Theses for doctoral dissertation (PhD)

COMPARATIVE EFFICIENCY ANALYSIS OF CONVENTIONAL AND GEOREFERENCED CROP PRODUCTION TECHNOLOGIES FOR CONVENTIONAL CROPS

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1. BACKGROUND, OBJECTIVES AND HYPOTHESES OF THE RESEARCH

I have been involved in precision farming, its practical application and implementation for more than a decade. The concept appears with increasing frequency, both in theory and in practice, mostly in technical and agronomic terms.

The development of crop production technology, the latest genetics, new solutions, technological interventions and the machinery responsible for their implementation are constantly evolving and are being adapted and incorporated into crop production technology. The benefits of applying precision farming technologies are most evident in the implementation of technological interventions in the cultivation of individual field crops.

When comparing traditional technologies, often referred to as conventional, with the latest, precision technologies, the advantages and disadvantages of technology change, the additional investment required for technology change, the calculation of the return on investment and the knowledge and technical skills of the human resources needed to professionally manage and operate the tools and equipment systems acquired during the technology change to implement the new technology are the focal points.

Studies and research on precision farming analyse the impact of the applied precision technology elements on crops, yields and income, or, in other technical approaches, measure and quantify the agrotechnical benefits of the knowledge built into the machines as an opportunity. Thanks to today's state-of-the-art remote sensing tools, partially or fully automated sensors built into machines and the data measured and transmitted by sensors and chips, and the computer developments, software, applications and information systems that can process them, the understanding of precision farming for crop production is taking on a new level.

The first step is the use of GIS for agricultural purposes, and the next step will be when the use of GIS for agricultural purposes becomes widespread and integrated into technology implementation practices. This is where we arrive at geo-referenced data-based crop production, i.e. when, by collecting, consolidating, processing and analysing deeper, more detailed geo-referenced data than the information at the field level, we are able to transform and exploit the benefits of a system that can recognise and manage crop-specific differences within a field at the cell level into everyday practice.

There is an undeniable need for further investigation and analysis of the practical application and use of geo-referenced data-based technologies in arable crop production, and for quantification of the indirect or direct effects generated by the technology. The adaptation and dissemination of the knowledge and practical experience gathered so far must be accelerated in order to have information not only for a specific field, crop sector, farm or company. Differences within a field must also be addressed so that we know what needs to be done to improve the technology. For information at the field level (even if it is crop-specific), deeper, more detailed data is needed, complemented by the collection, consolidation, processing and analysis of geo-referenced data. Today's technology (be it technical or IT solutions) is capable of collecting and consolidating data and batch processing them, but processing and analysing the data requires human knowledge in addition to the computer software used, which can be used to create a system capable of recognising and managing intra-field discrepancies at cell level. If it can be demonstrated that the differences arising from the spatial heterogeneity of the field or parcel, which is currently treated as the smallest unit of arable crop production, can be detected by data collection and analysis and that a map capable of treating the cells as a separate unit can be produced from the available data with the aid of geographic information software and applications, then the next step can be taken to ensure that the machine linkage implementing the technological intervention is capable of differentiating at the cell level, either in the case of soil cultivation or the application of inputs.

The practical benefit of translating cell-level information into technology could be to reach a higher, more competitive level of efficient arable crop production, even by international standards. At the current level, precision farming has the potential to allow for a degree of differentiation rather than averages. At the next level, farmers involved in arable crop production who put technological improvements and innovations into practice can further refine the management of intra-field variation. This will allow them to optimise their inputs by quantifying marginal efficiency indicators and marginal efficiency indicators in addition to average efficiency improvements. This, in turn, creates the possibility to increase the intensity of their production and to optimise their planting structure in economic terms.

The research topic and its purpose are highly topical in themselves.

It is timely, because if we only consider the impact of the economic effects of the last few years on Hungarian agriculture, its competitiveness, the economic organisations and individuals working in Hungarian agriculture and living from its income, it can be said in absolute terms that the general income situation of arable crop production and the farmers who earn income from it has changed very rapidly and to a great extent. In addition to the economic effects, changes in regulations and regulators (including the support system) also make the issue topical, since in many cases compliance with regulations not only entails an administrative burden, but also has an impact on the range of crops grown, including crop rotation, the technologies used and their implementation, documentation and validation in time or space. The research topic includes an econometric analysis of the effects of the latest technical and information technology solutions used in the application of geo-referenced crop production technologies and adapted to the technology, as well as a comparative effectiveness study of the practical application of the technology for the four largest field crops in Hungary.

Main objectives of the research

The studies carried out so far by researchers and technology developers who are knowledgeable and interested in the subject have mostly focused on a single technological element and have been carried out at plot, field or farm level. They have examined and measured the impact of the precision technology elements being compared on production costs, production value, income, and the return on investment required to introduce the technology, and have quantified them in terms of a narrower range of monetary indicators.

In order to complement and complexify the above, and to examine the technology from other points of view, I consider it important to carry out comparative efficiency studies over time, using data from sub-parts and farmers under the same conditions, using quantified, mapped, natural and value-based quantitative indicators, expressed in terms of their quantity, at farm, regional and national level. For the comparisons I aim to make, much more detailed data than field-level information is needed, which can be done by collecting, processing and analysing georeferenced data and it is worth reaching the highest level of aggregation, when we talk about efficiency at the societal (economic) level, which is often mentioned, but there are few (or no) credible, reliable and verified measurements and analyses available to provide economic operators with a basis for benchmarking.

1. My professional vocation, my business involvement and my knowledge and practical experience on the subject predetermined the primary objective of my thesis, which is to compare conventional and georeferenced crop production technologies by crop (the four crops studied, which are the crops grown on the largest area) and by year (each year of the five-year time series studied), to carry out efficiency studies based on quantifiable values, to establish and compare natural and economic efficiency indicators at farm, regional and national level, confirming the justification for the use of cultivation techniques based on georeferenced data, demonstrating their benefits in both economic and ecological terms.

My other goals include:

2. To investigate the impact of the application of geo-referenced farming technologies on future agriculture, with a particular focus on our natural environment and its sustainability.
3. Analyse the importance of technology change to comply with the European Green Deal.
4. To review the management of private and legal persons involved in arable crop production using the technology, in relation to its compliance with the main objectives of the new CAP strategy adopted by Commission decision on 7 November 2022.
5. **My main goal** is to make the benefits, usefulness and positive impact on efficiency of the geo-referenced crop production technologies, which are based on geo-referenced data and represent the highest level of precision farming in Hungary for more than a decade, measurable, demonstrable, proven, tangible, **widely published and easily accessible** to all agricultural stakeholders in both **economical and ecological terms.**

In addition, I consider it my task to deepen research and education cooperation with universities by using the knowledge and skills acquired in the form of student training.

Objectives and hypotheses

The fundamental objective is related to the basic hypothesis **H1**, **that the use of geo-referenced crop production technologies can lead to natural and economical efficiency improvements compared to conventional technologies.**

Comparable effectiveness tests can and should be carried out at different levels. Partial efficiency is usually treated as the smallest unit, but in order to prove the hypothesis, the data collection needs to be extended.

The filtered and processed, partially cumulated, data by crop species and by year from the farms included in the survey and completing the questionnaire constitute the sector, farm and region level data from the secondary data collection.

Farm-level data allow comparisons at farm level, within the farm (partial efficiency), regional, within the region and national (social efficiency).

The collection of partly primary and partly secondary data at national level should allow a targeted focus on the agricultural activities on the farms surveyed, including the operational data available through the various web-based platforms.

John Deere, as one of the world's largest manufacturers of agricultural machinery, is making extraordinary efforts to digitize agriculture, especially with regard to location accuracy, data communication, wireless data transmission solutions and web data services.

Of the different platforms, I chose MyJohnDeere's Operation Center, which, in addition to recording, documenting and storing individual farm operations, provides insight into field level operations data, allows for analysis and provides the basis for national analyses that are accessible to machine manufacturers, dealers, technical service providers, consultants, machine operators and farmers using the platform.

The terms ecological footprint and environmental sustainability are familiar concepts and are increasingly embedded in our everyday communication. Industrial agricultural production serves the efficient production of food raw materials, but at the same time, through increased use of chemicals or even over-cultivation of arable land, it also consumes and reduces the primary capital of production, the land, while at the same time harming the environment.

Thus, based on the second hypothesis **(H2)**, the **use of geo-referenced data based crop production technologies can have a positive impact on environmental sustainability**, which is partly related to my third hypothesis, which is not negligible given the relevance of the study.

The EU regulations that will enter into force soon and the agricultural support system in transition (CAP strategy 2023-2027, adopted by Commission decision on 7 November 2022, which should be implemented between 2023 and 2027 and should be in line with the objectives of the two key elements of the European Green Deal, the Farm2Fork strategy and the Biodiversity strategy) will have a major impact on Hungarian agriculture, its actors, its income generating capacity and competitiveness.

According to my third hypothesis **(H3), private and legal entities involved in arable crop production using geo-referenced data-based technology will be able to align their farming with the key objectives of the new CAP strategy.**

2. DATABASE AND DESCRIPTION OF THE METHODS USED

The analysis of the efficiency of arable crop production based on georeferenced data should be a priority area in digital agriculture, as the analysis of inputs, yields, income, profitability and efficiency indicators have a major decision-support effect on future agronomic, IT and technical improvements of arable crop farms, on increasing intensity and on crop rotation.

2.1. Databases, data sources

The data collection for my thesis was carried out at **four** levels:

1. Collecting independent data from national databases for comparisons.
2. Collecting field level data from the MyJohnDeere platform, documented by the harvester.
3. Targeted data collection from farms relevant to the research, using geo-referenced data based technology, using the precision farming extension services of KITE Zrt.
4. An in-depth analysis at farm and sector level of a selected target farm from the farms defined above.

2.1.1. Data from independent national databases

If we want to carry out national analyses, one of the most obvious solutions is to use professionally independent, credible, objective statistical databases that are a good representation of the situation of domestic agriculture, its structural state and its most important characteristics. The Hungarian Central Statistical Office (HCSO) has time-series agricultural data that effectively support complex analytical work. The agricultural censuses are carried out on the basis of the EU and national legal mandate, providing a detailed insight into all sectors of Hungarian agriculture.

An important element of my analyses and comparisons at the national level is the development of the area and yields of the main arable crops (winter wheat, maize, sunflower, rapeseed) published by the HCSO between 2018 and 2022 (Table 1).

Table 1. Trends in areas and specific yields of the main arable crops analysed

Year	Winter wheat		Maize		Sunflower		Rapeseed	
	Production area (ha)	Specific yield (t/ha)	Production area (ha)	Specific yield (t/ha)	Production area (ha)	Specific yield (t/ha)	Production area (ha)	Specific yield (t/ha)
2018	1 026 151	5,12	939 080	8,49	616 951	2,97	330 561	3,03
2019	1 015 640	5,29	1 027 592	8,06	564 112	3,03	300 601	3,03
2020	936 624	5,47	981 006	8,58	612 565	2,77	310 016	2,83
2021	892 794	5,93	1 054 566	6,13	654 693	2,68	257 535	2,85
2022	950 632	4,40	819 356	3,42	681 674	1,84	203 014	2,50

Source: own construction, 2024, based on data from the HCSO

Data collection at national level covered not only yields but also current selling prices. The current sales prices are taken from the Market Price Information System (PÁIR) of the Institute of Agricultural Economics (AKI). The PÁIR data include prices and quantities sold for each stage of the main product supply chains (cereals, oilseeds, soya, pork, beef, sheep, poultry, eggs, milk, fruit and vegetables, wine, tobacco), in accordance with the requirements of the EU regulations.

The HCSO database also provides a county-level breakdown, while, the data from the Market Price Information System (PÁIR) operated by the AKI, provides national-level, annual average producer prices. For winter wheat, in the absence of information on the quality of the harvested crop, the price of feed wheat is used as the basis for the calculations.

Table 2. Sales prices of the main arable crops included in the national analyses

Year	Sales price (HUF/t)			
	Winter wheat	Maize	Sunflower	Rapeseed
2018	47 441,3	46 467,4	92 070,9	107 679,1
2019	47 806,8	42 949,2	97 187,4	115 252,6
2020	53 111,5	50 336,1	121 085,8	128 410,0
2021	72 257,2	79 180,7	183 525,1	179 228,3
2022	127 683,4	111 388,7	261 624,6	268 431,5

Source: own construction, based on 2024 AKI PÁIR

In addition to yield data and sales prices, the quantification and collection of production technology inputs, such as production costs, can be a crucial or critical point of data collection and analysis.

Since 2000, AKI has been continuously compiling a database on the cost and income situation of the main agricultural sectors, based on data from test farms.

The Test Farm Information System monitors the assets, financial and income situation of Hungarian commodity-producing agricultural enterprises on a yearly basis through a representative sample of 2100 farmers.

I used the AKI data for the four crops (winter wheat, maize, sunflower, rapeseed) included in the study for the interval 2018-2022 and as a basis for comparing the different technologies across crop species. The database includes production value, direct variable cost, production cost (separately by cost item), contribution margin, sectoral result and prime cost of the main product. By type of enterprise, the data are split into individual farms (subsistence farmers, sole proprietors, family farms) and joint ventures, and national data representing the total of these. The national data have been used in the analysis.

2.1.2. Data from the MyJohnDeere portal

The machine information component of MyJohnDeere's Operation Center collects data on the current position, operating hours, fuel level and speed of the selected machine, which can be accessed anywhere and at any time.

The Field Information module stores data such as farm name, land location, field heuristics, field size and documented data linked to areas, allowing aggregation and analysis of individual agricultural operations at field level and management of the farm master database.

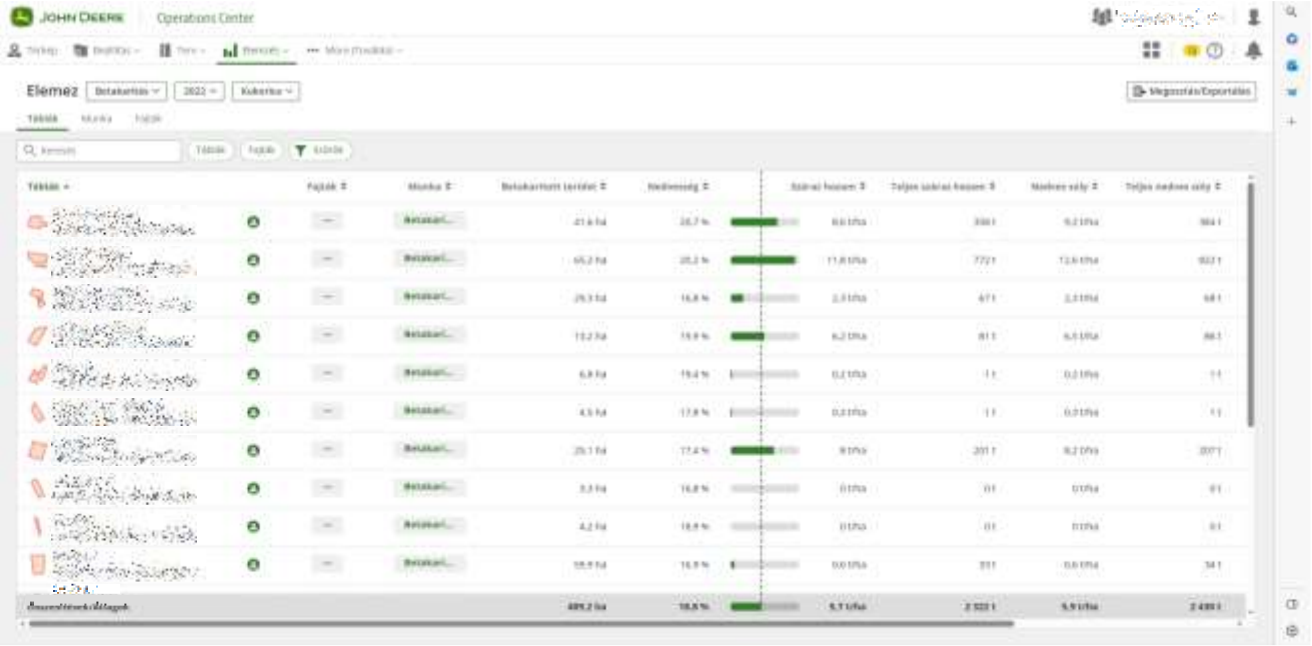
The MyJohnDeere portal was used as a central database of farms using geo-referenced crop production technology.

The data for each agricultural operation is grouped into four main types of work on the interface:

- Tillage
- Planting
- Application
- Harvesting

MyJohnDeere allows to batch collect farm data categorised by work type, by year, and even by crop type for planting and harvesting (Figure 1).

Figure 1: The MyJohnDeere Operations Centre analytics interface



Source: own construction, 2024, based on MyJohnDeere

For the four main crops, field level harvest data for the period 2018-2022 were collected from the MyJohnDeere portal (Table 3).

I processed the harvest data in Microsoft Excel, where I paid special attention to cleaning the data and removing outliers in a statistical sense.

Table 3. Yield data and harvested areas from MyJohnDeere, after data filtering, for the main arable crops (2018-2022)

Year	**Winter wheat**		**Maize**		**Sunflower**		**Rapeseed**	
	MyJD harvested area (ha)	*Specific yield (t/ha)*	*MyJD harvested area (ha)*	*Specific yield (t/ha)*	*MyJD harvested area (ha)*	*Specific yield (t/ha)*	*MyJD harvested area (ha)*	*Specific yield (t/ha)*
2018	20 460	5,84	18 460	9,84	11 517	3,46	7 999	3,25
2019	25 651	5,71	26 733	9,19	16 639	3,53	10 411	3,44
2020	35 351	5,94	37 117	9,18	23 431	3,09	15 274	3,09
2021	44 314	6,52	55 256	6,90	33 544	3,01	18 788	3,31
2022	59 336	4,94	44 683	4,60	42 606	2,23	15 548	2,86

Source: own construction, 2024, based on MyJohnDeere

It is a general fact that the more data settings needed to document an operation, the greater the potential for error and the lower the quality of the data. An incorrect calibration, a documentation with wrong parameters can result in unrealistic data in the documented data set.

In the case of maize and winter wheat, I filtered out data from fields with average specific yields below 0.5 t/ha and above 20 t/ha, respectively, while for rapeseed and sunflower I left fields with specific yields between 0.5-10 t/ha for further analysis.

Extremely small harvested field sizes, such as documented area units below 0.2 ha, were also excluded from the analyses. The total plots analysed comprise 95037 pieces of land, subdivided under about 364 groups of companies. In order to ensure the most accurate data processing possible, KITE Zrt. Precision Farming Managers and Precision Farming Manager Consultants, farms that have been collecting well-documented farm information for several years were selected. In this way, data that were problematic for analysis were filtered out on a professional basis, and then, using the filtering methods described earlier, the database was further refined.

2.1.3. Data from farms using technology based on geo-referenced data

The MyJohnDeere database is an organisation-customer-farm-field type hierarchical storage system, which is not directly suitable for spatial linkage analyses, i.e. during pre-processing I assigned farms to KITE sub-centres, counties and KITE regions (KITE regions do not fully correspond to administrative regions), thus allowing not only temporal but also spatial analyses.

KITE Zrt. Precision Farming Managers and Precision Farming Manager Consultants have classified farmers/farms/plants into the following categories based on pre-filtered MyJohnDeere data:

- Conventional farms: they do not have any precision activities (e.g. they do not use the RTK mark[1] for any agrotechnological operation except harvesting).
- Farms using precision farming elements: they use the RTK signal for each agrotechnological operation.
- Differentiating farms: differentiate the distribution of seed and/or fertiliser and/or plant protection products.

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[1] Real Time Kinematics: a real-time positioning system based on satellite positioning using a ground correction signal

Following the grouping, farms at higher levels of precision farming were contacted directly and I requested yield and production site data (2018-2022) and cost data for the four crops in a completely anonymous way. In total, data from **52** farms were processed for the five KITE regions.

Table 4. Baseline data returned by farmers at higher levels of precision farming using geo-referenced data

KITE region	**Year**	**Winter wheat**		**Maize**		**Sunflower**		**Rapeseed**	
		Production area (ha)	*Specific yield (t/ha)*	*Production area (ha)*	*Specific yield (t/ha)*	*Production area (ha)*	*Specific yield (t/ha)*	*Production area (ha)*	*Specific yield (t/ha)*
Northwest Transdanubian Region	2018	1 214	7,30	1 066	10,87	490	4,07	869	3,85
	2019	1 764	7,80	1 091	10,61	646	3,57	1 120	3,81
	2020	1 782	8,17	941	11,26	513	3,69	1 108	3,73
	2021	1 924	8,22	1 235	11,79	410	3,18	1 174	3,73
	2022	1 845	8,50	1 082	9,25	488	3,68	1 151	3,55
Central Hungary Region	2018	6 278	5,91	1 326	8,86	2 355	3,14	1 972	3,38
	2019	6 414	6,31	1 359	9,07	2 314	3,37	2 041	3,38
	2020	5 936	6,36	1 559	9,05	1 832	3,42	3 608	3,15
	2021	5 072	7,04	1 632	8,29	3 200	3,15	2 644	3,40
	2022	5 818	4,30	1 514	1,92	3 500	1,92	1 936	3,11
Southern Region	2018	1 395	5,94	1 341	9,81	630	3,07	539	3,19
	2019	1 231	5,90	1 087	7,71	844	3,17	745	3,06
	2020	1 306	6,21	1 257	10,11	592	3,21	751	3,33
	2021	1 283	5,65	1 242	8,23	820	2,98	560	2,87
	2022	1 409	6,49	1 204	6,57	782	3,08	530	3,78
North-Eastern Hungary Region	2018	1 098	7,30	1 563	9,53	1 019	3,52	287	3,55
	2019	1 207	7,72	1 451	10,69	1 006	3,66	286	3,84
	2020	1 616	8,02	1 641	10,36	1 487	3,81	498	3,80
	2021	1 770	7,34	2 017	9,90	1 210	3,70	534	3,32
	2022	1 663	5,29	2 058	6,21	1 318	3,31	671	3,05
South Transdanubia Region	2018	1 747	5,94	1 884	8,65	983	3,31	564	3,16
	2019	1 891	6,33	2 185	8,89	1 235	3,19	562	3,16
	2020	1 859	6,56	2 350	8,97	1 209	3,09	496	3,10
	2021	1 751	6,75	2 367	7,93	1 471	3,15	405	2,95
	2022	1 793	6,70	2 311	7,04	1 394	3,09	373	2,86

Source: own construction, 2024, based on secondary research

For the calculation of the production value (yield value) in the farms visited, I used the available AKI PÁIR sales prices per crop species for the year of the survey.

To quantify the production costs, I collected data by cost item, which were also used for the farms participating in the AKI test farm system:

- Seed cost
- Cost of fertiliser
- Herbicide cost
- Irrigation cost
- Cleaning costs
- Drying cost
- Direct insurance cost
- Other direct variable costs
- Cost of organic manure
- Machinery costs (variable costs, fuel and lubricants, repairs, etc.)
- Cost of external mechanical services
- Wages
- Public charges on wages and salaries
- Land rent
- Depreciation and amortisation
- Other costs
- Overheads of the activity
- Economic overheads

Data in natural units of measurement (in naturals) were provided by each farm participating in the study along the lines of their cultivation technology, i.e. from soil preparation to harvesting, fuel consumption of all mechanical work of each operation and input quantities used were available by crop and by year.

In addition, I asked farms targeted questions in order to assess and quantify the input savings and output gains from the use of geo-referenced data-based farming technologies:

How much input (in natural terms) do you save when using differentiated mode of operation (%), What are the diesel savings using RTK? (%), What is the saving in working time using RTK? (%), What is the yield gain using RTK? (%), Do you use consolidated operations? If yes, how much labour is saved (%). These targeted questions gave me a more precise insight into the natural efficiency of farms using geo-referenced data-based farming techniques, and I was able to use the wealth of information returned from 52 farmers to quantify production costs and conduct comparative studies (for the four crops, 2018-2022).

The question on input savings does not separately address savings in seed, fertiliser and pesticide use, i.e. savings were quantified for the total agronomic input use. Diesel savings are also one of the benefits of georeferenced data-based technologies. In the AKI database describing the cost and income structure, fuel costs are not included separately but are included in the machinery costs. Accordingly, I have adjusted fuel use upwards based on farmer responses. That is, in the secondary survey, I back-corrected the fuel consumption data received from the 52 farms for the four crops and the five years under study with the fuel savings data, simulating the fuel consumption that farmers using conventional technology would have presumably realized. Thus, the predicted specific fuel consumption data divided by the specific yields given by the HCSO can be used to calculate the specific fuel consumption per 1 tonne of grain yield (l/tonne), which can be expressed in monetary terms, as the average fuel prices for the period under study (2018-2022) are available in the HCSO database, which can be multiplied by the specific fuel consumption data, thus allowing the quantification of fuel costs for both geo-referenced and conventional technologies.

The data provided by the farmers have been subjected to a box-plot analysis, as any outliers could distort the results and lead to false conclusions.

To this end, I calculated the lower (Q1) and upper (Q3) quartiles of the returned data (separately for each data group), and then calculated the data filtering thresholds by a factor of 1.5 of the interquartile range (IQR), which is the usual factor for field sectors (upper data filtering threshold: Q3 + 1.5*IQR, lower data filtering threshold: Q1 - 1.5*IQR). Outliers identified as above were excluded from the analyses and comparisons.

2.1.4. Farm-level data

In addition to the regional and national data, I considered it necessary to use and analyse farm-level data in order to measure and compare partial efficiency at the farm level, i.e. for the sectors within a given company. To this end, a company using georeferenced data technology (Baki Agrocentrum Ltd.) was selected to provide the necessary information.

The company provided yield, area (Table 5) and cost data as defined above, supplemented by sales prices (Table 6).

Table 5. Development of the areas and specific yields of the four crops studied at Baki Agrocentrum Kft.

Year	Winter wheat		Maize		Sunflower		Rapeseed	
	Production area (ha)	*Specific yield (t/ha)*	*Production area (ha)*	*Specific yield (t/ha)*	*Production area (ha)*	*Specific yield (t/ha)*	*Production area (ha)*	*Specific yield (t/ha)*
2018	700	7,51	400	9,81	400	4,11	500	4,23
2019	750	8,04	300	11,15	400	3,48	550	3,84
2020	750	8,51	200	11,55	200	3,51	450	4,04
2021	900	8,31	400	12,51	60	1,15	500	3,89
2022	700	9,11	300	10,15	150	3,41	500	3,40

Source: own construction, 2024, based on secondary research

Table 6: Farm gate sales prices of the main arable crops included in the analysis

Year	Sales price (HUF/t)			
	Winter wheat	Maize	Sunflower	Rapeseed
2018	51 000	46 500	112 500	115 000
2019	51 000	46 500	112 500	115 000
2020	52 000	58 000	119 500	124 000
2021	72 500	82 000	207 000	176 000
2022	122 000	105 000	285 000	312 000

Source: own construction, 2024, based on secondary research

2.1.5. Methodological background for expressing efficiency indicators

The data collected during the research were processed following the logic and order of the answers to the questions in the questionnaires. Thus, firstly, the input-side savings and output-side increases realised by the farms using the geo-referenced technology were quantified, and then the natural efficiency indicators were constructed on the basis of the resulting values. According to the above, the following direct efficiency indicators (direct or inverse efficiency indicators, depending on whether the yield expressing the result is in the numerator or denominator of the indicator) were quantified and expressed: area productivity (specific yield), labour productivity, specific yield per input, fuel use per tonne of grain yield, specific yield per labour input. For the quantification of the indicators, the specific yields in the numerator are per crop for a given year, taken from the HCSO database and from the secondary survey (52 partner farms surveyed), while the denominator is set at 1 unit. To quantify the fuel consumption per tonne of grain yield, I used the predicted specific fuel consumption data according to the calculations defined earlier, as well as data from the secondary research.

The expression of natural indicators was followed by the quantification of indicators for comparing economic efficiency. As a first step, the production value (yield value) was quantified as the product of the specific yields (national CSO yield, yield from MyJohnDeere, yield from secondary research) and the unit price of sales (AKI PÁIR, unit price from secondary research) (Table 7).

For comparability, I have used both the AKI PÁIR and the unit sales prices from the research to quantify the production value (yield value) at farm level.

Other factors not having a yield content (area-based subsidies, additional area payment for conforming to greening conditions, etc.) have not been taken into account.

Table 7: Sources of returns and unit selling prices

Yield (t/ha)	Unit selling price (HUF/t)	Production costs (HUF/ha)
County and national HCSO data	National AKI PÁIR data	AKI data
Data from MyJohnDeere	National AKI PÁIR data	Corrected AKI data
Data from secondary research	National AKI PÁIR data	Secondary research
Farm-level data from secondary research (Baki Agrocentrum)	National AKI PÁIR and sales price from secondary research (Baki Agrocentrum)	Secondary research (Baki Agrocentrum)

Source: own construction, 2024, based on secondary research

As a next step, the cost of production was quantified. There are three sources of data on production costs: data from farms participating in the AKI test farm system, AKI data quantified and corrected by the value of input savings realised by the farms in the study (**seed**, **fertiliser**, **herbicide, fuel**) expressed as a percentage, and data collected from the farms in the study during the research. In all cases, the production costs were processed in the same format and with the same data content as the values reported and quantified by the farms participating in the AKI test farm system, by cost item. It is important to stress that in my calculations, land rent was not included in the production costs. Using the quantified production value (yield value), the cost of production and some of its cost components, as well as specific yields, the following indicators for measuring economic efficiency were quantified:

- specific income,
- wage-proportional profitability,

- agronomic input material cost-proportional profitability,
- fuel cost-proportional profitability,
- production values in proportion to costs,
- prime cost,
- profitability in relation to costs,
- income per unit of product,
- income level.

All quantified indicators are productivity or profitability indicators (based on a ratio), which are direct efficiency indicators, and some are direct and inverse efficiency indicators.

2.1.6. Comparative effectiveness analyses

In the analyses and comparisons, I used comparisons over time, sub-parts, and with data from farmers in the same conditions, resulting in farm-level, regional and national sectoral comparisons, according to the purpose of the analysis.

The comparisons were made using quantified, mapped, natural and value-based quantitative indicators.

In the relation of all efficiency indicators calculated, I compared the efficiency of conventional and georeferenced cultivation techniques by crop species and by year.

At the national level, I compared the natural and economical efficiency indicators of farmers using conventional technology with those using georeferenced data-based farming technology in secondary research and showed the differences.

As a next step, I compared the national data (both traditional and geo-referenced) with the aggregated values per region (five in total) of farms using geo-referenced data based on the KITE regions assigned to their partner code, and compared the different regions with each other.

Finally, I compared the farm-level data and indicators of the farm selected in the secondary survey with those of its own region, as classified by the KITE partner code, and with national data, including those of farmers using conventional and geo-referenced data.

3. MAIN FINDINGS OF THE THESIS

1. Hungarian arable farmers will only be able to comply with environmental requirements and remain profitable and competitive if they switch to geo-referenced crop production technologies as soon as possible.
2. The processed data from the farms involved in the study, based on geo-referenced crop production data, and the efficiency indicators derived from these data, show clear and well-established natural efficiency improvements for all crops studied, including winter wheat, maize, sunflower and rapeseed, at farm, regional and national economy level.
3. The analysis of the most relevant, measurable and officially available data on conventional farms has shown that, on a national scale, significant efficiency improvements can be achieved by switching to the technologies used by the farms analysed in my study.
4. The natural efficiency gains on both the input side and the yield side, including the profit side, are confirmed. Even if, for the five years under examination, the weather factors and seasonal effects which have a major impact on the yields of arable crops and the harvesting of the crops grown are ignored. Efficiency improvements on the yield side are present for farms using geo-referenced technology, irrespective of the crop type.
5. One of the main findings of the study, i.e. natural efficiency improvements are confirmed for all the crops studied, for the processed data from the farms producing the field crops based on the geo-referenced data used in the study and for the efficiency indicators derived from these data, does not imply that the same conclusion is reached for all the quantified econometric efficiency indicators used to compare the two different technologies.
6. The national comparisons (except for rapeseed) show that the specific income of farms using geo-referenced technology is higher than the specific income of farms using conventional technology. The positive impact of the geo-referenced technology is also confirmed for the economic efficiency indicator.

7. On the farms studied, the quantified agronomic input savings at the national level due to the use of the technology range from 4.28 to 13.46%, while fuel savings range from 4.86 to 9.9%. If, in addition to the direct environmental impact, the indirect impact of the technology on the carbon footprint is also taken into account, it can be clearly stated that the switch to a technology based on georeferenced data is a significant step towards carbon neutrality.
8. The nationally measured labour time savings, which vary from crop to crop and year to year, range from 4.71 to 7.87%, while the quantified closely correlated labour savings range from 9.52 to 14.92%, due to the reduction in the number of operations resulting from the reduction in the number of operations without overlaps and omissions, which are often automated and consolidated. The direct effect of this technology is less soil disturbance, less compaction and less pulverisation.
9. My most important finding is that farms based on geo-referenced data are more sustainable, efficient and competitive, both economically and environmentally. In addition, the direct effect of the use of this technology is that we can bring our farming into line with the increasingly stringent environmental requirements (e.g. European Green Deal) and the objectives, standards and criteria set out in the Common Agricultural Policy for the years 2023-2027, which also allows us to maximise direct and indirect subsidies.

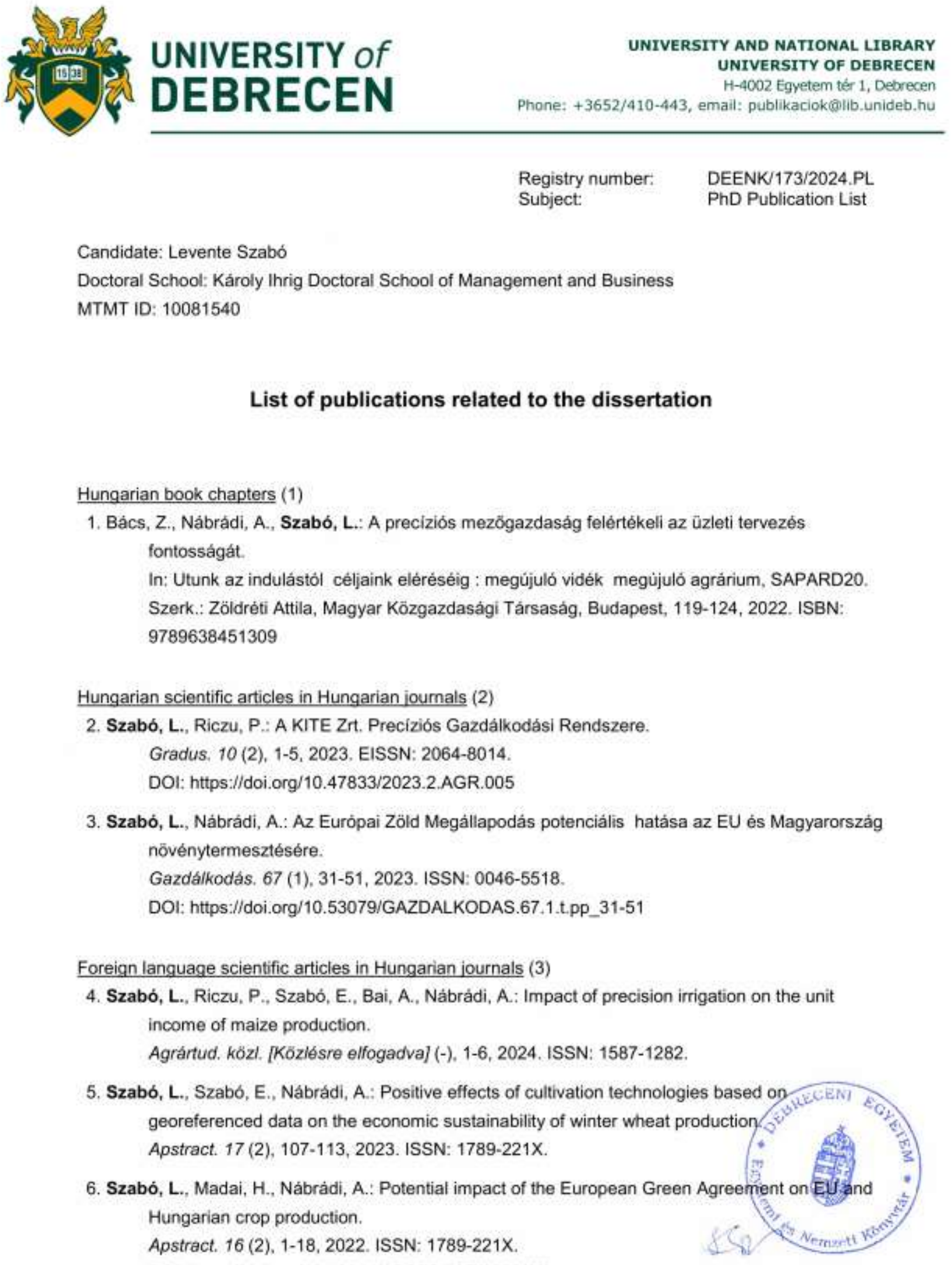
4. MAIN FINDINGS OF THE THESIS, NEW OR NOVEL RESULTS

1. I developed a methodology to compare the efficiency of conventional and georeferenced crop production technologies. Using data from independent domestic databases (HCSO, AKI), stored in the MyJohnDeere operations centre, data from the research participants providing data, and data from a deep analysis of a selected target farm at farm and sector level, I trained direct efficiency indicators to measure natural and economic efficiency, which allowed a multi-level (farm, region, country) comparative efficiency analysis of the two different technologies.
2. I have found that the most suitable econometric efficiency indicator for comparing conventional and georeferenced crop production technologies is the income per hectare, specific income (HUF/ha), which, in addition to the cost increase resulting from the different intensity of the technologies, takes into account and quantifies the yield increase associated with the increase in intensity of georeferenced crop production technologies and the resulting increase in production value (yield value).
3. I have shown that at the national level, the agronomic input savings measured for farms using geo-referenced data-based farming technology ranged from 4.28-10% for winter wheat, 4.58-10.54% for maize, 6.63-13.46% for sunflower and 4.66-11.05% for rapeseed over the period under study.
4. I have shown that at the national level, the labour savings for farms using geo-referenced data-based farming technology ranged from 9.54-10.93% for winter wheat, 12.77-14.92% for maize, 11.43-12.52% for sunflower and 9.09-10.73% for rapeseed over the period under study.
5. In a national comparison, I found that the largest efficiency improvement in the specific income of farms using geo-referenced farming technology was achieved for sunflower as a crop, ranging from +12% to +107%.

5. PRACTICAL USE OF THE OBTAINED FINDINGS

1. The results of a comparative effectiveness study of technologies based on geo-referenced data have practical benefits for farmers, professional and inter-professional organisations and policy makers. The positive impact of precision farming on efficiency, which has been present in Hungary for more than a decade now, has been demonstrated and proven for all agricultural actors in both economical and ecological terms.
2. Further analysis and investigation of the practical application and use of geo-referenced crop production technologies in an agrotechnological sense and quantification of the indirect or direct effects generated by the technology is needed to accelerate the adaptation and dissemination of the knowledge, knowledge base and practical experience gained so far. In order not only to have information on a specific field, crop sector, farm or company, but also to be able to deal with variations within a field, it is necessary to translate cell-level information into technology, so that efficient arable crop production can be more competitive in international comparisons.
3. As a direct consequence of the use of geo-referenced data, farms using geo-referenced crop production can comply with increasingly stringent environmental requirements (e.g. European Green Deal) and the objectives, standards and criteria set out in the Common Agricultural Policy for the years 2023-2027, which also allows for the maximisation of direct and indirect support.

6. PUBLICATIONS ON THE SUBJECT OF THE THESIS



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Registry number: DEENK/173/2024.PL
Subject: PhD Publication List

Candidate: Levente Szabó
Doctoral School: Károly Ihrig Doctoral School of Management and Business
MTMT ID: 10081540

List of publications related to the dissertation

Hungarian book chapters (1)

1. Bács, Z., Nábrádi, A., **Szabó, L.**: A precíziós mezőgazdaság felértékeli az üzleti tervezés fontosságát.
   In: Utunk az indulástól céljaink eléréséig : megújuló vidék megújuló agrárium, SAPARD20. Szerk.: Zöldréti Attila, Magyar Közgazdasági Társaság, Budapest, 119-124, 2022. ISBN: 9789638451309

Hungarian scientific articles in Hungarian journals (2)

2. **Szabó, L.**, Riczu, P.: A KITE Zrt. Precíziós Gazdálkodási Rendszere.
   Gradus. 10 (2), 1-5, 2023. EISSN: 2064-8014.
   DOI: https://doi.org/10.47833/2023.2.AGR.005
3. **Szabó, L.**, Nábrádi, A.: Az Európai Zöld Megállapodás potenciális hatása az EU és Magyarország növénytermesztésére.
   Gazdálkodás. 67 (1), 31-51, 2023. ISSN: 0046-5518.
   DOI: https://doi.org/10.53079/GAZDALKODAS.67.1.t.pp_31-51

Foreign language scientific articles in Hungarian journals (3)

4. **Szabó, L.**, Riczu, P., Szabó, E., Bai, A., Nábrádi, A.: Impact of precision irrigation on the unit income of maize production.
   Agrártud. közl. [Közlésre elfogadva] (-), 1-6, 2024. ISSN: 1587-1282.
5. **Szabó, L.**, Szabó, E., Nábrádi, A.: Positive effects of cultivation technologies based on georeferenced data on the economic sustainability of winter wheat production.
   Apstract. 17 (2), 107-113, 2023. ISSN: 1789-221X.
6. **Szabó, L.**, Madai, H., Nábrádi, A.: Potential impact of the European Green Agreement on EU and Hungarian crop production.
   Apstract. 16 (2), 1-18, 2022. ISSN: 1789-221X.
   DOI: https://doi.org/10.19041/APSTRACT/2022/2/9

Hungarian abstracts (1)

7. **Szabó, L.**: A gazdasági hatékonyság kérdése a hazai gabonatermesztésben, különös tekintettel a precíziós gazdálkodási rendszer (PGR) használatára.
   In: Növény és környezet - A debreceni tartamkísérletek 40 éve - Szántóföldi tartamkísérletek eredményeinek hasznosítása a gyakorlatban, üzemmérettől függetlenül / Kakuszi-Széles Adrienn, Debreceni Egyetem, MÉK, Fölhasznosítási, Műszaki és Precíziós Technológiai Intézet, Debrecen, 58, 2023. ISBN: 9789634905400

List of other publications

Informational/educational articles (1)

8. **Szabó, L.**: Always renewing.
   CEO Magazine. 20 (6), 100-103, 2020. ISSN: 2002-4401.

The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of the Journal Citation Report (Impact Factor) database.

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