception of risks and benefits on technology acceptance in agriculture has rarely been examined. Some studies have explored the risks and benefits with qualitative methods for the use of virtual fences in New Zealand and Australia [29,30], where, in contrast to Switzerland, these fences are already in use. Brier et al. [29] analysed benefits and barriers associated with the use of virtual fencing technology in pasture-grazed cattle systems. In their article on fully autonomous robots in arable farming, Sparrow and Howard [31] and Tamirat et al. [32] discussed the potential risks and benefits of autonomous hacking robots. Regan [33] explored farmers' perceived risks and benefits arising from the development of smart farming in Ireland. Although previous studies on the influence of the potential risks and benefits on the decision of farmers to accept virtual fences and fully autonomous robots are scant [34], we hypothesise that both high-benefit expectations and low-risk expectations will increase their acceptance by Swiss farmers.

1.3. Farm characteristics

Alvarez and Nuthall [21] pointed to the influence of farm characteristics on the acceptance of digital agricultural technologies. The size of the farm proved to be relevant for the adoption of new technologies [35,21,36,37,9,34,19,38]. Lowenberg-DeBoer and Erickson [39] showed a dependence on the rate of adoption, which has been slow on medium and small farms because very few precision agriculture technologies are cost-effective on these non-mechanised farms. Beyond the size of the farm area, other studies have shown a correlation between the digitisation rate and the number of animals (e.g. Gargiulo et al. [40]. However, the results are inconsistent. We expect an influence of farm size on the acceptance of digital farming technologies in small-scale Swiss agriculture.

Workload has also been shown to be critical for digital farming technology acceptance, as time is needed in the decision process to learn, understand, and adapt to new technologies [21]. The expected impact of technology on the workload of the company and its influence on the decision to use it have also been investigated [41]. We therefore assume that farmers with high workloads are less likely to accept these new technologies, because there is no time to familiarize oneself with new things.

Further, the workforce seems to influence the acceptance of new technologies on farms. Alvarez and Nuthall [21] and Heitkämper et al. [42] showed that the availability of family members (partner, son, or daughter) with the required operational skills and a positive attitude towards computerised systems influences the acceptance of the new technology on the farm. We expect a higher workforce to influence the acceptance of new digital farming technologies because this creates additional time and opportunities for acquiring further skills.

The financial situation of the farm has been repeatedly proposed as an important factor contributing to the acceptance of digital farming technologies [43,37,44,19]. Therefore, we expect a better financial situation to influence the acceptance of new technologies.

1.4. Sociodemographics

Age is another important factor contributing to the adoption of digital technologies [45,21,23,9,44,34,19,20,38]. However, available studies show mixed results, with age seemingly relevant, as the older generation has little experience with digital technologies. Thus, we assume that younger farmers are more likely to accept new technologies compared to older ones.

Higher education has also been shown to influence the acceptance of digital technologies in agriculture [35,21,46,47,12,48,44,34,19,49]. Alvarez and Nuthall [21] emphasised the potential of formal education in reducing the knowledge gap among farmers and enabling them to adopt new digital farming technologies. Based on this literature, we expect that farmers with higher education will be more likely to accept new digital farming technologies.

The aim of this study is to provide insights into the understanding of the technology acceptance of digital farming technologies, which have a complex and systemic character, and to explore drivers and barriers for the acceptance of digital farming tools among Swiss family farmers. Nuthall and Old [50] stated that on family farms, the farm manager mainly makes decisions, a key difference compared to more industrialised businesses. Swiss agriculture is dominated by family farms [51]. For this reason, Switzerland is a suitable field for studying the impact of farmers' internal factors on the decision-making process in family farming systems. The objectives of this study are to understand and explore the rarely analysed social and psychological factors that are assumed to have a higher impact on digital farming technology acceptance than structural variables.

The present study is guided by two main research questions: (1) What factors influence farmers' attitudes towards digital agriculture? and (2) What factors (attitude towards digital agriculture, risk and benefit perception, or other factors such as farm and farmers' characteristics) explain the acceptance of future digital technologies in farming?

2. Materials and methods

2.1. Swiss context

In Switzerland, agricultural production is defined by small-scale family farms (98 % of farms are family farms (Federal Office for Agriculture [52], 2021) with an average size of 21 hectares. Due to topographical conditions, only 30 % of the agricultural area is suitable for growing crops for direct human consumption (fruit, vegetables, arable crops) [53]. Half of the remaining 70 % of the agricultural area consists of meadows and pastures, and the other half consists of alpine areas (Thomas [54]). In 2022, these areas were covered by 48,344 farms, with an average of 22 hectares [53,55]. Since 1998, Swiss farmers have been required to fulfil cross-compliance requirements (proof of ecological performance) that guarantee minimum environmental and animal welfare standards to receive direct payments [56]. One of these programs is called "RAUS" (English: OUT), which stands for "regular outdoor exercise" and refers to a voluntary federal programme. It is intended to improve the well-being of farm animals through regular outdoor exercise. Dairy cows must receive 26 days of outdoor grazing per month from 1 May to 31 October and 13 days of outdoor grazing per month from 1 November to 30 April [57]. According to Thomas Jäggi [54], 84 % of ruminants live according to RAUS regulations.

Concerning the situation of the labour force, Swiss farms have few to no non-family employees [58]. In this business structure, the farm manager, who usually owns the business, is fully responsible for independent management decisions, thereby making the farmer fully responsible for his or her actions. Hence, Swiss farmers usually have no staff to maintain technical or IT infrastructure or legal obligations in this domain. This situation raises the question of whether digital agriculture is interesting only for large farms or could be valuable for farms of all sizes [59]. There is also the question of whether small family farms in Switzerland perceive the acceptance, usage, risks, and benefits of digitalisation in agriculture differently than in countries with more industrialised agricultural structures. The Swiss Confederation is promoting the adoption of digital technologies in the agricultural industry, encouraging farmers to shift towards a digital workspace (Federal Office for Agriculture (FOAG), 2023). In fact, Switzerland has raised multiple initiatives, such as the 'Charta Digitalisation' [60] and 'Swiss open data' [61], which are freely accessible platforms that publicly offer Swiss federal data to promote the digital development of the Swiss agricultural sector.

2.2. Sample

The study was registered with the Ethics Commission of ETH Zurich, Switzerland, EK 2021-N-17. The Swiss Federal Office for Agriculture (FOAG) selected a random sample of 3000 farms. It maintains a database of all farm households that receive direct payments (98 % of all Swiss farms). The written survey was conducted in April and May 2021. We invited all farmers to participate in an online survey. Two weeks later, we sent the (paper-and-pencil) questionnaire by mail to non-respondents. This approach has been proven to generate high response rates [51]. Kongsved et al. [62] furthermore recommended this procedure to avoid selection bias. For the online survey, the www.unipark.com tool was used. For the two-step procedure, a personal coding of the questionnaires was necessary, and the data were anonymised. The respondents needed 50 min on average to complete the questionnaire. During the study, the farm managers had to fill in a questionnaire with closed questions. Appendix Table A1 provides an overview of how the study variables are distributed according to the various farm types.. The questionnaire was also translated into French by Agroscope's translation service. The questionnaire contained different parts: (a) questions on the use of digital technologies, (b) questions about farm and household variables, (c) general questions about the person, (d) questions on the assessment of benefits and risks of new digital technologies, (e) questions on data handling, and (f) questions on social influencing factors. The survey was conducted in two of the three language regions of Switzerland (German and French). The questionnaire was translated by a professional translation service and pre-tested by eight farmers. The paper-and-pencil questionnaires were entered by hand and merged with the online dataset. The dataset was checked manually for plausibility.

The response rate was 31.3 % (939 utilisable questionnaires) from 12 farm types according to the farm typology ZA2015 of the Central Evaluation of Accounting Data [63]. Table A1 in the appendix presents the demographic and farm information of all participants. As our study focuses on the decisions of the farm manager, and the Swiss share of female farm managers is 6 % (Federal Office for Agriculture [52], 2021), we were not able to examine gender as an influencing variable on the acceptance of new digital agriculture in this study for missing variance.

The term digital technologies was defined as follows: "The term 'digital technologies' includes hardware, software, mobile apps, sensor technologies and big data applications, for example, the use of information communication technologies for operational decision-making/management, electronic measuring systems, and the use of robots and the automation of work processes. Exception: Data collection in the TVD ("Tierverkehrsdatenbank"; Eng.: animal transport database) and cantonal systems for direct payments are not to be taken into account here. Digital technologies that they use via contractors are not part of this survey".

To test the acceptance and future use of digital technologies on family farms, we chose two technologies that are currently being developed but not yet ready for use in agriculture, yet concrete enough for farmers to imagine, as we assess their risks and benefits for their own farms. If the farmers had livestock, they were to fill in the questions for virtual fences; if they had crops, they were to fill in the questions for the fully autonomous chopping robot. If they had both, they were expected to provide answers for both technologies.

The following description was provided for virtual fences for pasture management: "Using an app, the pasture areas are marked out by the farmers with virtual fences; the animals wear a collar that emits warning stimuli when they leave the area. There are no more physical fences. The animal is trained beforehand to have no more visual boundaries, only a sensory one. For the fully autonomously functioning chopping robots for weed eradication, we provided the following description: "Fully autonomously functioning chopping robots such as the 'Bonirob' drive slowly autonomously over the field and can distinguish crops from weeds. If it detects a weed plant, it is pressed into the ground or chopped with pinpoint accuracy. Chopping robots that spray with pinpoint accuracy are not meant here. When the weed robot has worked through its terrain, only young maize, rye, or beet seedlings are found on it. All weeds that could hinder their growth have disappeared in the depths without the need for the application of plant protection products".

A total of 423 farmers (45.6 %) answered the questions about hacking robots and virtual fences, 67 (7.2 %) answered none of these questions and were therefore excluded from the analysis, and 529 (57.1 %) answered questions about hacking robots and 754 (81.3 %) about virtual fences. Thus, compared to hacking robots, virtual fences were more suitable for a larger group of responding farmers.

2.3. Measures

2.3.1. Farmers' characteristics

The following three items were used to measure the participants' digital competences (adapted from the competence requirements of the survey of the IW Staff Panel, (adapted from the competence requirements of today survey of IW Staff Panel, Andrea [64]): "How do you rate their competences in the following areas?": (1) "Competences to use software". (2) "IT expertise (e.g. programming skills)". (3) "Knowledge of digital technologies in agriculture". They used a scale ranging from 1 (none) to 5 (very good). The scale's Cronbach's α was 0.84 (mean (M) = 2.56, standard deviation (SD) = 0.82). The scale's Cronbach's α of 0.84 indicates a high level of internal consistency in measuring the participants' digital competences. In general, Cronbach's alpha is a statistical measure used to assess the reliability or internal consistency of a set of items or scale components that are intended to measure the same underlying construct [65]

A value of 0.84 suggests that the items on the scale are highly correlated and consistently measure the same concept—digital competence in this case. Values of $\alpha \geq 0.70$ are generally considered acceptable, while values above 0.80 indicate good reliability [66].

Thus, across all domains of the instrument, this coefficient implies that the participants' responses are stable and coherent, providing confidence that the results accurately reflect variations in digital competences rather than random error or inconsistency in the measurement tool.

The "affinity for technology interaction" nine-item scale (ATI)" was developed by Franke et al. [25] to measure human and technology interactions. The following items from the study by Franke et al. [25] were used to measure the construct: (1) "I like to occupy myself in greater detail with technical systems". (2) "I like testing the functions of new technical systems". (3) "I predominantly deal with technical systems because I have to". (4) "When I have a new technical system in front of me, I try it out intensively". (5) "I enjoy spending time becoming acquainted with a new technical system". (6) "It is enough for me that a technical system works; I don't care how or why". (7) "I try to understand how a technical system exactly works". (8) "It is enough for me to know the basic functions of a technical system". (9) "I try to make full use of the capabilities of a technical system". The participants indicated their agreement with the statements using a scale ranging from 1 (not agree at all) to 5 (completely agree). The answers to the three negatively formulated items (items 3, 6, and 8) were inverted. The scale's Cronbach's α was 0.72 (M = 2.88, SD = 0.72). The variable is called "technology interaction" in what follows.

2.3.2. Farmers' perceptions

The participants were asked various questions regarding their perceptions and attitudes. Moreover, the participants had to answer, "How do you view the phenomenon of digitalisation in agriculture?" They indicated their attitudes using a scale ranging from 1 (not agree at all) to 5 (fully agree) (M = 3.32, SD = 0.95). The items measuring farmers' perceptions of the risks and benefits of autonomous hacking robots and virtual fences were adapted from the literature [29] and experts. The participants indicated their agreement with the statements using a scale ranging from 1 (not agree at all) to 5 (completely agree). The mean of the scale was calculated.

The following items were used to measure the participants' risk perception of virtual fences: (1) "Virtual fences are not reliable enough to be implemented effectively" (2) "The value of virtual fencing (e.g. in terms of profitability or labour savings) is not clear enough for farmers to engage with the idea of changing their current practices". (3) "Virtual fences are perceived by consumers and the public as cruel to animals because shocks are administered from a collar". (4) "The cost–benefit ratio of virtual fences is not sufficient for many farmers". (5) "Virtual fences need excessive training time". The scale's Cronbach's α was 0.83 (M = 3.53, SD = 0.71).

The following items were used to measure the participants' benefits perception of virtual fences: (1) "Virtual fences improve the protection of environmentally sensitive areas, including riparian margins and erosion-prone soils". (2) "Virtual fences promote more efficient forage allocation and promote the best balance between pasture productions, pasture quality, and pasture use". (3) "Virtual fencing enables grazing in areas that are not currently grazed as it requires a capital investment in fencing, such as forest blocks". (4) "Virtual fencing saves labour". (5) "Virtual fencing allows animals to be gathered in a herd and managed individually". The scale's Cronbach's α was 0.88 (M = 2.99, SD = 0.85).

The following items were used to measure the participants' risk perception of autonomous hacking robots: (1) "Fully autonomous hoeing robots are not reliable enough to be implemented effectively". (2) "The value of fully autonomous chopping robots (e.g. in terms of profitability or labour savings) is not clear enough for farmers to engage with the idea of changing their current practices". (3) "Consumers perceive fully autonomous chopping robots as unsafe because they travel autonomously”. (4) “The cost–benefit ratio of autonomous chopping robots is not sufficient for many farmers”. (5) “Fully autonomous chopping robots need too long a training period”. The scale’s Cronbach’s α was 0.76 ($M = 2.97$, $SD = 0.70$).

The following items were used to measure the participants’ benefits perception of autonomous hacking robots: (1) “Fully autonomous chipping robots protect the soil against compaction”. (2) “Fully autonomous chipping robots contribute to keeping groundwater and water bodies clean by avoiding/ reducing the use of herbicides”. (3) “Fully autonomous chipping robots save on labour”. (4) “Fully autonomous chopping robots fertilise the soil with the plant material left on the field”. (5) “Fully autonomous robot hoes allow for more accurate weeding”. The scale’s Cronbach’s α was 0.82 ($M = 4.05$, $SD = 0.56$).

2.3.3. Acceptance

The acceptance of future farming technologies was measured for virtual fences and autonomous hacking robots. The participants indicated their agreement with the statements using a scale ranging from 1 (no) to 5 (yes). The mean was calculated. We used a five-point scale to describe acceptance of future technologies, which is more accurate than a binary scale and in line with the recommendations of recent adoption research [67-69].

The following items were used to measure participants’ acceptance of virtual fences: (1) “I would use virtual fences in principle”. (2) “I accept virtual fences in principle”. The scale’s Cronbach’s α was 0.88 ($M = 2.61$, $SD = 1.24$).

The following items were used to measure the participants’ acceptance of autonomous hacking robots: (1) “I would use a fully autonomous hacking robot in principle”. (2) “I accept fully autonomous hacking in principle”. The scale’s Cronbach’s α was 0.89 ($M = 3.62$, $SD = 1.25$).

2.3.4. Farm characteristics

The participating farmers were asked various questions regarding the structure of their farms. Some farm variables were not surveyed but were linked from the dataset of the Federal Office for Agriculture (such as the size of the farm and workforce) to shorten the questionnaire for the farmers. The participants were asked, “How do you assess your overall financial situation?” The participants indicated their financial situation using a scale ranging from 1 (poor) to 5 (very good) ($M = 3.46$, $SD = 0.81$). The following variables were not normally distributed according to the Kolmogorov–Smirnov test ($p < 0.05$), they were presented as medians with interquartile ranges (IQRs). The farm size ranged from 1.96 to 134.23 ha (*median* = 22.82, *IQR* = 15.08–34.65). The farms had between 0.20 and 32.80 standard labour force (*median* = 1.61, *IQR* = 0.97–2.46). The participants were also asked, “What is your overall workload?” They indicated their workload using a scale ranging from 1 (much too little) to 5 (far too much) ($M = 3.66$, $SD = 0.65$).

2.3.5. Sociodemographics

The participants were askd various questions regarding their sociodemographic information, such as age and education. The farm managers’ ages were between 18 and 66 years ($M = 49$, $SD = 10$). The participants had to answer a question about their educational status. We reduced these categories to two groups: having a higher education in agriculture (master craftsman’s examination, technician, engineer FH, or ETH) was coded as 1 and otherwise 0.

2.4. Data analysis

The data collected through the online and written questionnaires were analysed using SPSS statistical software version 26.0.0.1 (IBM, Chicago, IL). The data were first screened for the accuracy of data entry and missing values and were found to be free of any multivariate outliers. Descriptive statistics, crosstabs, and bar charts were generated, as well as means and standard deviations. Next, parametric and non-parametric correlations were estimated. The effect size was analysed for statistically significant results following Cohen (1992). Bivariate and multivariate associations were examined with a series of multiple linear regression models to determine robust attitude and acceptance/usage of technology predictors. We applied a robust estimator (maximum likelihood estimation) to reduce the effects of outliers and influential observations. In this study, the robustness of our model was thoroughly assessed to ensure the reliability of our findings. We conducted tests to assess the normal distribution of the residuals. Following this assessment, any instances of high leverage and influential points were identified and excluded from our analysis using Cook’s distance. Upon recalculating the regressions without these influential points, our results remained unchanged, affirming the stability and robustness of our models against potential outliers or deviations from normality. This underscores the validity and consistency of our regression analysis, reinforcing the confidence in our conclusions. The results for continuous predictors are reported with standardised regression coefficients (r) and 95 % confidence intervals. Cronbach’s alpha was calculated to indicate the reliability of the scales.

Table 1
Frequency of attitude towards digital technologies in farming: “How do you view the phenomenon of digitalisation in agriculture?”.

	Frequency	Percentage
Rejecting	40	4.3
Rather rejecting	105	11.2
Neutral	400	42.6
Rather facing	291	31
Facing	96	10.2
Missing	7	0.7
Total	939	100

Table 2
Frequency and percentage of farmers’ general acceptance and perceived potential usage of autonomously functioning chopping robots for weed eradication and virtual fence for pasture management.

	General acceptance		Potential usage	
Frequency (%)	Hacking robots	Virtual fences	Hacking robots	Virtual fences
No	50 (9.5 %)	161 (21.4 %)	71 (13.4 %)	241 (32 %)
Rather no	38 (7.2 %)	169 (22.4 %)	55 (10.4 %)	160 (21.2 %)
Perhaps	95 (18 %)	178 (23.6 %)	101 (19.1 %)	180 (23.9 %)
Rather yes	152 (28.7 %)	151 (20 %)	142 (26.8 %)	91 (12.1 %)
Yes	188 (35.5 %)	86 (11.4 %)	156 (29.5 %)	75 (9.9 %)
Missing	6 (1.1 %)	5 (0.7 %)	5 (0.8 %)	7 (0.9 %)
Total	529 (100 %)	754 (100 %)	529 (100 %)	754 (100 %)

Table 3
Results of a multiple regression analysis of farmers’ attitude towards digital technologies as dependent variable and various variables as independent variables.

Independent variables	*B*	SE B	*β*	*p value*
(Constant)	1.08	0.28		0.001
Finance	**0.11****	0.04	0.09	0.002
Size	0.00	0.00	0.02	0.664
Workforce	0.04	0.36	0.05	0.289
Workload	−0.00	0.04	0.00	0.956
Age	**−0.01***	0.00	−0.06	0.048
Technology Interaction	**.46****	0.05	0.35	0.000
Higher Education	**0.13***	0.06	0.06	0.043
Digital Competences	**0.24****	0.05	0.20	0.000

Note: $R^2 = 0.33$ $N = 802$.

3. Results

3.1. Attitudes towards digital agriculture in general

We were interested in how the participants perceived the phenomenon of digital agriculture. As shown in Table 1, a small part of the sample rejected digital technologies in agriculture. About 40 % were in favour of these technologies.

3.2. Acceptance of future digital farming technologies

Regarding whether and to what extent the participants would accept and use future agricultural technologies, the response was inverse for the two technologies surveyed. A larger proportion accepted hacking robots than virtual fences (Table 2).

3.3. Regression analysis attitude towards digital agriculture in general

We used linear regression to assess the influence of farmer-related personal characteristics and farm characteristics on attitudes toward digital agriculture. The farmers' attitude towards digital technologies in agriculture showed a tendency towards the latter. The model for attitude was significant ($F = 37.88$, $df = 11$, $p < 0.001$) and explained 33 % of the variance (Table 3). The attitude of farmers towards digital technologies in agriculture in general was influenced by the financial situation, but the other tested farm characteristics—size, work force, and workload—were not significant predictors. The participants who were older showed significant refusal towards digital agriculture. The participants with a high level of the personality trait "extraversion" had a more positive attitude towards digital agriculture than those with a low level. Affinity for technology interaction was positively associated with a positive attitude towards digital agriculture. The participants who had higher education perceived digital agriculture as more positive than those without. Lastly, the assessment of digital literacy also had a significant positive impact on attitudes towards new farm technologies.

The correlations between constructs see Appendix Table A2

3.4. Regression analysis acceptance of hacking robots and virtual fences

Two new digital farm technologies that are not yet on the market in Switzerland but are conceivable, were presented: fully autonomous hacking robots for crop production and virtual fences for animal husbandry. Linear regression analyses were used to examine the predictors associated with Swiss farmers' acceptance of these technologies. The model for the acceptance of virtual fences was significant ($F = 45.47$, $df = 13$, $p < 0.001$) and explained 50 % of the variance (Table 4). Farmers with larger farm sizes were less likely to accept and use virtual fences. However, a higher number of available workers increased the likelihood of acceptance. The participants' attitudes towards digitalisation in agriculture was a significant predictor of the acceptance and use of virtual fences. High digital competencies had a significant positive association with the acceptance of this innovation. The participants with a higher risk perception showed less acceptance of virtual fences compared with those who had a lower risk perception. The opposite was the case with benefits perception, as the participants with a higher benefits perception showed higher acceptance of the fence. In other words, participants who perceived more benefits than risks for virtual fences were likely to accept this new technology.

The same set of predictors was used to explain the acceptance of autonomous hacking robots. The model was significant ($F = 17.94$, $df = 13$, $p < 0.001$) and explained 36 % of the variance (Table 4). The predictors of attitude towards digitalisation in agriculture—risk and benefits perception—had similar features as those of the acceptance of virtual fences. Furthermore, participants with higher education were more likely to accept autonomous hacking robots than participants without this education. Farm characteristics had no significant influence on the acceptance of this new technology.

The correlations between constructs, see Appendix Table A3

4. Discussion

The digitalisation of agriculture is not only described as a megatrend in the agricultural policy environment [6] but also by the Swiss Farmers' Union (Schweizer [7]). In the context of digitalisation in agriculture, there is rapid development towards ever-new technologies. Some of these have already reached market maturity and can generate benefits in agriculture, whether in terms of saving time and labour or reducing the environmental impact of agricultural practices. Further, there are many ongoing developments, as more and more far-reaching technologies are being developed, with public discourse being conducted accordingly. However, little is known about the underlying mechanism of farmers' attitudes towards digitalisation in agriculture, especially in small-scale farming structures. Moreover, the influence of farm managers' attitudes on the decision to adopt a future technology on the farm has rarely been studied.

The added value of this study lies in a sound and systemic understanding of Swiss farmers' decisions regarding digital technologies. Various studies have considered individual technologies [21,41] or surveyed technology-unspecific reasons for adopting digital technologies [70,37]. By contrast, our results present a comprehensive catalogue of influencing variables from various areas (including farm structure, farm manager characteristics, benefits, and risk perception). We tested these factors for two specific technologies in the area of animal and plant husbandry. The results of our study contribute to a better understanding of the factors that influence farmers' attitudes towards digitalisation in agriculture and the acceptance of future agricultural technologies.

Table 4
Results of a multiple regression analysis acceptance of hacking robots and virtual fence as dependent variable, and various variables as independent variables.

Independent variables	Virtual fence				Hacking robots			
	B	SE B	*β*	*p value*	*B*	SE B	*β*	*p value*
(Constant)	**0.93***	0.46		0.044	−0.16	0.68		0.816
Finance	−0.05	0.05	−0.03	0.340	0.08	0.07	0.05	0.219
Size	**- 0.18****	0.00	−0.25	0.000	−0.00	0.00	0.04	0.472
Workforce	**0.25****	0.05	0.23	0.000	0.08	0.06	0.08	0.208
Workload	0.03	0.06	0.01	0.653	0.14	0.08	0.07	0.070
Age	−0.00	0.00	−0.03	0.311	−0.00	0.01	−0.01	0.888
Attitude	**.21****	0.05	0.16	0.000	**0.24****	0.06	0.18	0.000
Technology Interaction	−0.07	0.07	−0.04	0.289	0.16	0.10	0.09	0.097
Higher Education	0.14	0.08	0.05	0.091	**.40****	0.11	0.15	0.000
Digital competence	**0.15***	0.06	0.10	0.015	0.05	0.08	0.03	0.530
Risks	**−0.31****	0.06	−0.17	0.000	**−0.35****	0.08	−0.20	0.000
Benefits	**0.71****	0.05	0.48	0.000	**.61****	0.09	0.27	0.000

$R^2 = 0.50$ $N = 608$, $R^2 = 0.36$ $N = 431$.

First, our results show that the attitude of farm managers towards the phenomenon of digitalisation in agriculture is affected by the farm's financial situation, age, their affinity to interact with technology, higher education, and digital competences. We briefly discuss the attitude of farmers towards the phenomena of digitalisation in agriculture, that is, the mindset of the farmers, before presenting a more detailed discussion of the acceptance of new technologies by Swiss farm managers, a farm decision beyond the mindset.

Attitude has been suggested to be an important factor influencing the acceptance of information technologies [71]. Davis [71] suggested that attitude influences the acceptance of new technologies. Our findings indicate that this is also the case for technology adoption on smallholder farms, where the farm manager makes operational decisions. Adrian et al. [72] pointed out the need to pay more attention to farmers' attitudes and perceptions when introducing new technologies. Our results narrow the research gap on what influences farmers' attitudes towards digitalisation in agriculture and, even further, the influence of this attitude on the decision to adopt new technologies. Our results show that one determinant of this attitude was the overall financial situation and thus the decision-making scope for acquisitions, which is in line with previous findings [34]. However, this could also be explained by working in off-farm work and the associated wealth of experience or the possibility of being able to finance additional support offers and training courses, which are important resources for the acquisition and adoption of new technologies [42,19]. Similar to findings from a previous study on the attitudes toward autonomous vehicles [23], we find that older age supports more disapproving attitudes. An obvious and not yet investigated influence variable is the affinity for technology interaction (ATI, [25]). It has an expected positive influence on attitudes towards digitalisation in agriculture and, similar to the following two variables, shows new qualities: the job profile that farmers need in the digital environment, which already has an influence on attitudes towards digitalisation in agriculture. Higher education also has a positive effect on acceptance. This is consistent with previous literature reporting that less educated farmers are less confident about digital technologies [72,34, 19,20]. This shows that the competences acquired during higher education compared to classical agricultural education are closer to the needs of digital agriculture and open up a wider space of experience and networks beyond digital competences. The not-very-high correlation between higher education and digital competences (0.169**) indicates useful competence gains for digitalisation in agriculture through higher education that go beyond the acquisition of digital competences. Engagement with the topic of digitalisation in agriculture also seems to be more frequent here and to shape positive attitudes through familiarity with the topic. Not surprisingly, of the various competence measurement scales (Andrea [64]), the digital competences scale alone influences acceptance of digital agriculture. As previously confirmed for the adoption decision of general technologies [24] and innovation [19, 22], we show that this digital literacy influences the attitude.

Second, our study shows that the acceptance of a specific technology is influenced by farmers' education and digital competence and their attitude towards the phenomenon of digitalisation in agriculture. Furthermore, the weighing of risks and benefits independently of the technology determines its acceptance, both in animal husbandry and crop production. We show that attitudes have a positive influence on the decision to use a new digital farming technology, both in crop production (autonomous chopping robots) and in animal husbandry (virtual fences); a positive attitude also indicates interest and makes an active movement towards a new technology more likely. Our result is in line with the findings from the literature on technology adoption [72,73,34, 19]. Attitude should therefore be taken into account when introducing digital technologies in Swiss agriculture, as is currently the case from the policy (Federal Office for Agriculture [74], 2023). The Federal Office for Agriculture (FOAG) is a governmental agency operating under the Swiss Federal Department of Economic Affairs, Education and Research. It is responsible for implementing agricultural policy and administering agricultural support programs, rather than making political decisions.

Furthermore, we find perceived benefits to influence the acceptance of digital farming technologies, in line with Pierpaoli et al. [19], Adrian et al. [72], Davis [71], and Marescotti et al. [34]. Our results show that risk and benefit perceptions have opposite effects on the acceptance of new digital farming technologies. When farmers associated high risks with the technology, they were less willing to accept it, while the perception of high benefits led to greater acceptance, with the influence of the latter being greater. This means that farmers are well aware of the potential risks of new technologies and consider them when deciding whether to use them. However, the perceived benefits of the technology carry more weight. Bronson [75] and Zscheischler et al. [76], who studied digitalisation in agriculture and its unequal adoption against the background of the responsible research on innovation framework, highlighted the necessity of the development process of new technologies in evaluating the risks of these technologies for the wider social environment. Some researchers, such as Iyer et al. [77], have measured farmer risk preferences in Europe, but they excluded research on the impact of risk on behaviour, such as technology adoption, which we addressed. The authors pointed out, however, that risk aversion is likely to be context- and circumstance-specific. Our analysis confirms that farmers' decisions to adopt new technologies are not a matter of general risk aversion, as Torrez et al. [38] indicated for the precision farming adoption of American farmers, but of weighing the concrete technology-specific risks. The issue of recommending adoption when benefits are perceived and rejecting adoption in cases of risk has thus far been largely neglected. Our results clearly show that the decision for new digital technologies is essentially about weighing the benefits and risks. Furthermore, we show that the number of risks and benefits differs regarding these technologies. The participating farmers perceived greater benefits and smaller risks for autonomous hacking robots than for virtual fences. This is because the latter technology has an impact on animals and is a major innovation, whereas fully autonomous hacking robots are more conceivable, as there are already semi-autonomous products on the market.

Although attitudes and perceptions of risks and benefits are strong predictors of the overall acceptance of new digital agricultural technologies, our study also identified factors that influence the acceptance of a specific technology. In our study, farm characteristics, number of employees, and farm size were found to be predictors of acceptance of virtual fencing. Grazing requires more time, so the standard labour force used to measure the work force indicates that these farms are more likely to graze their animals and are therefore more concerned with the risks and benefits of this very futuristic technology, which represents a major change in the way farmers work. That the size of the farm has an influence on acceptance is in line with the findings of Pierpaoli et al. [19], Adrian et al. [72] and Marescotti et al. [34], whereas Groher, Heitkämper and Umstätter [78] found no effect. The number of animals showed no significant influence in our model. The results of Gargiulo et al. [40] show a correlation between larger herds and the adoption of more precision technologies on farms for Australian dairy farms, investigating not only digital technologies for grazing but also for milking. It is also conceivable that larger farms in the case of virtual fencing, which would certainly benefit from this technology in terms of labour input, trust the technology even less.

Given that virtual fences are very futuristic, it is not surprising that having digital skills explains their acceptance. Conversely, one can also imagine that the presence of digital competences predetermines the idea of this technology and thus its acceptance. The acceptance of autonomous hacking robots is related to higher education. Digital competences seem to play less of a role because the technology is closer to what is currently used and familiar. Our findings are in line with those of Chavas and Nauges [48]. They referred to uncertainty, learning, and technology adoption in agriculture. Pierpaoli et al. [19] pointed to the influence of training in the adoption of new technologies in crop production, Annosi et al. [46] discussed managers' skills for the 4.0 technological innovations adoption process by Italian farmers, and Aubert et al. [12] found farmers' expertise to be the main predictor of Canadian farmers' precision farming adoption. According to Arendsen et al. [47], the ability to adopt, and so the competences, is more important than the benefits of adoption. The fundamental shift from purely mechanical devices in agriculture to increasingly digital ones suggests the need for specific training. Our results clearly show the great importance of digital competences, higher forms of training, and the complex balancing of the risks and benefits of new technologies. These results point to major changes in the profession of farmer. From a basic education perspective, this profession seems to develop towards a "knowledge profession". This must be taken into account by the training system to address the "growing concern that smaller farms will be left behind in digitalisation", as described by Rotz et al. [79].

The data for this study were collected from a random sample in the German- and French-speaking parts of Switzerland. To gain insight into the social and psychological reasons for adopting digital technologies across different farm types and regions, the farms were not specifically selected but were randomly drawn. This limited the analysis somewhat because too few characteristics were collected on the farms; therefore, the farm characteristics were not collected precisely enough. For example, we do not know how many days a farm grazes, nor do we know whether it sends animals to the alpine pastures during the alpine pasture period, which is not possible due to data protection. Since this is, of course, not an experiment but an empirical study, other factors may also play a role for which we cannot control here. For future research, an experimental setting is recommended, as well as a long-term study, to measure the change in the state of digitalisation more accurately and to capture the necessary competences more precisely. While our study clearly points to a change in the occupational profile of farmers, and a study in the Brazilian context has dealt with this [80], there is a clear research gap in the European area.

5. Conclusion

This article reports the attitudes of farmers towards digitalisation in agriculture in general and the acceptance and potential usage of two future digital farm technologies. We identified the most important drivers of attitude and evaluated whether the same drivers fit the usage decisions of Swiss farmers. The initial examination focused on individual attitudes, then delving into hacking robots and virtual fences. The acceptance of specific technologies has application-specific reasons and depends on risk–benefit assessments. Farm-specific variables influence virtual fence acceptance but not hacking robots. Nevertheless, farm characteristics influence individual technologies and risk–benefit examinations.

The findings extend beyond Switzerland, shedding light on decision-making in digital agriculture for small-scale farms. They underscore the varying paces between industry technology development and the farm adoption process, suggesting a focus on digital skill development and support for farmers in risk–benefit assessment. Peer networks and research settings, such as a model farm to visit, are recommended for support services. Governmental or independent institutions should test digital technologies, providing crucial information on development status, error susceptibility, usability, and required expertise. Given Swiss agriculture's limited workforce, such support is essential for the adoption of informed technology.

The presence of pioneer farmers who are adept at navigating digital agriculture independently should not overshadow the reality that most Swiss farmers require support at varying stages of adoption. This study's conclusion underscores the importance of prioritising responsible research on innovation (RRI) and embracing co-creation and transdisciplinary approaches to facilitate effective technology adoption. An emphasis on understanding risk–benefit perceptions underscores the need for researching technology-specific impacts on farms and stakeholders. This nuanced approach will shape the future landscape of agricultural digitalisation, identifying beneficial technologies while discarding impractical ones.

In conclusion, we recommend a differentiated perspective on digitalisation in Swiss agriculture. Farmers' experiences with digital technologies urge researchers to identify where digitalisation can sustainably benefit agriculture in social, economic, and environmental terms and where it should be resolutely avoided. Our study addresses future autonomous systems in agriculture. If agricultural systems advance to the point of complete farmer displacement, significant changes are inevitable. Future research must explore not only the acceptance of new technology but also the evolving roles individuals may assume in this transformed landscape, marking a crucial aspect of digitalisation's progression in agriculture.

Ethics approval

The study was approved by the Ethics Committee of ETH Zurich (EK 2021-N-17).

Table 1, Table 2, Table 3, Table 4

CRediT authorship contribution statement

Linda Reissig: Writing – review & editing, Writing – original draft, Software, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Michael Siegrist:** Writing – review & editing, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no conflict of interest.

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Appendix

Table A1, Table A2, Table A3

Table A1
Demographic and farm characteristics ($N = 939$ with 10 missing values for farm type).

			Education in %			Agricultural area	Number of employees self-claimed (standard workforce)							
Farm type	Number of participants	Average age farm mana- ger (years)	With federal certificate of professional competence in agriculture	Completed basic training in agriculture with federal certificate of proficiency	Further education in agriculture (master craftsman's examination, technician, engineer FH or ETH)	**Organic farms (%)**	**Share of non-agricultural work: 1 (none) to 6 (81–100 %)**	**Average in ha**	**Min. in ha**	**Max. in ha**	**Average**	**Min.**	**Max.**	**Agricultural income: 1 (very good) to 5 (very poor)**
Arable farming	86	51.4	16.3	57.0	30.2	4.7	3.3	31.5	7.50	119.2	1.1	0.2	5.8	2.5
Vegetables and horticulture	17	49.7	11.8	58.8	47.1	58.8	1.7	29.8	2.14	111.3	5.7	0.6	32.9	2.2
Dairy production without rearing or fattening	21	48.5	9.5	66.7	33.3	23.8	2.3	21.4	4.19	45.3	1.9	0.7	4.0	2.5
Dairy production with rearing or fattening	224	47.5	4.5	62.5	30.8	18.8	2.3	27.3	4.41	133.2	2.1	0.3	9.9	2.6
Suckler cows	100	48.9	10.0	49.0	18.0	26.0	3.5	19.0	3.47	118.7	1.2	0.3	6.1	2.7
Mixed cattle	64	47.6	14.1	51.6	14.1	20.3	3.0	23.2	4.14	113.1	1.4	0.2	5.9	2.7
Horses/sheep/goats	45	50.0	8.9	37.8	11.1	26.7	3.6	11.3	1.96	40.6	0.8	0.2	2.9	2.8
Combined dairy cows/farming	65	50.3	3.1	58.5	53.8	7.7	1.8	37.4	10.25	106.6	2.6	0.5	7.0	2.6
Combined suckler cows	52	49.5	17.3	57.7	30.8	15.4	2.7	32.3	7.89	125.5	1.7	0.4	4.2	2.5
Combined finishing	129	47.1	7.0	50.4	48.8	10.1	1.9	29.4	3.49	134.2	2.6	0.3	9.0	2.3
Combined other/dairy cows	83	50.9	9.6	60.2	48.2	12.0	1.9	36.9	9.56	129.3	2.8	0.8	7.7	2.4
Combined other/cattle	43	50.4	11.6	55.8	30.2	11.6	3.1	31.0	7.77	116.6	1.6	0.4	5.3	2.6
Missing	10													
Total	939	48.9	8.9	55.3	32.9	16.3	2.5	28.0	1.96	134.2	2.0	0.2	32.9	2.5

Table A2
Correlations between attitude and independent variables.

	1.	2.	3.	4.	5.	6.	7.	8.
1. Attitude								
2. Finance	.18**							
3. Size	.16**	.14**						
4. Workforce	.17**	.13**	.70**					
5. Workload	−0.00	−0.08*	.10**	.13**				
6. Age	−0.16**	−0.02	−0.08*	−0.14**	−0.02			
7. Technology interaction	.52**	.10**	.12**	.12**	−0.03	−0.17**		
8. Higher education	.19**	.22**	.21**	.23**	0.06	−0.07*	.16**	
9. Digital competences	.47**	.15**	.13**	.12**	0.00	−0.19**	.67**	.17**

$N = 939$.
$^{*}p < 0.05$; $^{**}p < 0.01$.

Table A3
Correlations between acceptance and independent variables (autonomous hacking robots below the diagonal, virtual fence above).

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12
1. Acceptance	–	.07*	0.03	.10**	0.02	−0.13**	.14**	.29**	.20**	.31**	−0.38**	.65**
2. Finance	.18**	–	.15**	.16**	−0.08*	−0.05	0.05	.09*	.22**	.15**	−0.05	0.07
3. Size	.14**	.13**	–	.84**	.12**	−0.05	−0.03	.10**	.19**	.12**	−0.06	.09*
4. Workforce	.17**	.13**	.65**	–	.17**	−0.096*	0.01	.11**	.24**	.14**	−0.04	.11**
5. Workload	.13**	−0.03	.10*	.11**	–	−0.03	0.07	−0.02	0.07	−0.02	.11**	0.02
6. Age	−0.09	−0.00	−0.08	−0.15**	−0.03	–	−0.03	−0.16**	−0.08*	−0.19**	0.03	−0.08*
7. Extraversion	0.09	0.02	0.01	0.07	.10*	0.04	–	.16**	−0.01	.18**	−0.06	.10**
8. Technology interaction	.32**	.09*	.11*	.11**	0.01	−0.13**	.12**	–	.18**	.66**	−0.21**	.29**
9. Higher education	.26**	.20**	.23**	.24**	.10*	−0.05	0.05	.12**	–	.20**	−0.04	.18**
10. Digital competences	.30**	.13**	.15**	.13**	0.03	−0.17**	.14**	.65**	.16**	–	−0.19**	.33**
11. Risks	−0.32**	−0.17**	0.00	−0.05	0.00	−0.03	−0.08	−0.19**	−0.08	−0.21**	–	−0.36**
12. Benefits	.41**	.10*	0.07	0.07	0.08	−0.04	0.04	.14**	.10*	.16**	−0.18**	–

Hacking robots $N = 431$.
Virtual Fence $N = 608$.
$^{*}p < 0.05$; $^{**}p < 0.01$.

Data availability

The data that has been used is confidential.

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