

HOW FAR HAS PRECISION FARMING AND DIGITALIZATION PROCEEDED IN HUNGARY?

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Abstract: Climate change and rapidly shifting market dynamics have driven input manufacturers, breeders, and farmers to explore new ways, increasingly offering machines, tools, and varieties that meet new ecological challenges. The successful farmers have increased their land holdings to utilize their machinery's efficiency, taking advantage of land concentration, which contrasts with Brussels' political intent aimed at increasing the number of small farms. Opposing trends are evident: the number of farms continues to decline while land per farm steadily increases. The accumulated researches and databases in the field of crop production and precision agriculture at the Hungarian University of Agriculture and Life Sciences Research Institute of Karcag span several decades. Promising innovations include conservation tillage combined with precision agriculture, and mastering and applying these skills has become a major challenge for farmers. Our survey series conducted among farmers confirmed that those with specialized qualifications are willing to make significant financial sacrifices to improve their farming results. The solutions to the complex problem package presented are also intricate, as they must involve crop production, animal husbandry, and the related food industry.

Keywords: precision farming, conservation tillage, agricultural machine distribution, vocational training

INTRODUCTION

The definitions of precision agriculture (hereafter PA), established two and a half decades ago, are quite complex and multifaceted. Győrffy noted in 1999 that "PA encompasses site-specific farming, variable rate technology within fields, integrated pest management, high technology, remote sensing, spatial information systems, geostatistics, the mechanization of crop production, and the infiltration of information technology into agriculture". These definitions significantly differ from the concise and refined description used today: "...Precision agriculture is an approach that allows farmers to measure, control, and optimize the various parameters of agricultural production with greater accuracy" (Fóliavezérlés, 2023). Some authors have simplified it further, referring to PA as a means of effectively utilizing the existing modern agricultural machinery fleet (Popp, 2018), where GPS applications are mentioned only as an important "tool" of the PA system. According to Tamás (2002), PA represents the reflection of the information society in the agricultural sector. Studies conducted around the turn of the millennium, overseen by the Hungarian Academy of Sciences, validated and anticipated the viability and usefulness of PA. Morgan and Ess (1997) and Reichardt and Jürgens (2009) describe PA as encompassing the management of spatial and temporal variability in fields to reduce costs, optimize yields, improve quality, and minimize environmental impact. Furthermore, in practice, PA can serve as a tool to mitigate environmental damage and reduce risk for producers (Auernhammer, 2001; Takácsné, 2006).

In addition to PA, the efficiency of farming can also increase through the application of new, no-till agricultural systems (Czimbalmos et al., 2019) and diversification of activities within the farm, as well as the adoption of multifunctional agriculture (Czimbalmos, Kovács, 2017; Fehér et al., 2010). Due to their high cost and complexity, PA tools were primarily operational at pilot project levels in academic and university settings, as well as among machinery dealers, at the end of the 20th century and around the turn of the millennium. Experts and dealers predicted a rapid spread of these systems among farmers as prices for PA systems drastically decreased; however, this did not occur. According to national data from the 2020 Agricultural Census, only about 12 percent of farmers utilized any form of precision tool, compared to 23 percent in Denmark in 2018 (KSH, 2020). Even more sobering is that those farms equipped with precision tools barely use them; only about eight percent utilize their existing PA technologies appropriately. The explanation for this includes a clear lack of appropriate qualifications and continuous manufacturer support. The primary barriers to the spread of PA are its costs and farmers' fear of acquiring new knowledge (Kemény et al., 2017). Regarding ecological conditions, Futó and Sárvári's analysis of the climate and yields in 2022-2023 revealed that the extremely drought-stricken year of 2022 saw yields in the Great Plain decrease by 40-50 percent due to extraordinary drought, despite "everything being in place for achieving significant results with considerable input. Modern biological foundations are suitable for intensive cultivation, but increasingly frequent droughts and water shortages make this uncertain and reduce production security." What caused the drought that ravaged especially the plains in 2022? It certainly was not due to the scapegoat

*Correspondence: Róbert, Czimbalmos, Hungarian University of Agriculture and Life Sciences, Research Institute of Karcag, Hungary, Kisújszállási street 166. Tel. +36 30 403-2650, email: czimbalmos.robert@uni-mate.hu, Gergő, Asbolt, Hungarian University of Agriculture and Life Sciences, Research Institute of Karcag, Hungary, Kisújszállási street 166. Tel. +36 20 348-1162, email: asbolt.gergo@uni-mate.hu, István, Csízi, Hungarian University of Agriculture and Life Sciences, Research Institute of Karcag, Hungary, Kisújszállási street 166. Tel. +36 30 903-1516, email: csizi.istvan@uni-mate.hu, Csilla, Bojté, Hungarian University of Agriculture and Life Sciences, Research Institute of Karcag, Hungary, Kisújszállási street 166. Tel. +36 20 3995346, email: bojte.csilla@uni-mate.hu, Alajos, Fehér, Kompolt, Hungary, Tel. +36 30 963-6988, email: adrfeher@gmail.coM of farming conspiracy theories or hail damage prevention networks. According to researchers from ELTE and geographers, large-scale, traditional plowing completely dried out the cultivated areas in the eastern regions due to the implementation of long-standing armored plow layers, preventing significant evaporation from the surface, and thus hindering the formation of surface water vapor layers and precipitation zones (Timár, 2024).

Recent macroeconomic and political developments (explosive rise in input prices, the pandemic years, the European Parliament's decisions in 2022-2023, and the ATM regulation that facilitated the duty-free import of agricultural products from Ukraine, leading to a flood of Ukrainian goods overwhelming member states' grain markets) have completely reshuffled the priorities of Hungarian farmers. The current goal for farmers is survival. In such a situation, the introduction of a PA system appears as a luxury expenditure in farmers' thinking, causing its implementation to be postponed for a long time. Paradoxically, if farmers could invest in this and apply it sustainably, ideally in combination with a renewed crop rotation and new cultivation systems, it could significantly stabilize and improve their economic situation. EU regulations that strictly govern production, procurement, and crop quality for producers in every member state do not apply to "Ukrainian" producers outside the Union. Alongside Ukrainian farmers, producers with predominantly ownership from the U.S., Saudi Arabia, and the Cayman Islands by the end of 2023 had acquired over 30 percent of the 33 million hectares of Ukrainian arable land (Kohout, 2023; Frédéric-Eve, 2023). As there have been no regulations or restrictions on them so far, they present on European markets with products that do not meet EU regulations, yet they are still allowed access. With this competitive advantage, they have quickly driven down commodity prices at exchanges and have been undermining member states' farmers for two years. The current collapse of commodity prices has been affecting producers in member states for two years, and these unfavorable economic impacts also inherently affect input material producers: fertilizer production has skyrocketed in price, and the distribution of pesticides, fuels, and machinery sales have all declined, leading to more expensive financing. Due to economic hardships and sectoral losses, farmers across Europe took to the streets with their tractors in early 2024. "Agriculture and animal husbandry have not been in such dire straits for twenty years, accompanied by complete indifference from politics and institutions, a web of bureaucracy, agricultural products sold at unprofitable prices, and increasingly frequent natural disasters and animal diseases have crippled the sector," stated Tore Piana, president of the Sardinian Agricultural Research Center (Agroinform, 2024). Globally, tractor sales showed steady growth until 2022, with a clear halt emerging in the second half of 2023 (Fodor, 2024). In EU member states, including the Hungarian machinery market, a decline in the number of sold machines began in 2022, influenced by inflation and rising interest rates. Similarly, tractor sales in Poland are now in recession, experiencing a 21.2 percent drop compared to the same period in 2023 (Farkas, 2024); in Italy, data from the

Italian Association of Agricultural Machinery Manufacturers reported a 19.2 percent decrease in the first five months of the year (FEDER Unacoma, 2024). As per CEMA (the European Agricultural Machinery Association), there was an average decline of 10 percent in tractor sales across the EU in 2023 compared to 2022 (CEMA, 2024). CEMA attributes this process primarily to the effects of the COVID-19 pandemic and the Russian-Ukrainian war. In Hungary, 2023 was marked as a year of dramatic decline in agricultural machinery sales (Szedlák, 2023). If we consider 2021 as the base year, data from late November 2023 indicate (Faar, 2023) that 2023 remains significantly below the sales figures of 2022. Farmers purchased 48.1 percent fewer tractors by December compared to 2022. Economists and researchers had timely warned of this unfavorable trend. This trend continued into 2024. In Hungarian farms, alongside the increasing concentration of holdings, the number of employees in agriculture has also declined. This unfavorable process from the perspective of the "rural economy" (Fehér, 2005) had been exacerbated for decades by continuous machinery investment subsidies aimed at enhancing the competitiveness of farms: farmers increased their fleet of power and working machinery through multiple waves of support for machinery grants. As opportunities in the land market shrank, a burgeoning and underutilized machine capacity emerged, which in turn affected intentions to increase holding sizes and further reduced employment (Fehér et al., 2010).

Today, the advantages and opportunities provided by agricultural digitalization are not adequately utilized by the Hungarian farming community. Stringently stated, "...agriculture will need less horsepower and more intelligence in the future" (Agroinform, 2023). The depletion of the funding for grants aimed at facilitating the transition to precision farming in 2023 has left a void. Another question is that a significant portion of the farmers who acquired digital and PA technology using just 7 percent of the designated grant fund do not even use it. Several reasons contribute to this: primarily the lack of expertise, the altered market environment, and the significant drop in tractor sales in 2023 (Kónya, 2024).

The mechanization level of farms has now reached a stage where the application of PA systems can be supported. However, this can only work sustainably and effectively if a farm has a leader or specialist, as well as an engineer or operator capable of managing the systems, interpreting the data obtained, processing large databases generated annually, and expertly operating power equipment (tractors, combine harvesters, sprayers, and fertilizer spreaders). If this condition is not met, the high-value investments in PA systems will not vield returns, and the results of farming—driven by the hope of making these investments-will fall short of expectations. Among numerous professional forums addressing this topic, the PREGA (Precision Agriculture) conference series is one of the most popular, showcasing the latest practical applications. According to Baklanova (2024), PREGA's "mission is to enable participants to gain practical experience at the daily operational level regarding the latest agrotechnological methods and related tools. Beyond Studia Universitatis "Vasile Goldiş", Seria Ştiinţele Vieţii



showcasing domestic and international best practices, speakers and exhibitors provide specific application advice to interested parties. Digital solutions are now assisting farmers from sowing to harvesting and have become indispensable in various segments of horticulture and animal husbandry, providing datadriven decision support."

METHODOLOGY

The solutions to the complex problem package presented are also intricate, as they must involve crop production, animal husbandry, and the related food industry. The accumulated experience and research in the field of crop production at the MATE (Hungarian University of Agriculture and Life Sciences) Research Institute of Karcag (hereinafter RIK) span several decades. Our database related to rural development covers a period of two decades, starting with a questionnaire survey in 1997 in Jász-Nagykun-Szolnok (hereinafter JNSZ) County (Hungary), where we reached out to farmers in seven surveys. All districts of the county are represented; the survey series was a longitudinal panel study conducted using a quantitative method, ensuring reliable comparisons by targeting the same circle of farmers. The stratified sampling used provided greater reliability. This paper synthesizes our previously conducted rural development analyses, publications, comparative examinations of the cultivation systems we applied over several years, as well as the outcome studies of RIK's own bred crop varieties. In addition to our findings published on these topics, we used databases from the KSH (Central Statistical Office, hereinafter CSO), the ÁMÖ (General Agricultural Censuses, hereinafter GAC) covering the years 2010-2020, and the Hungarian State Treasury's regional and municipal support databases, which contain farmers' specific data related to agriculture. Institutional

research in the areas of PA and non-tillage cultivation commenced in 1997, establishing a suitable measurement tool system through a duration trial, where we continuously examined and measured the draft power requirements of conventional and non-tillage farming, as well as fuel consumption of agricultural machinery in both systems. We also recorded soil compaction, yields of indicator crops in the crop rotation, changes in their quality parameters, and the application possibilities of the PA tool system. Alongside the production and sale of high-yielding (Basic, I. and II. grade) winter wheat and winter barley seeds, we conducted macro- and micro-environmental analyses, examined the production structure, and prepared an economic analysis of the two cultivation systems, calculated the cost, value, contribution margin per hectare, and average net income related to the cultivation of our own bred first-generation winter wheat seeds.

RESULTS

The results of the surveys conducted within the framework of our rural development research confirm the findings also present in the literature. The agricultural results and intentions spanning over two decades indicate a distinct process of land concentration in JNSZ county as well. The ecological and economic characteristics typical of the county, along with the structural features characteristic of agriculture, determine the opportunities available to the farmers we examined. Farms have increased their land areas through leasing and purchasing, while the number of smaller-sized farms has stagnated (Table 1). Among the two sectors in the county's municipalities, crop production is predominant, with its share consistently increasing over the two decades studied.

Table 1.

43,2

6,0

	1997		2002		2015		2018	
	Area	Farmers	Area	Farmers	Area	Farmers	Area	Farmers
Under 10 ha	0,1	2,7	0,3	5,1	0,2	4,0	1,5	21,8
10,1 – 30 ha	2,5	11,7	3.8	25,5	4,4	27,4	6,1	29,0

66,3

3,1

53,4

41,9

62,3

33,6

The investigated farmers, and the distribution of the areas, they used in percent between 1997 and 2018

Source: Own database (1997-2018)

30,1 – 300 ha

Above 300 ha

Parallel to the mechanization of farms, their productivity has also increased, while employment has significantly decreased. This phenomenon is clearly observable in the case of a typical agricultural town, Karcag. In this article, we utilized data from the municipal-level comprehensive support database, accessible as public interest data on the Hungarian State Treasury's website (Figure 1.). It can be noted that a small number of medium and large farms with extensive landholdings have seen their revenues from area-based subsidies grow year after year. From 2010 to 2021, the number of farmers receiving area-based support in the town fluctuated between 452 and 473. More than fourfifths of the area-based payments in Karcag were received by those farming on land larger than 30

56,2

41,2

79,3

6,3

hectares. Among them, those with 30-300 hectares account for 25-30 percent of all arable land in Karcag, while those with over 300 hectares use 55-60 percent of the arable land. In 2021 alone, 3 billion 667 million forints were paid out to 474 farmers in Karcag, of which over 2.4 billion forints went to large farms using over 300 hectares, while medium-sized farms (30-300 hectares) received 1 billion, and small farms barely 183 million forints. Breaking down by size category (Figure 2.), it is evident that a smaller number (35) of large farms (>300 hectares) utilize 68 percent (33,110 hectares) of the total area, while a large number (305) of small farms (1-30 hectares) operate on barely five percent of Karcag's agricultural land.

61,4

7,3

45,2

47,3





Fig. 1. Development of the number of farmers in Karcag, and area-based subsidies (2010-2021). Source: Hungarian State Treasury, own editing



Fig. 2. Land area used by farmers in Karcag, by farm size categories (2021). Source: Own database

It is important to emphasize that we observed similar trends and proportions in our analyses of other small settlements in the county as well. As a result of the significant processes of land concentration over the past three decades, large farms now utilize more than twothirds of the cultivable land in the county, while the area used by smaller farms is continuously decreasing. Analyzing the cumulative frequency of farms and the arable land they use (Lorenz curves), we found that the curve increasingly deviates from the straight line, clearly indicating a strengthening of land concentration. Farms larger than 100 hectares employ less than oneseventh of the workforce compared to those in farms smaller than 50 hectares. The vulnerability and economic "weakness" of small farms were evident in recent land auctions, where farmers with small to medium-sized landholdings and modest resources could only take on smaller loan burdens, resulting in a more creditworthy large landowner segment acquiring over two-thirds of the land. In the county, 27,000 hectares of state land were announced for auction, of which 18,689 hectares were acquired by farmers through the auction process. With this land data, JNSZ ranks second after Fejér County in terms of area. Of the 1,110 parcels of land auctioned in the county, 444 had new owners. An overview of the distribution of land parcels by size category (Table 2.) shows that nearly half (40.5%) of the winning farmers purchased parcels smaller than 10 hectares, yet this accounted for only 5.4 percent of the total area sold. The number of successful bidders for parcels over 100 hectares was 59, who obtained more than half of the total sold area. Two-thirds of the acquired areas were arable land, while the remaining areas were classified as meadows or pastures. The cultivation and harvesting of these newly acquired areas posed no problem for the winning farmers, as they could continuously enhance their power and machinery fleets through consecutive successful bids in the series of machinery tenders during the "peace years" of 2010, and they could also finance the acquisition of stable machinery and buildings through tenders. They were able to access favorable bank loans with significant interest rate support to finance their own contributions to these bids.

Table 2.

	The winning farmers					
Land-size categories	Nun	nber	Acquired area			
	Person	%	ha	%		
<10 ha	180	40,5	1 005	5,4		
10-50 ha	153	34,5	3 363	18,0		
50-100 ha	52	11,7	3 839	20,5		
100-200 ha	41	9,2	5 941	31,8		
>200 ha	18	4,1	4 550	24,3		
Total	444	100,0	18 698	100,0		

Distribution of land purchased at auctions by size category

Source: Hungarian National Land Fund database, own editing

Farms have sought to utilize their increased machinery capacity, but as all developing economies have raised their levels of mechanization, a growing amount of unused machinery capacity has emerged. This has impacted both the increase in farm size and the reduction in employment. Recent funding sources aimed at acquiring precision tools to promote the spread of precision agriculture (PA) have further amplified targeted mechanization in farms; however, they have not truly achieved their originally stated objectives, as surveys indicate that power and work machines fitted with PA tools are not being used according to the intended PA goals. Given the decline in tractor sales in European countries, including Hungary, the farms' financial situations, high bank interest rates, and sales anomalies, a rapid improvement in the situation cannot be expected. According to Datahouse, tractor sales experienced a significant rise in 2022 after three years of stagnation (2019-2021), but due to the aforementioned negative market effects, 2023 brought another substantial decline in tractor sales in Hungary. The high number of units sold in 2022 (4,536) fell to around three thousand in 2023, indicating nearly a 50 percent decrease in the sales of new power machines. The situation worsened further: compared to the first half of 2023, the agricultural machine sales in the first half of 2024 fell by 49 percent(!) compared to the first half of the previous year.



Fig. 3. Changes in the number of new tractors purchased by farmers between 2018-2023. Source: Own database

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In addition to tractors, the market for agricultural machinery (planters, sprayers, fertilizer spreaders, and soil cultivation equipment) has seen a decline of between 12-48% in 2023 compared to the base data of 2022. One consequence of this is that the machinery market and parts distribution showed a positive shift in 2023. Farmers are generally holding back on high-value investments, preferring to save, when possible, while

smaller operators are currently depleting their reserves and postponing investments for an uncertain period. According to data from the first quarter of 2024, the sale of new tractors is down by 343 compared to the same period in 2023, with only 404 new tractors entering the market (half of which fall into the categories of under 100 horsepower).

Table 3.

Country	2022	2023	Change (%)	
Austria	5 349	4 982	-6,9	
Belgium	3 179	2 936	-7,6	
Bosnia Hercegovina	682	1 326	+94,4	
Croatia	1 004	1 011	+0,7	
Czechia	3 348	2 776	-17,1	
Denmark	2 005	1 764	-12,0	
Estonia	554	494	-10,8	
Finland	1 605	1 606	+0,1	
France	35 731	36 396	+1,9	
Germany	28 769	28 881	+0,4	
Greece	1 259	1 667	+32,4	
Hungary	4 093	2 793	-31,8	
Iceland	163	150	-8,0	
Ireland	2 133	2078	-2,6	
Italy	20 119	17 534	-12,8	
Latvia	753	651	-13,5	
Lithuania	1 387	1 014	-26,9	
Luxemburg	262	247	-5,7	
Moldova	1 599	995	-37,8	
Netherlands	2 861	3 151	+10,1	
Norway	2 799	2 568	-8,3	
Poland	11 733	10276	-12,4	
Portugalia	3 030	2 550	-15,8	
Serbia&Montenegro	2 457	2 293	-6,7	
Slovakia	1 244	1 436	+15,4	
Slovenia	1 358	1 103	-18,8	
Spain	9 338	7 699	-17,6	
Sweden	2 347	2 248	-4,2	
Switzerland	2 099	2 165	+3,1	
United Kingdom	12 987	13 304	+2,4	
Total Registration	166 247	158 094	-4,9	

Development of the number of new tractors registered in the European countries.

Source: Systematics International

During our satisfaction analysis conducted in the 2008-2015 period, the proportion of respondents perceiving a positive shift increased from 50% to 66%. With the resolution of anomalies related to area-based subsidies, such as AKG (Agricultural Environmental Management) and SAPS (Single Area Payment Schemes) payments, the amounts of support have risen annually. The proportion of skeptical farmers decreased from 41% to 25%, indicating a cautious optimism within the county's farming community. The most significant motive for economic development among respondents was securing livelihoods for their families, with the increasing land area (through leasing and purchasing) seen as a crucial tool for strengthening their position. Over the past decade, the economy in Jász-Nagykun-Szolnok County has exhibited a notable positive shift towards multifunctional agriculture and diversification. Despite negative ecological impacts, widening agricultural gaps, market uncertainties, and ongoing wars have pushed farms towards implementing innovative practices. Since 2021, a strong restraint has been observed in terms of infrastructure development and machinery investments for farms, as domestic and international price effects distinctly and directly impact them. In Hungary, during the first half of 2024, there was a 49% decrease in machine sales compared to the same period in 2023 (AKI, 2024). The procurement of high-performance, capital-intensive agricultural machinery has thus seen a collapse not witnessed since 2018. Even optimistic estimates foresee further declines in 2024. In the market for grain combines, the drop was even more drastic at 82%. Given the postponement of developments and investments, what options remain for farmers now, as the macroeconomic environment and ecological changes pose increasingly severe challenges-especially for smaller farms that face existential threats? It is essential for the Hungarian farming community to formulate a strategic response, considering the following elements to be ideally introduced and applied by individual farmers or SU

enterprises engaged in agriculture:

a. Research and development:

• Development of efficient agricultural technologies/methods (such as no-till farming and the combined application of PA) to increase productivity and reduce production costs.

• Support for local farmers in the introduction of innovations that increase crop yields and safety while reducing production costs.

b. Acquisition of a quality advantage:

• The transition to the production of processed products that represent higher added value for which customers are willing to pay a higher price.

• Highlight their own cereal or alternative plant varieties among competitors with certified quality products.

c. Market research and diversification:

• Understanding regional and global market needs.

• Diversifying production by focusing on other agricultural products that are in demand.

d. Cooperation and collaboration:

• Establishment of local farming communities to collectively achieve better market positions.

• Development of foreign trade relations.

e. Application of legal instruments:

• Understanding the legal options that help combat abuses.

• More robust utilization of government support and advocacy.

f. Environmental protection and sustainability:

• The application of sustainable agricultural practices can enhance the product's appeal to conscious consumers.

• Acquiring environmental and sustainability certifications that provide a competitive advantage.

g. Communication and marketing:

• Effective communication of the product's benefits to the market and consumers.

• Establishing a brand identity that can help differentiate their products.

Among the seven-point strategy, the first four points are particularly critical and decisive. By implementing these, the farmer can primarily reduce production costs while significantly decreasing environmental impact, partially mitigating ecological disadvantages, and stabilizing their economy. Furthermore, a concise overview of RIK's related research will be presented, outlining the solutions that farmers can follow in the upcoming period.

Development of effective agricultural technologies/methods (such as no-till farming and the combined application of PA) to increase productivity and reduce production costs, while supporting local farmers through the demonstration of innovations.

The effectiveness of crop production is determined by the chosen plant variety, the cultivation system employed, and the site factors (soil, precipitation,

Vol. 32, issue 3, 2022, pp. 109 - 118 © 2022 Vasile Goldis University Press (www.studiauniversitatis.ro) temperature sum) in a ratio of 30-30-40 percent. Therefore, it is crucial to select and use the most suitable certified seed for the specific site. The cultivation system that best fits a given landscape region should be applied (low-tillage with no tillage is recommended). If unfavorable ecological conditions in a given growing season are combined with improper agronomy, the potential of a well-genetically endowed crop will not be realized, leading to yield depression. The ecological advantages of new no-till mulch cultivation (it facilitates soil maturation, improves soil life, enhances and regulates microbial activity in the soil, and restores degraded soils, positively influencing humus-building and breaking processes; particularly noteworthy is the moisture-retention effect of mulch cultivation) significantly reduce production costs, along with its economic effects (less soil compaction damage, lower tillage frequency, reduced diesel consumption, and lower labor usage). The results of RIK's long-term experiments have clearly confirmed this.

Economic Effects: The economic analysis of the cultivation technology plan for the self-bred "KG Vitéz" winter wheat variety grown as first-class seed on the RIK's "H-1" plot of 16 hectares confirmed that seed production using no-till mulch cultivation combined with site-specific farming has lower production costs per hectare compared to conventional wheat production based on plowing. The costs of mulch cultivation per hectare were approximately 25% lower than those of multi-pass, plow-based cultivation. The examination of cost structure showed that fuel savings of 35-45% can be achieved within auxiliary operational costs. The vield-cost analysis revealed that the share of auxiliary service costs in the production cost structure can reach half of the total cost, followed by material costs at 35-45%. A 40% reduction can be achieved in auxiliary costs, while another 5-10% reduction is possible within material costs (including seed and plant protection product costs), while the cost of fertilizers applied at low doses remains unchanged. The economic advantage lies in increased sector efficiency, significant reductions in production and operational costs, and reduced environmental impact. Overall, the 20-25% savings in production costs achieved in this way is considered remarkable.

Acquiring a quality advantage, meaning the production of processed products with higher added value, aims to create a quality product (through breeding and seed production), thereby distinguishing their own plant varieties from competitors.

The "KG Vitéz" winter wheat variety¹ produced from "Basic (Elite)" winter wheat seeds with a high multiplication rate, represents high added value as a first-class seed, which can be sold at a premium in the cereal seed market. It is important to highlight that breeding varieties adapted to the local environment significantly contributes to environmental sustainability, as cultivating varieties capable of adapting to local conditions imposes the least environmental burden under specific agro-ecological,

winter wheat, it ranked second in 2021 and first in 2022-2023 in terms of raw protein and wet gluten content within the medium-late maturity variety group.

¹ The "KG Vitéz," a variety of winter wheat under the RIK variety protection, has been a quality standard for over a decade. In the Hungarian post-registration variety trial for *Studia Universitatis "Vasile Goldiş", Seria Ştiinţele Vieţii*

soil, and agronomic conditions, allowing for economically viable and highly stable production of landscape-appropriate varieties.

The exploration of regional and global markets can primarily be supported by harnessing local markets for stable operational foundations. If production and processing capacities allow, a medium-sized economy can shift towards European markets, provided that it is sufficiently diversified and can effectively utilize available market research results in its operations. In the districts of Karcag and Kisújszállás in JNSZ County, several economies operate that specialize in the production of spelled flour, hospitality services, products made from oilseeds, honey products, as well as rice flour and rice-based foods (e.g., Üllőparti Farmer's Cooperative, Agroperfekt Ltd., Kun-Agro Ltd.), and are recognized and sought after in foreign markets for their value-added products. A new approach is necessary in terms of nutrient replenishment. Following the explosive price increase of classic fertilizers, farmers must first create a field-level nutrient balance using mandatory soil test results to practically apply the options provided by PA. The heterogeneously managed plot serves as the fundamental unit. The mulching system ensures that chopped crop residues are evenly distributed across the field, significantly returning nutrients to the soil. A well-designed crop rotation, judicious use of legumes, proper reuse of high-quality manure, and cover crops greatly support effective farming.

CONCLUSIONS

In the agriculture of the county, after a significant structural change in the 1990s, a stabilization phase was reached where, alongside the decreasing number of small farms, medium and large farms have strengthened, becoming more creditworthy and continuously expanding their land areas. Our survey results have proven that the local farming community should develop an economy that meets today's expectations by processing and marketing plant and animal products in both domestic and foreign markets through diversification processes. Multifunctional agriculture in JNSZ County must go beyond merely producing traditional food industry raw materials; farms need to diversify their activities in both agricultural and nonagricultural areas, including regional, ecological, and social directions. Multifunctionality is a good alternative for reducing production exposure; however, its implementation requires extensive professional knowledge in addition to economic background, which unfortunately has significant deficiencies in the examined farming sector. The current level of multifunctionality in the region is attributed to landscape and landscape maintenance, as well as agrienvironmental management, nature conservation, and organic farming.

• The main objective of the agricultural ministry should be to ensure long-term complete self-sufficiency in food raw materials.

• To achieve this goal, the ministry aims to continuously strengthen the producers through its land policy; however, in many cases, land auctions used as a tool have contradicted the ministry's original intentions, further distorting the structure of agricultural ownership rather than alleviating it.

• Our survey results have proven that in JNSZ County, farmers still lag significantly in terms of age composition, education, and innovation processes.

• The powerful changes over the past four years since our last 2018 survey (the COVID pandemic, explosive price increases for input materials, necessary for the secure operation of agriculture and the food industry, the Russian-Ukrainian war, and the historical drought of 2022, particularly affecting the Tiszántúl region) indicate the need for a paradigm shift.

The new cultivation systems and the full spectrum of precision agriculture require a new farmer mentality. There is a need for a layer of farmers who are professionally skilled and willing to develop further, capable of handling the complex ecological and economic impacts that affect their farming from one growing season to the next. When examining the future vision of Hungarian agriculture within the EU, it can be concluded that the following cornerstones might provide new momentum for Hungarian agriculture, which has been struggling from crisis to crisis since the regime change in 1990:

- rejuvenating the farming society,

raising the level of professional qualifications,

- promoting diversification and multifunctional farming,

- adopting an agribusiness management mindset,

- ensuring high-level professional training, and implementing new cultivation methods and systems due to drastic environmental changes.

- supporting the organization of farmers into Producer and Marketing Cooperatives.

AUTHORS CONTRIBUTION

Conceptualization: Róbert Czimbalmos and Alajos Fehér; methodology: Róbert Czimbalmos, Alajos Fehér, Gergő Asbolt, István Csízi; data collection: Róbert Czimbalmos, Alajos Fehér, Gergő Asbolt, and Csilla Bojté; data validation: Alajos Fehér, István Csízi, Csilla Bojté; data processing Róbert Czimbalmos, Alajos Fehér, Gergő Asbolt and Csilla Bojté; writing—original draft preparation: Róbert Czimbalmos and Alajos Fehér; writing—review and editing: Róbert Czimbalmos, Alajos Fehér, Gergő Asbolt and Csilla Bojté.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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