A COMPARISON OF PRODUCER ADOPTION OF PRECISION AGRICULTURAL PRACTICES IN DENMARK, THE UNITED KINGDOM, AND NEBRASKA IN THE UNITED STATES

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Introduction

While a lot of research and commercial development has taken place in precision agriculture in recent years there is little information available about the experience and opinions of the producers who are trying to make it pay its way in the field. Information about producer experiences in precision agriculture would be useful in guiding future research and development in both the public and private sectors. Important questions could include: – what types of precision agriculture practices are producers adopting and why? What are the advantages or disadvantages of using precision agricultural practices on farms? What are the expected economic benefits from precision farming?

To address these questions, we conducted a survey of producers in three countries in autumn 2000 – Denmark, Great Britain and the United States (Nebraska). This was not a random survey – it was only sent to producers who have used some components of precision agriculture. As such, it represents the opinions of those 'early adopters' who have participated in the initial development of precision agriculture, and does not necessarily represent the opinions of the broader producer population in any of the countries surveyed.

A Comparative Analysis Among Denmark, the United Kingdom, and the United States
Production agriculture is quite different in Denmark, the UK and the US – the average farm size in Denmark is about 114 acres (46 ha), compared to about 166 acres (67 ha) in the UK and 865 acres (350 ha) in Nebraska – yet producers in all three have the common challenge of maintaining a profitable farming operation in an increasingly complex and regulated system.

We chose to study three countries that have a number of common characteristics. The importance of the agricultural sector in terms of gross national product (GNP) and fraction of the workforce (about 5% or less) employed in agriculture is about the same. Adoption of agricultural technology is relatively similar among the three countries. All three countries or regions have been using some precision farming technologies for the last 10 years.

However, there are also substantial differences in agriculture among the three countries. Arable farming has traditionally been performed extensively with moderate inputs in the state of Nebraska, focused on cash crops such as corn (maize), soybean, grain sorghum, winter wheat, alfalfa and edible beans. The total land area per farmer is relatively high. Due to the semi-arid climate, crops such as corn and soybean are often irrigated in Nebraska. In the United Kingdom cereals receive higher inputs than in Nebraska due to the more favorable climate for cereal production. Common crops in Britain are winter wheat, winter and spring barley, oilseed rape, beans, linseed, peas, beets and potatoes.

The Danish agricultural sector has many similarities with the British farm business due to common weather conditions, similar crop rotations and inputs. Climate in both Denmark and the UK is significantly influenced by the Gulfstream, which moderates temperature extremes relative to the northerly latitude of both countries. Common arable crops in Denmark are winter wheat, winter barley, oilseed rape, potatoes, peas, beets and potatoes, maize silage and grass silage. Denmark also produces significant quantities of grass seed. In Denmark, there is considerable emphasis on animal production, with lesser emphasis on livestock in the UK and US. Consequently, the efficient use of animal manures and slurries is a significant issue in Denmark.

Finally, there are differences in regulation among the three countries. Due to denser human populations and heightened environmental concern, producers in Denmark must deal with greater regulation than in the UK, both national and European Union (EU) regulations, on fertilizer and pesticide inputs as well as manure use, and both countries face greater regulation than Nebraska producers. (Langkilde, 1999).

The Survey Process

The survey was sent to a total of 349 users of precision agriculture technology in October 2000. Of this total, 102 were located in Denmark, 103 in the United Kingdom, and 144 in Nebraska in the United States. These producers were not selected at random, but rather were chosen to include only those who have had experience with one or more precision agriculture technologies. Survey participants were obtained from lists provided by Massey Ferguson (AGCO) and LH Agro in Denmark and the UK, and from the University of Nebraska Cooperative Extension in the US. A total of 206 producer responses were included in the analysis of the survey: 78 from Denmark (76% response), 51 from the UK (50% response), and 77 from Nebraska (53% response).

Objective

The objective of this study was to collect and assess the practical experiences of producers with precision agriculture practices, and to provide guidance for future research and technology development. Further, we expected that the comparative experiences of producers using precision agriculture technologies in other countries would be of interest to farmers in each country, and perhaps provide useful information on further adoption of practices in each country. We expect that this information will also be useful to crop consultants and others engaged in advising producers on effective use of precision agriculture technologies.

About the Survey

The survey consisted of 34 questions about different issues related to the adoption and use of precision agriculture technologies. Questions were the same in all three countries, with adjustments in how the questions were phrased in order to reflect language differences. This approach allowed the statistical comparison of responses among the three countries for most of the categorical questions. When respondents were asked to fill in a blank with their opinion, the responses were classed for statistical comparison. Individual comments were also used as qualitative arguments in the further assessment and impact analysis. For comparative purposes on economic questions, the relative value of currencies in the three countries were: 12 DKK = £1.00; $1.50 = £1.00; 8 DKK = $1.00.

In order to consolidate the long lists of crops produced in each country for comparative purposes, the following categories were used in some analysis:

Beets	Sugar beets and fodder beets
Grass	Grass hay and pasture
Grass seed	All types of grass for seed production
Clover	Red and white clover
Potatoes	Potatoes for both human consumption and starch
Wheat	Winter and spring wheat
Barley	Winter and spring barley
Corn	Corn (maize) for grain (animal and human consumption, silage and fodder

Responses were analyzed statistically when possible. Frequency of response, or in some cases mean values, for each question were evaluated among countries, using SAS (Statistical Analysis Systems, SAS Institute, Cary, NC, US) procedures of chi-square and linear regression. In some cases, analysis was conducted across, rather than among, countries. The majority of questions summarized in the Results and Discussion section have statistically significant differences ($P<0.05$), unless otherwise noted.

Demographics

The age distribution of farmers adopting precision agricultural practices tends to be similar among the three countries (Figure 1). In general, younger farmers may be interested in precision agriculture but have less economic flexibility to invest in equipment, while older farmers may be reluctant to invest in the time necessary to learn new technologies.

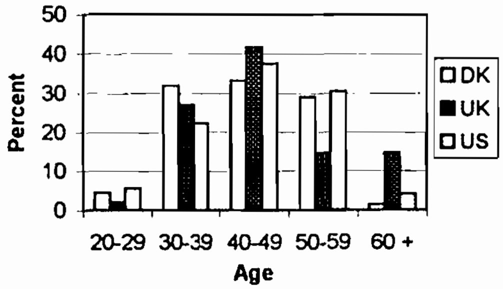

Figure 1. Age distribution of producers using precision agriculture.

Farms in the US tend to be larger, followed by the UK, then Denmark (Figure 2). The land area farmed by producers using precision technologies in all three countries tends to be larger than the average in each country.

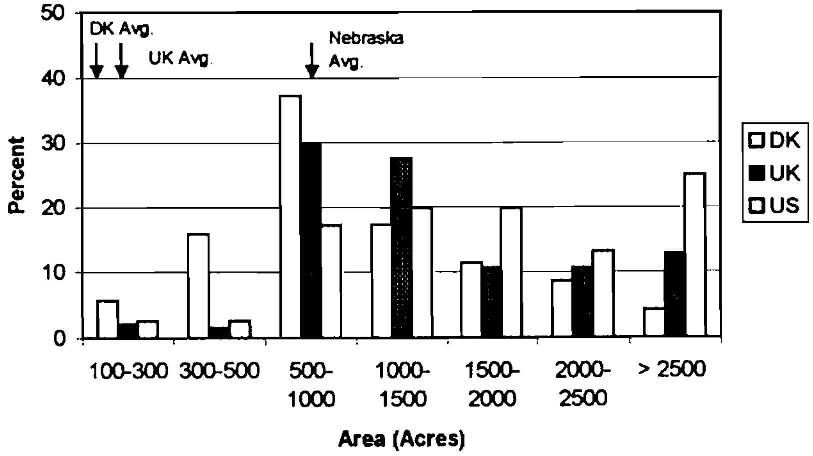

Figure 2. Area farmed by producers using precision agriculture.

Results and Discussion

Farm Type and Farming Practices

There are differences in how survey respondents use or provide precision agriculture services (Figure 3). The largest category is those who 'provide all precision agriculture services on their own farm'. There is a larger proportion of farmers in the US and UK who contract with others for some services, while a larger proportion of Danish and UK farmers will provide some services as well as use them on their own farm. These responses in particular may not necessarily represent substantial differences among countries as a whole, since the survey was not from a random sample. It was known, for example, that the survey list in Denmark contained a number of individuals who provided precision services and also used them on their own farms.

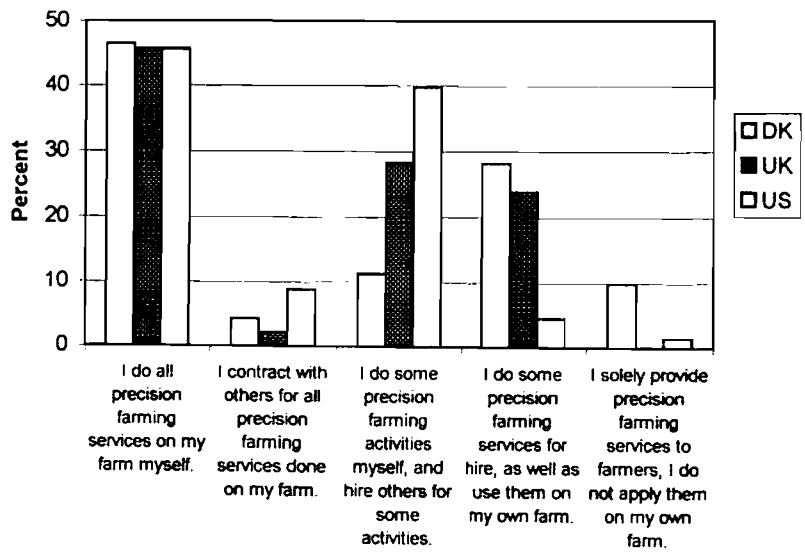

Figure 3. How producers use or provide precision agriculture services.

Precision farming practices have been applied on a large variety of crops, although the most common application is to grain crops that can be harvested by a combine harvester (Table 1). This finding was anticipated given that the UK and Denmark survey participants were customers of companies producing yield-mapping combines. Precision technologies have been used on a wider variety of crops in Denmark and UK than in Nebraska in the US. In Nebraska, 100% of respondents have used precision practices for corn production, and 87% have used them for soybean production. In Denmark and the UK, 91% and 95% respectively use precision practices on wheat, as well as on barley, oilseed rape, grass seed, peas and tubers (beets and potatoes). It should be stressed that Table 1 only includes crops where some type of precision practice has been used. It does not address the *extent* of current farm practices within each country on each crop.

Table 1. Percentage of respondents in each country who have used a precision practice for the given crop.

Crop	DK	UK	US
	----------------	%	----------------
Wheat	91	95	13
Barley	82	72	0
Rye	16	5	0
Oat	7	9	1
Triticale	11	0	0
Oilseed Rape	36	67	0
Corn (maize)	4	0	100
Grass seed	45	0	0
Flax	7	0	0
Beets	5	2	0
Potatoes	9	7	0
Peas	13	21	0
Linseed	0	14	0
Beans	0	28	0
Soybean	0	2	87
Grain sorghum	0	0	10
Other [1]	10	2	9

[1].Crops where 5 percent or less precision practices are used in the three countries include: Seed corn, grass, herbage seed, edible beans and alfalfa.

Farmers in the US tend to use precision agriculture practices on a greater percentage of the land area they farm (Figure 4). This likely relates to fewer crops being grown in Nebraska, relative to Denmark and the UK, and the applicability of precision technologies to those crops. For example, yield mapping of grains such as corn, wheat and soybean is a relatively mature technology compared to yield mapping of root crops such as sugar beet or potatoes. Figure 4 illustrates that over 60% of Nebraska producers who are using one or more precision technologies use those technologies on 80-100% of the area they farm, compared to around 40% for UK producers and 35% for Danish producers.

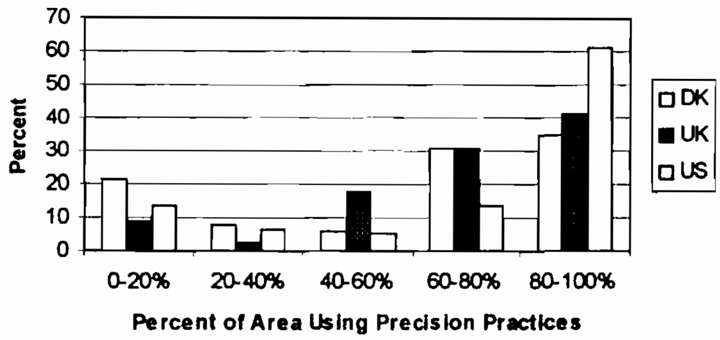

Figure 4. Use of precision practices on proportion of land farmed.

There are differences among countries in how long farmers have used precision practices, with farmers in the UK tending to have used them longer than farmers in the US or Denmark (Figure 5). The majority of Danish and US respondents have used one or more precision practice between two and four years, while the majority of UK respondents have used a precision practice between five and seven years. The fifty percentile line, for example, shows ½ of Danish respondents have used precision practices almost 3 years, ½ of Nebraska farmers have used them almost 4 years, and ½ of UK farmers have used them almost 5 years.

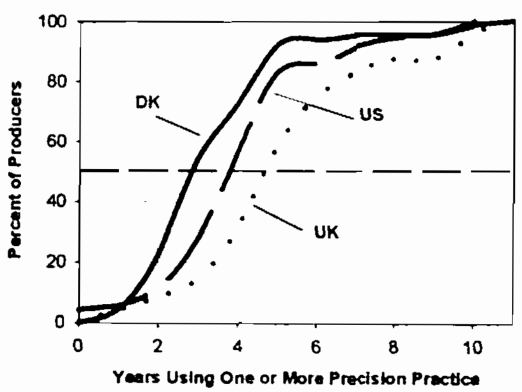

Figure 5. Length of time producers have used a precision practice (cumulative distribution).

The use of precision practices varies among countries. Table 2 illustrates the response when asked what precision practices producers had used at any time on their farm.

Table 2. Use of precision practices among countries (Percent of respondents in each country who indicate they have used the practice).

Practice	DK	UK	US
		%	
Information Gathering			
Grid soil sampling	49	56	50
Directed soil sampling	14	27	39
Yield monitoring (no GPS)	7	17	29
Yield mapping (GPS)	80	100	76
Aerial photography	3	27	40
Remote sensing	3	17	19
GPS-pest monitoring	1	2	3
Soil conductivity mapping	14	19	6
Soil topography mapping	1	4	22
Conventional soil mapping		17	
Mean	19	29	32
Taking Action			
VRT fertilization	26	58	47
VRT lime	37	33	26
VRT pesticide	10	10	3
Mean	24	34	25
Other	3	6	14

Yield mapping with GPS is the most common practice used in all three countries. This is not surprising, particularly in Denmark and the UK, as the survey list in those countries was derived from customer lists of manufacturers of yield mapping combines. Yield monitoring without GPS is used significantly only in the US, where producers with yield monitors without GPS have used them to compare variety performance and differences among fields. Grid soil sampling is another common practice, along with VRT fertilization or lime application. Directed soil sampling, according to yield maps or other spatial information, is a practice of increasing popularity in the US and UK, given the high investment required for grid sampling. A larger percentage of producers have tried aerial photography or remote sensing in the US relative to the UK and Denmark, probably reflecting climate differences (number of cloud-free days during the growing season) and the availability of those services. Surprisingly few producers are using GPS to scout for pests or VRT application of pesticides in any of the countries. More producers in the UK and Denmark have mapped soil conductivity on their farms than in the US. A significant number of producers in the UK indicated they had used conventional soil surveys on their farm (this question was not asked of producers in the US or Denmark). In the US, a significant percentage of producers had had their fields mapped for topography, primarily in relation to leveling for irrigation. The most commonly mentioned 'other' practice was variable rate seeding.

Precision soil sampling, either grid-based or directed according to a yield map or other spatial resource, is a common practice in all three countries. In the UK, 48% said they used some type of precision soil sampling, compared with 44% in Denmark and 35% in the US. Of farmers using grid sampling, those in the UK and Denmark have used it on a higher percentage of the land precision sampled than in the US – 91% (UK) and 83% (Denmark) vs. 57% in the US. The opposite is true for directed soil sampling – when respondents used directed sampling, they applied it on 55% of their land in the US, vs. 26% in the UK and 17% in Denmark.

Division of precision practices into information gathering (evaluative), and taking action (prescriptive) is also useful. Table 2 shows that, on average, US and UK producers are highest in adoption of evaluative, or information gathering, practices (32% and 29% average adoption, respectively, compared to an average adoption of 19% in Denmark). Producers in the UK are more likely than Danish or US producers to take action on the information they have gathered, with 34%, on average, adoption of prescriptive practices, compared to 24% and 25% in Denmark and the US.

Investment and Expected Impact on Farm Economy

The capital investment in precision agriculture, such as field equipment, computers, software and training, varied somewhat among countries. The greatest investment tended to be in the UK, followed by the US, with the least investment by producers in Denmark (Figure 6). This trend is likely related to the length of time producers have been using precision agriculture (with UK producers tending to have used precision practices longer), and total farm size (with Danish farms smaller on average than UK or Nebraska farms).

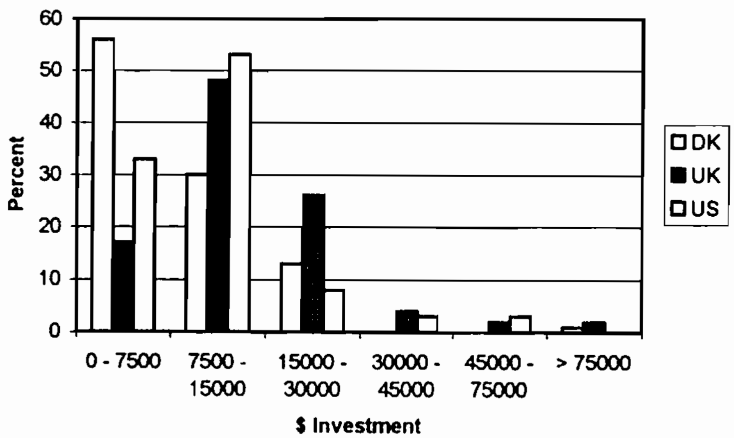

Figure 6. Capital investment by producers in precision agriculture.

When producers do grid soil sample a field, they tend to invest about the same in all three countries – $7.80/acre (£13/ha) in Denmark, and $8.40/acre (£14/ha) in both the UK and US. However, there are significant differences in the average densities used for grid sampling among the countries. Farmers in the UK on average collect 3 soil samples per ha (1.2 per acre), farmers in Denmark 2 samples per ha (0.8 per acre), and farmers in the US only about one sample for every 3.4 acres, or about 0.7 samples per ha. There was also a tendency for the grid sample density to be less with larger farm size across all three countries.

There were significant differences in farmers' attitudes about the potential for yield increases with precision agriculture (Figure 7). Producers in Denmark and the US were equally optimistic that yield increases could be obtained on their farms through precision agriculture, while significantly more UK farmers were less optimistic. The same percentage of producers in all three countries were unsure about the potential for increased yield on their farm.

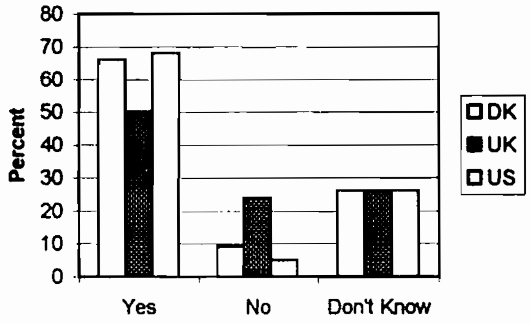

Figure 7. Proportion of producers who feel precision agriculture will increase yield on their farm.

There were, however, no significant differences in perception about profitability of precision agriculture among producers in the three countries (Figure 8). Farmers were generally quite optimistic about the potential for precision farming to increase their gross margin, with the majority expecting an increase between $3 and $12/acre. However, most respondents expect that it will take about 5-10 years to obtain the expected potential profit from precision farming.

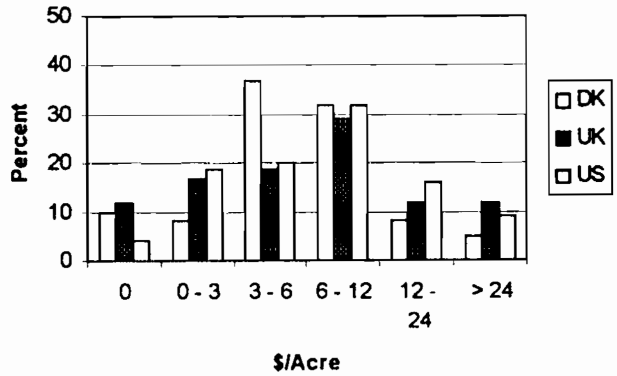

Figure 8. Expected eventual impact on gross margin per acre.

When asked to list the top three practices they felt would have the most potential economically for their farm, producer responses varied somewhat by country (Table 3). The most commonly listed practice among all three countries was variable rate fertilization. The second most commonly listed practice in the UK and US was yield mapping, while in Denmark the second most commonly listed practice was variable rate lime application. The third most commonly listed practice in the US and UK was grid soil sampling, while the third most commonly listed practice in Denmark was variable rate pesticide application.

When grouped according to practices which are information-gathering or taking action, it is clear that Danish producers currently see a greater economic benefit to taking action than do producers in the US or UK. Two-thirds of Danish farmers believe either variable rate fertilization, liming, or pesticide application will be economically beneficial, compared to 34% in the UK and 25% in the US. This is likely related to restrictions on N rates below the economic optimum in Denmark, as well as substantial taxation on the use of pesticides (Langkilde, 1999).

Table 3. Precision farming practices that farmers believe to have the greatest potential economic impact on their farm.

Practice	DK	UK	US
		%	
Information Gathering			
Grid soil sampling	16	28	33
Directed soil sampling	2	13	14
Yield monitoring (no GPS)	5	0	20
Yield mapping (GPS)	28	58	46
Aerial photography	0	5	3
Remote sensing	3	10	10
GPS-pest monitoring	10	5	0
Soil conductivity mapping	3	5	3
Soil topography mapping	2	5	1
Conventional soil mapping		3	
Mean	8	13	14
Taking Action			
VRT fertilization	81	60	54
VRT lime	66	18	20
VRT pesticide	53	25	1
Mean	67	34	25
Other	9	38	39

Note: The respondents were asked to mention up to three practices they believed would be beneficial on their farm.

Variable Rate Application

Producers in different countries sometimes had different opinions regarding the impact of adopting precision agriculture practices on the total amounts of inputs, such as fertilizer and seed, for crop production (Table 4). Many of these differences relate to different crops grown, different climates, and different regulations among the countries. Respondents were asked to indicate whether they felt precision practices would increase, decrease, or leave unchanged the total amounts of inputs listed. In Table 4 below, ↑ indicates an increase, ↓ indicates a decrease, and ↔ indicates no change in the total amount of input used on their farms. Responses indicate what producers think will be the impact of precision agriculture in the future – not necessarily what has occurred on their farms to date.

Table 4. Impact of adoption of precision practices on total inputs (↑ indicates an increase, ↓ indicates a decrease, and ↔ indicates no change in the overall total of each input; where two arrows are shown, there were significant numbers of farmers who held each opinion – the first arrow shown is the predominate opinion).

Input	DK	UK	US
Nitrogen	↔	↔	↔
Phosphorus	↔↓	↔↓	↔↑
Potassium	↔↓	↔↓	↔
Other Fertilizers	↔	↔	↔
Lime	↓	↔	↔↑
Herbicides	↓	↔	↔
Insecticides	↔↓	↔	↔
Fungicides	↓↔	↔	↔
Seed	↔↓	↓↔	↔
Growth Regulators	↓↔	↔	↔

Only nitrogen and other fertilizers showed no difference in opinion among countries, with all farmers feeling there would be no change in these total inputs. Farmers in Denmark and the UK felt precision practices would leave unchanged or decrease their total use of phosphorus fertilizers, while farmers in the US felt if anything it would increase total P use. Farmers in Denmark and the UK felt potassium use would remain the same or decrease, while farmers in the US believe it would remain unchanged.

Producers in Denmark felt lime use would decrease, while US farmers felt it would increase. Danish farmers also felt herbicide, insecticide, and fungicide use would decrease or remain unchanged, while producers in the other two countries felt they would be unchanged. US farmers felt that total seed and growth regulator use would remain unchanged, while farmers in Denmark and the UK felt they would remain the same or decrease.

In Denmark and the UK, where agriculture is often more intensive than in Nebraska, soil phosphorus levels are generally higher. Soil potassium levels generally are higher in Nebraska than in the UK or Denmark due to relatively younger, less weathered soils. Also, the use of fungicides and growth regulators is more common in Denmark and the UK for intensively grown cereals. Producers in Nebraska use relatively little fungicide or growth regulators on corn and soybean. The expectation that precision practices will decrease overall herbicide use in Denmark may be related to more stringent regulations on the use of herbicides in Denmark, compared to the UK or US.

An interesting observation is that respondents in Denmark and the UK felt precision practices would leave unchanged or reduce total inputs, while respondents in Nebraska felt that inputs of phosphorus and lime would increase or remain unchanged, and that other inputs would remain the same overall.

For comparative purposes, recent average N, P and K fertilizer rates and yield for principle crops in the three countries are provided in Table 5.

Table 5. Average annual fertilizer application rates and yield for principle grain crops.

Country	N	P_2O_5	K_2O	Yield
	-----	*lb/acre*	-----	*bu/acre*
United Kingdom[1] – winter wheat	163	43	47	121
Nebraska[2] – corn (maize)	142	34	22	145
Denmark[3] – winter wheat	156	20	58	138

[1]. *1998 British Survey of Fertiliser Practice, Fertiliser Manufacturers Association; Farm Management Pocketbook, John Nix, Wye College, University of London; Ministry of Agriculture, Fisheries and Food, Government Statistical Service, 1997.*

[2]. *1998-1999 Nebraska Agricultural Statistics, State of Nebraska.*

[3]. *1997/98 Ministry of Food Agriculture and Fisheries, Plantedirektoratet, Denmark, Estimate based on norm in fertilizer accounts; Danish Statistics (2000): Agriculture 1999, Copenhagen, DK.*

A significant majority of producers who use precision technologies feel that those practices are beneficial to the environment. A total of 67% of all respondents indicated that precision agriculture will ultimately either increase the efficiency with which fertilizers and pesticides are used, decrease their overall use, and/or reduce the environmental impact of crop production. There were no differences among countries in this opinion.

There were no differences among countries in the perception that site-specific application of manures or slurries would be beneficial on their farms. On average, 57% of respondents felt the practice would be helpful to them.

Other Costs and Benefits of Precision Farming

In order to assess precision farming practices beyond economic and environmental impacts, producers were asked if they found the use of precision farming practices helpful in their dealings with government agencies, landlords, consumers, etc. Although the largest percentage found the practices helpful in all three countries in such interactions, a significantly larger proportion of US producers found them helpful, while a significantly larger proportion of UK producers did not (Figure 9).

Farmers in general were not overly concerned about the use of precision farming data by government agencies, lending institutions, etc., although farmers in Nebraska did show slightly greater concern than in Denmark or the UK. When asked what their concerns might be, the most common was the use of data by government agencies for regulatory purposes. In the US, there was also concern about use of the data for competitive purposes. In the UK, there was concern about the underlying scientific basis for precision agriculture recommendations.

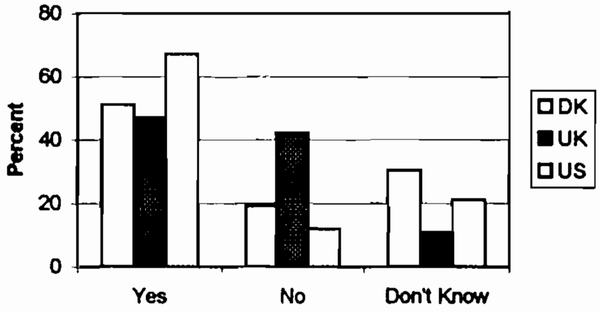

Figure 9. Proportion of producers who find precision practices helpful with landlords, government agencies, consumers, etc.

When asked if they felt there were any disadvantages to the use of precision farming practices, farmers in the US and UK felt there were, while farmers in Denmark generally felt there were not (Figure 10).

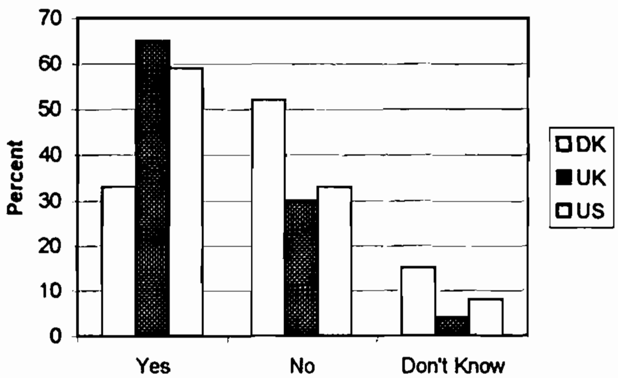

Figure 10. Proportion of producers who feel there are disadvantages to the use of precision agriculture.

The most common disadvantage listed in all three countries was the cost of using the technology, and the apparent lack of economic return (Table 6). (An interesting concern given the generally optimistic outlook producers have for the eventual positive economic impact of adopting precision agriculture – see Figure 8). The second most commonly listed disadvantage in all three countries was the time required – for making equipment work and analyzing and summarizing data.

Table 6. Proportion of disadvantages listed among all producers (%).

Cost vs. Return	Equipment Problems	Potential Government Regulation	Lack of Research and Advice	Time Spent on Precision Agriculture
58	5	4	12	21

There are slight differences in the amount of time producers invest in precision agriculture among countries (Figure 11). Counting time spent analyzing and summarizing data, learning new procedures, attending workshops, etc., producers in the UK tended to invest more time per week than producers in Denmark or the US. This is likely related to the greater length of time that respondents in the UK have been using precision practices, and to their greater investment in the technologies. However, the majority of all farmers in all three countries spend less than 2 hours on precision farming practices per week.

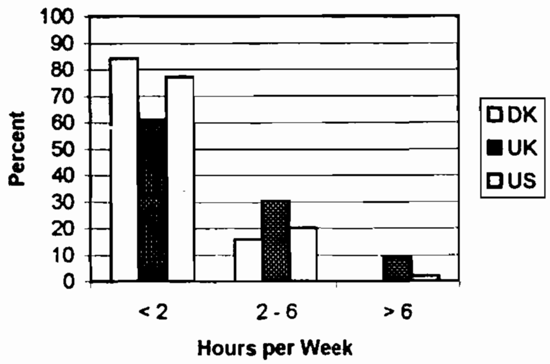

Figure 11. Time spent per week on precision agriculture.

When asked if they found information and advice on precision farming readily available and adequate, most farmers in the US felt information and advice was adequate, while a significant number of farmers in Denmark and the UK felt information and advice was inadequate (Figure 12).

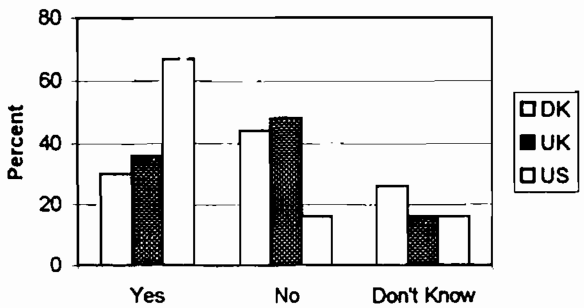

Figure 12. Proportion of producers who feel information and advice about precision agriculture is adequate.

Recommendations for Improved Precision Farming Technology

We categorized responses when producers were asked what they would recommend for future improvements in precision technologies into seven categories (Table 7). This allowed the comparison of general categories for improvement by country. In all countries, there seems to be a general concern that different technologies are not always compatible. Respondents were interested in standards where software and hardware can "speak together" with ease. Better advice on the use of precision technologies, and evidence of profitability and economic returns are also recommended

Table 7. Recommendations to improve the further development of precision farming technology.

Recommendation	DK	UK	US
		%	
More accuracy	6	0	15
Better advice	13	28	2
Compatibility	23	31	15
Less expensive equipment and profitability	10	19	34
Other specific technological developments	32	11	22
User friendly technology	13	6	5
Other recommendations	3	6	7

When asked who the primary data processor for precision farming related data should be, the majority recommended that the farmer should play a key role in the data processing (Table 8). Especially in Denmark respondents felt that it would be helpful to have a crop consultant involved in processing precision farming data. This difference may be related to the availability and use of consulting services in Denmark and Nebraska relative to the UK.

Table 8. Recommended data processors for precision farming related data.

Data Processor	DK	UK	US
		%	
Farmer, farm manager, or employee	25	76	60
Crop consultant, or consultant in collaboration with farmer, employee, or fertilizer dealer	75	18	30
Fertilizer dealer	0	4	7
Other	0	2	3

There were differences among countries in how encouraging producers would be to others regarding getting started with one or more precision agriculture practices (Figure 13). In general, US producers were the most enthusiastic about encouraging their neighbors to try it. In both the UK and Denmark, the largest proportion was positive, but a significant number in the UK were negative, and a significant number in Denmark were unsure. Particularly in the UK, producers had reservations about recommending the use of new practices given the current economic climate in agriculture.

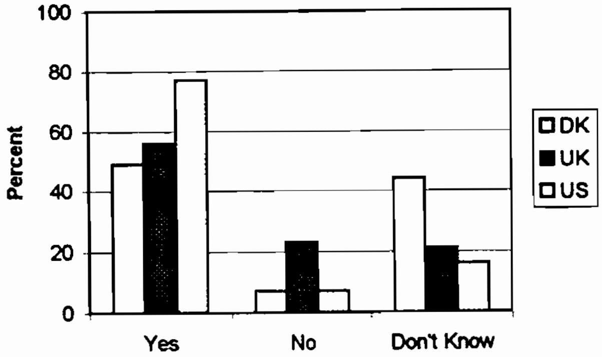

Figure 13. Proportion of producers who would encourage other farmers to try one or more precision practice.

The most commonly listed practice that producers would encourage others to try was yield mapping, especially in the US (Table 9). Grid soil sampling was the other commonly mentioned evaluative practice. Variable rate application of fertilizer and lime were the most commonly mentioned prescriptive practices.

Table 9. Practices farmers would recommend to others (across countries).

Practice	% Recommending
Information Gathering	
Yield mapping	39
Grid soil sampling	17
Directed soil sampling	4
Soil mapping	3
Soil electrical conductivity mapping	3
Remote sensing	1
Taking Action	
Variable rate fertilization	15
Variable rate liming	15
Variable rate pesticide application	4
Variable seeding	1

Conclusions

Findings from this survey need to be considered in light of this being a targeted, rather than random, survey. In particular, the mailing lists in the United Kingdom and Denmark were derived from customer lists of manufacturers of yield mapping combines. Consequently, a high adoption of yield mapping as a precision practice was to be expected. The US survey was conducted only in Nebraska, and represents primarily producers who use irrigation. This survey provides a summary of the opinions of early adopters of precision agriculture technologies, and does not necessarily represent the opinions of the broader producer population in any of the three countries evaluated.

Producers in all three countries use a range of precision technologies on a variety of crops, but mostly on crops that are combine-harvestable – cereals, corn and soybean.

Producers in the UK appear to have the longest-term experience with precision practices, at least in yield mapping, and have invested the most heavily in precision technology of producers in the three countries. They also have the most experience with prescriptive practices, such as variable rate fertilization. However, producers in the UK also tended to be more skeptical of the potential for precision practices to increase yield on their farms.

Yield mapping is the most common precision practice in all three countries, followed by grid soil sampling. Both of these technologies are evaluative rather than prescriptive. Variable application of fertilizers and lime, both prescriptive technologies, are the third and fourth most commonly used practices. Practices which are relatively new and appear to be increasing in use are soil conductivity mapping and directed soil sampling, again both evaluative technologies.

Participants are generally quite optimistic about increased profitability with precision agriculture, but figure it will take 5-10 years to achieve their expected level of profitability. Variable rate application of fertilizer was the practice most commonly cited as that likely to increase profits on their farm – either through decreased total applications of phosphorus and potassium (DK and UK) or increased total application of phosphorus (US). Participants in all three countries felt that total nitrogen use on their farms would remain unchanged with the use of precision practices.

In general, producers found precision farming to be useful in their interactions with consumers, landlords and government agencies. They were somewhat concerned about the use of precision farming data by others (government, lenders, etc.) – more so in the US and the UK than in Denmark.

They felt the greatest disincentive to adoption of precision agriculture was the cost of the equipment coupled with a current lack of evidence of increased profit with precision farming. In spite of this, producers were generally optimistic about the potential for increased profit with precision farming in the future. The second major disincentive to the use of precision practices is the time required, although many admit an incentive to their adopting precision farming was a fascination with the technology.

A majority of producers feel that the use of precision practices will help them use inputs more efficiently and reduce the environmental impact of crop production.

In summary, these early adopters of precision farming remain optimistic about the future of precision farming technologies, but are cautious about encouraging others to jump into precision farming, given the cost, a current lack of economic return, time required, and the depressed farm economy. This was particularly the case in the UK and Denmark. The apparent lack of scientific evidence is still a key issue in all three countries. More thorough and scientifically based advice about input application is needed as well as development of compatible technologies.

Recommendations

Compatibility of hardware and software used in precision agriculture continues to be a significant concern of producers. Greater compatibility of hardware and software, and ease of use, should increase the potential for the 'average' producer – those not so fascinated by the technology – to adopt one or more precision practices. Given the current economic stress in the agricultural economies of all three countries, manufacturers should strive to provide low-cost options for producers interested in precision agriculture but unable to afford large-scale investment.

Researchers and advisors need to make producers aware of precision practices that are most likely to be profitable for local conditions. Specifically, there has been little research evidence to date for increased profitability with variable rate fertilizer application, yet that is the practice perceived by producers as the most likely to be profitable for them. Studies evaluating the economic benefit of precision agriculture have shown mixed results at best (Schnitkey, et al., 1996; Swinton and Ahmed, 1996; Swinton and Lowenberg-DeBoer (1998; Watkins, et al., 1999; Schmerler and Jurschik, 1997; and Schmerler and Basten, 1999). It is likely that in many cases precision technologies have helped producers to learn that they were applying fertilizers at rates above the economic optimum, and they have been able to reduce total fertilizer application without yield reduction. In this sense, precision agriculture has provided a 'teachable moment' and helped producers use fertilizers more efficiently, but variable rate application was not necessarily critical to accomplish this. At the same time, it would be profitable for researchers to study situations where producers feel variable rate fertilization is a profitable practice. There is research evidence that variable rate lime application can be a profitable practice (Bongiovanni and Lowenberg-DeBoer, 1999), although the potential return is low due to low cost input. Advisors should encourage producers to consider this practice where feasible. Scouting fields for pests, such as weeds, insects and disease, using GPS, along with site-specific control of pests, are practices which many researchers believe have considerable economic potential in some cropping systems, but are not currently viewed as attractive by survey respondents (Leiva, et al., 1997; Daberkow, 1997; Audsley, 1993; Gerhards et al., 1999).

Comments by survey respondents reflected considerable practical knowledge of the use of precision practices gained through years of trial and error. Sharing this knowledge with fellow practitioners, or with those interested in starting in precision farming, would be quite helpful. Producers interested in precision agriculture should consider joining a local precision farming association, or creating one if none exists, for the purpose of sharing information and pooling resources.

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