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Impact of precision irrigation on the unit income of maize production

Levente Szabó[1,*] – Péter Riczu[1] – Emese Szabó[1] – Attila Bai[2] – András Nábrádi[2]

[1]KITE Zrt., Nádudvar
[2]University of Debrecen, Faculty of Economics and Business,
Institute of Applied Economics
[*]Correspondence: szabol@kite.hu

SUMMARY

The study of the economic/economic impact of precision farming should be a priority area in digital agriculture, as the results, profitability, and efficiency indicators can have a significant decision-support effect on the development of both the agronomic and the technical regions of individual farms both in the longer and shorter term. Individual firms, companies, farmers, and family farms quantify the effectiveness of their farming processes. The modern age offers the possibility of digitally recording all the elements of farming technology, making it possible to analyse the cost-effectiveness of a farm more effectively and, in some cases, to carry out more detailed analyses. Nevertheless, the number of farms demonstrating their profitability with such precise economic calculations is still minimal.

Our analyses were conducted on a 56,02 ha field of Balogh Farm-Tépe Ltd. The agricultural operations carried out were fully documented so that the inputs (seeds, fertilisers, pesticides, crop enhancers) were recorded in coordinates and kind, as well as the specific yields, grain moisture data, irrigation norms, and irrigation rotations. At the same time, the company's owner provided the data's monetary value. The main econometric indicators (yield, production value, cost of production, income, cost price) related to the evaluation of the enterprise management were evaluated along with the spatial data in the irrigated and non-irrigated tables. Our calculations show that a given year's climatic and market characteristics fundamentally determine the cost and income relations of a plot of land (and thus of an entire farm). In addition to additional inputs, introducing some elements of precision farming and intensification and increasing yields improves yield security and allows for excellent yield stability.

Keywords: *economics; GIS; PGR; MyJohnDeere*

INTRODUCTION

The effectiveness of precision farming is of paramount importance both at the national level and in the life of a significant agricultural integrator such as KITE Zrt., as the evaluation of the results of different farming technologies and their feedback to farmers allows for more efficient, more innovative and environmentally conscious and sustainable farming, which can be particularly important in a farming environment where we are facing the challenges of escalating input prices or even compliance with the European Green Agreement.

The efficiency of production and the evolution of crop yields are significantly affected by our changing and often capricious climate (Ciscar et al., 2011; IPCC, 2023). One way to adapt to climate change is to make realistic use of water economically, socially, and environmentally sustainable over the long term, involving investments in irrigation improvements at both farmer and national economic levels. Currently, the share of irrigated land in Hungary is 2.4%, below the EU average (8%), but in recent years, tenders have been. They are expected to be opened to support the modernization of existing irrigation schemes and the construction of new ones, which is expected to increase the share of irrigated land in Hungary in the coming period (Kemény et al., 2018), which is confirmed by the fact that in Hungary there are currently about 200,000 hectares under irrigation and potentially about 350–400,000 hectares of irrigated land (Rakonczai, 2021). Besides increasing yields, irrigation also provides crop security, as climatic exposure can be significantly reduced (Birkás, 2001).

Irrigation management must be given special attention, as inappropriate irrigation technology, not adapted to the needs of the crop and soil conditions, poorly chosen irrigation rotations and irrigation standards can lead to soil structure degradation, siltation and secondary salinization processes can be initiated or intensified (Darab, 1958; Ligetvári, 2008; Várallyay, 2002), which in many cases is difficult or impossible to correct, and which imposes additional costs on the producer. Sensors that measure the soil-plant-atmosphere system, on the other hand, can effectively help to irrigate with the proper precision, taking into account the needs of the plant and the soil texture, thus avoiding the adverse environmental and economic effects of over-irrigation. Current technology can already provide variable rate irrigation (VRI) within the field, by irrigation zone or even by sprayer (LaRue and Evans, 2012; Evans et al., 2013; O'Shaughnessy et al., 2019), taking into account the topography and fertility conditions, thus adapting to a more profound or poorly watered soil.

To analyze the effects of irrigation as a function of the heterogeneity of our field, we also need to know the agrotechnological interventions of a given farming year. Thanks to digitalization, the number of agricultural operations data being recorded is increasing every year. The data's reliability and accuracy are also improving rapidly, thanks to automated solutions developed by power and machinery manufacturers and the work of machine operators and precision advisors.

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These digital operations data can be accessed and queried on various web-based platforms. JohnDeere, as one of the largest field machinery manufacturers, has made and continues to make extraordinary efforts to digitize agriculture, particularly regarding positioning accuracy, data communication, wireless data transmission solutions, and web data services. The JDLink™ Dashboard is a web-based platform through the MyJohnDeere portal that helps farmers monitor and analyze farm operations, improve machine utilization, simplify maintenance and operation cost documentation, predict potential machine failures through automatically sent alerts, and maximize the potential of John Deere machines, resulting in increased profits and improved productivity for farmers (Szabó, 2019). MyJohnDeere's Operation Center provides farmers with efficient data storage and visibility and enables table-level analysis of individual farm operations. Moreover, it is an online farming system that allows access to farming data anywhere and anytime. The application can be divided into two parts: the machine information element provides information on the current position, operating hours, fuel level, and speed of the selected machine; it allows remote machine monitoring. The table information module enables the management of the farm master database, one of the most critical points for processing the documentation data from the machines (Szabó, 2020). Farmers with a proper master database and good documentation can perform efficient analyses. One of the most essential conditions for this is that the data recorded are valid, as data of insufficient quality can lead to incorrect results and wrong conclusions**.**

As described in agricultural economics, the easiest and most expressive way to visualize the efficiency of farming (Buzás et al., 2000) is to construct a matrix of resources (land, labor, and means of production), inputs, production costs, yields, production value, and income, and to represent all the indicators that express the interrelationship of these factors. If input data are available at a suitable resolution, direct (yield, production value, income) and indirect efficiency indicators (direct and inverse) can be calculated, while valuable conclusions can be drawn. Precision farming increases yields for Hungary's most significant area of arable crops. Also, it has a beneficial effect on the profitability of farmers and farms using precision farming (Molnár et al., 2018). The impact of irrigation on yields has been discussed in several studies (Mustek and Dusek, 1980; Payero et al., 2006; Bondesan, 2023), but its economic implications are less researched. Therefore, we prioritized investigating the statistically verifiable economic benefits of precision irrigation using the MyJohnDeere portal as a central database.

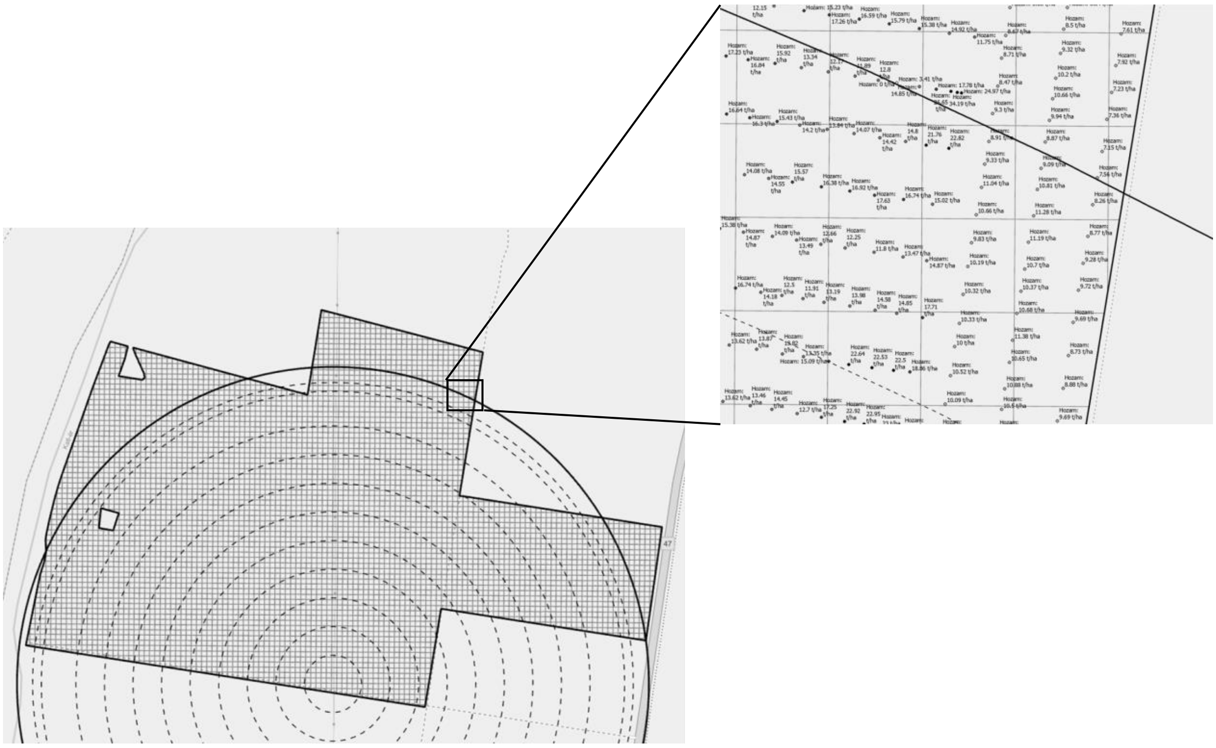
MATERIALS AND METHODS

One of the highest levels of econometric analysis is data processing within the agricultural table. Arable fields with spatially different fertility potentials may have different micro- and mesodomain characteristics, soil texture, water management characteristics (water holding and water supply capacity), and nutrient supply capacity (Hadászi, 2022; Szabó et al., 2022), which affect both the quantity and quality of the crop. The documentation of power machinery operation data is done in a fixed location for about 1 second so that in addition to the continuous analysis of the operation, the applied seed rate, pesticide, or fertilizer rates can be accurately recorded, and valuable topographic information is available. Likewise, all the harvesting stages can be monitored, with high-resolution information on specific yield, grain moisture, and spatial and temporal variations in harvesting parameters, which can be compared with the parameters that influence them, allowing the operator to intervene immediately by changing the parameters (threshing gap, aspiration gap, grain gap, etc.).

Our study was carried out on a 56.02-ha irrigated field of Balogh Farm-Tépe Ltd., located south of the village of Tépe. The digitization of agricultural data across the entire farm can be traced back to 2014 on the MyJohnDeere platform. Still, at that time, only a single GPS antenna and an onboard computer for documentation were available, so only certain work operations could be tracked. From 2018 to 2019, all the operations for the entire farming year were recorded. In 2019, a significant investment was made in the farm, installing a Valmont recirculating irrigation system for variable dose irrigation. This investment involved interventions (e.g., laying the power line to supply the center pivot, replacing the overhead cable with an underground cable, removing the electric poles, etc.) that defined certain cultivation features, and the field was only partially cultivated. For this reason, we have examined the cultivation data for 2021–2023 and the evolution of cultivation years within and between years.

We collected all documented operations from the MyJohnDeere portal and processed and analyzed the data in a geospatial software environment (ArcGIS Pro) (*Figure 1*). This was necessary because some operations (mainly sowing and pesticide or fertilizer application) were carried out with differentiated input rates, thus allowing the spatial separation of inputs and the separation of irrigated and non-irrigated fields. This also allows for a more efficient evaluation of yield data, as the harvested crop is analyzed in the light of the applied variable dose inputs.

Figure 1. **Geometric characteristics of the experimental board, the grid data on which the calculations are based, and the spatial relationships of the operating points**



Operation points represent a spatial detail of the 2021 yield data

In consultation with the owner of Balogh-Farm Tépe Ltd., we obtained agronomic unit costs, machinery costs and crop sales prices for each year, and then performed a cell-level data conversion. The cells used for the analysis were derived from Sentinel-2 satellite images, which is the spatial basis of the KITE Zrt. productivity-based technology planning service. The highest available geometric resolution (10x10 m) from the Sentinel-2 system provided the basis for the cell-level econometric calculations, for the analysis of cost and income relationships within the grid. The calculation procedure was as follows, illustrated by the example of sowing costs (differential sowing):

$$X = \frac{D_{cella}}{\bar{D}_{cella}} \cdot AK \cdot \frac{T_{cella}}{10000} + GK \cdot \frac{T_{cella}}{10000} \qquad (1)$$

Where:

- X - The cost per cell (Ft cell^{-1})
- Dcella - Specific input dose per cell (seed ha^{-1})
- $\bar{D}$cell - Average input dose for the whole table (seeds ha^{-1})
- Tcella - Area of the cell (m^{2})
- AK - Average specific agronomic cost (HUF ha^{-1})
- GK - Average specific machinery cost (HUF ha^{-1})

In cases where it is possible to channel the price directly to the given input, the formula is simplified:

$$X = D_{cella} \cdot AK \cdot \frac{T_{cella}}{10000} + GK \cdot \frac{T_{cella}}{10000} \qquad (2)$$

Where:

- X - The cost per cell (HUF/cell)
- Dcella - Specific input dose per cell (l ha^{-1}; kg ha^{-1})
- Tcella - Area of the cell (m^{2})
- AK - Average specific agronomic cost (HUF ha^{-1})
- GK - Average specific machinery cost (HUF ha^{-1})

Using the given formulae, the individual agronomic input material and machinery costs can, therefore, be obtained at the cell level, and these costs are then summed. Particular attention had to be paid to those cells that were located within the field contour but where no machinery or equipment had been present, and no input material had been delivered, as no input material and machinery costs were recorded in these areas; if there was no harvest in the cell, then no harvest revenue should be included.

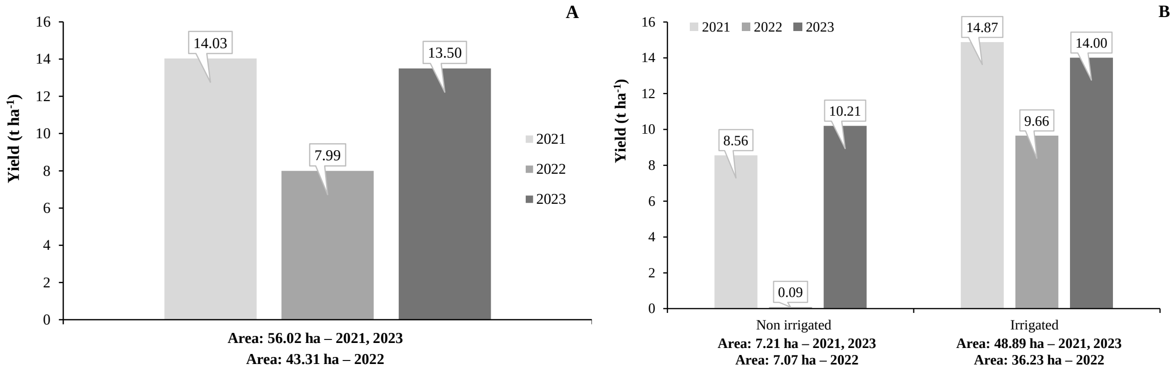
RESULTS AND THEIR EVALUATION

The econometric study was carried out for the period 2021–2023. In all three years, the crop was maize throughout the whole field. Still, due to the extreme drought year 2022, on the one hand, the crop was not harvested in some non-irrigated parts of the field, and on the other hand, the crop was ensiled in some irrigated parts of the field, so in our calculations, we weighted the field size in 2022 with 43.31 ha instead of 56.02 ha. The year 2022 was a historic drought, affecting the lowland areas significantly. Although in 2021, the area received relatively little rainfall (35 mm) during the maize flowering and setting (mid-June to mid-August), in 2022, the total rainfall over three months was only 6.2 mm. 2023 was wetter but still did not reach the multi-year average (121.6 mm), with nearly 35 mm less precipitation in 2023.

Looking at the trend in yields at the table level (*Figure 2/A*), the highest yields were recorded in 2021, while the lowest yields were understandably recorded in the drought year 2022. 2023 can be considered an average year, but yields were lower compared to 2021, which can also be explained by the fact that the farmer reduced the seed and fertilizer doses applied based on the experience of 2022 and the hectic input prices.

If the yields of irrigated and non-irrigated fields are evaluated separately, the effect between the different years is also remarkable. In 2022, there was practically no yield in non-irrigated conditions (0.09 t ha^{-1}), while the non-irrigated fields had the highest specific yields due to the wetter year 2023 (*Figure 2/B*).

Figure 2. **Evolution of the yield data of the experimental plot in the years under study**



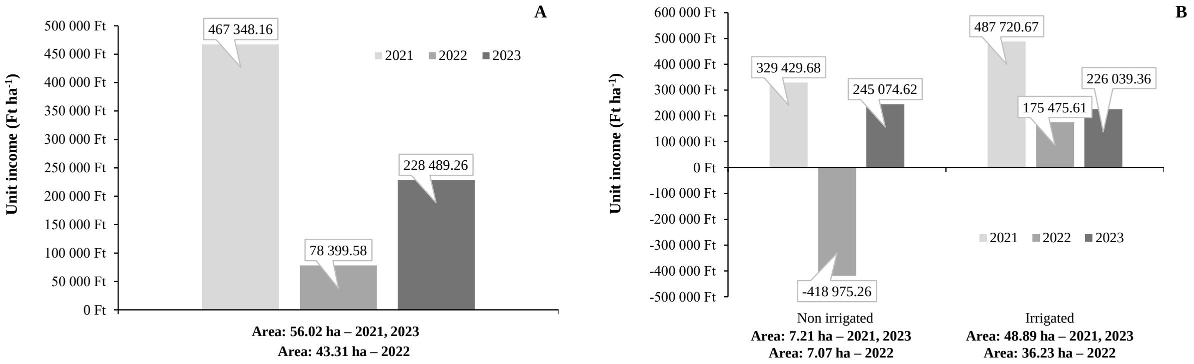
Regarding value of production (PV) and cost of production (CoP), market events have had an exceptional impact on crop prices and input costs, with a particularly marked effect in 2022. Indeed, in 2022, high crop prices resulted in the highest production value of the three years despite the lowest yields. Nevertheless, in 2023, the PV was about 5% higher than in 2021, even though yields were almost 4% lower than in 2021. The increase in input prices in 2022 is also observed in the cost of production (CoP). With similar cropping technology (similar input doses) in the two years, CoP was 37.01% higher. Due to the extreme vintage in 2022 and the market characteristics, the farmer reduced the inputs in 2023, so the CoP was also the lowest (570 282.6 HUF ha^{-1}). However, the more rainfall meant that almost 50% less irrigation water was applied, which was also reflected in the costs. However, when we look at the evolution of production costs in 2021 and 2023 under non-irrigated conditions, we find that the specifics of the two years were almost identical, with less input in 2023 (*Table 1*).

Table 1. **Evolution of costs for irrigated and non-irrigated fields (2021–2023)**

Year	Irrigated				Non-irrigated			
	Input material cost (Thousand HUF ha^{-1})	Machinery cost (Thousand HUF ha^{-1})	Drying cost (Thousand HUF ha^{-1})	Irrigation cost (Thousand HUF ha^{-1})	Input material cost (Thousand HUF ha^{-1})	Machinery cost (Thousand HUF ha^{-1})	Drying cost (Thousand HUF ha^{-1})	Irrigation cost (Thousand HUF ha^{-1})
2021	182.4	163.1	81.9	274.0	173.4	156.4	30.8	0.0
2022	260.2	117.7	43.8	314.4	305.5	116.9	0.4	0.0
2023	216.7	123.2	21.1	240.0	231.5	117.0	8.5	0.0

The unit incomes were the highest in 2021 (467 348.2 HUF ha^{-1}) for the years studied due to the relatively high PV and lower CoP. In contrast, in 2022, they had the lowest income (78 399.6 HUF ha^{-1}) for the whole table. When analyzing the irrigated and non-irrigated tables separately, it can be observed that in both cases, the highest incomes were in 2021. In 2023, a more rainy year did not lead to a significant difference in income between irrigated and non-irrigated fields (only 0.8% difference), but the non-irrigated fields had a higher income, precisely because the farmer applied the same homogeneous technology without taking into account the field conditions; irrigation costs were given in the irrigated field, which was ultimately reflected in the income. The impact of the drought year 2022 on the non-irrigated fields resulted in a loss (almost 420 000 HUF ha^{-1}), which is a clear result of the fact that production costs were maintained on these fields with a yield of nearly 0 t ha^{-1} (*Figure 3*).

Figure 3. **Evolution of income relations of the pilot table in the years under study**



In 2022, the unit costs were also much higher, both at the board level and in the separation of irrigated/non-irrigated boards. While in 2021 and 2023, the cost price of maize production exceeded HUF 46 000/t and HUF 42 000/t, respectively, in 2022, it was HUF 112 699.9/t. Under irrigated conditions, the unit cost price was 12% and 22% higher in 2021 and 2023 compared to non-irrigated fields, respectively.

CONCLUSIONS AND RECOMMENDATIONS

Investigating the economic efficiency of precision farming technology is paramount for its broader uptake. When calculating cost and income relationships, it is worth considering all elements of the production technology to demonstrate the impact of precision farming on its application's natural and economic efficiency. For most companies, cost and income analyses are carried out traditionally for the farm as a whole, in a small number of cases at the table level and even less often at the intra-table level. However, advanced information technology and innovative solutions from field machinery manufacturers are increasingly enabling all operations in the field to be recorded, thus enabling accurate documentation of agro technological and technical interventions within the field. This information can be the basis for deep analyses that can fundamentally determine the crop technology for the coming years, as it can effectively map the fertility conditions of the field/plots and their topographic and hydrological heterogeneity (Szabó et al., 2007; Hadászi, 2022).

In addition to agro technological data recorded in natural terms (l ha^{-1} pesticide, kg ha^{-1} fertilizer, t ha^{-1} crop, etc.), unit sales prices and unit costs expressed in monetary terms are also essential for such a complex econometric calculation.

Our calculations have clearly shown that a given year's climatic and market characteristics fundamentally determine the cost and income relations of a piece of land (and thus of an entire farm). In addition, additional inputs such as irrigation or intensification with fertilizer at variable rates tailored to the crop's needs, based on the knowledge of the growing area, not only allow yields to increase but also safe production (Bora et al., 2012) while at the same time increasing efficiency and sustainability by reducing environmental pressure (Wolf and Buttel 1996).

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