Precision Agric (2011) 12:2–17
DOI 10.1007/s11119-009-9150-0

The role of communication and co-operation in the adoption of precision farming

T. Kutter · S. Tiemann · R. Siebert · S. Fountas

Published online: 21 November 2009

Abstract Research on Precision Farming (PF) relates the adoption of PF primarily to economic incentives as well as farm attributes, whereas social factors are commonly ignored. Therefore, the present study analyses the importance of farmers' communication and co-operation strategies in the adoption of PF and their relation to farm attributes. Forty-nine qualitative interviews with stakeholders from the agricultural sector were conducted. The survey was based in Germany where most interviews took place and reflected with findings from the Czech Republic, Denmark and Greece. It is revealed that farms differ in their communication strategies depending on farm size. Joint investment in PF was only reported from some regions. It can be assumed that agricultural contractors will be major driving forces behind the adoption of PF over the next 10 years, especially in areas with smaller-sized farms. Agricultural data processing by service providers is seen as a common issue. Concerns regarding potential data misuse, over-regulation and software compatibility were raised.

Keywords Technology assessment · Contractors · Innovation · Interviews

Introduction

Precision Farming (PF) is commonly considered to be a holistic crop management concept. It allows for the management of spatial and temporal variability within a field, reduction of costs, improvement of yield quantity and quality and reduction of environmental impacts (Reichardt and Jürgens 2008). Input decisions on fertilizers, seeds or pesticides can be facilitated by means of computer-based decision-support systems. As several studies have

T. Kutter (✉) · S. Tiemann · R. Siebert
Leibniz-Centre for Agricultural Landscape Research (ZALF), Institute of Socioeconomics, Eberswalder Str. 84, 15374 Müncheberg, Germany
e-mail: Thomas.Kutter@zalf.de

S. Fountas
Farm Mechanization Lab, Crop Sciences and Rural Environment, University of Thessaly, Fytoko Street, 38446 Nea Ionia, Greece

demonstrated the economic and ecological benefits of PF tools over conventional techniques (Silva et al. 2007; Sylvester-Bradley et al. 1999; Takacs-Gyorgy 2008), it is of interest which factors favour or inhibit PF adoption. Several PF technologies such as auto-guidance and yield measurement are well known, but the combination of site-specific machinery is still regarded as a major innovation in agriculture. Accurate adoption rates of PF cannot be obtained from literature because some studies consider PF as the use of single technologies while others prefer the systems approach (Griffin et al. 2004; Zhang et al. 2002).

In Europe, PF is applied less frequently than expected (Fountas et al. 2005; Griffin et al. 2004; Pedersen et al. 2004; Reichardt and Jürgens 2008). This is mostly attributed to the high investment costs for PF equipment as well as the high learning costs associated with the complexity of the system. Edwards-Jones (2006) identifies five non-financial variables that influence the decision to adopt particular technologies in agriculture: farmer characteristics, household characteristics, farm structure, the wider social milieu and the characteristics of the innovation to be adopted. Daberkow and McBride (2003) reported that mainly young, well educated full-time farmers operating large farms are interested in PF.

Due to the coexistence of various definitions, we define farmers' adoption of PF as the combined utilization of several site-specific technologies using Global Positioning Systems (GPS) such as auto guidance and variable rate applications (VRT) of inputs and/or yield mapping on farm. This definition does not imply that these practices have to be carried out by farm staff but can be offered by a third party as well.

The "innovation-theory" (Rogers 2003) provides a theoretical basis for explaining the process of technology adoption, the so called "diffusion" process. He proposes five categories of adopters: innovators, early adopters, early majority, late majority and laggards. The "innovators", who actively seek out new information, are the first to take up a new product. They are followed by a larger group of "early adopters" often composed of highly educated farmers with a local leadership role. The group of "late majority" is generally more sceptical. They accept the innovation only when the majority is already using it. The last group, the traditionally-minded "laggards" cling to the "old ways" and will only accept a new technology if it has already entered the mainstream or even become part of tradition. Lamb et al. (2008) successfully used this concept to describe the adoption of PF in Australian viticulture.

Adoption is a learning process where information needs to be collected, integrated and evaluated (Pannell et al. 2006). Organizational arrangements (Leeuwis 2004) and networks (Allaire and Boiffin 2004) are also addressed in adoption theory. Fuchs et al. (2006) demonstrated with regard to crop farming that horizontal integration and outsourcing of special tasks in order to reduce production costs is already a common practice in Germany. Contractors target two groups of customers: (1) small farms where mechanization would result in high costs and (2) farms, where the owner does not have enough management skills or time. Single tasks such as weeding or even field management as a whole can be out-sourced. The co-operation between farmers and contractors can result in specialization and scale effects that enable farmers to participate in technological innovation processes.

Social aspects and work arrangements are not covered by literature on the adoption of PF. We assume that communication and co-operation strategies are of major importance in this context. The present study therefore seeks to address the role of these factors in decisions for or against the adoption of PF.

Within this survey, we aim to:

(1) Assess the role of communication by focussing on different information sources and communication channels in terms of their relevance to farmers' investment in PF.
(2) Analyse the effects of co-operation and horizontal integration on the adoption of PF. Three aspects of co-operation will be discussed: joint investment, agricultural contracting and data outsourcing.
(3) Analyse the impact of farm size on forms of communication and co-operation in PF.

Materials and methods

Since social aspects, such as communication and co-operation patterns, have been somewhat ignored by the literature on PF, we chose an exploratory research approach. Exploratory work is a common way to develop new fields of research (Patton 2002). Core elements of the survey were qualitative expert interviews. A mixed panel of experts has been surveyed instead of polling individual farmers at random. Experts can be expected to be more attuned to current trends and therefore provide representative information. Following Meuser and Nagel (1991), experts are (1) persons who possess privileged access to information about groups of persons and/or decision processes or (2) persons who are responsible for the development, implementation or control of solutions, strategies or policies. The interviewed stakeholders were considered as experts due to their position within a work environment related to PF and their extensive experience in this field. They were employees of agricultural technology firms related to PF, experienced researchers, staff members of the farmer union in the field of crop farming technology, governmental and private agricultural consultants familiar with the topic and farmers that were well known practitioners of PF.

We employed a partially standardized interview guideline with mostly open (semi-structured) questions, which offered the opportunity for pursuing questions in greater depth. The interviews were conducted either face-to-face or by phone. Before phone interviews took place, the interview guideline was sent to the interviewees as recommended by Atteslander (2008). We explained our definition of PF adoption (see Introduction) to the participants. The Interviews consisted in an initial part to define the regional work area of the interviewees, the kind of institution they were employed, and three thematic sections focussing on PF (Table 1). The influence of farm size on communication and co-operation patterns was addressed during the interviews.

The study was based in Germany (mainly Eastern part) where 30 out of a total number of 49 interviews were conducted. To discuss PF adoption and the relevance of communication and co-operation in an international context, we compared our findings from Germany with qualitative interviews from the Czech Republic, Denmark and Greece where a total of 17 interviews took place. This comparison was integrated in the Discussion section of the present work. The survey was conducted from November 2008 till February 2009. Eleven interviewees were identified using established contacts within the EU funded FutureFarm (www.futurefarm.eu) project. Further interviewees were identified via internet research on stakeholders involved in the PF sector in the study regions. Contacts were established via e-mails and phone calls. The exploratory approach justified a small sample (Table 2).

An exploratory approach requires qualitative sampling and analysis procedures. According to Mayring (2000), it is possible to further incorporate quantifications where

Table 1 Semi-standardized interview guideline

Interview guideline (shortened questions)	Reply facility
Section I: Regional aspects: adoption, incentives and constraints	
1. Farmer's adoption of PF technologies	<1%, 1–5%, 6–10%, 11–20%, >20%[a]
2. Farmers perceived interest in PF	Interest is growing, It is a constant topic in recent years, Interest is decreasing, It is not an actual topic; Comments: Open field[a]
3. Description of the typical PF farmer	Farm size (in ha): <50, 50–200, 201–500, 501–1000, >1000[a]
	Farm types: Family farms, Commercial farms, Farm co-operatives, Corporate entity, Other[a]
	Age of farm operator: <30, 30–40, 41–50, 51–60, >60[a]
	Years of farming practice: <5, 5–10, 11–20, >20[a]
	Education: No agricultural education, Vocational college, Professional/technical schools, University; Comments: Open field[a]
4. Encouraging or adverse conditions for PF	Open field
Section II: Communication: organizations and information channels	
5. Ranking (each item) of importance (from 0 "not important" to 4 "very important") of different persons or organizations and different information sources in spreading PF information among farmers	*Items*: Other farmers, Private extension service, Government advisory service, Research institutes, Agricultural technology firms, Farmer union, Educational centres, Professional literature, Scientific journals, Advertisement, Internet, Exhibitions/trade fairs, Seminars/workshops, Demonstration farms, Field days, Others (please name); Comments: Open field
6. Ranking (each item) of importance (from 0 "not important" to 4 "very important") of different communication channels to farmers for the interviewees organization	*Items*: Internet (web page), Internet (e-mail), Phone, Fax, Letter post, Farm visits; Comments: Open field
7. Information seeking behaviour in PF of large and small farms	Open field
8. Internet access on farms	Internet access on most farms: Yes, No; Comments: Open field[a]
9. Estimation of farmers' preferential decision regarding online submission of farm documents instead of letter post or fax	Positive towards online submission: Yes, No; Comments: Open field[a]
10. Description of internet based communication between farmers and state authorities and estimation of this development during the next 5–10 years	Open field
Section III: Co-operation: joint investment, contracting and data outsourcing	
11. Evidence of joint investment of farmers in PF technologies	This is the usual case, Happens frequently, This is the exception, Not known; Comments: Open field[a]
12. Description of farmers (regarding for example farm size, age, education) engaged in joint investment in PF	Open field
13. Arrangements of joint investment in PF	Open field

Table 1 continued

Interview guideline (shortened questions)	Reply facility
14. Description of contractors offering PF field services and estimation of their role in PF in the near future (5–10 years)	Open field
15. Description of the arrangements made for the analysis of PF data	Open field

[a] Select from list: only one item could be selected from the list

Table 2 Interviewees employment and geographic distribution ($N = 49$)

Institution/country	Germany	Czech Republic	Denmark	Greece	International	$\sum$
Agricultural Technology Firm	12	1	1	1		15
Research Institution & University	4		4	3	1	12
Farmer Union	2					2
Government Advisory Service	2				1	3
Private Extension Services	2	2	1			5
Agricultural NGO	1	1				2
Farmer/Contractor	7	1		2		10
Total	30	5	6	6	2	49

this is meaningful and appropriate. In the first step of analysis, we stored the interviews in the project database. Then we employed the content analysis method according to Patton (2002) to analyse the qualitative material. To highlight certain aspects, some closed (quantitative) questions were used.

Results

Adoption of precision farming in Germany

The adoption rate of PF in Germany was estimated to be below 10% of all German farms. The participants perceived an increasing interest of farmers in the topic. The size of a typical PF farm ranges between 200 and 1000 ha of farmland. Managers of these PF farms are experienced farmers in the age range 30–50 years with at least five years of farming experience and a university education. Adoption rates of PF and the perceived interest of farmers in the topic are higher in areas with larger average farm sizes. This was the case for Eastern Germany, where, due to post-socialist structures, the average farm size exceeds the fragmented farm structure prevailing in the South-West of the country.

Interviewees agreed that economic reasons are major driving forces behind the adoption of site-specific field management (Table 3). Large farm sizes were thought to stimulate the use of georeferenced data on field and soil conditions. The reluctance of local resellers towards site-specific technologies was explained by their fear of additional support services related to the product. Uncertain strategies especially of older farmers whether to maintain the farm or to leave the farming sector impede the investment in new farm equipment.

Table 3 Motives and constraints for the adoption of PF

Motives	Constraints
Possibility of reducing costs (fertilizer, seeds, pesticides)	Increased costs (equipment, learning)
Increased reporting requirements (traceability, environmental compliance)	Compatibility problems of PF tools and machinery
Proximity of PF related agricultural technology firms	Rejection of site-specific machinery by local resellers and advisors

Communication in precision farming

To understand the role of communication in the adoption process, the interviewees were asked to evaluate the importance of different stakeholders and media for spreading PF-relevant information among farmers. Experts were invited to weight the importance of persons and organizations regarding the spread of information on PF on interval scales in numeric format from 0 being not important to 4 being very important (Table 4). Agricultural technology firms, other farmers and private extension services were considered the most important promoters of PF.

Farmers that are satisfied practitioners of PF are regarded as very important for gaining their colleagues interest in the topic. Technology firms offer special training related to site-specific technologies, but experts criticize that they basically promote their own products and are not interested in an integration of different tools from different producers. Private consultants were perceived to be closer to the technological state of the art and less reluctant towards the topic than governmental extension services. Research centres were given little to medium importance for the adoption of PF. Educational centres were ambivalently discussed in that context. While the stakeholders generally consider these institutions as important for spreading information in the agricultural sector they see PF only partly integrated in the agricultural curricula. Agricultural chambers and farmer unions were mainly discussed regarding their role within networking and agricultural bulletins.

All interviewees were asked to weight the importance of information sources regarding PF (Table 5). Professional literature such as agricultural magazines were perceived to have

Table 4 Importance of stakeholders and institutions regarding the spread of information on PF ($N = 28$)

Stakeholders and institutions	Weighting from 0 to 4[a]					$\sum$[b]
	0	1	2	3	4	
Agricultural Technology Firms	–	–	4	18	4	78
Other Farmers	–	2	7	7	7	65
Private Extension Service	–	6	7	9	3	59
Government Advisory Service	9	9	6	1	–	24
Research Institutes	3	10	9	3	1	41
Educational Centres	7	3	10	4	1	39
Farmer Union	9	5	8	4	–	33

[a] Numbers of answers per category; 0 being not important and 4 being very important

[b] $\sum$ = (number of ratings) × (weighting) per category

Table 5 Importance of information sources regarding the spread of information on PF ($N = 28$)

Information sources	Weighting from 0 to 4[a]					$\sum$[b]
	0	1	2	3	4	
Professional literature	–	3	4	7	13	84
Field days	1	–	4	15	7	81
Exhibitions/trade fairs	–	2	4	14	7	80
Seminars/workshops	1	6	7	7	6	65
Internet	1	3	13	6	4	63
Advertisement	1	6	12	6	1	52
Demonstration farms	6	5	5	9	1	46
Scientific journals	10	9	6	2	–	27

[a] Numbers of answers per category; 0 being not important and 4 being very important

[b] $\sum$ = (number of ratings) × (weighting) per category

a high importance regarding the spread of information on PF. Agricultural events such as field days, exhibitions and trade fairs, seminars or workshops were considered important in this context as farmers use these opportunities to exchange their knowledge. Advertisement and the internet were considered to be of medium importance. In the context of PF, the Internet is merely used as a resource for detailed research and for exchanging experiences in agricultural blogs and portals. Although the impact of demonstration farms was considered high in this context, the participants could not provide concise information on such farms in their region. Less impact was expected from scientific journals in that context.

The importance of different media to communicate with farmers was described as follows (Table 6). Phone calls, e-mail, farm visits and websites play an important role while the use of fax and letter post are decreasing. However, many stakeholders mentioned that e-mail services are still not established in the farm context. Phone calls are often preferred by farmers because answers are immediate and confidential. Experts further stated that the regional infrastructure usually provides internet, but some rural areas do not offer broadband connections.

The internet is generally considered important for the distribution of information technologies (IT) in agriculture. We discussed if farmers would prefer to submit farm

Table 6 Ranking of the importance of different media in the interviewees' company to communicate with farmers ($N = 28$)

Media	Weighting from 0 to 4[a]					$\sum$[b]
	0	1	2	3	4	
Phone	1	2	5	3	11	65
Internet (e-mail)	–	3	10	4	7	63
Visits	4	2	4	5	9	61
Internet (webpage)	6	1	5	4	6	47
Fax	6	7	3	4	4	41
Letter post	5	8	7	3	–	31

[a] Numbers of answers per category; 0 being not important and 4 being very important

[b] $\sum$ = (number of ratings) × (weighting) per category

documents online instead of sending them via letter post or fax. Most experts (17) agreed while several (5) dissented. The disagreeing experts explained that especially senior farmers do not perceive an advantage of online submission and that there is still some resentment against submitting sensitive information through this means. The other experts explained that E-Governance will also increase in the agricultural sector. Some German states already offer online application services for the Integrated Administration and Control System (IACS) and livestock records. IACS is used for farmers' application for direct payments under the Common Agricultural Policy (CAP) of the EU. It is assumed that online submissions will outnumber other forms of application in the near future. Whereas larger farms handle online applications in-house, smaller enterprises and older farmers make use of the assistance of consultants.

Co-operation in precision farming

Within the scope of the study at hand, three different forms of co-operation were taken into consideration:

(1) Joint investment between farmers to use PF machinery on the farm,
(2) Contracting of agricultural services to integrate PF technology into farming practice, and
(3) Outsourcing of certain services such as data processing and interpretation when PF technology is already implemented on the farm.

Joint investment in precision farming

The adoption of PF tools is related to a modernization of farming machinery. In the German case, joint investment of farmers in PF technologies was generally perceived to be not very common, when stakeholders responded to an interval scale in a semantic format (Fig. 1).

As learning costs are high, it is more convenient for farmers to individually specialize in one machine or operation and then offer these services to other farmers. Larger farms, like in eastern Germany, were reported to predominantly own their equipment. As examples for shared equipment, tools for variable rate fertilization, soil sampling, yield mapping and precision guidance were mentioned most often by the experts. They are not needed on a permanent basis and can therefore be shared. Permanent sharing of installed differential GPS (DGPS) antennas was mentioned as a possible co-operation of neighbouring farms.

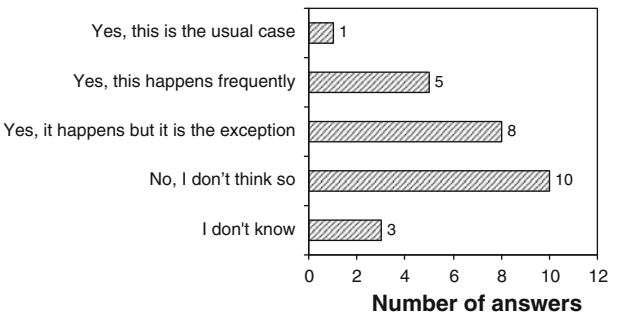

Fig. 1 Do you think that farmers jointly invest in PF technologies in your region? ($N = 27$)

ISOBUS technology, a standard for enhancing the compatibility of agricultural machinery, is regarded as very important in the context of joint investment.

Subcontracting

Agricultural contracting is common in German agriculture. Services such as soil mapping, tillage, fertilization and harvesting are currently on offer. Most interviewees stated that contractors offer PF services in their region. But farmers' demand for these services was described as focusing only on soil sampling and yield mapping. Interviewees agreed that measurements and georeferencing are usually outsourced to contractors. They stated an increasing demand for these services within the next 10 years. However, selling yield maps was described as problematic. Farmers accepted this service when the technology was introduced and the service was offered for free, but rejected it in the following years. There are difficulties with processing the cartographic information and economic benefit from yield mapping.

Especially small farms were considered to increasingly outsource PF tasks because they cannot afford the machinery, but still need to reduce input costs. Integrated software solutions that solve compatibility problems are eagerly anticipated. The interviewees expected contractors to be compelled to develop PF competencies in order to stay in the market. The auto guidance system was perceived as a first step towards the adoption of PF technologies for both farmers and contractors.

Contractors who manage the fields of several individual farms need different PF tools and software solutions than managers of single farms. Contractors may achieve a comparative advantage by offering site-specific field services that allow for reduced input costs for fertilizers and pesticides. They are further enabled to document their work via application and harvest maps. PF technology can therefore be used to support co-operation between farmers and contractors. The joint usage of GPS auto guidance data by farmers and contractors was discussed as an example. This would allow both operators to follow the same track lines for different operations. Beneficial aspects such as the possibility to carry out sensitive tasks by night and to reduce soil compaction may be achieved. A maize harvester of a certain contractor may then follow the same field track as did the farmer when drilling the seed.

Outsourcing of data processing and interpretation

In Germany, most interviewees stated that PF data is usually analysed outside the farm. Time and knowledge constraints were considered as the main reasons for data outsourcing. Consultancy and the processing of application maps were reported to be widespread. In many cases, these services are provided by the companies that sold the technology to the farm. Interviewees further stated that data outsourcing is a matter of trust and a sensitive issue. Personal ties with consultancies are regarded as crucial in this context.

The impact of farm sizes on forms of communication and co-operation in PF

A majority agreed that large farms (>500 ha) use different strategies to inform themselves about PF than smaller ones and forms of co-operation differ depending on farm sizes. Joint investment or use of PF equipment and the relationship with agricultural consultants and technology firms was discussed in that context.

Small farms were reported to be mainly connected to their local agricultural consultants with whom they tend to have personal ties. Weekly agricultural newspapers were regarded as very important for spreading information. Farm equipment is purchased at local resellers who were described as being often reluctant about PF. The relation between farmer and reseller is characterized by mutual trust and regarded as the only way small farms can get special offers for they rarely buy in bulk. Managers of small farms were perceived to be more interested in governmental advisory services, co-operation with the farmers' union and grass-roots information networks. Equipment needs for smaller farms differ from the machinery used in large companies. Joint investments are considered as an option for smaller farms but outsourcing of field management tasks is more probable.

Large farms are able to afford professional consulting and make use of different networks including international experience exchange groups. They possess resources to participate in pilot projects and can thereby benefit from up-to-date knowledge. Farm managers were described as entrepreneurs who rarely go to the fields themselves. Information gathering on these farms is intense. Staff members are sent to training courses and exhibitions. Some farms had their own research and development sections. Large farms tend to act on a supra-regional or even international level. They welcome service providers and companies regarding technological innovations, specific solutions and prices. Internal division of labour includes specialized staff for field and livestock management, administration, purchase, trade and technologies. As farm data has to be used by different employees, farm staff were perceived as being more familiar with data management. Industry seems to be more attentive towards larger companies offering them long term service contracts and special services. Consultants are faced with high expectations as company employees are highly skilled and consultants can easily be exchanged. It was stated that large companies usually do not have as much contact with their neighbours as compared to smaller farms. They tend to have close relations with similar companies no matter where these are located.

Discussion

Adoption of precision farming in Germany, the Czech Republic, Denmark and Greece

PF was considered to be an important topic for farmers in Germany, the Czech Republic and Denmark. A survey by Reichardt and Jürgens (2008) revealed that most German farms that are involved in site-specific crop management are located in eastern Germany. In Greece, only a few farmers who were described as young, well-trained professionals showed interest in the topic. This finding can be explained by a study of Daskalopoulou and Petrou (2002) who grouped Greek farms in three categories: "subsistence farms", "survivalist farms", "productivist farms ". The first two groups engaged little hired labour and often only worked part-time in farming. Applying these categories, we may consider that only the full time "productivist" farmers operating with high percentages of mechanisation, rented land and hired labour would allow for the broad adoption of PF. This group was described as a minority.

The average farm size in the studied regions seems to correlate with the perceived regional spread of site-specific farming. PF is more likely to be adopted on larger farms than on smaller ones. We may therefore conclude that the adoption is highly dependant on farm sizes that allow for economic benefits due to site-specific farming. These findings are reflected in the literature (Daberkow and McBride 2003; Pedersen et al. 2004; Reichardt

and Jürgens 2008). Some scientists even calculated the farm sizes necessary for the profitability of site specific tools (Knight and Malcolm 2007; Takacs-Gyorgy 2008). It was expressed by an interviewee from Greece that predictable increases in farm size, either through renting land or outsourcing field operations, could provide major impetus to the adoption of PF in this country.

But farm sizes are only one indicator among others. According to Rogers (2003), the success of innovations depends on certain criteria: advantages over traditional techniques, materials or behaviours; high compatibility with existing values; "low complexity"; the possibility to try out the innovation and easily observe its benefits. Our study revealed that these criteria are not always met by PF. The advantage of PF compared to traditional techniques depends to a large extent on the users' skills. This problem is well known. Pedersen et al. (2004) demonstrated in a study in Denmark that although yield and soil mapping were implemented by 80–90% of the interviewed farmers, less than 20% found yield maps really useful. Compatibility problems with PF machinery were frequently reported from the participating experts in the present study and literature (Pedersen et al. 2004; Reichardt and Jürgens 2008). Observability of benefits in PF is difficult to manage as demonstration farms, where farmers can observe the functioning of different tools, were hardly reported by the interviewees. Many participants stated that while investment is high, direct economic benefits from site-specific crop farming do not accrue quickly and often remain uncertain.

Communication in precision farming

Peers, agricultural technology firms and agricultural consultants, professional literature and agricultural fairs are the most important information sources for spreading PF-relevant information among farmers. While in Germany the farmer union was not considered too important for the adoption of PF, the Danish farmer union plays a decisive role in this context. This is due to the reason that they offer agricultural extension on approx. 90% of the area and thereby have a strong influence on farmers' decision-making. Little importance was ascribed to educational centres in the context of PF adoption. Reichardt and Jürgens (2008) reflect this situation in a study among teachers of professional schools for agriculture in Germany. Although teachers were quite aware of the topic, it was not included in the exams and considered difficult to teach.

Hansen et al. (2005) showed in a study from Denmark that around 76% of the Danish farmers use internet for farming/business purposes. Our findings demonstrate that although E-mail is widely established in the agricultural sector and could slowly substitute letter post and fax, farmers still prefer phone calls because answers are immediately obtained and remain confidential. Participants of our survey expressed, similar to the findings of Batte (2005), that younger farmers catch up more easily with new IT-technologies than their senior peers. It was reported from Greece that the importance of the internet as an information source for PF increases when specialized advisors are rare and little professional literature on the topic is available.

Several web services are already established in the agricultural sector. We highlighted their role in communicating with authorities. In Germany and Denmark, a major part of the communication between farmers and authorities (e.g. application forms, reporting for subsidies) is already internet-based. The department of agriculture of the Czech Republic even provides a web portal (www.farmar.mze.cz) to store agricultural field data. Spilke and Zürnstein (2005) discussed the possibilities of online area indices in the context of encouraging communication between the production and supply chain. But our findings

showed that many farmers may fear data misuse and exaggerated surveillance of individuals during their working day. We therefore assume that web services will facilitate the future adoption of PF. We also conclude that relationships of mutual trust or obligatory compliance are essential to stimulate the spread of web-based services in the sector.

Co-operation in precision farming

While similar adoption patterns were reported from Germany and the Czech Republic, our participants from Denmark explained that recently, farmers started to jointly employ farm managers to run several farms together. This process leads to a "virtual" increase in farm size that may favour PF adoption in Denmark in the near future.

Contractors in Germany are dominant in areas where livestock farming prevails and farmers try to outsource field operations. In 2006, about 3000 agricultural contractors operated full time throughout the country. Their mean number of clients was 110 (BLU 2009). The economic opportunities for PF are actively discussed by this group. Interviewees from Denmark and the Czech Republic stated that in their countries, contractors will greatly widen their PF services, too. The "Danish Field Database" (http://www.landbrugsinfo.dk/Sider/Startside.aspx- in Danish) will allow access to third parties and may be later compatible with PF datasets. In the Czech Republic, many farms have already purchased their own PF machinery and started working as contractors for others. Some interviewees from Greece reported that no PF services were offered by contractors in their region.

Schwaiberger (2004) stated that machinery rings, contractors and specialized service providers are the most capable practitioners of PF. They are more likely to be in need of software solutions than single farms. They further have the capacity (1) to specialize in machinery, services and staff; (2) perform centralized data processing and (3) offer data-based consultancy. Our findings support these arguments and lead to the assumption that contractors will play a decisive role in the adoption of Precision Farming in Germany, the Czech Republic and Denmark in the near future.

Data processing for the development of site-specific application maps is a specific cost factor in PF (Robert 2002). Wendt et al. (2004) demonstrated in a literature review that information technology (IT)-outsourcing was little addressed in the agricultural sector and that contractors often only employed staff with little IT knowledge. A study by Soerensen et al. (2002) revealed that only 12% of the interviewed farmers would like their data to be stored outside the farm. Wendt et al. (2004) explained farmers' reluctance towards an online area index that was offered by a private service provider. They described farmers' unwillingness to buy licences for programmes that are not installed on their farm computer. He further mentioned that farmers were highly sceptical of centralized data storage while they did not acknowledge the advantages regarding data security. We may assume that IT-outsourcing in PF is frequently practiced. But data security is still a problem. We may highlight the importance of mutual trust for processing farm data by third parties. This argument is supported by an example from Denmark, where PF data is processed by the Danish Advisory Service. This service is run by The Danish Farmer Unions and The Danish Family Farmers Association that cover about 95% of the 66 000 Danish farmers. We assume this service to be highly trusted by farmers and therefore conclude the Danish Advisory Service to be an important promoter of PF.

Compatibility problems between different PF tools were frequently addressed by the survey participants as well as in the literature (e.g. Zhang et al. 2002). Auernhammer (2001) stated that industry favoured closed systems to gain competitive advantages. This

behaviour of agricultural technology firms was also criticized by the interviewees of the present study. In this context, we may refer to the actual developments in AgroXML (www.agroxml.de) and the ISOBUS standard. These are "joint efforts" of global players to meet certain standards in agricultural technology and encourage system compatibility. We consider this development to stimulate data outsourcing and co-operation in PF and thereby encourage PF adoption.

The impact of farm size on forms of communication and co-operation in PF

As most interviewees and the literature highlight the importance of farm size for the adoption of PF, we may consider contractors and extensive crop farms as principal adopters of PF. We showed that large and small farms apply different information, purchasing and co-operation strategies. Literature on adoption (Rogers 2003) suggests that larger farms tend to be more innovative. They are in a better position to overcome the economic barriers (farm size, specialization, etc.) that prevent the adoption on smaller farms. Large farms employ specialist staff, distribute responsibilities and may further calculate the costs for the in- or outsourcing of PF technology more easily than smaller farm units. We stated that large farms are offered better service packages by the industry. They may benefit from a combination of tools e.g. variable rate application combined with soil mapping and yield monitoring. Their co-operation strategies are more directed towards consultants and contractors. Reichardt and Jürgens (2008) listed the "wish to use modern technology" as one of the motivations expressed by German farmers when asked about reasons for PF adoption. Small farms preferably opt for individual and independent tools such as the N-Sensor. Joint investments and other agreements to share PF equipment were mostly regarded as individual solutions for smaller farms and not considered very common.

Conclusion

This study reflects the critical views of different agricultural stakeholders on the adoption of precision farming in Germany and other EU countries. Social aspects such as forms of communication and co-operation were evaluated in that context.

We assume that satisfied practitioners of PF, agricultural technology firms and private consultants are the most important promoters of site-specific farming in Germany, the Czech Republic and Denmark. For stimulating the adoption of site-specific farming technology, professional literature, exhibitions and field days are of major importance. Communication habits in agriculture may change in the near future due to a need for exchanging increasing amounts of data. Web services and e-mail play an increasing role. In Germany and Denmark, communication between farmers and authorities could shift towards online technologies within the next 10 years. We assume that this process is slower in Greece. It may increase between farmers and consultants or contractors. But farm data is considered sensitive and fears of data misuse are widespread.

We showed that farm sizes influence the communication and co-operation patterns of agricultural enterprises. While large farms employ specialized staff and preferably own their technology, joint investment in site-specific technologies are an option for smaller farms. Farmers frequently operate as contractors themselves to use their PF machinery to their full capacity. The role of contractors in PF is only marginally covered in the literature. We consider agricultural contractors as a major driving force behind PF in the next

5–10 years, especially in areas of small farm sizes or high concentration of livestock farming. Contractors, who usually operate with modern technology and due to scale effects, have the possibility to employ specialized staff. There is a tendency towards offering field services and consultancy at the same time. Industry will have to increasingly face the requirements of this group regarding compatibility, software solutions and data management.

Since exploratory research was exploited to first study the communication and co-operation patterns in PF, a more in-depth study should be conducted to prove the outcome of this paper. Special interest should be given to the particular role of contractors in PF in Europe that has shown a low adoption of PF. The particular means of communication and co-operation among contractors, farmers and the industry should be examined in order to enhance the adoption of PF.

Acknowledgements This project was part of the collaborative research project FutureFarm. The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007–2013) under grant agreement no 212117. This publication does not necessarily reflect the European Commission's views and does not anticipate the Commission's future policy in this area. Its content is the sole responsibility of the authors. The authors would like to thank all participants of the survey. Special thanks are given to Jörg Pilz for the technical assistance as well as to Armin Werner, Frank Dreger and Edward Nash for providing contacts to potential interviewees and overall project management and to Markus Kienscherf and Ingo Zasada for proof reading and comments.

References

Allaire, G., & Boiffin, J. (2004). Innovation and development: Intensification/disintensification paradigms—Reflections from French experience. In A. Cristóvão (Ed.), *Proceedings of the sixth European IFSA symposium (2)* (pp. 517–525). Vila Real, Portugal.

Atteslander, P. (2008). *Methoden der empirischen Sozialforschung* [Methods of empirical social research]. Berlin, Germany: Erich Schmidt Verlag GmbH & Co.

Auernhammer, H. (2001). Precision farming—The environmental challenge. *Computers and Electronics in Agriculture, 30*(1–3), 31–43.

Batte, M. T. (2005). Changing computer use in agriculture: Evidence from Ohio. *Computers and Electronics in Agriculture, 47*(1), 1–13.

Bundesverband für Lohnunternemnen (BLU) e.V. (2009). *Wichtige Strukturdaten der Lohnunternehmer 2006* [Important data on agricultural contractors 2006]. http://www.lohnunternehmen.de/wirtschaftsfaktorluleistungsdaten. Accessed 25 August 2009.

Daberkow, S., & McBride, W. (2003). Farm and operator characteristics affecting the awareness and adoption of precision agriculture technologies in the US. *Precision Agriculture, 4*(2), 163–177.

Daskalopoulou, I., & Petrou, A. (2002). Utilising a farm typology to identify potential adopters of alternative farming activities in Greek agriculture. *Journal of Rural Studies, 18*(1), 95–103.

Edwards-Jones, G. (2006). Modelling farmer decision-making: Concepts, progress and challenges. *Animal Science, 82*, 783–790.

Fountas, S., Blackmore, S., Ess, D., Hawkins, S., Blumhoff, G., Lowenberg-DeBoer, J., et al. (2005). Farmer experience with precision agriculture in Denmark and the US Eastern Corn Belt. *Precision Agriculture, 6*(2), 121–141.

Fuchs, C., Kasten, J., & Bauer, U. (2006). Perspektiven für Managementgesellschaften im Marktfruchtbau am Beispiel Nordostdeutschlands. [Perspectives for management bodies/companies in crop farming at the example of North East Germany]. In Landwirtschaftliche Rentenbank (Ed.) *Organisatorische und technologische Innovationen in der Landwirtschaft* [Organizational and technological innovations in agriculture], Schriftenreihe 21 (pp. 57–96). Frankfurt am Main: Landwirtschaftliche Rentenbank, Germany. http://www.rentenbank.de/cms/dokumente/10011465_262637/f118faa2/Rentenbank_Schriftenreihe_Band21_.pdf. Accessed 25 August 2009.

Griffin, T. W., Lowenberg-DeBoer, J., Lambert, D. M., Peone, J., Payne, T., & Daberkow, S. G. (2004). *Adoption, profitability, and making better use of precision farming data*. Staff Paper #04-06. USA: Department of Agricultural Economics, Purdue University.

Hansen, J. P., Hansen, N. F., Hørning, A., & Schultz, E. (2005). landmand.dk—A personal portal for farmers. In J. Boaventura Cunha & R. Morais (Eds.), *Proceedings of the EFITA/WCCA 2005 joint conference, 5th conference of the European Federation for Information Technology in Agriculture, Food and Environment and the 3rd World Congress on Computers in Agriculture and Natural Resources*, 25–28 July 2005, Vila Real, Portugal. http://www.lr.dk/landbrugsinfo/diverse/landmanddk_-_a_personal_portal_for_farmers_med_toptekst.pdf. Accessed 25 August 2009.

Knight, B., & Malcolm, B. (2007). *A whole-farm investment analysis of some precision agriculture technologies*. Paper presented at the 51st Annual Conference of the Australian Agricultural and Resource Economics Society, Queenstown, NZ. http://ageconsearch.umn.edu/handle/10406. Accessed 25 August 2009.

Lamb, D. W., Frazier, P., & Adams, P. (2008). Improving pathways to adoption: Putting the right P's in precision agriculture. *Computers and Electronics in Agriculture, 61*(1), 4–9.

Leeuwis, C. (2004). Changing views of innovation and the role of science. The 'socio-technical roots stem' as a tool for identifying relevant cross-disciplinar research questions. In A. Cristóvão (Ed.), *Proceedings of the sixth European IFSA symposium (2)* (pp. 773–782). Vila Real, Portugal.

Mayring, P. (2000). *Qualitative Inhaltsanalyse. Grundlagen und Techniken* [Qualitative content analysis. Basics and Techniques]. Weinheim, Germany: Deutscher Studien Verlag.

Meuser, M., & Nagel, U. (1991). ExpertInneninterviews—vielfach erprobt, wenig bedacht. Ein Beitrag zur qualitativen Methodendiskussion.[Interviews with experts: Often used, seldom discussed. A contribution to debates on qualitative methods]. In D. Garz & K. Kraimer (Eds.), *Qualitativ-empirische, Sozialforschung. Konzepte, Methoden, Analysen* [Qualitative-empirical social research. Concepts, methods, analysis] (pp. 441–471). Opladen, Germany: Westdeutscher Verlag.

Pannell, D. J., Marshall, G. R., Barr, N., Curtis, A., Vanclay, F., & Wilkinson, R. (2006). Understanding and promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture, 46*, 1407–1424.

Patton, M. Q. (2002). *Qualitative research & evaluation methods*. Thousand Oaks, CA, USA: Sage Publications.

Pedersen, S. M., Fountas, S., Blackmore, B. S., Gylling, M., & Pedersen, J. L. (2004). Adoption and perspectives of precision farming in Denmark. *Acta Agriculturae Scandinavica, Section B-Soil and Plant Science, 54*(1), 2–8.

Reichardt, M., & Jürgens, C. (2008). Adoption and future perspective of precision farming in Germany: Results of several surveys among different agricultural target groups. *Precision Agriculture, 10*(1), 73–94.

Robert, P. C. (2002). Precision agriculture: A challenge for crop nutrition management. *Plant and Soil, 247*(1), 143–149.

Rogers, E. M. (2003). *Diffusion of innovations*. New York: The Free Press.

Schwaiberger, R. (2004). Software Lohnunternehmer [Software contractors]. In A. Werner & A. Jarfe (Eds.), *Precision agriculture: Herausforderung an integrative Forschung, Entwicklung und Anwendung in der Praxis* [Precision agriculture: Challenges for integrative research, development and practical application] (pp. 321–338). Bonn, Germany: KTBL-Sonderveröffentlichung 038. http://www.preagro.de/Veroeff/preagro_Endbericht_SoftwareLohnunternehmer.pdf. Accessed 25 August 2009.

Silva, C. B., Do Vale, S. M. L. R., Pinto, F. A. C., Muller, C. A. S., & Moura, A. D. (2007). The economic feasibility of precision agriculture in Mato Grosso do Sul State, Brazil: A case study. *Precision Agriculture, 8*(6), 255–265.

Soerensen, C. G., Fountas, S., Blackmore, S., & Pedersen, H. H. (2002). Information sources and decision making on precision farming. In P. C. Robert, R. H. Rust, & W. E. Larson (Eds.), *Proceedings of the 6th international conference on precision agriculture* (pp. 1763–1775). Madison, USA: ASA, CSSA, SSSA & ASAE. CD-Rom.

Spilke, J., & Zürnstein, K. (2005). Webservices—Beschreibung eines Ansatzes zur Anwendungskopplung und von Nutzensmöglichkeiten im Agrarbereich [Web services—Description of an approach for joint application and its exploitability in the agricultural sector]. *Zeitschrift für Agrarinformatik, 2*, 33–40.

Sylvester-Bradley, R., Lord, E., Sparkes, D. L., Scott, R. K., Wiltshire, J. J. J., & Orson, J. (1999). An analysis of the potential of precision farming in Northern Europe. *Soil Use and Management, 15*(1), 1–8.

Takacs-Gyorgy, K. (2008). Economic aspects of chemical reduction on farming: Role of precision farming—Will the production structure change? *Cereal Research Communications, 36*, 19–22.

Wendt, K., Spilke, J., Thiede, J., & Piotraschke, H. (2004). Outsourcing von IV-Aufgaben landwirtschaftlicher Unternehmen—Einordnung und Nutzungsperspektiven [Outsourcing information processing

tasks of agricultural enterprises—Classification and potential use perspectives]. *Zeitschrift für Agrarinformatik, 2*, 34–42.

Zhang, N., Wang, M., & Wang, N. (2002). Precision agriculture—A worldwide overview. *Computers and Electronics in Agriculture, 36*(2–3), 113–132.