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Author(s): Kernecker, Maria; Knierim, Andrea; Wurbs, Angelika; Kraus, Teresa; Borges, Friederike

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Abstract

Technological innovations are changing mechanisation in agriculture. The most recent wave of innovations referred to as smart farming technologies (SFT), promise to improve farming by responding to economic, ecological, and social challenges and thereby sustainably develop agriculture throughout Europe. To better understand the ongoing technological progress' relevance to farming systems across Europe, we conducted a survey with 287 farmers operating in 7 EU countries and in 4 cropping systems, alongside 22 in-depth semi-structured interviews with experts from the agricultural knowledge and innovation system. Although nowadays, SFT are broadly perceived as and generally expected to be useful to farming, when it comes to specific on-farm challenges, farmers are less convinced of SFT potential. Farmers' perceptions of SFT vary according to SFT characteristics and farming context. Interestingly, both adopter and non-adopter farmers are hesitant regarding SFT adoption, and they have a number of suggestions for SFT to become more relevant to a broader range of farms. Both farmers and experts consider peer-to-peer communication as important sources of information and deplore a lack of impartial advice. Experts are generally more convinced of SFT advantages and positive regarding the long-term trends of technological development. Our findings both support and differ from previous studies on technology adoption for precision agriculture. In particular, our study suggests that differences related to agricultural structures and farming systems across Europe states have to be considered for improving SFT development and their adoption.

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Executive Summary

The following manuscript was submitted to the journal "Precision Agriculture" on 30.07.2018, after the initial submission to the journal "Agronomy for Sustainable Development" was declined (submitted 23.06.2018, editorial decision 10.07.2018). The manuscript is based on work from Task 2.2 and 2.3.

1. Introduction

Digitisation in agriculture is contributing to a revolution in farming, mirrored in the development of smart farming technologies (SFT) that range from apps on smart phones to in-field autonomous systems. It is widely assumed that SFT will contribute to agricultural sustainability because of their ability to increase the precision of inputs to crops and soils based on site-specific needs. Plant and soil input needs are linked to farm management systems (Basso et al. 2015), such that SFT can potentially make farmers more prepared to cope with both labour shortage and climate change by growing crops in a more efficient way (Walter et al. 2017; Poppe 2013). However, the ability of SFT to contribute to a more stable and equitable food production, with reduced environmental impacts, is still debated (i.e. sustainable intensification) (Scherer et al. 2018).

Apparently, in the past years, farmers across Europe have not been completely convinced by SFT and their adoption is clouded by hesitancy (Reichardt and Jurgens 2009). In 2011, 20-80% of farmers in the USA used some kind of SFT, while in Europe only 0%-24% of farmers did (Lawson et al. 2011). Low SFT adoption rates in Europe are explained in part by inconsistencies in information about SFT (Long et al. 2016). Since SFT are relatively new on the market, it can be assumed that knowledge and experience about SFT is rather limited which makes access to information one bottleneck for farmers' SFT adoption. Also, the diversity of technologies is considerable and ranges from apps to autonomous machines. In line with Fountas et al. (2015) we distinguish here (a) recording and mapping technologies, which collect precise data for subsequent site-specific application, (b) tractor GPS and connected tools that use real time kinetics to appropriately apply variable rates of inputs and accurately guide tractors, (c) apps and farm management and information systems (FMIS) which integrate and connect with mobile devices for easier monitoring and management and (d) autonomous machines operating autonomously. Sociological innovation theories suggest that there is a broad range of factors that matter for adoption (Rogers 2003; Hoffmann et al. 2009). In the case of SFT, these factors could comprise farmers' characteristics (e.g. education level, Reichardt and Jurgens 2009), farm structures (e.g. farm size, Daberkow and McBride 2003; Kutter et al. 2011), their direct social communities (Oreszczyn et al. 2010) and the wider embedding environment (e.g. regulations, political incentives, advisory systems, Long et al. 2016; Tey and Brindal, 2012). Additionally, an innovation's characteristics strongly impact its adoption (Rogers 2003). These are: 1) the relative advantage of SFT compared to preceding technologies, 2) how compatible the SFT is with farmers' values, past experiences, and their needs; 3) how complex or difficult it is to use SFT; 4) the degree to which SFT can be experimented with and incrementally adopted; and 5) how visible the outcomes of using SFT are to other farmers. Understanding how the factors related to farmers, their farms, and SFT characteristics will affect SFT adoption is critical to gaining insight to the gap between SFT potential and application.

In order to study this knowledge gap, the conceptual model for voluntary change of behaviour as formulated in extension sciences is used (Hoffmann et al. 2009:55ff), where an individuals' new agronomic practice or the adoption of an agricultural innovation results from a combination of driving and hindering factors. Essentially, how these factors influence the decision-making process depends on how they are subjectively perceived by the individual (farmer). This concept relates farmers' innovation adoption to their value system of professional and personal objectives, strategies, norms and interests. For example, farmers may have strategic ideas and specific concerns about ecological sustainability that correspond to the context of their farms (Preissel et al. 2017), and so understanding how SFT respond to farmers' perceived needs for sustainable farming can be of high relevance. Therefore, differences in the perceived usefulness of SFT types are expected in relation to farmers' interests and perceived needs, to a farm's dominant cropping system (for example, arable systems, orchards, vegetable fields' production, or vineyards) and other farm-related structural factors (Burton 2014), in addition to the embedding socio-political environment. We assume that farmer perceptions of SFT potential to make agricultural sustainable will vary accordingly.

Prioritizing a thorough understanding of the agricultural context, the farmers and their farms in which SFT are or could be adopted is key to understanding how digitalization in farming could contribute to agricultural sustainability. In this paper, we rely on the work from the EU Horizon 2020 project Smart-AKIS (www.smart-akis.com) to update insights on farmers' SFT adoption in Europe and in particular, to present and contrast farmers' perspectives and experiences with experts' expectations and views. We make use of the agricultural knowledge and innovation systems (AKIS) concept to identify the various groups of relevant actors contributing to successful innovations, and thus knowledgeable as experts (EU SCAR 2012; 2013; Knierim et al. 2015). We focus on farmers' needs and interests with regard to digital and smart farming technologies across a selection European countries and farming systems, and investigate factors affecting the generation, adoption and diffusion of SFT. With this background, the objective of this paper is to further an in-depth understanding of:

- What motivates farmers with different cropping systems to adopt SFT, what are supporting factors?
- Which barriers to SFT adoption do farmers and experts perceive? and
- Which suggestions do farmers and experts have to improve SFT?

To study these questions, a mixed method approach is used that combined a farmer survey with expert interviews (Punch 2005).

2. Materials and methods

The empirical data stems from seven European countries. It was collected in the frame of the EU project 'smart-AKIS', a 'coordination and support action' conducted with 10 partners from March 2016 to August 2018.

2.1. Sampling

A survey was designed by the authors and implemented in cooperation with the Smart-AKIS partners in seven European countries. The sampling followed a purposive scheme combining a) the 4 European-wide dominant cropping systems arable farming, orchards, field vegetable and vineyards, b) the range of farm size classes, and c) adopters and non-adopters of SFT from a wide range of ages. We aimed to conduct surveys with 5-15 farmers from the relevant size classes for each cropping system, and reflect the heterogeneity of European cropping systems to capture the technological needs, ideas, interests, and perceptions from a stratified farming population. Notwithstanding, as the sampling of farmers was purposive and restricted by consortium partners' resources for field work, a bias towards organisationally related farmers can not be excluded.

As a complement to the farmers' survey, 22 interviews with experts from several AKIS actor groups were conducted, namely from research (8), industry (10) and the wider public (4 from administration, media and interest associations) from 9 European countries.

2.2. Data collection

The research design followed social sciences' standards (Babbie 2015). Integrating scientific and practical expertise from the smart-AKIS partners, we constructed a questionnaire with a total of 129 questions from which here, we rely on a sub-selection of 18 questions that focus on farmers' contexts, their opinions regarding SFT, including usefulness, potential to deal with certain challenges, and suggested improvements (Note: the questionnaire can be downloaded from the project's website.) Farmers were asked to agree or disagree with statements representing different points of views (e.g. using a forced Likert Scale, strongly disagree – 1, to strongly agree – 4), answer multiple-choice questions, and respond to a few open questions.

The questionnaire was pre-tested with farmers in July 2016 in France, Germany, Greece, the Netherlands, Serbia, Spain and the UK, and adjusted and finalized accordingly. The surveys were conducted face-to-face or via telephone in the respective national languages, and responses were transferred to a master excel file via a Google Form. Each farmer was provided with an accompanying letter ensuring the anonymity of the data collected.

For the expert interviews, a guideline was developed and structured thematically regarding socio-demographic, economic, political and societal factors that foster and/or hinder the use of SFT. Specifically, questions addressed a) the future of agriculture and the role of SFT; b) drivers for and aims of innovation in agriculture; c) factors motivating farmers to adopt SFT; d) the role and interactions of different AKIS actor groups in influencing direction of innovations; e) change of societal values shaping farmers' SFT adoption and interest and f) political influence and strategies on the innovation and adoption of SFT (Borges et al., 2017). The expert interviews were semi-structured, and the interview guide was adapted to each of the experts being interviewed (Newing et al. 2010). The interviews were conducted face-to-face, via telephone or Skype.

2.3. Data analysis

All survey data was downloaded from the form as a spreadsheet and used for analysis. The data set (n= 287) had very few instances of non-response and was analysed using descriptive statistics. To test the effect of country, cropping system, farm size, and age on adoption, Kruskal-Wallis test was used. A post hoc analysis for differences between explanatory factors was used with Dunn-Nemenyi tests using Chi-square differences to adjust p-values for ties that are common in ordinal and binary data. To analyse farmers' perceptions of SFT, we ordered all statements by mean Likert score. We used the mean score and associated standard deviation of Likert data us to identify the relationship between the strength of agreement (i.e. mean score) and how contested it is (i.e. standard deviation of mean score). Quantitative data was complemented with qualitative analysis of short open answers using a form of annotation in the text (Newing 2011).

The recorded expert interviews were transcribed using the f4transkript (Version 6.2.3 Pro) software, according to the simplified transliteration guidelines by Dresing & Pehl

(2015). Qualitative Content Analysis (QCA) using MAXQDA (Version 10) software was utilized for coding and categorizing the transcripts. QCA is a flexible method, focused on the specific research objective (Mayring 2010). Specifically, we used the content-related structuring with deductive category assignment according to Mayring (2014) to extract the valuable information from the interviews.

3. Results

3.1 Characteristics of surveyed farmers and their farms

In total, 287 farmers participated in the survey, which included only 19 women. The greatest number of farmers (n=68) were interviewed in Greece, and the least number of farmers (n=28) were interviewed in both Germany and Spain. Farmers from open field vegetables in France and the Netherlands were the smallest group included. Orchards and vineyards were covered most predominantly in Greece, which correspond to their major crops (see Eurostat, 2010). Serbia and the Netherlands were the only other participating countries that conducted surveys with farmers from orchards. The number of vineyards in the survey came from countries traditionally associated with wine production: mostly France, Greece, Serbia, and Spain. The farm sizes in these latter two cropping systems are characteristically much smaller than arable and open field vegetables, and the farm size surveyed rarely surpassed 50 ha (Table 1).

There were 144 SFT adopters and 143 non-adopters. There were significant differences between countries (χ^2= 84.7, df = 6, $p < 0.0001$), farm size (χ^2 = 89.9, df = 6, $p < 0.0001$), and cropping system (χ^2 = 26.2, df = 3, $p < 0.0001$) in adoption. Greece and Serbia had lower rates of adoption than Germany, the Netherlands, and the UK. We also found that the larger the farms, the greater the adoption rate, such that farms under 10 ha had significantly less adopters than farms that were 101 ha and larger. Farms that were over 500 ha were exclusively adopters. Arable farmers had a significantly higher rate of adoption than both tree crop and vineyard farmers, which likely corresponded to farm size differences. Similarly, most arable farmers were adopters, and tree crop farmers were mostly non-adopters.

Table 1: Stratification of farmers surveyed; Number of adopter (A) and non-adopters (NA) are listed according to farm size class, and both country (above) and cropping system (below).

	0-2 ha		2-10ha		11-50ha		51-100ha		101-200ha		201-500ha		over 500 ha				
	A	**NA**	**A**	**NA**	**A**	**NA**	**A**	**NA**	**A**	**NA**	**A**	**NA**	**A**	**NA**	**Total A**	**Total NA**	**Total**
France	0	0	2	8	3	7	3	6	8	6	4	0	2	0	22	27	**49**
Germany	0	0	0	1	1	0	3	1	2	1	5	0	14	0	25	3	**28**
Greece	0	9	14	33	3	7	0	2	0	0	0	0	0	0	17	51	**68**
Serbia	1	3	2	17	1	6	1	5	0	0	0	0	0	0	5	31	**36**
Spain	0	0	0	1	4	10	2	1	5	4	1	0	0	0	12	16	**28**
Netherlands	0	0	2	1	12	2	6	5	9	3	4	0	0	0	33	11	**44**
UK	0	0	0	2	0	1	1	0	4	0	6	1	19	0	30	4	**34**
Total	**1**	**12**	**20**	**63**	**24**	**33**	**16**	**20**	**28**	**14**	**20**	**1**	**35**	**0**	**144**	**143**	**287**
Arable	1	3	2	10	6	6	10	15	21	11	18	1	29	0	87	46	**133**
Orchards	0	8	6	21	7	4	0	0	0	0	0	0	0	0	13	33	**46**
Vegetables	0	0	0	9	3	7	4	4	5	2	2	0	6	0	20	22	**42**
Vineyards	0	1	12	23	8	16	2	1	2	1	0	0	0	0	24	42	**66**
Total	**1**	**12**	**20**	**63**	**24**	**33**	**16**	**20**	**28**	**14**	**20**	**1**	**35**	**0**	**144**	**143**	**287**

Experts that were interviewed had contested opinions about the role of farm size in regard to SFT adoption. One expert from Germany stated that "of course big farms' managers will more probably adopt the technology to deal with all the work on a big farm without spending much costs on labour". Experts also emphasized that economic size was possibly more important for SFT adoption. For example, a Greek expert stated that ", maybe you have 20 hectares with high value crops like, like olive oils etc. and the incomes (are) very good. Or maybe you have 20 hectares of wheat and you don´t have any good income - so (…) I cannot tell it (if it is) farm size or crop size - it´s (a) combination".

3.2 Factors supporting farmers' interest in SFT adoption

To assess farmers' perceptions of SFT we asked them (i) to estimate SFT' potential to overcome certain challenges related to farm sustainability and (ii) to evaluate SFTs' usefulness. First, we asked farmers if they agreed or disagreed with various statements regarding what SFT can do for them (Table 2). We then asked farmers about which of the four SFT types (recording and mapping technologies, GPS based steering tools, apps and FMIS and autonomous machines) would be most useful for their farms, and which SFT type adopters had/used (Fig.1). In regard to SFT potential, aggregated results show that the two statements with the strongest agreement were that SFT are useful for farming and that SFT are better than the tools before. In contrast, the farmers agreed the least with the statements that using SFT would improve the farm impact on nature (e.g. by protecting biodiversity), and that SFT can improve farm income. These latter rankings also had some of the strongest variation (i.e. see the standard deviation). One of the other most strongly contested statements was in regard to SFT providing better information for decision-making.

The variation in these responses regarding farmers' perceptions of SFT potential can be explained by country-level, cropping system, and SFT type differences. There was a country effect regarding farmers' perceptions of SFT to improve both farm income and impact on nature. Farmers from Serbia and Greece, which are countries with the lowest adoption share, agreed most strongly with these statements, and farmers from The Netherlands disagreed the most. Farmers' perception of SFT ability to improve the farm impact on nature can also be related to differences in cropping system: Vegetable farmers agreed the least with the statement (average of 2.55), and orchard farmers agreed the most (average 2.91). Equally, farmers' perception of SFT potential to improve farm income can largely be explained with differences between cropping systems: Vegetable farmers agreed the least (average ranking of 2.67) and orchard farmers agreed the most with the statement (3.26). The variation in the perceptions of SFT ability to provide better information for decision-making was best explained with SFT-type differences: Almost 45% of all farmers disagreed that autonomous machines provide information for decision-making. In contrast, all farmers agreed with the statement specifically in regard to apps on their smart phones. Experts were ambivalent regarding the question if SFT can fulfil farmers' expectations. They made clear that the potential of SFT is widely discussed, but that expectations are clearly related to lowering the costs of production, and increasing farm income. Furthermore, they see still wide gaps between the farm's daily work requirements and the capability of the new technologies and also their users.

Table 2 Ranking of overall strength of farmers' agreement on different SFT potential; the higher average, the more strongly farmers agreed: 1 for "strongly disagree," 4 for "strongly agree".

SFT potential	Overall average	Standard Deviation
Improves farm impact on nature	2,65	0,86
Improves farm income	2,84	0,77
Reduces farm pollution	2,92	0,76
Decreases input costs	2,96	0,79
Provides better information for decision-making	3,02	0,81
Improves work comfort	3,10	0,70
Increases productivity	3,11	0,63
Improves work processes and workload	3,13	0,75
Better than tools before	3,32	0,65
Useful for farming	3,43	0,62

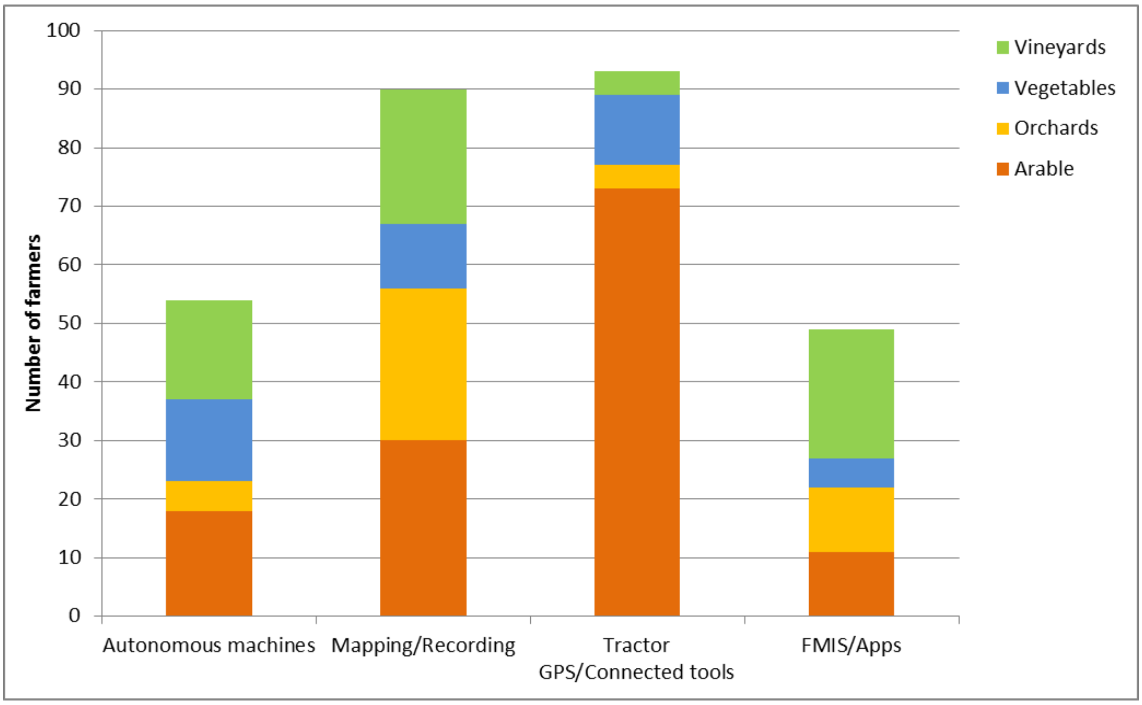

Fig. 1 Most useful SFT type according to farms' dominant cropping system

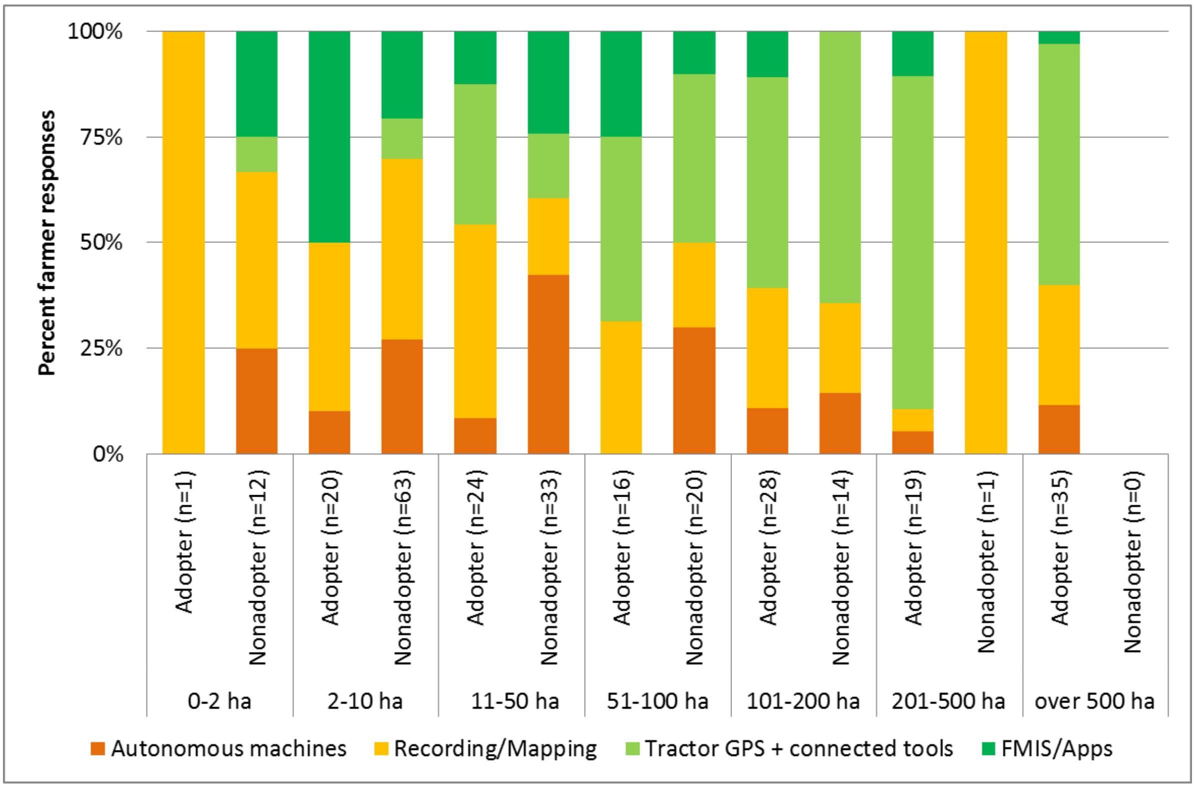

Fig. 2 SFT type perceived as most useful to their farm, according to size class and adoption

In general, farmer' perceptions of which SFT are most useful seem to depend on the cropping system and farm size (Fig. 1). The SFT selected as most useful for surveyed farmers were tractor GPS and connected tools. 93 out of 287 farmers selected these SFT, and over 70 of them were arable farmers. Mapping and recording technologies were selected by 90 farmers, and almost equally frequently by wine growers, tree fruit farmers, and arable farmers. Apps/FMIS were selected by 49 farmers, again most frequently by wine growers. Autonomous machines were selected 54 times, equally frequently by wine growers, vegetables and arable farmers, and least by tree fruit farmers. Tractor GPS and connected tools were selected as most useful by farms over 101 ha by over 60% of the responses. Autonomous machines, mapping/recording, and FMIS/apps were selected on average by 70% of farmers from farms with less than 50 ha. Across countries, there are similarities in favoring SFT related to cropping systems: while GPS related technologies matter most in arable farming, mapping and recording tools, related to e.g. the monitoring of weather events are more appreciated in horticulture and viticulture where the micro-climate or plant diseases have a more important impact on yields and incomes per ha.

Out of the 287 farmers surveyed, 144 have already adopted at least one SFT. We asked these adopters which SFT they have, and compared their answers to the SFT they selected as being the most useful. About 30% said that a different SFT than the one that they had already adopted would be most useful. Most of the adopters used tractor GPS/connected tools and the least number of farmers used autonomous machines. Over 80 farmers owned/used tractor GPS/connected tools, and 80% of them said they considered them useful. In contrast, only 1 adopter out of 144 used an autonomous machine, but 12 perceived this SFT type as most useful. 37 adopters had recording or mapping tools, but 45 farmers considered these SFT most useful. Non-adopters across most size classes did perceive autonomous machines to be most useful for their farms. Non-adopters tend to have slightly higher expectations with regard to autonomous machines than adopters. Moreover, in the smaller sized farms (< 100 ha), farmers who were non-adopters regularly stated that they thought autonomous machines would be most useful for their farms (Fig 2).

With very few exceptions, the experts predict a general trend towards technology and smart farming in the future of European agriculture. This anticipated development includes further intensification of farming, specifically by minimizing inputs and maximizing output by single plant processing ('intelligently targeted inputs', research). This expected optimization of resources is assumed to function in combination with combined with the establishment of a data environment associated with the technology of individual farms and networks used to streamline data transfer and to optimize data use automatically. However, the economy of size (of farms) may become obsolete as a result of the drift towards autonomous machines and robotics with a more flexible scope of application. As the lack of qualified labour is considered to become even more critical in the future, experts of all groups are convinced that technology development is going to impact the work and the profile of farmers. Farmers will function more as managers and supervisors of machinery instead of actually working in the field. The next generation of farmers are expected to somehow naturally adopt SFT as they are "*sons of the internet*" (expert from industry).

3.3 Barriers to SFT adoption

Adopter and non-adopter farmers identified a few similarities and some differences between the perceived barriers to SFT adoption. A common barrier is the threat of high investment costs and a lack of clarity with regard to the added value that SFT (may) bring (Table 3). Differences exist with regard to the appraisal of their use, their farm compatibility and the access to reliable information. Adopters are frequently confronted with the challenge to interpret data and to assure devices' connectivity and preciseness, and they miss reliable advice. Non-adopters have a general concern which is that SFT do not match with their farms' profile. Also, there is a barrier that can be related to farmers' knowledge and capabilities: they perceive SFTs as too complex and miss observable and reliable information. Experts mirror farmers' statements, by reiterating that public funds for investments are not available, but that neither are the appropriate technologies. As well, the cost-benefit and added value is still not clear, complexity is an issue, and neutral advice that is not brand-specific is missing. An expert from industry in Spain stated that "…main issue regarding the implementation of technology in the farms, for Spain, , is the availability of farm income. That is for sure." Moreover, an expert from Italy confirmed, "the basic consideration that I have in mind is that most of the technologies are not really available, if we speak of smart farming."

Table 3: Barriers to SFT adoption as perceived by non-adopters and adopters

Non-adopters	Adopters
High investment costs	High investment costs
Too complex to use	Too difficult to interpret data
Technology not appropriate for farm context and size	Devices are not interoperable and not precise enough
Unclear added value of SFT use	Added value is unclear
Lack of access to live demonstrations of SFT use with neutral contact	Lack of neutral advice

Regarding non-adopters, a Greek practitioner said: "First of all most of the growers, I mean, up to 99%, they´re not familiar with new technologies. And […] nobody until right now informed about new technologies (…) and what´s the benefits from that and at the beginning, the growers are very sceptical to adopt these technologies." All experts stated that improving mobile infrastructure is crucial to SFT adoption and diffusion processes and that the lack of a GPS correction signal (e.g. RTK) limits farmers when using automatic steering. In general, poor connection to broadband was stated as an infrastructural barrier to SFT adoption, both by farmers and by experts from research, practice, and industry, and from across Europe, which combined with a lack of current information and high costs, greatly determine access to SFT.

3.4 Suggestions to improve SFT adoption

Farmers are experimenters, curious, and seek information and solutions to overcoming challenges, including SFT. We therefore asked farmers to list improvements they would make to SFT, to make them more acceptable or useful for farmers. In total, 171 farmers (60%) provided suggestions for improvements which we grouped into 4 categories:

- Enhancing access (45 times, 31% of responses):
  - Improve access to information about SFT (i.e. cost-benefit models) (16 times)
  - Reduce cost (23 times)
  - Infrastructure (i.e. internet connection, satellite imagery) (6 times)
- Improving the technology system (32 times, 22% of responses):
  - Simplification and consolidation of SFT and apps (8 times)
  - Compatibility between devices (24 times)
- Improving the device (36 times, 25% of responses):
  - Efficiency (11 times)
  - Reliability (7 times)
  - Reduce complexity (16 times)
  - Device adaptation (i.e. size reduction, transferability to another cropping system) (2 times)
- Enhancing data management and usability (33 times, 23% of responses):
  - Data mobility (i.e. with tablets or smart phones) (9 times)
  - Data transfer between devices (i.e. from computer to tablet or smart phone) (12 times)
  - Make the transformation of data into information better so that it can improve decision-support in the field (i.e. improve data presentation) (10 times)
  - Data security (2 times)

Access to SFT in terms of affordability, but also in terms of information and infrastructural conditions was the most frequently mentioned improvement. At the level of the technological system as a whole and with regard to single devices, farmers' statements suggested improvements with regard to simplification and compatibility between devices. A third overarching concern is related to both data mobility and data processing (while data safety was of unexpectedly low importance). Accordingly, one expert from the industry sector in The Netherlands stated, "… make it as easy to use as possible, because currently we see a lot of complex systems. And because of the interoperability of all the different machines and the brands (…) all these data exchange and relationships between all the different systems are way too complex. (…) So it´s not complex to operate a machine, it should be working and being set up properly to be working as autonomous, or automatic as possible." An expert from research in Serbia confirmed that the technologies for farmers are too complex: "… put everything in a language that farmers can understand."

When addressing the availability of reliable information about SFT, farmers ranked the roles of private, independent advice, other farmers and agri-tech providers in order of their importance. Although experts clearly confirm these roles of professional and personally related actors, there was also doubt whether there is really a lack of information, e.g.: "Every single farmer has (…) all the information they need. And they know (…) a lot of things about new technologies. And they go to the trade shows to ask the manufacturers about those technologies" (Industry, Spain) and "Also in (the) German press there are many articles about the topic. So whoever is interested in it can access the information" (Practice, Germany).

4. Discussion

Generally, our results confirm and update a number of findings from preceding studies. For a selection of seven European countries, we show that technology adoption and farm size in terms of farm area are positively correlated, thereby confirming previous findings from precision agriculture studies that farm size in terms of area matters for the adoption and use of smart farming technologies (Daberkow and McBride, 2003; Kutter et al. 2011; Paustian and Theuvsen 2016). However, our results also indicate that this general trend has to be differentiated with regard to both the farm's dominant cropping system and the SFT to be adopted. So far, the existing literature mostly concentrates on arable farming and respective technologies as e.g. GPS based technologies, which in turn tends to serve larger farms in the EU's north-western countries better than smaller farms elsewhere. Our results indicate that mapping and recording is the more relevant SFT type in orchards and vineyards, since for example weather and crop disease monitoring have a high priority, while in arable systems, tractors with connected GPS are most important. These preferences reflect clearly the relationship between cropping system and farm size on the one hand, and type of SFT on the other.

Expectations on SFTs as expressed in the literature are very high – SFT are considered as starting point for a 'technical revolution' and thus, the basis for smart farming which is key for sustainable farming as it "reduces the ecological footprint of farming" and "can make agriculture more profitable for the farmer" (Walter et al. 2017:6148). While almost all consulted experts consented to this view, farmers' expectations are far more differentiated when it comes to concrete statements. They tend to support positive assessment at a very general level, but looking at both impacts on economic profitability as well as on environmental performance of SFT, the level of conviction is clearly moderate. Moreover, we found that perceptions of SFT to improve farming depend on exposure or experience, and those higher expectations of SFT come from farmers with less experience with SFT. In particular, non-adopters tend to have slightly higher expectations with regard to autonomous machines than adopters, a finding that we interpret as a certain 'disillusion' of the adopters' side about what they can really expect from SFTs (e.g. risk aversion, Marra et al. 2003). To our knowledge, such findings have not yet been comprehensively portrayed in literature.

The most frequently mentioned barrier to SFT adoption is still their high costs – a characteristic that inflicts on their trialability and relative advantage (Rogers 2003). This hindering factor has been reported on in a number of references (e.g. Aker 2011; Kutter et al. 2011; Tey and Brindal 2012; Paustian and Theuvsen 2016; Long et al., 2016) with no major change in trend. Not surprisingly, decreasing costs for the technology has been emphasized as a pre-requisite for adoption for more than a decade already, and profitability is considered a key criterion for individual adoption decisions, as several studies address economic viability of certain technologies (Pedersen et al. 2008).

Experts also reiterated that another Europe-wide barrier to the widespread dissemination of SFT is the lack of information about existing innovative technologies as well as individual and impartial advisory services for farmers. This lack was also mentioned by many of the surveyed farmers and confirms earlier findings from e.g. Kutter et al. (2011) and Maffioli et al. (2013). Here, we point to the fact that farmers appealed for independent private advice in particular, which actually corresponds to the increasing pluralism of advisory service across the European member states (Knierim et al. 2017). Nevertheless, such independent private advisory service providers frequently struggle with adequate access to current knowledge (i.e. on available SFT and how to best implement them) as they have comparatively low resources and human capacities, so targeted governance activities are recommended (Knuth and Knierim 2016).

Finally, we highlight the finding that many farmers are actively experimenting with technologies and farming practices on the one side and deplore technological compatibility of SFT with existing on-farm technologies on the other. Carolan (2017) points to the fact that with digital technologies farmers no longer have the possibility to rely on 'do it yourself' strategies when mending or adjusting devices (which is directly related to compatibility). Farmers would not only need very specific knowledge, but even risk illegal practices as software are protected as intellectual property. To overcome this gap between adjustment needs and heavily restricted rights, SFT developers and providers have to invest more into a "continuing dialogue with end-users", or "understanding the specific concerns that producers have" (Reichhardt and Jürgens, 2009). Providing farmers more widely with experimental access to a variety of SFT could be the first step in evaluating whether or not SFT correspond with farm contexts and respond to farmer needs and expectations. This study underlines the fact that while farmers broadly perceive SFT as useful and beneficial for farms, the specific benefits remain unclear.

5. Conclusion

We found that farmers have high general expectations of SFT, which is in line with experts' opinions regarding SFT. However, looking closer at specific challenges for farming and SFT potentials, farmers give more cautious assessments and reveal certain doubts about the promises of SFT for improving agriculture's sustainability. More specifically, farmers' perception of SFT potential to improve farming in multiple ways varies with the farm context, defined in this study as country, cropping system, and farm structures (i.e. farm size). Furthermore, distinguishing between SFT types explained some of the differences in farmers' perceptions of SFT, which can be related to the innovation-specific characteristics. Whether or not farmers had adopted SFT also influenced their perceptions of SFT potential to deal with agricultural challenges, and in identifying which SFT would be most useful for farm systems.

Although it is not certain that subjectively perceived factors can objectively be measured with surveys, it is clear that exploring farmers' perceptions of widely applauded technological innovations is a crucial first step to investigating how these solutions can contribute to agricultural sustainability in the future. Although almost all experts perceive digitization as a strong, irreversible trend of which farmers should take advantage of, so far there are only few examples that clearly prove such strengths. Some of the central barriers to observing the added value of SFT include cost and information. Farmers are experimenters and look widely for information on SFT, particularly from private independent advice, which implies that these services could be a key focal point for improving access of SFT for farmers. Our results highlight that socio-technical change requires a more interactive and targeted approach to farmers' needs and interests, and also requires a socially sensitive, dialogic accompaniment to technical development processes.

6. Declaration on conflict of interest

We have no conflict of interest.

7. References

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