ECONOMIC ASPECTS OF PRECISION FARMING: A GERMAN VIEW-POINT

B. Kilian

Department of Farm Economics
University of Hohenheim
Stuttgart, Baden-Wuerttemberg, Germany

ABSTRACT

At the current time precision agriculture is a very extensively discussed topic both in agricultural science and the farming community. One of the most controversial points is the question of the profitability of these new technical possibilities. This study gives a short overview of experiments in Germany according to precision agriculture and carries out an economic assessment, which differentiates between sensor systems and mapping systems. By the sensor (or online)-systems the nitrogen fertilization with the N-sensor has reached a already remarkable extent in Germany. But a significant difference is hard to find as regards the agronomic and economic effects. Solutions for a site-specific pest control management are still missing, although they are considered to have a high potential for economic profitability. By the mapping systems, a comparison of the costs for essential site-specific measures between farm-owned and contracted services is given. The comparison shows, that it is recommended to use contracted-services for starting precision agriculture. Furthermore, site-specific fertilization experiments of nitrogen and basic nutrients are investigated, but also using the mapping approach, an economically significant benefit cannot be found. In conclusion, similar to other studies, the author anticipates that precision agriculture improves productivity and product quality, but there will be no significant impact on farmers' income.

Keywords: economic assessment, profitability, sensor-system, mapping systems

INTRODUCTION

At the present, the profitability of agricultural use of GPS technology is a controversial subject among experts. Apart from various special editions in technical magazines, there are also important agricultural trade fairs and exhibitions dedicated to the theme precision agriculture. Since the beginning of the past year, this subject is considered in the nation-wide compound project *pre agro*. The incriminating statements, if and under which conditions the application of precision agriculture is profitable for agricultural companies, cannot not be provided at the present. Therefore, in preparatory meetings and also at the onset of the project, the particular interest was expressed for an economic assessment of subplot-specific management from the side of the commercial users (trial companies, employers and producers), plant production and also from the administrative-political side. This interest corresponds to the fact that to this point in the Euorpean context no scientifically-based economic investigations were conducted and published, which directs particular expectations on the work and results of the compound project *pre agro*.

The reason for the absence of thorough economic assessments is because in the investigations already completed, the aspects of the technical transformation and the suitability for practice of precision agriculture uses stood in the foreground. As this was not foreseen at the conception of the experiment, it was not possible to produce a detailed economic assessment. Therefore, in the *pre agro* project, the Economics sub-project was integrated into the methodological determination of the trial arrangement from the beginning. This maintained conditions necessary for recording economic results that withstand scientific scrutiny.

METHODS

In this interdisciplinary project, the methodological approach allows a subdivision into interdisciplinary approaches of the entire project and the specific methodology of the Economics sub-project. In this discussion, the interdisciplinary approaches are of particular importance as the Economics sub-project builds upon the preparatory work of the project's partners. There has to be a interdisciplinary agreement and common methodological approach for the selection of participating farms because for the economic subproject it is important to gain transferable results, which allows conclusions on one hand for different sizes of farms and for different kind of landscape. This is necessary due to the enormous differences of farm size between the former east-Germany and most parts of west Germany. The project coordination was able to integrate farms of all parts of Germany, so that there is a high variability in farm size and landscape conditions. In each participating farm, fields were selected, which have a high variability of characteristic patterns within the field and the field should be dividable. All experimental fields are divided in a site-specific managed part and in a "conventional" managed part. Through this measure the variability of yield influencing factors can be reduced, because the former management history like fertilization with manure, tillage system, crop rotation is identical, so that yield differences between site-specific and conventional farming can be put down to few or even better to one factor.
For the economic assessment of the profitability of precision agriculture three different platforms can be divided:

- the crop level,
- the farm level and
- the machinery contractor level.

The following figure shows the mapping-system approach, which is regarded to be the most important one. In the economic assessment it is planned to regard the whole circle of precision agriculture activities and to develop a site-specific gross margin map. This gross margin map is not only for the economic purpose, it is also a important part of the precision agriculture system in that way that agronomist has to verify their algorithms due to the economic results.

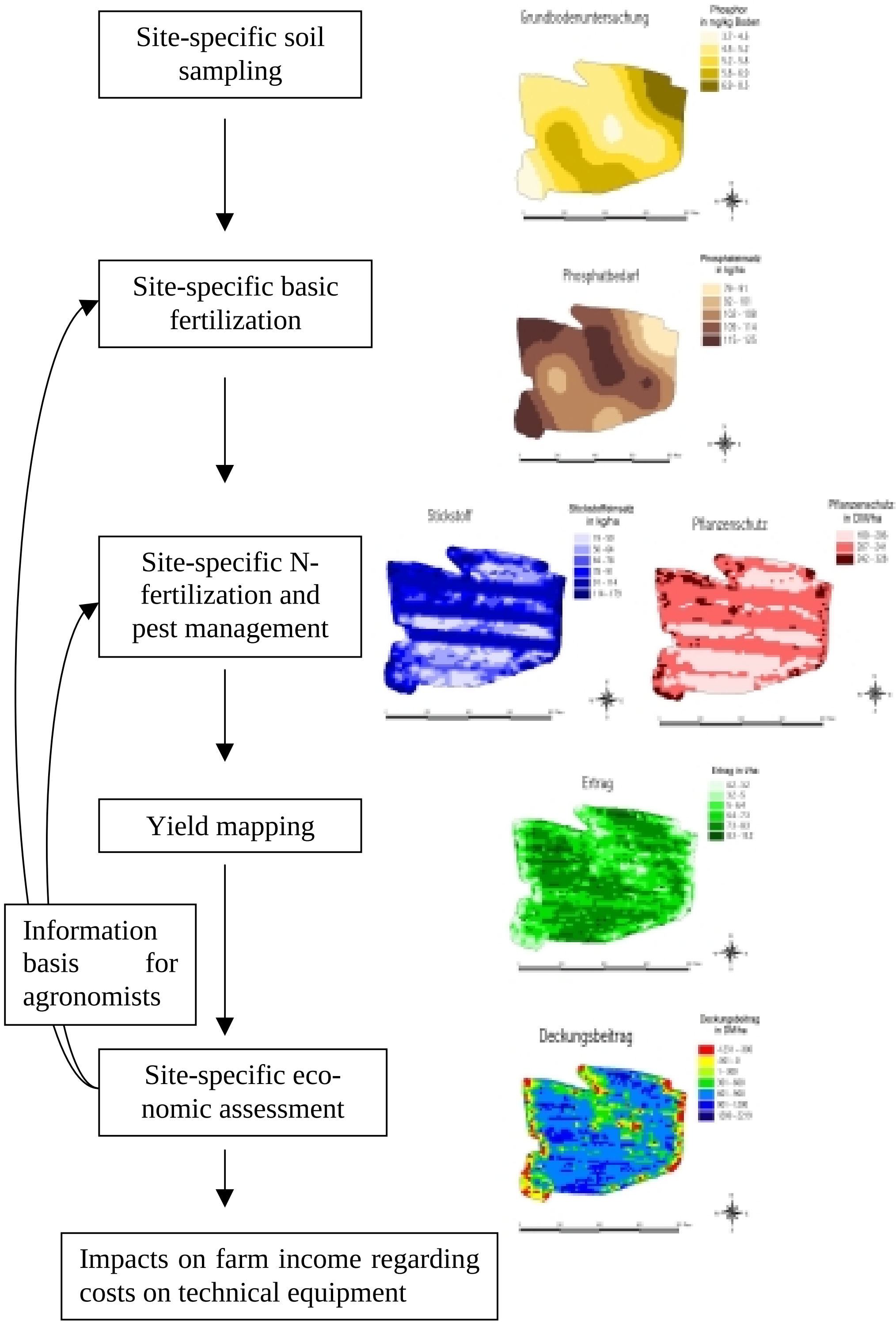

Figure 1: Methodical approach for the economic assessment on farm level

ECONOMIC ASSESSMENT

Based on a literature review and project-internal information, the first assessment of site-specific cultivation began. In this assessment, the two different concepts for precision agriculture were considered:

a) The derivation of differentiated cultivation of plots from secondarily determined site-specific base data (Mapping systems),
b) Determination of the site-specific cultivation through online procedures (also Real-Time-(Sensor) Systems or On The Go procedures).

Due to the limited number of scientific, as well as practically investigated production procedures, a precise management assessment of the agricultural production procedures is restricted at the present. The previously completed investigations were carried out predominantly in winter wheat grain cultures. Thus, the results are only partly transferable to other types of grain. For example, the N-sensor for the determination of the amount of N-late fertilization in cultures does not qualify. This is because the entire nitrogen has already been applied to the seed (or shortly afterwards), as the amount of chlorophyll of the leaves at this point do not provide any information. In other cultivars, except grains, the most fundamental technical problems still exist, e.g. the yield coverage in sugar beets and potatoes as well as in forage cropping. These restrictions lead to the situation that the application of precision agriculture, as a rule, can not be applied to all of the company's plant production. Consequently, the investment costs can only be considered on field sections, which leads to higher costs per ha.

Economic assessment on crop level

In this section, the existing online procedures will be considered, as the costs arising here can be directly correlated to each production procedure and thus also be economically assessed.

Economic aspect of site-specific nitrogen fertilization with the N-sensor

At the present, the sensor controlled site-specific nitrogen fertilization is the first practice relevant procedure operated by an online business. The sensor controlled N-fertilizer is a joint development project of the firms Hydro-Agri Germany, the Amazonen-Werken Hasbergen-Gaste, Germany and Dronningborg agri systems Denmark. For the technical explanation of functions, see Wollring and Reusch 1999 and Jürschik 1999.

In the first investigation results of the agronomic and economic effects, higher yields at an unchanged average amount of fertilizer are often reported. Moreover, in addition to higher yields, a more even development and ripening of the crop was documented. Further effects included homogenous protein contents, reduced stem break tendency and reduced infection pressure. Table 1 displays results of experiments conducted by several authors regarding yield and crop growth effects of N-sensors.

Table 1: Crop growth and economic effects of the N-sensor fertilization

Author	Yield effect	Additional agronomical results
Jürschik 1999	1-3 dt ha^{-1} extra yield in winter wheat	- reduced fertilizer applied
Wollring et al. 1999	1,8 % average extra yield	- reduced stem break - even ripening - more homogenous protein content
Wollring and Reusch 1999	up to 4,2 dt dry weight ha^{-1} extra yield in 12 of 16 experiments	- more uniform development/growth - reduced infection pressure - decreased N_{min} in autumn
Dampney et al. 1999	no significant differences in yield	- reduced N discharge

From the cited results, a certain uncertainty remains regarding yield effects because there is limited information concerning the statistical significance and often only maximum values were mentioned. Additional agronomical effects and results appear plausible so that with the cost of a new sensor at about 37.000 DM (compare Table 2; Meißer 1999) and yearly costs of about 7.680 DM for a N-sensor, at the assumed average gross margin increase from 20 - 30 DM ha^{-1} and from a input level of at least 300 ha, one can assume a profitable investment due to these investigations.

Table 2: N-sensor costs

Purchase price respectively depreciation	37.000 DM / 6 years =	6.200 DM · a^{-1}
Yearly interest (costs)	37.000 DM / 2 * 0,06 =	1.110 DM · a^{-1}
Yearly maintenance and repair costs	37.000 DM * 0,01 =	370 DM · a^{-1}
Sum		7.680 DM · a^{-1}

Source: the author's findings

In addition to the published results, a further experiment on the effects of the N-sensor could be evaluated (Agri Con 1999). The objective of this experiment was to show how farmers could improve nitrogen efficiency using the N-sensor. Therefore a field was divided into two parts, one part with two tramlines site-specific fertilization, the other part with three tramlines constant fertilization. The experiment is carried out for the second and third application of nitrogen. In the following table the results are presented, whereas data of the edges of field was not taken into consideration.

Table 3: yield and economic impacts of the N-sensor

	2nd N-application	3rd N-application	Total N	Yield	Gross margin
	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	dt ha^{-1}	DM ha^{-1}
	part 1: site specific fertilization, total of tramline 1 and 2				
Mean:	34,96	29,95	64,92	7,20	1401
Max:	80,28	57,59	112,77	10,71	
Standard deviation	17,55	7,85	20,03	0,97	
Coefficient of variation	0,50	0,26	0,31	0,14	
	part 1: site specific fertilization, tramline 1				
Mean:	47,30	32,02	79,33	7,14	1377
Max:	80,28	57,59	112,77	9,50	
Standard deviation	14,49	7,39	13,10	0,78	
Coefficient of variation	0,31	0,23	0,17	0,11	
	part 1: site specific fertilization, total of tramline 2				
Mean:	21,56	27,71	49,27	7,26	1431
Max:	42,02	47,71	83,87	10,71	
Standard deviation	8,33	7,72	13,43	1,14	
Coefficient of variation	0,39	0,28	0,27	0,16	
	part 2: constant fertilization, total of tramline 1, 2 and 3				
Mean:	35,00	60,00	95,00	7,13	1382
Standard deviation				1,06	
Coefficient of variation				0,15	
	part 2: constant fertilization, total of tramline 1				
Mean:	35,00	60,00	95,00	7,28	1416
Standard deviation				0,91	
Coefficient of variation				0,13	
	part 2: constant fertilization, total of tramline 2				
Mean:	35,00	60,00	95,00	6,95	1340
Standard deviation				1,35	
Coefficient of variation				0,19	
	part 2: constant fertilization, total of tramline 3				
Mean:	35,00	60,00	95,00	7,16	1388
Standard deviation				0,80	
Coefficient of variation				0,11	

Source: Agri Con 1999 and the author's findings

At first glance, the results seems to show that the farmers are indeed able to reduce the total amount of nitrogen fertilizer with the N-Sensor (reduction from 156 kg ha^{-1} to 126), whilst at the same time to improve the average yield (from 71.3 dt ha^{-1} to 71.9) and consequently gain a higher gross margin (from 1382 DM ha^{-1} to 1401).But there are some points requiring discussion. Firstly, it is significant in the site-specific fertilization that the variation coefficient of the total amount of nitrogen is considerably smaller than the variation coefficient of the second application (see table 3). This means that the third (site-specific) application corrected the second one and lead to a much more homogenous total site-specific application of nitrogen. Furthermore, regarding the yield differences in the individual tramlines of the uniform fertilized part of the field, there are considerable differences. The lower average yield of the constant fertilized part is mainly caused by one tramline, with a high yield depression. There is also one wheel track with the overall highest yield and so it can be concluded that the yields are not only influenced by the fertilization. So, consequently a higher gross margin of the site-specific part cannot be put down to the fertilization. For a correct assessment of the economic aspects of the N-sensor, further factors (especially soil conditions) have to be taken into account.

Economic aspect of site-specific weed regulation

In addition to a sensor for N-fertilization, at the present a sensor supported application technique for site-specific herbicide application is under development. Currently, site-specific weed regulation is only possible after classification by hand of the corresponding fields. However, because this approach is extremely time consuming and, therefore, impractical and uneconomic for many businesses, the future of site-specific weed control clearly lies in sensor technology. According to temporary estimates, this can mean an average savings of 40 % of the applied herbicides (Dampney et al. 1999, Wartenberg and Schmidt 1999), which corresponds to a savings of ca. 40 - 60 DM ha^{-1}. As cost figures presently do not exist for this technology, an economic assessment is not possible. The fact that this technology can achieve a high contribution to environmental quality, an area in which society possesses a high measure of sensibility, an extensive use potential is to be expected in this sector in the future. Moreover, the area of weed control/plant protection belongs to the plant production measures with the highest production costs.

Assessment at the farm level

At this level, the so-called Mapping-Systems will be considered because here a linked application stands in the foreground as the separate work measures build upon one another. This area is described as the so-called new paradigm. The objective from the agronomic viewpoint is not only to carry out singular measures on a site-specific basis. Rather it is carried out by using a soil or site inventory with the average soil parameters, soil nutrients and topography. This includes the linked measures such as soil preparation, sowing, green manure and plant protection on a site-specific basis. Plot specific yield mapping serves as the first assessment but also as an instrument for future decisions, which ultimately should lead to a corresponding site-specific gross margin contribution map. But the economic analysis must go beyond the year-old cultivar-specific gross margin, because singular site-specific measures have no, or only difficult to attribute to agronomic and economic effects. This makes a comprehensive business consideration of the system "precision agriculture" necessary. The objective of precision agriculture is to identify yield limiting factors and yield ineffective expenditures and correspondingly to eliminate the existing possibilities (Meißer 1999). The entry into precision agriculture means substantial investment costs which can be divided into three categories (Wagner 1999):

1. for data procurement (soil mapping, yield mapping, location),
2. for data processing (Hardware and Software) and

3. for the site-specific application (job calculator/computer-and electronic control).

In the entry into precision agriculture, the manager must decide whether to invest in company- owned technology or purchase services from a provider. In addition to the results of Table 4, the investment in company-owned technology is connected with higher costs than the purchase of services from providers (apart from a few large companies in the new German states), whereby in this survey the substantial time demanded for practice with this new technology is not considered.

Table 4: Costs for essential site-specific measures

Measure	Company-owned (2000 ha AF)	Contracted Services
Soil sampling with nutrient mapping	24 DM ha^{-1}	13 - 25 DM ha^{-1}
Basic fertilizer application with distribution mapping	26 DM ha^{-1}	20 - 30 DM ha^{-1}
Yield mapping	29 DM ha^{-1}	0 - 2 DM ha^{-1} (additional)
Total	79 DM ha^{-1}	33 - 55 DM ha^{-1}
N-fertilizing	9 DM ha^{-1}	

Source: Meißer 1999, Jürschik 1999

If the economic performance cost relationships of these site-specific measure are to be examined for N-fertilization and plant protection, the previously presented results are to be referred to. However, with soil sampling and yield mapping, direct proceeds cannot be connected. Rather, they serve purely as informational instruments for assessment and future cultivation.

Site-specific nitrogen fertilization using the mapping approach

The institute of agricultural engineering from the University of Kiel (Isensee and Engeln 2000) carries out an experiment where the yield is correlated with the field relief and the nitrogen fertilization is adapted. Through yield mapping it could be shown that in hollows the yield is significantly higher than on elevations and so there are different nutrient requirements. In the following table 5, the most important results are presented. In this experiment three different fertilization strategies were adopted:

- Conventional, which means fertilization as routinely applied by the farmers;
- Site-specific, which means fertilization according to the yield potential depending on the relief;
- Reduced site-specific, which means fertilization similar to the previous strategy, but with a reduced nitrogen input.

Table 5: Agronomical and economical impacts of a N-fertilization according to the field relief

Strategy	Nitrogen	Yield	Gross margin I	Cost of pa[1]	Gross margin II	Nitrogen productivity	N-balance
	kg ha^{-1}	dt ha^{-1}	DM ha^{-1}	DM ha^{-1}	DM ha^{-1}	kg N/dt yield	kg ha^{-1}
field 1, winter wheat, 1996							
Conventional	187	109	2184		2184	58	-53
Site-specific	183	110	2210	19	2191	60	-59
Reduced site-specific	149	110	2241	19	2222	74	-93
field 1, winter barley, 1997							
Conventional	183	95	1804		1804	52	1
Site-specific	146	93	1819	19	1800	64	-33
Reduced site-specific	133	98	1938	19	1919	74	-55
field 2, winter wheat, 1997							
Conventional	196	110	2198		2198	56	-46
Site-specific	164	105	2114	19	2095	64	-67
Reduced site-specific	131	107	2189	19	2170	81	-104
field 2, winter barley, 1998							
Conventional	159	85	1602		1602	53	-5
Site-specific	132	86	1643	19	1624	57	-33
Reduced site-specific	108	87	1681	19	1662	73	-58
Mean							
Conventional	181	100	1947		1947	55	-26
Site-specific	156	98	1947	19	1928	61	-48
Reduced site-specific	130	100	2012	19	1993	76	-78

[1]: pa = precision agriculture

Source: Isensee and Engeln, 2000 and the author's findings

This experiment was carried out for winter wheat and winter barley on two fields in northern Germany. Regarding the results it can be shown, that through the site-specific nitrogen fertilization, depending on the relief no yield increase could be achieved, but a reduction of nitrogen of 15 to 30 % was possible. However, due to the higher costs for creating the application maps (around 19 DM ha^{-1}) for site-specific fertilization, the strategy "site-specific" is less profitable than the "conventional" strategy. Only the "reduced site-specific" strategy is more profitable than the "conventional", but owing to the enormous negative nitrogen balance the question of sustainability/durability of this strategy arises. Some questions also remain in this experiment, for example, why the "conventional" and "reduced site-specific" strategies have the same yield potential while the "site-specific" strategy has a lower yield? So, as in the experiment with the N-sensor, further influencing factors have to be identified and integrated in the recommendations for fertilization.

Economic aspects of site-specific basic fertilization

Accompanying the project study, a master's dissertation on the economic aspects of site-specific basic fertilization (fertilization with phosphorus and potassium) was completed in our department. In this dissertation on four different farms, covering a broad range of size and also landscape conditions, several strategies for basic fertilization were investigated:

- Basic fertilization according to the nutrient extraction of the plants.
- Basic fertilization by averaging the results of soil sample analyses.
- Basic fertilization according to the results of soil sample analyses.

In former times, farmers very often adopted the first strategy because of the simplicity of this approach. But in the year 1992, following the publication of the EU nitrate-directive, which was transformed into national law for Germany in 1997, farmers were obliged to carry out regular soil sampling and to adapt their basic fertilization to the corresponding results. With the technical possibilities of precision agriculture, the question arises, whether through site-specific basic fertilization the economic results can be improved by an optimized fertilizer management.

According to the results in table 6, the average amount of fertilizer over all investigated farms is nearly identical. But due to the considerably higher costs for technical equipment to realize a site-specific application of fertilizers, this strategy is the least profitable. The average additional costs are about 60 DM ha^{-1} between the already quite precise second strategy and the third one. A fully comparison to the first one may be difficult because due to this quite imprecise application of nutrients, negative consequences for the yield may occur. So in a further step, increasing yields (max. 10 %) were assumed through a reduction of the under-supplied parts of the field. But also considering this optimistic assumption of increasing yield, potential site-specific fertilization is economically inefficient. The income improved on average 28 DM ha^{-1} in respect to at least 60 DM ha^{-1} higher costs.

Table 6: Economic aspects of site-specific basic fertilization

Farm	Fertilization strategy	Phosphorus costs	Potassium costs	Application costs	Total
		DM ha^{-1}	DM ha^{-1}	DM ha^{-1}	DM ha^{-1}
1	field 1: phosphorus supply: 16mg/kg; potassium supply 15mg/kg				
	replace extraction	73	133	10	216
	averaging analysis	73	133	29	235
	site-specific	79	182	83	344
1	field 2: phosphorus supply: 25 mg/kg; potassium supply 13 mg/kg				
	replace extraction	176	142	10	328
	averaging analysis	88	213	29	330
	site-specific	79	226	83	388
2	field 1: phosphorus supply: 23 mg/kg; potassium supply 21 mg/kg				
	replace extraction	100	92	8	200
	averaging analysis	50	92	28	170
	site-specific	39	103	83	225
2	field 2: phosphorus supply: 20 mg/kg; potassium supply 19 mg/kg				
	replace extraction	100	92	8	200
	averaging analysis	100	138	28	266
	site-specific	75	94	83	252
2	field 3: phosphorus supply: 13 mg/kg; potassium supply 18 mg/kg				
	replace extraction	97	125	10	232
	averaging analysis	97	188	33	318
	site-specific	111	193	83	387
3	field 1: phosphorus supply: 14 mg/kg; potassium supply 25 mg/kg				
	replace extraction	59	146	5	210
	averaging analysis	89	146	23	258
	site-specific	65	142	81	288
4	field 1: phosphorus supply: 15 mg/kg; potassium supply 16 mg/kg				
	replace extraction	51	133	6	190
	averaging analysis	51	133	18	202
	site-specific	55	139	81	275
4	field 2: phosphorus supply: 14 mg/kg; potassium supply 19 mg/kg				
	replace extraction	52	94	6	152
	averaging analysis	78	94	18	190
	site-specific	78	110	81	269
	average of all farms				
	replace extraction	89	120	8	216
	averaging analysis	78	142	26	246
	site-specific	73	149	82	303

Source: Rumetsch 2000

In a final investigation, it was tried to identify dependence of economical factors like reduced costs, increased yields and gross margins from the following factors: variation of the nutrient supply, average value of nutrient supply and from the size of the field (see table 7). The result was, that not one of the mentioned factors in isolation can explain the economic implications. Only if all factors were considered (multiple regression), can economic implications be drawn carefully.

Table 7: Statistical analyses of explanatory variables for the economic impacts of site specific basic fertilization

Variables		Phosphorus			Potassium		
Dependant	Explanatory	R^2	F	$F_{0,05;1;N-2}$	R^2	F	$F_{0,05;1;N-2}$
Increasing gross margin	variation coefficient	0,0004	0,002	6,61	0,27	2,17	5,59
	Mean	0,72	12,78	6,61	0,3	2,55	5,59
	field size	0,12	0,69	6,61	0,22	1,73	5,59
	vc, mean, fs[1]	0,79	3,69	6,61	0,76	4,25	5,59
Reduced nutrients	variation coefficient	0,43	1,51	18,51	0,98	148,71	10,13
	Mean	0,19	0,46	18,51	0,05	0,15	10,13
	field size	0,31	0,9	18,51	0,76	9,39	10,13
	vc, mean, fs[1]				0,99	24,55	10,13
Increasing yield	variation coefficient	0,009	0,029	10,13	0,34	2,63	6,61
	Mean	0,92	36,36	10,13	0,55	6,13	6,61
	field size	0,27	1,09	10,13	0,009	0,05	6,61
	vc, mean, fs[1]	0,95	6,82	10,13	0,95	18,07	6,61

[1]: vc = variation coefficient; fs = field size

Source: Rumetsch 2000

CONCLUSIONS

In this research an economic assessment of initial precision agriculture activities in Germany is presented. A main conclusion of the presented investigations is that the current state of precision agriculture still has deficits in knowledge of the site-specific yield influencing factors and so no clear economical benefit can be shown. In all investigations the site-specific regarded and applied input factor is not able to explain the yield differences sufficiently. This is compatible with the results of Mallarino et al. (1999), who measured eleven soil factors but still found no consistent correlation between variables across fields and the proportion of yield variability. It was therefore concluded that the corn yields were affected by one or more non-measured variables. In relation to the sensor system, the question may arise if it is useful to carry out site-specific fertilization with sensor-systems without using the support of mapping systems. The future should combine sensor- and mapping systems to achieve a higher correlation between variables across the field and yield. In addition to the variability in space, a further problem is the variability in time, which may be even harder to overcome.

For the economic perspectives of precision agriculture, an analysis by Hitt and Brynjolfson (in Stenka 1997) may describe quite well the real opportunities. They found out that expenditure on information technology results in increased productivity and increased consumer value without altering business profitability. This result corresponds very well with the results presented here, where in most cases, despite an input reduction, an increased gross margin is rather unlikely, due to the higher costs of technical equipment.

REFERENCES

Agri Con (1999): N-Effizienz. Unpublished paper. Jahna, Germany.

Dampney P., M. Froment, M. Moore, J. Stafford and P. Miller (1999): Ertragskartierung und teilflächenspezifische Pflanzenproduktion. ADAS Boxworth, Cambridge, United Kingdom.

Isensee, E. and P. Engeln (2000): Technik und Wirtschaftlichkeit der Teilflächenspezifischen Düngung und Ertragsmessung. Institute of agricultural engineering, university of Kiel, Germany.

Jürschik, P. (1999): Teilflächenspezifische Düngung – Grundlagen, Konzepte, technische Lösungen. DLG Merkblatt 315, Frankfurt am Main, Germany.

Mallarino, M., E. S. Oyarzabal and P. H. Hinz (1999): Interpreting within-field relationships between crop yields and soil and plant variables using factor analysis. Precision Agriculture. Volume 1, p. 15-25.

Meißer, J. (1999): Wann und wie mit Precision Farming beginnen? – Teilflächenspezifische Bewirtschaftung betriebswirtschaftlich betrachtet. In: Neue Landwirtschaft, Nr. 9, p. 70-74.

Rumetsch, H. (2000): Ökonomische Analyse einer teilflächenspezifischen Grunddüngung mit Phosphor und Kalium. Masters Dissertation, University of Hohenheim, Germany.

Stonka, S. (1997): Precision Agriculture in the 21st Century – Geospatial and Information Technologies in Crop Management. National Academy Press, Washington, USA.

Wartenberg G. and H. Schmidt (1999): Fotooptische Sensoren. In: Landtechnik, Nr. 6, volume 54, p. 340f.

Wagner, P. (1999): Besseres Management – Produktionsverfahren lassen sich effizienter einsetzten. In: dlz agrarmagazin, Sonderheft 10, BLV-Verlag, München, p. 96-99.

Wollring, J. and S. Reusch (1999): Stickstoff variabel düngen – Sensor mißt Versorgung der Pflanzen. In: dlz agrarmagazin, Sonderheft 10, BLV-Verlag, München, p. 30-34.

Wollring, J., S. Reusch and A. Link (1999): Teilflächenspezifische Düngung: Planung, Bedarfsermittlung, Ausbringung und Nutzen. Agrocom Seminar: Precision Farming auf dem Weg in die Praxis 1999, p. 50-54.