ICT in Precision Agriculture – diffusion of technology

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Abstract

Precision Agriculture (PA) is the management of spatial and temporal variability of the fields. This management concept incorporates a range of management as well as ICT tools to assess and treat the variability within the field. The adoption and diffusion of PA is discussed in this chapter. PA has been practiced over the last 15 years mostly in North America and Northern Europe. Despite its promises, PA has not yet managed to be adopted widely by farmers. This chapter's results are based on the findings of six mail surveys, focus groups and personal interviews with PA practitioners in the UK, Denmark and the USA over six years (1998-2003). The information related to ICT adoption in PA is presented, including software and hardware aspects, data ownership, data handling, data interpretation, internet and e-mail use, as well as information preferences to invest and practice in PA. It is a common belief that the use of PA technologies has been tremendously improved over the years. However, findings from these studies showed that lack of agronomic and technical skills are key problems for adopting PA practices and there is an urgent need for holistic decision support systems. Moreover, compatibility between hardware and software, as well as user friendliness and particularly time consumption are for many users a serious impediment for PA adoption.

An overview of Precision Agriculture

Precision agriculture applications and trends

The recent advances in information and telecommunication technologies have allowed farmers to acquire vast amounts of site-specific data for their fields, with the ultimate aim being to reduce uncertainty in decision-making (National Research Council, 1997; Blackmore, 2000). Precision Agriculture (PA) or site-specific crop management can be defined as the management of spatial and temporal variability at a sub-field level to improve economic returns and reduce environmental impact (Blackmore et al., 2003). Within the concept of PA the main activities are data collection and processing and variable rate applications of inputs. The tools available consist of a wide range of techniques and technologies from information and communication technology as well as sensor and application technologies, farm management and economics.

PA is intrinsically information intensive, and farmers face many difficulties in efficiently managing the enormous amount of data they collect. They may lack sufficient time or are reluctant to invest the time needed to analyze the data and interpret the information. Additionally, the economic benefits of PA practices have not been proven yet and especially applications such as variable rate nitrogen application and patch spraying (Swinton and Lowenberg-DeBoer 1998; Pedersen 2003).

The first applications of PA around the world started in the early nineties but the initial adoption started at the end of the nineties. Yield monitors connected to a GPS receiver was the first real attempt to conduct site-specific management on their fields and continued with variable rate applications of mainly lime, fertilizer and recently chemicals. Soil sampling has also been also a very important PA application; however the sample size varies among the farmers depending mainly on the soil analysis cost. Sensing devices, such as Electromagnetic Induction (EC) measuring soil structure and water content and the Hydro-Nitrogen sensor, which senses the chlorophyll and automatically adjust the fertilizer dozes, have been very promising, but farmers are still skeptical on their reliability and effectiveness. Finally, remote sensing has recently attracted the focus on many research projects, while commercial companies and advisors are using aerial photos or satellite pictures to relate them with yield potential, nutrients' deficiencies and stresses.

When commercial yield mapping started, it was expected that parts of a field would constantly yield well, while other parts would produce poor results. This was due to the assumption that permanent soil characteristics would always behave in the same way each year. Therefore, many researchers have devoted their time to develop trend maps, both spatial and temporal over a number of years to be able to show these trends in the fields. While these expectations, the spatial trends that were expected to become more stable over time, Blackmore *et al.* (2003) proved that spatial trends over 6 years in four fields in the UK became less pronounced than the variability found in individual years. This was a significant reversal of existing wisdom and has profound implications on how spatial and temporal variability should be managed. Each year, individual yield maps often show significant spatial variability but they appear to cancel out each other over time. A major implication of these findings is that the treatment of fields based entirely on historical yield trends can no longer be supported. The corollary of this is that management should now concentrate more on managing the variability within one year. In this matter, the design of DSS should incorporate such factors. The lack of DSS in PA as the main impediment in adopting PA has been also supported by a wide range of researchers (e.g. McBratney, et al., 2005).

Global adoption of Precision Agriculture

The global adoption of yield monitors has been predominated in North America, Europe and Australia but countries like Argentina, Brazil and some East Asian countries have also adopted PA practices. Nowadays, the adoption rate is in stationary state, mainly since yield increases are not well documented to cover the cost of equipment, together with the agricultural commodity prices that are continually falling. We have seen similar trends with other high-tech technologies. It took for instance about 10 years to adopt the Internet and mobile phones among the large majority of consumers. In this respect we might see a similar or even slower adoption pattern and a reduction in production costs of PA technologies in line with these technologies.

Technical enthusiasts were the first to adopt PA practices. In the USA, about 90% of the yield monitors in the world are operating there. The main crops that use PA practices are corn, soybeans and recently cotton. Griffin et al. (2004) have referred to specific numbers of yield monitors, soil sampling, remote sensing and variable rate applications in the USA and around the world. In the USA, it is estimated that in 2003, there should be around 45.000 combines equipped with yield monitor where about 46% of corn, 36% of soybeans and 15% of wheat had harvested with a combine equipped with the yield monitor (Lowenberg-Deboer, 2003). In Europe, the adoption rates are far smaller than in the USA. It is assumed that about 400 Danish, 400 British, 300 Swedish and 200 German farmers have adopted yield monitors by the year 2000 (LH-technologies, 2001).

A general trend is that larger farmers, with more than 300 ha, tend to be the first to invest in the new technology, whereas small farmers are more reluctant to invest in GPS equipment (Pedersen, 2003). A nation wide survey in America concludes that the adoption of PA technologies has been related to farm size and large farmers are the first to adopt (Daberkow and Mcbride, 2001). Compared with other farm technologies such as GMO's (Genetical Modified Crops), the adoption of PA practices has been relatively slow (Daberkow, 2001). The main reason is that PA is time demanding approach, while GMO crops are time-saving, which is highly appreciated by farm managers. On top of that, the techniques and the management skills to use the GM-crops was already established at the launch of the seeds, while in PA, the agronomic and economical interpretation as well as the data analysis was still in its infancy, when the first practices were used by farmers. It seems however, that the adoption rate has been a little faster in North America compared to Europe. A reason for that is likely to be larger farm sizes and specialisation in certain cash crops. Whereas the European crop producers traditionally have been smaller in terms of farm size and less specialised compared with their American colleagues.

The adoption of yield monitors and especially satellite pictures have been relatively popular in the US compared with Europe – probably because of large areas with cash crops and less cloudy days in the landlocked areas. Variable treatment with fertilizers and weed detection seems however to be well adopted in Europe. In the US, the application of yield monitors without GPS positioning is a rather common practice in most states (Pedersen 2001), where it is estimated that only one third of the yield monitors are connected to a GPS receiver.

Innovation and diffusion aspects of Precision Agriculture

The development from the first idea to practical application of a new technology can be defined as a process in three steps: Invention, innovation and diffusion. Invention usually relates to the first idea of using a new technique. In PA, the invention was the first research trials to map the site-specific yield with yield meters on the field according to longitude and latitude using the GPS-system. A technical innovation is defined as the first commercial application or production of a new process or product (Freeman 1974). Innovation has also been defined by Nielson and Winter (1974) as a change of decision rules to fit with the surrounding requirements (Coombs et al. 1987). An innovation includes all activities that create technological change. It may depend on several activities such as research and development, product design, process engineering, distribution and marketing. Diffusion however, is related to the wide spread adoption of an innovation among potential users. What causes a successful diffusion and how can we expect a general adoption among the users?

The primarily parameters in the process of diffusion are the population of potential adopters and their process of decision making. Moreover, the interacting flow of information between the adopters and manufactures has an impact as well. It also seems evident that the size of the potential users and their economic capabilities have an impact on diffusion. Moreover, studies have shown that the complexity of the innovation might influence the diffusion and adoption speed and the general impact on productivity among adopters.

S. Davies has developed a model that characterises two different types of innovation (see figure 2). The first model is the A group which illustrates the labour productivity for technologies that are fairly simple. The learning effects of this simple technology is initially very high but after some time the productivity gains from that technology will be limited implying that the curve falls and stabilises at a given level.

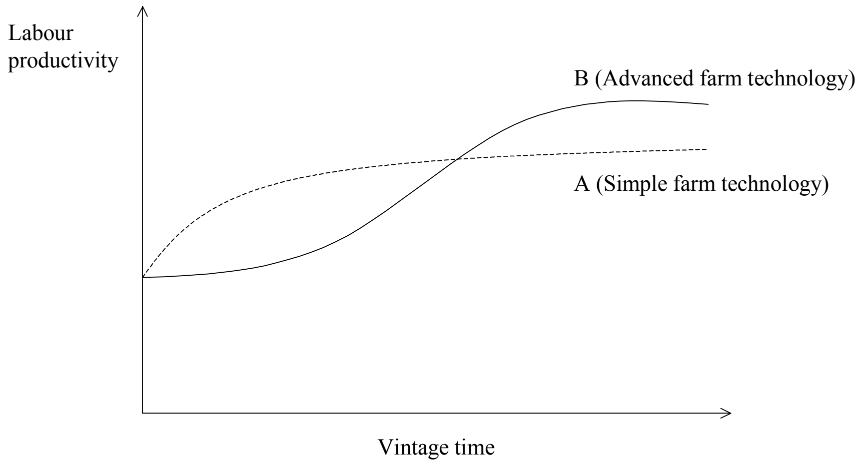

FIGURE 1. Labour productivity for group A and B innovations
Pedersen 2003 based on S. Davies (1979).

The other group of technologies (group B) be can be characterised as fairly complex. It requires some time to be familiar with the technology and the productivity gains from that technology will take place at a much later stage compared with the technologies in group A. Methods of site-specific application is likely to follow the process as described in group B. The concept of PA is highly technical and requires skills that go beyond technical knowledge. It requires an understanding of the interrelated impact that various data and information have on yields, crop quality and nutrient leaching. The adoption and diffusion of various techniques for practising PA is therefore dependent on the provision of advice and technical as well as biological management guidelines.

Griffin et al., 2004 argued that it is important to understand farmers' reasons for non-adoption first and then try to help the farmers address their questions to make them more confident adopting the technologies to use. A number of detailed studies refer to the profitability of PA (Lambert and Lowenberg-Deober, 2000) and reasons for non-adoption (Kitchen et al., 2002; Wiebold, 1998).

ICT adoption aspects in Precision Agriculture

This section addresses the findings of six mail surveys, focus groups and personal interviews with key stakeholders of PA in the UK, USA and Denmark over the last six years (Pedersen, et al., 2001, Pedersen, et al., 2004, Fountas et al., 2005). The information related to ICT adoption in PA was extracted and is presented here. Additionally, a global search on ICT issues in PA has given the state-of-the-art in this domain. The issues presented here are innovation and diffusion of PA, demographics, PA software, data ownership, data handling, data interpretation, Internet and e-mail use and information sources to invest and practice PA.

Demographics of Precision Agriculture

The practitioners of PA tend to belong to a younger generation and they cultivate larger areas than the average farmer. The average age of the Danish respondents was 43 years old and 46 for the American respondents (Fountas, et al, 2004). In Denmark, the average age of farmers in 2000 was 52 years old (Danish Agricultural Council, 2000) and in the USA in 2002 was 55,3 (USDA, 2002). The average cultivated area per farm in Denmark and the US Corn Belt was 422 ha and 790 ha respectively (Fountas, et al, 2004). The average cultivated area of the survey group was considerably higher than the average farm holding in both Denmark and the US. In comparison, an average farm area in Denmark is about 50 ha (Danish Agricultural Council, 2000) and the average farm holding in the USA is about 178 ha, while in the State of Indiana the average is about 102 ha (USDA, 2002).

Precision Agriculture software

There are several types of PA software. The most common are software to generate maps (e.g. yield, soil); software to filtering collected data; software to generate variable rate applications maps (e.g. for fertilizer, lime, chemicals); software to overlay different maps; and software to provide advanced geostatistical features. There are a few companies that operate world-wide and provide integrated software packages from generating all different types of maps, having statistical analysis tools and also record keeping. The machinery companies that provide yield meters also offer software to generate yield maps and fertilizer companies provide software to generate variable rate applications maps. Finally, universities as well as regional companies provide a range of software for filtering of data, advanced statistical tools and record keeping incorporating PA data. Some of the packages are very complicated for farmers to use and they are fairly expensive, while some others are considerably simpler and cheaper with fewer options.

According to interviews with farmers about their perceptions on the available PA software, they believe that the software has been improved tremendously over the last 5 years. The packages are more user-friendly and have many options for the farmer to use. However, there are still problems related to data transfer between farmers, and between farmer, co-op and consultant. To overlay maps, mainly soil and yield maps, is also a difficult task so far. One farmer mentioned that the PA software has to be as fast and easy as the "Microsoft Windows programs". Other farmers mentioned, that just to keep up with new products was a significant task.

The majority of the PA farmers who do yield mapping own the software themselves, while only a small number of farmers who practice variable rate applications own the software. About 65% of the respondents who did yield mapping own the software in Denmark and 90% in the US Corn Belt. Some 48% of the Danish respondents who have used VR fertilizer applications own the software for VR applications and 38% of the American respondents (Fountas et al., 2004). Danish respondents own less software for VR applications than hardware (48% own the software and 71% the hardware), while the American respondents own more software than hardware (38% own the software, 27% the hardware) (Fountas et al., 2004). In the Danish case, this may be explained by the fact that local advisors produce the application maps for farmers and the farmers carry out the PA applications themselves; while in the US Eastern Corn Belt, the fertilizer dealers or co-ops provide these services from the production of maps to the VR applications.

Presentation and storage of PA data

The majority of the PA practitioners print out the yield maps and soil maps on paper and only a marginal number of farmers look at the papers on the screen. Yield data are mainly saved on the farmers' personal computers, while soil data are saved either on farmers computers or on co-ops or local advisors' computers, who carry out the soil sampling. An important issue is the backing up of data and only about 49% of the Danish and 53% of the US Corn Belt farmers make back ups of the yield data and 17% of the Danish and 26% of the American respondents make backups for the soil data (Fountas, et al, 2004). The low percentage making backups could be due to lack of awareness regarding data safety among farmers. Further research should examine more specific reasons and potential actions.

Data ownership and data handling

Farmers are very reluctant in entrusting the data storage and data protection to entities outside the farm. Eighty-one percent of the Danish and 78% of the US Corn Belt farmers indicated that they would prefer to store the data themselves, while 88% of the American respondents would prefer not to store the data in a shared Internet-based database (Fountas et al., 2004). This is an interesting indication on contrary to many potential benefits from data exchange and benchmarking on a regional level (National Research Council – Board on Agriculture 1997). Regardless these figures commercial companies have recently started to provide Internet-based services to farmers, mainly in the USA and Australia. Farmers can send their data to the companies through e-mail and the companies can generate the maps, produce variable rate application maps, as well as agronomic recommendations.

The major problem in handling PA data (fig. 2) is the time requirement, where 74% of the Danish and 69% of the American respondents found data handling too time consuming. Additional surveys have mentioned time requirement as one of the main impediment to PA adoption (Pedersen et al. 2001; Smith, 2002). Future developments of PA must focus on a better way to handle the large amount of data in order to limit the amount of time for handling the data. More specifically Smith 2002 gave an analogy to PA with biotechnology, where the adoption of biotechnology has been considerably faster than PA. She referred to PA as being time consuming for farmers, while biotechnology is time saving, which is very important in farm management. The American respondents also believed other important factors were lack of technical knowledge and use of software packages. Danish farmers show a similar attitude towards lack of technical and agronomic knowledge, as well as use of software and data transfer (one third of the respondents mentioned all these factors).

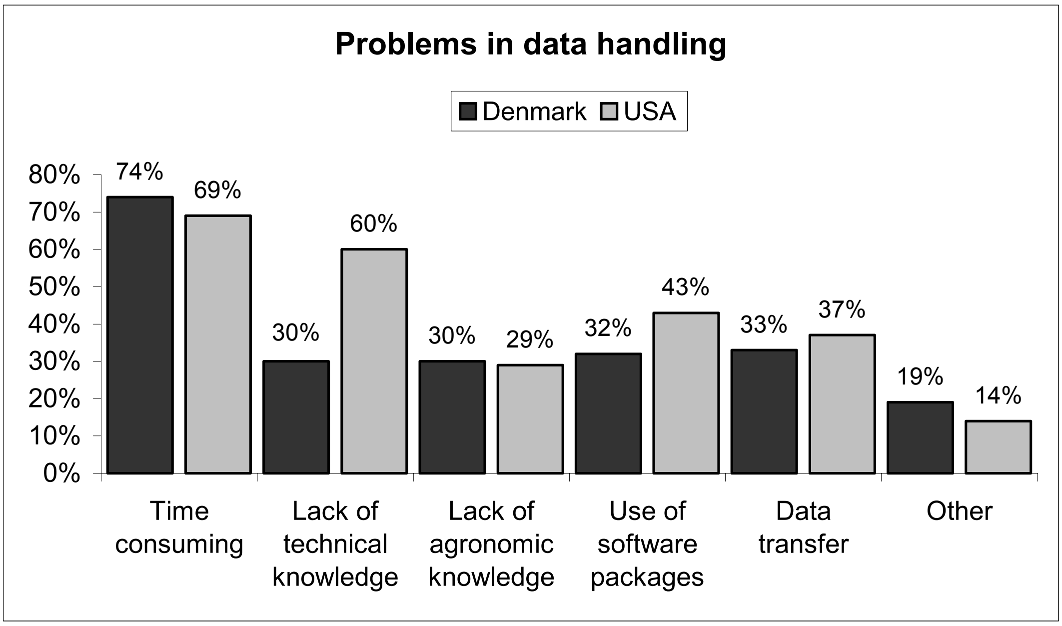

Fig. 2. Farmers concern and problems about PA data handling
Fountas et al., 2004

Interesting indications were drawn comparing the responses to the time requirements and lack of technical knowledge by age, years of experience with PA and acreage. The results showed that only years of experience had an influence to responses to time requirements. The American respondents, with 3-5 years of PA experience composed the largest proportion who said that PA was too time consuming; whereas farmers with the least amount of experience found it less time consuming. This is logical, as the first two years of practicing PA is experimental and from the third year farmers start to reasoning about the causes of variability among the accumulated maps. In addition, in the American survey, respondents' age showed to have an influence on responses to the lack of sufficient technical knowledge. Therefore, the youngest category (20-29 years) had the smallest proportion that said insufficient technical knowledge is a problem (17%) and the largest proportion was among the age group (50-59 years) that 63% of the respondents who said insufficient knowledge was a problem.

From the personal interviews, one American farmer suggested that "a farmer should have a good structure, good understanding and good record keeping for data tracking, when he first starts collecting data, otherwise, it would be a big mess and the data would not be easily accessible and easy to analyse. The best way of storing the yield and soil data is in a raw format, as it will be easier to be analyzed in the future with new software packages and or overlay them together."

Data interpretation

An important issue in dealing with PA data is their interpretation. It is not that complicated to collect site-specific data, but the interpretation of these data has been a difficult task for farmers. An interesting comparison has been between the easiness of interpreting yield data and years practicing PA, in the US Corn Belt (Fountas et al., 2004). About 74% of the respondents who responded that yield maps are "very easy" to be interpreted have used PA for more than 5 years, while 52% of the respondents who answered “difficult” also belonged to that group. Apparently, even farmers who have been collecting yield maps for a number of years did not find yield maps of practical help. It is possible that the aggregation of maps over successive seasons may cause problems due to temporal variations that many farmers cannot explain or there are still many gaps in agronomic knowledge than issues related to the technology.

Compatibility

A general concern among farmers is hardware and software compatibility and to choose the right technical systems for conducting precision farming. It is in principle the hardware compatibility, which is the most vital obstacle for adoption. Hardware is expensive to change and should in principle be mounted on the tractor for up to 10 years. Several companies have tried to develop their own systems based on ISO-standards but often without chosen solutions that are compatible with other brands. In addition, most of the previous electronic systems for precision farming have not been compatible with a traditional windows-platform. Instead the farm equipment manufactures have developed their own software (Pedersen 2003).

Internet and e-mail use

Most respondents in Denmark and US Corn Belt mentioned to use extensively the Internet and E-mail for farm purposes. Only 10% of respondents in both countries have never used the Internet and the majority of them use it daily (about 35%) or weekly (about 32%). High Internet use is consistent with the general observation that farmers who use PA are among the most comfortable with new technologies. Additionally, younger farmers use internet even more on daily basis, as farmers in the age group 20-29, indicated to use the internet for agricultural purposes daily at about 75% in Denmark and 50% in the US Corn Belt (Fountas et al., 2004). However, the PA practitioners, respondents of the two surveys in Denmark and US Corn Belt, showed that they don’t use the internet for PA. The low percentage of those farmers who use the Internet for information about PA may indicate the lack of related web services, and only a small percentage of farmers could recall some PA related internet sites.

Concurrent with the use of Internet for information retrieval, widespread use of e-mail was observed (table 1), where about 90% of the respondents in Denmark and the US Corn Belt have used e-mail. More specifically, Table 1. illustrates the e-mail use for specific agricultural purposes.

Table 1. E-mail use for agricultural purposes

	% Denmark	% USA
Communicate with other farmers	49	60
Communicate with consultants or co-ops	48	53
Communicate with fertilizer dealers/wholesalers	29	24
Subscribe to Ag websites	37	49
Seek information from commercial companies	24	30
Private correspondence	73	76
Other agricultural purposes	10	29

Source: *Fountas et al., 2004*

E-mail is an important means of communication for most respondents. The high rate of e-mail usage can be useful for dissemination of PA information and experience. So far, some companies have established these methods for exchanging information with farmers. In general terms, both Internet and e-mail use show that this group of farmers is among the most technologically advanced in agriculture.

Information preferences for practicing and investing in PA

The information sources to invest and practice PA are quite different among countries, depending on the agricultural structure and the extension or advisory services. In the UK, farmers acquire information about PA from their private agronomist and from machinery manufacturers (Fountas, 2001). In Denmark, machinery manufacturers and local advisors are the main sources to invest in PA, while local advisors, fertilizer dealers and wholesalers are the main information sources to practice PA (Fountas et al., 2004). In the US Corn Belt, the most important sources to invest and practice PA were fertilizer companies, information from other farmers, agricultural consultants and the agricultural press. The Internet contribution to information on how to implement PA was low both in Denmark and the US Corn Belt (Fountas et al., 2004). Figure 2, shows the information sources to practice PA in Denmark and US Corn Belt. Among the Danish respondents, the prominent role of agricultural consultants can be attributed to the extended supportive organisational structure of the advisory service in Denmark. In addition, Danish PA respondents own, to a large extent, their machinery and have a closer relationship with the PA machine dealers. On the other hand, in the US Eastern Corn Belt, commercial services from fertilizer companies, coops and crop consultants are typical used to implement PA.

In 1995, a mail survey conducted by Purdue University with agribusiness specialists and large-scale farmers from the Corn Belt region reported that the most important information sources for PA were agricultural press, university specialists and consultants (Lowenberg-DeBoer and Boehlje, 1996). That shows a shift in the information sources to practice PA in the USA, from public sources, such as press and university specialists, to private sources, such as fertilizer companies and agricultural consultants.

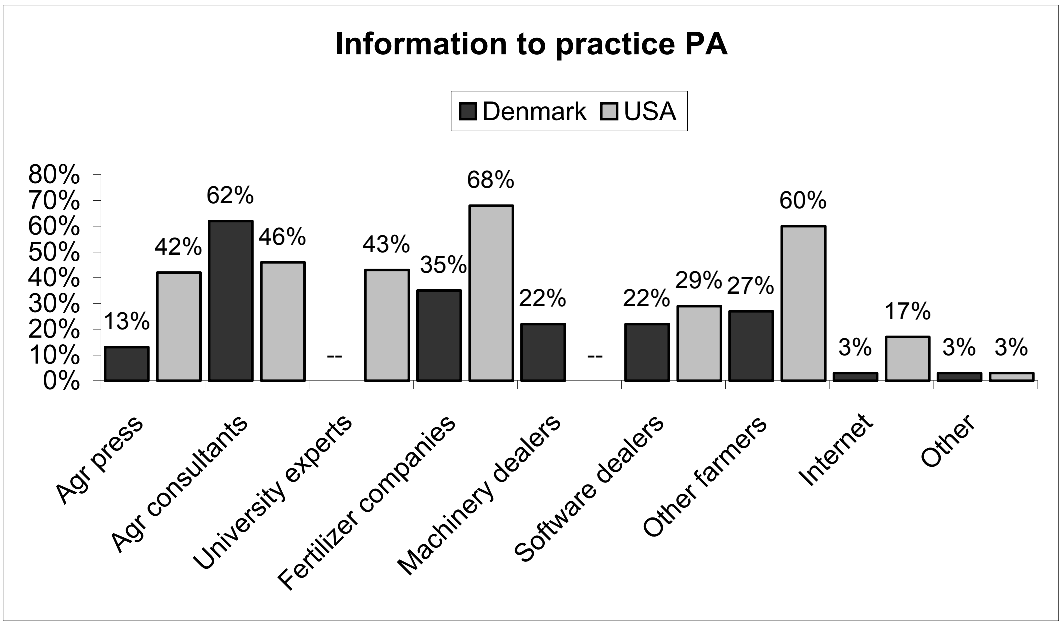

Figure 2. Preferred information sources for practicing PA
Source: *Fountas et al., 2004*

Table 2 demonstrates the satisfaction from different service providers in PA between Danish ands US Corn Belt farmers (Fountas et al, 2004). In the American survey, the satisfaction with university specialists and county extension educators was also assessed. About 41% of the US respondents have never used the service, while of those farmers who have used the service, 77% are satisfied with it. For the university specialists, this result may indicate that more attention needs to be devoted to communicating with a broader group of farmers.

Table 2. Satisfaction from different service providers

	Crop advisors		Fertilizer dealers		Machinery dealers		Software vendors		Hardware vendors	
	%DK	%USA	%DK	%USA	%DK	%USA	%DK	%USA	%DK	%USA
Yes	50	52	23	69	39	31	29	33	50	31
No	26	12	16	16	20	37	16	24	29	25
Not used	19	28	56	9	29	26	44	39	11	37
Don't know	6	8	5	6	12	6	11	4	10	7

Source: *Fountas et al., 2004*

Discussion and conclusions

The objective of this chapter was to better understand how PA practitioners are using the technology. ICT aspects were addressed mainly from the findings of mail surveys and personal interviews in Denmark and the Eastern Cornbelt, in the USA. These ICT aspects inclucded PA software; Internet and email use; data handling, interpretation and ownership; information sources for practicing and investing in PA; as well as satisfaction with PA service providers.

Survey responses indicate that PA users are quite similar in both countries. The PA practitioners found to be a decade younger than the average farmer, cultivating larger farms than the average farm holdings. Growers use essentially the same technology and experience many of the same problems. Most respondents in both countries use the internet and e-mail for farm purposes, but not for PA information. Over three quarters of respondents in both countries printed out yield maps for more than half of their fields. The majority save yield data on their hard disks, and about half make backup copies of the data. In both countries, about 80% would prefer to store the data themselves and they would prefer to avoid internet based data warehouses for storage. However, about 70% in both countries found data analysis too time consuming. Both Danish and American respondents identified lack of technical knowledge and software skill as being key constraints.

Some differences among the farmers in the two countries were also noted. Danish farmers were more likely to own VR equipment than their US counterparts, even though the US farmers had more experience with VR. This can be linked to widespread use of custom operators for PA services in the US. About 70% of US respondents used VR lime, while less than half of Danish farmers did.

While the PA practitioners already use the Internet and e-mail as a part of their daily routine, only a small number of farmers mentioned to use the Internet for PA purposes. Nevertheless, several experts believe that the Internet and downloading of data from external sources will become the future information source in PA. One example is the program from the Danish Advisory Center "eRådgivning", which includes Internet based decision programs among others for irrigation and fungicides. The advantage from using Internet based decision support systems is that farmers will be able to download the latest developments and electronic versions of software packages and recommendations from experts. Moreover, it is possible for the local crop advisor to follow and guide the farmer about his specific field plans and farm operations from a central office (see Thysen 2003). Especially, in PA, the farmer could send his PA maps to his advisors (crop advisor, fertilizer advisor, seed dealer) using e-mail and faster decide the strategies for the next year. With the use of chat programs in the Internet, the farmer with his advisors could also exchange ideas, saving time and money.

In the short run, farmers are not expected to save time using GPS systems and variable rate technologies. With some technologies it might be possible to save time due to better logistics in the process of handling and harvesting the crop. Less overlaps during tillage might also be possible due to very precise handling of farm vehicles on the field, using auto-guidance systems. On the contrary, PA requires that the farmer spend time on analysing data, learning new farming procedures, attending meetings, courses and workshops. An advanced technology often requires time in getting to know the system.

Compatibility between hardware and software, as well as user friendliness are for many users a serious impediment for adoption. Until now, it has been common that tractor manufactures have tried to market their equipment on unique features with special design, hardware devices and even software applications. On the contrary, market-leading manufacturers are also trying to organise standards for hardware equipment to be implemented by other manufacturers. It is important that different manufacturers agree upon ISO-standards at a general level.

It is a common belief that the use of PA technologies has been tremendously improved over the last 15 years. However, farmers have mentioned that they would like to see hardware in the form of "plug and play" and software as easy as "windows applications". At present, it is possible to develop fairly easy connections between different software programs to transfer data. Yearly updates are necessary, which eventually have to be paid for by the users (farmers), who, however, are not accustomed to pay services of this kind. Other studies about implementing IT-technologies have shown that to gain any productivity from IT-technology it is vital that the manufacturers of IT-equipment consider the organisation and management of the IT-technology. It is vital that the "human software" is considered, which includes education and the desire to redefine farm management according to the use of new IT-technology (Pedersen JL 2002).

Until now, there is no complete and sufficient Decision Support System (DSS) software available to lead PA practitioners in transforming the vast amount of data gathered to useful decision making. The need for a software package to support farmers when make decisions, using PA, was already stated in the early years of PA, in 1994, (Blackmore et al, 1994). Nelson et al. (2002) described the use of "discussion support software" to facilitate dialogue with farmers about management practices that are significant or relevant to the decision maker. They argued that this approach is distinct from traditional DSS in that it de-emphasizes the role of technology as opposed to the goal of improving decision-making. The majority of PA software packages deal with the transformation of data to information in the form of recommendations for variable rate applications, limited to tools to manage data in more user-friendly formats. A successful DSS should have the ability to incorporate the farmer's personal experience and management goals to data management, as well as economic risk or model prediction uncertainty under different scenarios, in a user-friendly and interactive way. This still remains a challenge for the researchers in this domain around the world.

In PA terms, a holistic DSS software package should enable the farmer to better plan and manage the field cultivation practices. , Firstly it could help as a guide to understand weather or not invest in PA; Secondly it could provide recommendations for variable rate applications according to available data; and finally, to provide the most profitable application scenarios balancing costs and revenues. The lack of successful DSS in PA may also be explained due to the fact that the first 15 years of PA practice, the research and development was targeted towards the development of electronics and software components, while the agronomic and economical interpretations, as well as data analysis and decision making was falling behind.

The most common source of PA information for US respondents was fertilizer dealers. In Denmark, machinery dealers were the most common source of PA investment information, while farm advisors were the most common source for information on implementation of PA. The importance of machinery dealers in Denmark is probably related to the fact that many Danish farmers own VR equipment, while many US farmers rely on custom services from fertilizer dealers for VR. The role of farm advisors in Denmark is related to the fact that these government supported farm advisory services are much more involved in the day-to-day management of farms than extension or other government services are in the US. The US does not have an agency like the Danish farm advisors. Extension provides information, but usually does not become directly involved in management of individual farms. In the US, agricultural retailers have been aggressive about offering PA services and, as a consequence, play a major role in farmer's use of the technology. The shift from public to private advisory service in US farming is a good sign, which indicates that the PA technology is starting to mature from basic ideas to commercial implementation.

The experiences of Danish and US farmers documented by this survey suggest that if PA is to grow and mature as a standard technology an effort must be made to develop the required skills and reduce time requirements. Respondents identified lack of both agronomic and technical (electronic) skills as key problems. Some of the problems require further research and development in better DSS, especially regarding variable rate nitrogen application. Nevertheless, there is already avaliable knowledge about weed patches and site-specific methods to reduce chemicals and lime application that may improve farmers decision making in the short run. In this matter, we recommend better training, education and management cources for PA . However, management time is a scarce resource in modern agriculture. If PA technology is to reach beyond the innovators to the majority of farmers, it must be easier to use and less time consuming.

Improved interpretation of yield and soil maps as the basis for VR applications may be obtained through an intensive use of PA specialists, such as crop advisors, fertilizer dealers, extension experts, both as facilitators of specific on-farm tasks and as providers of basic agronomic knowledge. They could also facilitate training on cause and effect relationships between crop and soil attributes and the application of variable inputs. Farmers have shown themselves willing to pay for information services (e.g. accounting, legal, pest management) that they perceive as essential and profitable. In the US, there has been a substantial growth in crop consulting services based on PA techniques but it remains to be seen which PA information services will be profitable enough to survive.

In attaining the full benefit of the use of PA data, the PA specialists may be the channels through which knowledge and skills will be transferred to growers. To play this role, they need to build closer relationships to their farmer-clients and bring added value to their services. They need to be updated on new developments. This requires close collaboration with research institutes and universities on information dissemination and training. The 1990's witnessed a steady increase in the development of PA hardware and software, while this first decade of the 21st Century may need to focus on bringing all PA stakeholders together to develop the skills and knowledge necessary for practical and profitable PA management.

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