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Doctoral School of Management and Business Administration

Theses of doctoral (PhD) dissertation

ECONOMIC ANALYSIS OF
THE PRECISION (SITE-SPECIFIC) FARMING TECHNOLOGY

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1. INTRODUCTION

1.1. Relevance of the research topic

One of the most important challenges of the modern agricultural production is to suffice the food needs of the growing population on a reducing growing area. The support of the food needs cannot be solved by giving up the chemicals. Many new or rediscovered technologies have appeared against the harmful effects of the chemicalization of the agricultural production without yield loss or with yield similarity (for example ecological, mid-tech farming and precision farming technologies).

The central idea of the precision farming technology is to rationalize the inputs differentiated on plot-to-plot of the field and not on the average of the whole field. These smallest treatment plots are called management zones. Due to the zone-to-zone input rationalization and treatments the environmental damage effects of the production will decrease and the profitability of the production may increase.

Numerous international and Hungarian research works were published with the technology elements of precision farming technology (yield mapping, precision sowing, precision nutrient supply, and precision weed management) from its introduction in the early 1990s. The precision farming technology is older than 20 years but it is still evolving and boarding. The focus points of the development are the precision of the treatment and the wider scale of the adaptation. Many farmers know about or at least have already heard about the advantages and disadvantages of the precision farming technology. Numerous farmers think that they not able to introduce and operate the precision farming technology because of the high investment cost of technology. Another barrier of the fast spread of the precision farming technology among the farmers is that the theoretical advantages of the technology in the practice may highly depend on the heterogeneity of the field, the knowledge and skill of the operational staff and the commitment of the management.

1.2. Problem raising

The two main actual research topic of the precision farming technology is the technical innovation (for better site-specific and precise treatment) and the exploration of the motivation factors of expansion. Another research area is connected to the economically viable precision farming technology variations, which can increase the income and decrease the environmental damage of the plant production.

If we would like to understand the reasons of the slow expansion of the precision farming technology, firstly we should explore the motivation factors of users because it plays key role in the adaptation of the technology. Furthermore, worth examining the innovation plans of precision farming technology users and the plans of farmers who want to adopt one or more elements of the technology as soon as possible.

Based on the scientific literature, the most impending factors of adaptation of precision farming technology are the high investment cost (which is sometimes true, but sometimes just supposed) and the knowledge and the behaviour of the farmers with the information science and technology equipment.

It is not necessary to adopt the complex precision farming technology with all elements, by which the high investment cost may be avoided. It is possible to apply only one or few technology elements at a time – for example precision weed management – and later to improve the technology step by step. The reason of this step by step improvement is that the precision farming technology elements fit well into the conventional plant production machinery park (provided that this machinery park is not too old-fashioned). Thanks to this good combination possibility the advantages of the precision farming technology is available with the 3-5 million HUF investment in contrast with the complex technology investment which cost is more than 50 million HUF. The question is that for the given farm which precision farming technology elements may be suggested in economic point of view in a combination with the conventional technology.

Nevertheless, ensuring the financial background of the precision farming technology adaptation is not enough for the successful operation, the active participation and positive attitude of the farmer and the full staff is also necessary.

1.3. The objectives and the hypotheses of the dissertation

The following research aims were drafted in relation to the examination of precision farming technology:

- to examine awareness of the precision farming technology in Hungary (by structured interviews);
- to explore the features of the adaptation process of precision farming technology (in Hungary and Denmark);
- to make an investment model to help the Hungarian farmers to find the most profitable version of precision and conventional farming technology combination (by additional investments).

In the first step of my researches, the following hypotheses were formulated:

Hypothesis (H1): The adaptation rate of the precision farming technology is lower in Hungary than in Denmark, which was one of the first country where this technology was introduced.

- **H1/a:** The number of farmers who use precision farming technology is higher in Denmark than in Hungary.
- **H1/b:** In Denmark more kind of precision farming technology elements are used than in Hungary.

Hypothesis (H2): The adaptation of precision farming technology depends on economical and personal factors.

- **H2/a:** The precision farming technology elements are mostly used in the farms with bigger cultivated land.
- **H2/b:** The precision farming technology elements are used in farms with bigger economic size.
- **H2/c:** The adaptation of precision farming technology highly depends on the age of farmer.

Hypothesis (H3): The opinion of precision and non-precision farmers about the advantages and disadvantages of precision farming technology is clearly distinguishable.

Hypothesis (H4): Precision farming technology variations may be found for all farm sizes, which payback period is shorter than the planned time of use.

Hypothesis (H5): The complex precision farming technology investment is profitable only for farms with bigger economic size.

1.4.The theoretical background of the research

Modern plant production systems are faced to numerous challenges, for example, they have to satisfy the growing food necessity with moderate environmental damage and to produce quality product with profit. All over the world the common challenges of the agriculture is to satisfy the growing food necessity on the smaller and smaller agricultural area.

In my opinion, the future of the agricultural production is to keep the input (artificial or natural) usage within a reasonable level and spread out only that amount which is really necessary for the produced plant considering the heterogeneous conditions of the field.

The main idea of the precision farming technology, like a sustainable farming strategy, is breaking the field into smaller treating areas, which called management-zones and optimize the amount of inputs zone-by-zone. Lots of technical conditions should be made to carry out this idea in the practice. The most important task is to define the exact place of the management-zones. For this the more and more precise GPS equipment are available. The basis of the smallest treating unit is the knowledge about the local field conditions (physical and chemical conditions of the soil, soil fertility, presence of weeds and pests).

Precision farming technology should not be considered as a modern plant production technology or a new agro-management tool. In my opinion the precision farming technology is achieved only when the results of electronic and IT equipment are realized and can be differentiated in the variable rate treatments zone-by-zone. Furthermore, application maps are necessary for it, which are based on soil sampling with DGPS, yield mapping and the tractor guidance system, which decrease the overlapping and the extra input under the treatment. This equipment is the basis of precision farming technology but in itself, I do not consider as precision farming technology function.

The spreading of the precision farming technology does not fit perfectly to the technology spreading life-curve of Rogers. One part of the scientific literature examine only the different elements of precision farming technology while other authors assess precision farming technology systems in a complex way. It is hard to define exactly which farms could be considered as a user of precision farming technology. The question is that the farms where use only one of the elements of the precision farming technology can be considered as “user” or only those farms may use this name where the complex precision farming technology have been already realised.

Otherwise the application of the precision farming technology elements depend on the plant, on the field, on the weed and pest population and on the management. The biggest problem with the precision farming technology according to my opinion is that the possible advantages and disadvantages of the technology highly depend on the professional knowledge and attitude of the manager and the staff. This is the reason why sometimes the farmers think that the investment for precision farming technology will not give the expected advantages so they do not buy other additional elements of the technology or start to use their precision equipment in a conventional way.

SWINTON and LOWENBERG-DEBOER (2001) said that key factor of the spreading of precision farming technology was the increasing efficiency of input use. It means that the more efficient input use makes the spread of the technology faster. In contrast with their opinion, the most impressionable factors of its spread are the following (DABERKOW and McBRIDE,(2003):

- size and geographical situation of cultivated land;
- quantity and quality of human resources;

- risk-sensitivity of the manager.

There are many literature sources about the scientific results of economic viability of the precision farming technology. According to some researchers, precision farming technology is profitable only above 250 hectares. According to others, the farmers need a minimum of 1500 hectares for precision weed management or fertilization. In my opinion, the reason of these differences is that the economical threshold level highly depends on the correlation between savings and additional costs, which is strongly determined by the heterogeneity of the given plots. If the farmers can use precision farming technology on bigger field, they could experience more advantages of the technology.

2. MATERIAL AND METHOD

Secondary and primary databases were used in my PhD research. The secondary data come from the following sources: Hungarian and Danish Central Statistical Office, Eurostat, FADN and FAO Agricultural Statistic.

Between the autumn 2010 and spring 2011 the own data collection was made for examining the knowledge about the precision farming technology and the spread of this technology among Hungarian farmers producing field crops. The results of these data collection were compared with a representative Danish survey in FutureFarm project which published by LAWSON and co-workers (2010), and KIRKETERP-SCAVENIUS and PEDERSEN (2010). The Danish survey was made December 2010.

The own data collection contained 72 farmer's opinion about the precision farming technology. In my survey, the farmers were chosen with random sampling in different agricultural exhibitions. Some interviewed farmers have used precision farming technology for years, some have planned to adopt this technology and some have heard about the technology but does not want to use it.

Different statistical methods were used for the efficient processing of the database. Cross-table analyses were used to identify the correlation between two non-metric variables. In case of cross-table analyses the Chi-square (χ^2), the Cramer's V value, and their significance level were examined. The variance analyses help to identify the effect of the non-metric independent variables on the metric dependent variable. In case of the statistical analyses, the validity criteria like the probability of mistake (α) was 5% which is generally admitted in social sciences. [SZŰCS, 2002] In both statistical analyses the null-hypothesis is the lack of the dependence of the variables.

Five different plant production technology elements (soil sampling, nutrient supply, sowing, plant protection, harvesting) which are available in conventional and in precision farming system (in case of nutrient supply and plant protection with on-line and off line methods) were the basis of the investment analysis of precision farming technology. The precision farming technology elements can be combined well with the conventional technology elements.

The most profitable precision farming technology variation was chosen according to the net present value and the value of the dynamic payback period at the end of the planned period of usage. The basis of the net present value calculation was the additional costs and savings of the used precision farming technology. In the investment model calculations the changes of precision farming technology were compared to the conventional technology based on the results of the structured interviews.

According to the findings of the structured interviews, the farmers have expected changes in the following areas after the introduction of the precision farming technology: gross production value, seed cost, fertilizer cost, herbicide and pesticide cost, fuel cost, human costs, therefore only these were drawn into the model. In the model calculations the initial values of these factors were defined based on the FADN database in six different economic size units.

I examined the break-even area of the complex on-line and off-line precision farming technology in six different economic farm sizes based on the optimistic, realistic and pessimistic expectations of farmers – based on the findings of the structured interviews – who have already introduced or plan to introduce precision farming.

The complex off-line precision farming technology includes the following: yield mapping, soil sampling, off-line precision nutrient supply, precision sowing, off-line precision plant protection and the use of basic precision equipment. The investment cost of this off-line precision farming technology version is more than 46 million HUF, if farmers buy only one tool for each technology elements.

The complex on-line precision farming technology includes the following: yield mapping, soil sampling, on-line precision fertilizer use, precision sowing, on-line precision plant production and the use of basic precision equipment. The investment cost of this on-line precision farming technology version is more than 50 million HUF if farmers buy only one tool for each technology elements.

In my model I used the MS Excel "Solver Evolution Methods" to define the break-even area for complex precision farming investment. The restricting conditions of the model were the following: the average income during the period of use (7 year) shall be zero or near zero, while the net present value in the 7^{th} year shall be positive.

The main steps of the investment model for the different variations of precision farming technology are shown in Figure 1.

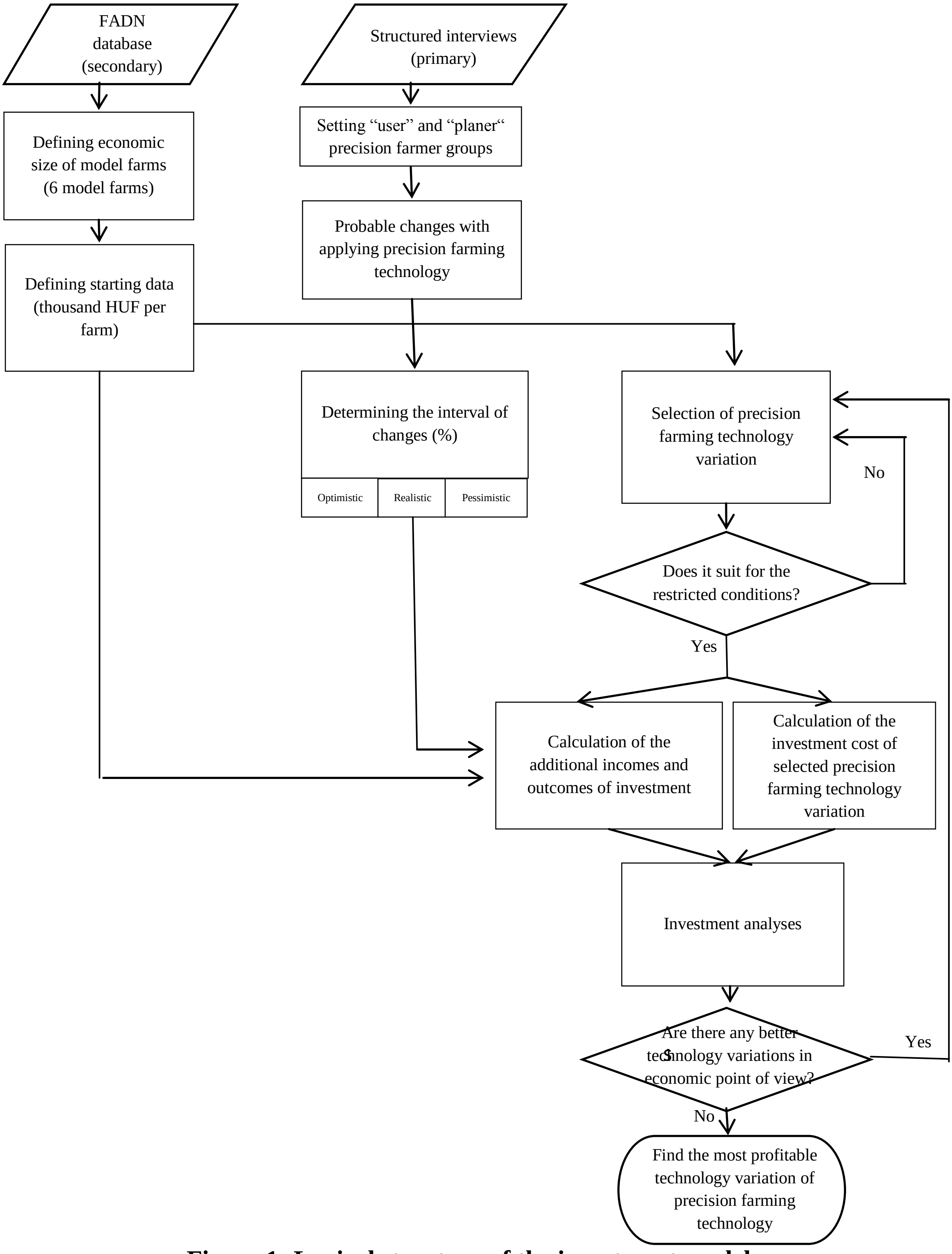

Figure 1: Logical structure of the investment model
Source: own construction

3. RESULTS

I summarized results of my PhD dissertation in two subsections. In the first subsection the results of the structured interviews were presented, in the second part the results of the investment model were presented. I also compared my results with the international scientific literature.

3.1. The results of the structured interviewed research

The examined database includes the data of 72 farms. All farms produce field crops. Thanks to the personal interviews, nobody was excluded from the examination because of missing data. The available sample database was divided into three sub-samples according to the used farming technology:

1. non-precision farmers (n_1=48) [1]
2. precision farmers (n_2=8) [2]
3. farmers planning to introduce precision farming (n_3=16).

3.1.1. Adaptation of the precision farming technology in the examined sample

The databases of Hungarian Central Statistical Office or Research Institute of Agricultural Economics do not include information about the adaptation frequency of the precision farming technology elements. The primary aim of the structured interviews was to identify the factors which have effects on the adaptation decision of precision farming technology.

Precision farming technology used in 11% of the interviewed farmers, the rate of non-precision farms was 89% (7% of these farms used ecological farming). Some of the non-precision farmers used GPS based soil-sampling (7%) or GPS tractor guidance (12%) which is part of the precision farming technology, but did not use any other elements which lead to the site-specific production. 25% of the conventional farmers planned to adopt precision farming technology in the future. The frequency of the use of precision farming technology in the database may be distorted, because the structured interviews mostly happened in agricultural exhibitions where particularly those farmers take part, who are more open to novelties.

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[1] Include farms which use net-based soil sampling or rd but the treatments do not act on the management-zones.

[2] Include farms which use at least one from the following elements: precision fertilization, precision plant production, precision tillage, precision weed management, precision sowing, sensors (soil, leaves, etc.).

In Denmark according to the FutureFarm Project the 14% of the farmers (24 farms) used precision farming technology elements. [LAWSON et al., 2010] The reason that precision farming technology used in wider range in Denmark is that the Danish farmers could meet the technology in the early 1990s. [PEDERSEN et al., 2004] Precision farming technology is available from only the late 1990s or early 2000s for the Hungarian farmers.

According to the cross-table analysis, the size of the cultivated land and the age of the farmers were the factors which influenced the adaptation of precision farming technology in my database. (Table 1)

Table 1: Correlation between selected farm characteristics and the adaptation of precision farming technology

Independent variables	**Pearson χ^2**		**Uncertainty co-efficient**		**Cramer's V**		**Strength of relationship**
	value	α	value	α	value	α	
ESU size	11,16	0,35	0,103	0,25	0,28	0,35	no relation
Size by cultivated land	13,99	0,01	0,135	0,003	0,314	0,01	medium*
Heterogeneity of soil	0,55	0,8	0,005	0,754	0,08	0,8	no relation
Rank of plant production technologies according to profitability	5,15	0,27	0,05	0,191	0,19	0,27	no relation
Age of farmer	8,90	0,46	0,09	0,02	0,25	0,46	medium*
Education of farmer	8,14	0,61	0,08	0,48	0,24	0,61	no relation

Note: * the significance level is lower than 5%

Source: own construction based on structured interviews

3.1.2. Adaptation rate of the precision farming technology elements

Based on the frequency of the application of precision farming technology elements the first in the rank among farmers using precision farming technology was precision fertilization, the next was precision plant protection. The tractor guidance GPS tractor guidance and the soil sampling were not in the most common elements in the precision farmers sub-sample, while GPS tractor guidance was a widely used element among conventional farmers. The reason for that so many conventional farmers use tractor guidance may be that the operation of this element does not need additional work and its advantages may be detected in a short time. (Table 2)

Table 2: Adaptation frequency of different precision farming technology elements

Name of precision farming technology elements	Adaptation frequency among HUNGARIAN farmers		Adaptation frequency among DANISH farmers	
	% (n=8)	pieces	% (n=24)	pieces
GPS tractor guidance	12,5	1 (+5*)	n.d.	n.d.
Grid soil sampling	25	2 (+3*)	41,7	10
Precision nutrient supply	75	6	29,6	7
Precision plant protection	62,5	5	20,9	5
Precision tillage	37,5	3	n.d.	n.d.
Precision weed management	12,5	1	n.d.	n.d.
Precision sowing	12,5	1	n.d.	n.d.
Air photography	-	- (+1*)	8,3	2
Yield mapping	-	- (+1*)	20,9	5
Sensors (soil, leaves)	-	-	-	-
Weed mapping	-	-	-	-

Note: * number of conventional farms which used a precision farming technology element
n.d.: no data available

Source: own construction based on structured interviews
and LAWSON et al. (2010)

Two third of the precision farmers have used more than one elements of the precision farming technology. These farmers have started the technology with grid soil sampling. The farmers who used three or four different precision farming technology elements have bought all elements at the same time.

3.1.3. Opinion of farmers about the advantages and disadvantages of the precision farming technology

Adaptation of precision farming technology may bring both advantages and disadvantages. Advantages of the precision farming technology are the following: higher yields, better yield quality, income increasing, decreasing environmental impact, decreasing chemical use. Disadvantages of the precision farming technology are the increase of working time and operational costs.

The respondents of the interviews could tell their opinion about the advantages and disadvantages of precision farming technology on a list which included 11 possible changes. They could use the Stapel-scale[3] to classify the changes resulted by the introduction of the precision farming technology. Table 3 summarizes the result of these answers.

There was no significant difference between the average values of the three sub-samples according to the ANOVA-test. Otherwise, the ranking of the possible changes based on the average value (in absolute value) were completely different. Only the changes in the income and in the labour need showed significant differences between opinions of the interviewed sub-samples.

In the rank of changes the most remarkable differences could be observed in the yields the organization of work according to the opinion of precision farmers. Otherwise the improvement of the organization of work was in the 6th or 7th place in the other two sub-samples. The higher yield was on the 4th place in these two groups. All these experiences suggest that besides the realized extra yield and cost saving, the organizational change is may be also noticeable by the farmers in the practice.

According to the scientific literature sources the most important advantage of precision farming technology is the decreasing of the negative environmental impacts. In my survey, non-precision farmers placed this advantage in the first place, according to the precision farming planners it was in the second place, while according to the precision farmers this impact was only on the 8th place. There were similar changes in the area of the chemical changes, which has a strong link with the decreasing of environmental damage. The precision farmers put the chemical changes only on the 9th place.

[3] Stapel-scale: scale from -5 to +5. If there is no changes compared to the conventional farming 0 was used. Negative numbers means decreasing, positive numbers means increasing. [SAJTOS and MITEV, 2008]

Table 1: The opinion of the different subsamples about the changes resulted by the adaptation of precision farming technology

The most important effects of precision farming technology	User of precision farming technology		Planner of precision farming technology		Non-user of precision farming technology	
	average (n=8)	**rank**	**average** (n=16)	**rank**	**average** (n=48)	**rank**
yield change	2,75	1.	2,81	4.	2,26	4.
income change*	2,12	6.	4,44	1.	2,45	2.
change of chemical use	-0,63	9.	-2,87	5.	-2,36	3.
change of environmental damage	-1,38	8.	-4,19	2.	-2,70	1.
change of labour force needs*	2,37	3.	0,62	9.	0,7	9.
change of work time	2,25	4.	0,44	10.	0,57	10.
change of operational costs	0,37	10.	2,50	6.	2,02	5.
change of organization	2,75	1.	2,44	7.	1,74	6.
change of yield quantity	2,25	4.	2,13	8.	1,66	7.
change in planning process	2,00	7.	2,88	3.	1,57	8.

Note: large-scale increase: +5; large-scale decrease: -5; corresponding to conventional farming: 0;
* the results of sub-samples are significantly different based on the ANOVA test

Source: own construction based on the structured interviews

According to the farmers who have already used precision farming technology the changes after the introduction of precision farming were smaller in practice than it was expected from the theoretical knowledge. In my opinion, it shows the information about the precision farming technology given in newspapers or agricultural exhibitions emphasize more advantages of the technology.

3.1.3.1. Sentiment of the variable cost of the precision farming technology

I examined the opinion of the farmers about the changes in percentages of operational cost, herbicide cost, fertilizer cost and human resource cost resulted by the adaptation of precision farming technology compared to the conventional technology. I used the box-plot analysis for this examination.

According to the correlation analysis there were no significant differences between the judgment of the cost changes and the adaptation of precision farming technology. In summary it can be stated, that the biggest cost saving were in the fertilizer cost and herbicide cost according to the opinion of precision farmers. The precision farmers also mentioned the increase of the operational costs and human resource costs.

3.2. The results of the investment-model

The aim of the investment model was to establish a decision supporting system which may help the Hungarian farmers to choose the most profitable precision farming technology variation for their farms. In the model calculation the examined investment possibilities were planned as an improving investment for such a farm where conventional farming elements were formerly used.

3.2.1. Selection of the most economical technology variation of the precision farming technology

For the individual farmers it was not possible to make investment for precision farming technology according to the model calculation, which was based on the pessimistic opinion of the interviewed farmers. In case of individual farmers the net present value was negative in the end of the planned time of use which was 7 years. According to model calculation based on the realistic opinion, some applicable precision farming technology variations could be found for medium and large sized farms. These technology combinations included the off-line precision plant protection. The payback period of these investments was 2 or 4 years depending on the farm size.

For agricultural enterprises there also were not profitable precision farming technology version according to the investment analysis based on the pessimistic opinion of interviewed farmers. In this case every precision farming technology variation had a payback period longer than 7 years. According to the model calculation based on the optimistic opinion, the most profitable technology variations included more than one precision farming technology elements, such as precision plant protection, precision fertilizer use. According to the model calculations, the on-line precision farming elements have been introduced only in the large sized farms.

3.2.2. The break-even area of the complex off-line and on-line precision farming technology variations

The Solver Evolution Methods in MS Excel helped to define the break-even area for complex on-line and off-line precision farming technology investment. The restrictive conditions were the following: the average income under the time of use is zero or close to zero and the net present value is positive after the 7th year.

The model calculations have led acceptable results only in the case of optimistic expectation. The break-even area, which was given by the optimistic model calculation for off-line[4] complex precision farming technology was smaller than the available field of model farm in case of medium and large farms. These model calculations were based on the opinion of precision farmers and the planners group about the expected changes of variable cost and gross margin resulted by the adaptation of precision farming technology.

The model calculations showed that investments of precision farming technology were profitable only in case of optimistic expectation, if the on-line[5] complex precision farming technology were examined. Furthermore, only in case of medium and large sized enterprises was enough cultivated area for the necessary break-even area resulted by the model calculation.

3.3. New and novel scientific results

1. I defined with the exploratory structured interviewed survey that in the group of Danish and Hungarian farmer the popularity rank of precision technology elements is the same (1. precision nutrient supply (off-line), 2. precision plant protection (off-line), 3. grid soil sampling).

2. The cultivated land and the age of the farmers significant influenced the adaptation of precision farming technology. Primarily young farmers with bigger cultivated land adopted the precision farming technology. The farmers who have planned to adapt one or more elements of precision farming technology in the next 2-5 years were mostly middle aged farmeres

[4] Complex off-line precision farming technology variation include the following: yield mapping, net-based soil sampling, off-line precision nutrient supply, precision sowing, off-line precision plant protection and the use of basic precision equipment.

[5] Complex on-line precision farming technology variation include the following: yield mapping, grid soil sampling, on-line precision nutrient supply, precision sowing, on-line precision plant protection and the use of basic precision equipment.

with a bigger cultivated land. Otherwise, the precision farmers have not planned further expansion of the technology in the next 5 years.

3. The changes resulted by the introduction of precision farming technology may be experienced in the agricultural practice. The farmers who have already used the precision farming technology assessed the changes resulted by the adaptation of the technology less significant, than the farmers who know the technology only from theory according to the exploratory structured interviews. The farmers who adapted precision farming technology could observe the advantages of yield increase, of income increase and the improvement of work organization in the practice.

4. I verified with model calculation that in case of small-sized individual farms there are no profitable precision farming technology variation. These farms could observe the advantages of precision farming technology only as a member of machinery co-operation or using machinery service.

5. In case of the medium and the large individual farms, the most profitable technology variation included conventional farming with off-line precision plant protection. For agricultural enterprises the on-line precision plant protection as own investment may be justified economically. I verified with another model calculation that the investment of complex precision on-line or off-line precision plant protection is profitable for medium and large sized enterprises because they have more cultivated land than the necessary break-even area.

4. Conclusions and recommendations

4.1. Confirmation or rejection of hypotheses

According to the statistical and mathematical methods from my hypotheses that were based on the scientific literature, I verified four and rejected three of them, and in one case, the further research is necessary. (Table 4)

According to the structured interviews, 11 % of the respondents (8 farms) were considered as precision farmers. This rate was 14 % (24 farms) in the Danish survey. This suggests that in Denmark the use of precision farming technology is wider than in Hungary. According to it I could verify H1 hypothesis but because of my database is not representative for the Hungarian plant producers I suggest a further national survey.

The same precision farming technology elements were adapted both in my survey and in the Danish survey. However, I observed that according to the frequency of using of precision farming technology elements twice more farmers used grid soil sampling in the Danish survey than in my survey. The frequency of the precision nutrient supply and precision plant protection is 5-10 % higher among Danish farmers. In summary, I determined that all of the precision farming technology elements, which were used in Denmark, were also used in Hungary. However, according to the frequency of use (in percentage) precision farming technology elements were used in wider range in my survey. Based on these results the H1/a and the H1/b hypotheses were disproved. I suggest a further national survey in this topic too.

Based on the results of the cross-table analysis, I determined that only the size of cultivated are and age of farmers had significant effects from the examined factors on the adaptation of precision farming technology in the practice. According to these results, the H2/a and the H2/c hypotheses were verified. There were no significant correlation between the adaptation of precision farming technology and the economic size unit of farms. Therefore, if the farms belonged to the bigger European Size Unit it did not mean that they used the precision farming technology. Based on these results, the H2/b hypothesis were disproved. In summary, I may be stated that according to my exploratory survey, precision farming technology was adapted in the farms with more than 300 hectares by younger than 40 years old farmers.

The farmers who have already used the precision farming technology assessed the changes resulted by the adaptation of the technology less significant, than the farmers who know the technology only from theory. According to my opinion, it suggests that the information about the precision farming technology in newspapers or agricultural exhibitions is more optimistic than the advantages in the practice. Based on the cost calculations, the average opinion of the non-precision farmers and the planners are very similar, but the opinion of non-precision farmers moved in wider interval. Based on these the H3 hypothesis was verified.

According to my investment model, the H4 hypothesis was disproved. Based on the results of the investment model there are no precision farming technology variation, which has shorter payback period than 7 years in each farm sizes. According to the investment model, for the small sized farms there were not any profitable precision farming technology variations that could be managed by the available own equipment.

I verified with my model calculation that the complex off-line or on-line precision farming technologies are economically viable only in the case of medium and large sized enterprises. According to the model calculations, only these enterprises have more cultivated land than the necessary break-even area, therefore H5 hypothesis was verified.

Table 4: Verification or disproving the hypotheses

Number of hypotheses	Content of hypotheses	Verify or disprove
H1	The adaptation rate of the precision farming technology is lower in Hungary than in Denmark, which was one of the first country where this technology was introduced.	further examination
H1/a	The number of farmers who use precision farming technology is higher in Denmark than in Hungary.	further examination
H1/b	In Denmark more kind of precision farming technology elements are used than in Hungary.	disproved
H2	The adaptation of precision farming technology depends on economical and personal factors.	verified
H2/a	The precision farming technology elements are mostly used in the farms with bigger cultivated land.	verified
H2/b	The precision farming technology elements are used in farms with bigger economic size.	disproved
H2/c	The adaptation of precision farming technology highly depends on the age of farmer.	verified
H3	The opinion of precision and non-precision farmers about the advantages and disadvantages of precision farming technology is clearly distinguishable.	verified
H4	Precision farming technology variations may be found for all farm sizes, which payback period is shorter than the planned time of use.	disproved
H5	The complex precision farming technology investment is profitable only for farms with bigger economic size.	verified

Source: own construction

4.2. Further conclusions and recommendations

The positive impacts of the precision farming technology – which are well communicated towards the farmers – may be experienced in the agricultural practice. One of the observations of my research, namely that there were no significant differences between the average opinion of precision and non-precision farmers has also confirmed this opinion. A great part of the farmers knows the advantages and disadvantages of precision farming technology but most of them thinks that the investment costs of the technology is too much for them or the commitment of management for the technology is missing. Nevertheless, the commitment of the management for the precision farming technology is not enough if the working staff do not pay enough attention for the settings of equipment or the maintenance.

I defined that the rankings of effects of precision farming technology are different in the group of user, group of planners and group of non-users of precision farming technology. For the precision farmers the most important advantages of this technology are the better organization and yield increase (in quantity and in quality) and the increase of the profit. The most important disadvantages are the increase of human resource needs and working time.

In my opinion the most important results of my survey are that I defined the factors which have effects on the adaptation of precision farming technology. According to my survey the size of cultivated land and the age of farmers significantly correlate with the adaptation of precision farming technology. According to these motivating factors, the precision farming technology may spread primarily in those farms, which have large cultivated land and are managed by younger farmers. Although in Hungary, where many small sized farms are operated, it would be expedient to innovate the precision farming technology tools even for smaller farms. The other driving factor should be the improving of co-operation, because in a machinery co-operation, the investment cost of precision farming technology may be shared among the farmers and the capacity utilization is better.

According to the answers of interviewed farmers the most adopted element of precision farming technology is the tractor guidance (it was used in 6 farms, precision and the conventional farms together). The using frequencies of the net-based soil sampling and of the off-line precision nutrient supply (which get strong link with soil sampling) and of the off-line precision plant protection were similar. In my opinion the reason of lack of on-line precision farming technology elements are that the investment cost of these technology elements are much higher than the off-line equipment and the possible savings are the same.

The farmers who have used one or two elements of the precision farming technology are planning to adapt the precision fertilization of precision plant production in the next 2 or 5 years. Those farmers who have adapted three or four elements of precision farming technology have adapted these elements at the same time are not planning any technology improvement in the next 5 years.

4.3. Conclusions and recommendations based on the model calculation

In case of six different sized model farms, I defined the most profitable precision and conventional farming technology combinations for Hungarian farmers with my investment model analysis, which was based on the advantages and disadvantages explored by a structured interview survey of the farmers.

My model calculations have verified that the combination of conventional and precision farming technology makes the highest profit. However, it should not be forgotten that the profitability of the precision farming technology strongly depends on the heterogeneity of the yield effecting factors. If a farm has more heterogeneous conditions it can utilize better the advantages of precision farming technology.

In addition to the restrictive conditions, I determined that viable economic variations of precision farming technology could not be applied for all farm sizes.

According to the model calculations, in the case of individual farms, only the large sized farms are able to adopt more than one elements of precision farming technology. Based on the opinion of planners' group, the large sized is the only farm size, where the most profitable precision farming technology variation – which includes both on-line precision fertilization and off-line precision plant protection – may be introduced economically.

The results of the model in case of agricultural enterprises are much more diversified in the view of diversity of technology elements. The on-line precision farming elements have appeared in the half enterprises in the model.

In case of the enterprises with average conditions, based on the realistic opinions, the on-line or off-line precision plant protection was the most profitable precision farming technology element. In this case, the payback of these investments may be manifested in the first year (or even in the year) of the investment.

I verified with model calculations, that complex off-line or on-line precision farming technologies are economically viable only in the case of medium and large sized enterprises. Only these enterprises have more cultivated land than the necessary break-even area according to the model calculation. However if the investment analysis was based on the realistic and not on the optimistic opinion of the respondents, there were no precision farming technology variation which had shorter payback period than 7 years. This period is not either for large sized farms.

In the practice the investment of the complex precision farming technology is acceptable only when it is adapted by the combination of own equipment and service or in a kind of machinery co-operation which helps to increase the capacity of utilization of the machinery.

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