UDC 04.032.26
DOI: 10.15587/1729-4061.2024.298478

EVALUATING THE EFFECTIVENESS OF PRECISION FARMING TECHNOLOGIES IN THE ACTIVITIES OF AGRICULTURAL ENTERPRISES

Alexandr Neftissov
PhD, Associate Professor
Research and Innovation Center «Industry 4.0»*

Andrii Biloshchytskyi
Corresponding author
Doctor of Technical Sciences, Professor**
Vice-Rector of the Science and Innovation*
E-mail: bao1978@gmail.com

Yurii Andrashko
PhD, Associate Professor
Department of System Analysis and Optimization Theory
Uzhhorod National University
Narodna sq., 3, Uzhhorod, Ukraine, 88000

Oleksandr Kuchanskyi
Doctor of Technical Sciences, Professor
Department of Computational and Data Science*

Volodymyr Vatskel
Senior Lecturer**

Sapar Toxanov
PhD, Director of Center
Center of Competency and Excellence*

Myroslava Gladka
PhD, Associate Professor
Department of Information Systems and Technology
Taras Shevchenko National University of Kyiv
Volodymyrska str., 60, Kyiv, Ukraine, 01033
Department of Biomedical Cybernetics
National Technical University of Ukraine
«Ihor Sikorsky Kyiv Polytechnic Institute»
Beresteyskyi ave., 37, Kyiv, Ukraine, 03056
*Astana IT University
Mangilik Yel ave., EXPO Business Center, Block C.1.,
Astana, Kazakhstan, 010000
**Department of Information Technology
Kyiv National University of Construction and Architecture
Povitroflotsky ave., 31, Kyiv, Ukraine, 03037

This paper describes approaches to improving the efficiency of agricultural enterprises. It has been established that the use of technology transfer, in particular, precision farming technologies, makes it possible to enhance the efficiency of agricultural enterprises, in particular, to increase the yield of agricultural crops and, accordingly, to improve the profitability of enterprises. As an example, the activities of agricultural enterprises in the Republic of Kazakhstan were analyzed. The share of agricultural enterprises in the Republic of Kazakhstan that use elements of precision farming technology in their activities was determined. It was established that since 2019, the use of precision farming technologies in the activities of agricultural enterprises in the Republic of Kazakhstan has intensified. At the same time, from 60 to 75 % of enterprises already use elements of precision farming technologies in their activities. Using crop yield data for the past 32 years, estimates of the effectiveness of using precision farming technologies by agro-enterprises in the Republic of Kazakhstan were constructed based on forecasting yield indicators using the linear-weighted moving average method. The efficiency of using precision farming technologies in the activities of agricultural enterprises in the Republic of Kazakhstan in 2022 reached 8.46 %, and the average efficiency for the period 2019–2022 was 4.21 %. Therefore, the use of precision farming technologies makes it possible to improve the validity of decision-making in the management of an agricultural enterprise and to obtain a higher profit from the sale of produced agricultural products for any agricultural enterprise in the world. On average, the results allow us to estimate the possible profit of an agro-enterprise when growing agricultural crops in the case of using precision farming technology

Keywords: efficiency of agricultural enterprises, yield of agricultural crops, smart agribusiness, precision farming technologies

Received date 24.11.2023
Accepted date 02.02.2024
Published date 28.02.2024

How to Cite: *Neftissov, A., Biloshchytskyi, A., Andrashko, Y., Kuchanskyi, O., Vatskel, V., Toxanov, S., Gladka, M. (2024). Evaluating the effectiveness of precision farming technologies in the activities of agricultural enterprises. Eastern-European Journal of Enterprise Technologies, 1 (13 (127)), 6–13. doi: https://doi.org/10.15587/1729-4061.2024.298478*

1. Introduction

Ensuring a high yield of agricultural crops is an important component that makes it possible to improve the efficiency of the entire agricultural production chain of the enterprise. For quality management of the agricultural production process in this context, it is necessary to carry out innovative activities, in particular, to use technology transfer in agriculture. The use of technology transfer in this area, in particular precision farming technologies, makes it possible to potentially improve the efficiency of agricultural enterprises, in particular to increase the yield of agricultural crops and enhance their profitability.

Different approaches can be used to improve the efficiency of agricultural enterprises. In particular, effective yield forecasting methods are devised and implemented. Yield forecasting is a scientifically based prediction of the possible volume and quality of the harvest of agricultural crops for a certain period. Enabling satisfactory accuracy of yield forecasting is important for the management of agar enterprises, influencing the pricing schemes of traders and insurers. It also affects the formation of stocks of suppliers of agricultural products and consumers, as well as influences the organization of routes of logistics companies operating in the agricultural sector. Yield forecasting results are also needed by government agencies to maintain food balance and manage imports or exports.

The construction of crop yield models is relevant. More than three hundred studies from 2004 to 2019 focus on predicting the yield of a wide range of agricultural crops, taking into account different geographical conditions [1]. In traditional yield forecasting models, three data sources are most often used: historical weather data, satellite images of fields, and statistical data on the cultivation of the corresponding agricultural crop.

The agricultural sector in the Republic of Kazakhstan is interesting from the point of view of improving the agricultural sector through the introduction of smart technologies. This is due to the fact that the Republic of Kazakhstan plays a key role in food production in Central Asia, especially in the cultivation of cereals, despite difficult natural conditions, such as a harsh continental climate and limited water resources. The Republic of Kazakhstan has large areas of fertile land suitable for growing cereals, especially wheat and barley. This allows the country to be one of the largest grain exporters in the world. The Government in the Republic of Kazakhstan has invested significant funds in the modernization of agricultural infrastructure and the introduction of smart technologies in this area. The concept of modernization includes the improvement of storage and transportation systems of agricultural products, as well as the introduction of modern agricultural technologies, which allow for operational control of the cultivation of agricultural crops.

Smart agricultural enterprises are enterprises that carry out production activities in agriculture with the aim of obtaining an appropriate profit and take into account modern approaches to farming. These include the technologies of the Internet of Things, artificial intelligence, satellite data recognition, modern technical means of data collection to increase the efficiency, productivity, and sustainability of agricultural production, as well as technology transfer [2]. However, most agricultural enterprises lack a systematic approach to managing innovative development and operational processes in agricultural production. In addition, there is a significant gap between the needs of science and technology in agriculture and the needs of agribusiness. The use of technology transfer, in particular precision farming technologies, in the activities of agro-enterprises could potentially allow solving a significant part of problems that the management of agro-enterprises solves in its activities. This makes it possible to increase the yield of agricultural crops, which, accordingly, makes it possible to improve the profitability of agricultural production.

The planned use of technology transfer and precision agriculture at all levels of agribusiness activity allows an agricultural enterprise to accurately plan production, optimize the use of resources, and manage risks. This is especially important in the context of climate change, food shortages in the world, and the instability of the agricultural market. With the help of precision farming technologies, it is possible to distribute water resources, fertilizers, and other resources and materials more efficiently, reducing the company's costs and reducing the negative impact of agricultural activities on the environment. Sufficiently accurate yield forecasts help agricultural enterprises better understand and manage risks associated with changes in weather conditions, the spread of crop diseases, and other external factors of influence. Accurate yield models make it possible to increase yields and ensure the required crop quality by using data to accurately determine the optimal growing conditions for each specific crop. This makes it possible to ensure the sustainability of agricultural enterprises. Therefore, studies aimed at evaluating the effectiveness of application of precision farming technologies in the activities of agrarian enterprises are relevant.

2. Literature review and problem statement

The construction of models and methods for increasing the productivity of agricultural enterprises is a topic that is intensively researched. The study of the activities of agricultural enterprises in the Republic of Kazakhstan is particularly relevant, in particular due to the climatic and geographical features of this state. At the same time, methods for yield forecasting, methods of decision-making theory, optimization theory, artificial intelligence, etc. are being investigated in this area.

In [3], a statistical yield model was built that takes into account weather conditions for forecasting wheat production. The advantages of this model are the use of open verified weather and yield data, as well as proven low computational complexity. However, the accuracy of the model is about 95 %. Under conditions when the management of an agribusiness and its profitability depend on the forecasting results, or if the forecasting results are planned for use by government agencies, such a result of accuracy should be improved.

Study [4] built a dynamic-statistical biomass model for forecasting the yield of agricultural crops. Using the methods of comparative and retrospective analogy, as well as mathematical modeling, the indicators used to forecast the yield of agricultural crops were determined. The main drawback of the study is the need to define model parameters separately for each region. This task is complex and requires the involvement of additional financial and human resources.

Study [5] shows the effectiveness of using the primary data from the Sentinel satellite images and statistical indicators for the last few years for the agricultural territories in the Republic of Kazakhstan. In combination with machine learning algorithms, this approach makes it possible to calculate the forecast of the yield of agricultural crops and to compile general statistical recommendations for increasing the yield. However, the computational complexity of such a yield forecasting system is complex and requires significant resources.

Study [6] demonstrates that the combination of climate and satellite data can provide high efficiency of yield forecasting. Satellite data track crop growing conditions and gradually capture yield changes throughout the growing season, and their contribution to yield forecasting typically peaks during the period of maximum growth. Climatic data provide additional and unique information that complements satellite observations for yield forecasting, and empirical modeling shows the added value of climate variables throughout the season, not just at specific stages. However, despite improvements in yield prediction accuracy using empirical methods by combining climate and satellite data, the contribution of different data sources is still poorly understood. In particular, work [7] describes a linear regression model for forecasting the yield of agricultural crops in the northern part of the Republic of Kazakhstan, but many other factors need to be investigated for effective yield forecasting.

An important task is the construction of decision-making models regarding the activities of an agricultural enterprise under conditions of uncertainty to improve productivity. Work [8] describes a conceptual model of decision-making but it does not take into account the full set of factors influencing the yield of agricultural crops. In study [9], the component of functionality for the model of the information system for supporting decision-making in the agrarian domain under conditions of environmental uncertainty was considered. This component includes those mathematical models and methods that enable the functioning of the information system for supporting decision-making in the agricultural domain under conditions of environmental uncertainty. The main assumptions of the study are that there is no activity that can be completely avoided, and there are no risks that cannot be managed. However, the work describes general recommendations for managing the risks of an agricultural enterprise without specifying the key parameters that influence the activity of an agricultural enterprise in terms of ensuring higher yields.

In many studies, vegetation indices calculated from the infrared and red ranges of the spectrum are used to estimate the yield of various crops. The authors of study [10] showed that a single index cannot provide a reliable assessment in all cases, the effectiveness of the index depends on such factors as climate, soil, type of crop, growing season, etc. Therefore, more than 150 types of vegetation indices are proposed in [11]. Yield assessment is represented by various indices: historical data of local hydrological monitoring with a higher resolution and distributed controller data [12]. All these components must be taken into account in a set to increase the yield of crops.

Another important component of the successful functioning of an agricultural enterprise is the construction of an information management system that takes into account the conditions of risk and uncertainty. Such conditions characterize the agricultural market. Paper [13] describes such an information system and provides recommendations for its use under the specified conditions.

Yield forecasting is based on the analysis of time series that reflect changes in various indicators. Work [14] describes the features of using fractal analysis of time series to determine the characteristics of the series, which are directly used in forecasting, in particular, yield forecasting. Adaptive time series forecasting models based on similarity identification are described in [15], but they are general in nature. The specificity of crop yield time series and their forecasting have not been separately investigated. Paper [16] describes the features of application of neural networks for the problem of yield forecasting on the example of the northern regions in the Republic of Kazakhstan.

In general, the described approaches to increase productivity should be taken into account in combination with the use of precision agriculture technologies based on technology transfer. It can be assumed that the use of the transfer of precision farming technologies is a key component of improving the efficiency of agribusiness, which includes increasing the yield of agricultural crops and enhancing the profitability of the enterprise.

3. The aim and objectives of the study

The purpose of our work is to evaluate the efficiency of application of precision farming technologies in the activities of agricultural enterprises. This will make it possible to estimate the possible profit of an agro-enterprise when growing agricultural crops in the case of using precision farming technology.

To achieve the goal, the following tasks were set:

– to establish the state of development of the agricultural industry using an example of the Republic of Kazakhstan based on the analysis of crop yield indicators;

– to devise a procedure for evaluating the efficiency of agricultural enterprises under the conditions of technology transfer in precision agriculture.

4. The study materials and methods

The object of our study is the efficiency of agricultural enterprises. The hypothesis of the study is to verify the fact that the intensive use of the transfer of precision farming technologies makes it possible to obtain greater efficiency, in particular, greater productivity and, accordingly, an increase in the volume of produced products and an increase in the profits of agricultural enterprises.

The work uses methods of quantitative analysis, in particular, the use of statistical tools for the analysis and forecasting of time series of crop yields. These tools are necessary in order to show the effectiveness of the use of precision agriculture technologies in the activities of agribusinesses. It is known that the agricultural sector, in addition to cultivation, also includes the processing of agricultural products and the production of agricultural machinery. This study examined the efficiency of agricultural enterprises in terms of growing agricultural crops. For simplicity, other components of the agro-industrial complex were not considered.

The calculation of the effectiveness of the use of precision farming technologies in the activities of agricultural enterprises was carried out using an example in the Republic of Kazakhstan. Data on the yield of cereals, oilseeds, in particular sunflower, potato, sugar beet, melon crops, and open ground vegetables for the period from 1990 to 2022 were analyzed. The data are obtained from the official statistics of the Bureau of National Statistics of the Agency for Strategic Planning and Reforms in the Republic of Kazakhstan [17] and the Aerospace Committee of the Ministry of Digital Development, Innovation, and Aerospace Industry of the Republic of Kazakhstan [18].

5. Investigating the effectiveness of application of precision farming technologies in the activities of agrarian enterprises

5. 1. Studying the state of development of the agricultural sector using an example of the Republic of Kazakhstan

A total of 321,387 subjects in the agro-industrial sector operate on the territory of the Republic of Kazakhstan. Taking into account the specificity of the current legislation in terms of the creation and operational activities of subjects of the agro-industrial sector, it is possible to make a clear gradation of all subjects into the following categories:

– small business legal entities – 20,353 enterprises;

– legal entities of medium-sized enterprises – 257 enterprises;

– individual enterprises – 20,810 enterprises;

– peasant or farm holdings – 279,967 enterprises.

Since 2019, precision farming technologies have been actively used in Kazakhstan. The introduction of precision farming technologies is carried out gradually, not all components are immediately involved in the process of agricultural production. However, the positive effect of using the transfer of precision farming technologies is clearly visible in all regions in the Republic of Kazakhstan without exception. For example, in 2019, the gross output of agricultural products in the Akmola region amounted to USD 1,089.8 million. After the use of precision farming technologies by subjects of the agro-industrial sector, in 2023 the gross output of agricultural products in this region increased to a volume equal to about USD 1,584.4 million.

Precision agriculture involves an integrated approach to agricultural production management based on global positioning systems (GPS), geographic information systems (GIS), remote sensing of the earth (DSR), and other methods and tools. As of December 31, 2022, there were a number of enterprises in the field of "Agriculture, forestry, and fisheries" in the territory of the Republic of Kazakhstan that used RFID technologies (1,468 enterprises), tools of information systems and technologies (4,377 enterprises) [17].

As of January 15, 2020, during the operation of the space system, Kazakhstan's DZZ satellites photographed 1,134,246,996,997 km^2 of the Earth's territory. In 2019, more than 11,000 space images covering 22 million square meters of the country's territory were developed and provided, including space monitoring, for the state authorities. During the period of operation of the space system of remote sensing of the Earth in the Republic of Kazakhstan (KazEOSat-1 and KazEOSat-2) from 2015 to 2020, the sale of space images on the domestic market brought in USD 33.3 thousand. As for sales on the foreign market, revenues amounted to USD 701.5 thousand. In 2020, state bodies were provided with 2,876,400 km^2 of high-resolution space images of DZZ and 3,006,003 km^2 of medium-resolution space images of DZZ [18].

Statistics on the use of precision farming technologies in the Republic of Kazakhstan:

1. Area cultivated using GPS technologies: according to the latest data, more than 20 % of agricultural land in the Republic of Kazakhstan is cultivated using GPS technologies for accurate plant placement and resource optimization.

2. More than 30 % of agricultural enterprises in the country use drones, which are used to analyze the soil, determine the level of moisture, detect diseases and pests.

3. About 40 % of large agricultural producers in the Republic of Kazakhstan actively use smart agricultural technologies: they implement the use of sensors, automation and monitoring systems, as well as crop management systems (Precision Agriculture).

As part of the scientific and technical program "Transfer and adaptation of technologies from precision agriculture in the production of plant products according to the principle of "demonstration farms (polygons)" in the Akmola region", studies of the effectiveness of technologies of precision agriculture were conducted. Based on the results of these studies, it was established that enterprises save working capital on the following scales: fuel and lubricants (USD 7.7 per hectare), labor and materials (USD 2.3 per hectare). At the moment, the Akmola region has 5,472,776 hectares of total arable land at its disposal, which are in operation at 7,007 enterprises of the region in the field of agricultural production [19].

On average, taking into account that 5,325 enterprises of the region use precision farming technologies, the size of the sown area of each such enterprise is an average of 781 hectares.

Thus, the economic efficiency of the application of precision farming technologies makes it possible to achieve the following positive economic indicators:

1. Savings of working capital from the use of precision farming technologies for one farm averages USD 7,873 annually, and USD 58.9 million for the entire industry as a whole in the territory of the Akmola region.

2. Increase in industrial production of agricultural products. Taking into account the average indicators of output, it can be said that the increase in output from 2019 to 2023 of products of the agro-industrial sector amounted to USD 494.6 million dollars in 4 years. The output increase amounted to 55,700.975 million annually as a whole for the subjects of the agro-industrial sector in the territory of the Akmola region. Taking into account the number of enterprises using precision farming technologies, the direct increase in the production of agricultural products for each enterprise amounted to an average of USD 23,221.

From 60 to 75 % of all agro-industrial enterprises in the Republic of Kazakhstan use precision farming technologies at various stages of the production process, starting from planning and ending with harvesting from the fields.

5. 2. Devising a procedure for evaluating the efficiency of agricultural enterprises under the conditions of technology transfer in precision agriculture

In general, the efficiency of agricultural enterprises is determined by a set of indicators, which should include the efficiency of the use of technologies from the point of view of production costs, production growth, and the use of assets of an agricultural enterprise. However, the basic indicator that determines the efficiency of agricultural enterprises is productivity. As the yield increases, the company's profit increases. In addition to weather conditions, the growth of yields is directly influenced by the amount of use of smart technologies, in particular precision farming technologies. The yield of the main agricultural crops in the Republic of Kazakhstan is given in Table 1 [17]. Gross performance indicators of agricultural enterprises on average in the Republic of Kazakhstan are given in Table 2.

To assess the efficiency of agricultural production, we shall consider the forecast of crop yield time series from 2019, taking into account the beginning of the intensive use of precision farming technologies by agricultural enterprises. The forecasting results can be compared with the real yield indicators recorded after 2019. It is clear that the productivity can be affected by many different factors, including weather conditions in the regions, the presence of diseases, etc. However, the use of precision farming technologies makes it possible to adjust and correct possible violations in the mode of cultivation of agricultural crops. Accordingly, productivity will potentially increase.

Let the time series of productivity (quintal from one hectare) for agricultural crops K_d take the form:

$$\left(W_1^d, W_2^d, \ldots, W_s^d\right), \quad d=\overline{1,h}, \tag{1}$$

where h is the number of agricultural crops, $\langle K_1, K_2, \ldots, K_h \rangle$ is the list of agricultural crops, s is the number of observation periods.

The yield forecast with horizon one can be defined as some functional F from retrospective data:

$$\hat{W}_s^d = F\left(W_{s-u}^d, W_{s-u+1}^d, \ldots, W_{s-1}^d\right), \tag{2}$$

where u is the number of retrospective data that are selected for the calculation of the forecast.

The yield forecast with horizon two is determined by the formulas:

$$\hat{W}_{s+1}^d = F\left(W_{s-u+1}^d, W_{s-u+2}^d, \ldots, W_{s-1}^d, \hat{W}_s^d\right), \tag{3}$$

where $\hat{W}_{s+1}^d$ is the forecast of the yield of agricultural crops 2 points ahead; F is a functional that determines the forecast.

Similarly, it is possible to determine estimates of the yield forecast with a horizon of three or more. For example, in the case of the yield time series, to simplify calculations for F, you can choose a linearly weighted moving average, which is calculated according to the formula:

$$\hat{W}_s^d = \left(\sum_{k=1}^{u} k\right)^{-1} \sum_{k=1}^{u} k \cdot W_{s-u+k-1}^d, \quad d=\overline{1,h}, \tag{4}$$

where $\hat{W}_s^d$ is the forecast of the potential of the subject scientific space 1 point ahead based on a linearly weighted moving average.

The resulting difference between the forecasted yield values and the actual values recorded during the last period of time can be considered the efficiency of agricultural enterprises. In the context of the growing number of enterprises using precision agriculture technologies starting in 2019, this assessment may be an indicator that indicates the potential of using these technologies for farming.

The study used data on the yield of grain crops, oilseeds, in particular sunflower, potato, sugar beet, melon crops, and open ground vegetables. Data were collected for the period from 1990 (for oilseeds from 1999) to 2022 from an official source [17]. Based on the obtained data, we shall construct discrete time series of yield and determine the base period of time when the use of precision farming technologies in the activities of agricultural enterprises in the Republic of Kazakhstan was insignificant (the period until 2018). Taking into account the assessment of the use of precision agriculture technologies [18], since 2019, the share of enterprises using smart technologies in their activities has increased sharply.

To assess the efficiency of agricultural enterprises, we forecast the yield of agricultural crops that they grow for the period from 2019 to 2022 using the linear weighted moving average method. To cover a larger number of agricultural enterprises, we forecast yields for different crops, h=7 – the number of crops for which data are available. We forecast the yield of cereals, oilseeds, in particular sunflower, potato, sugar beet, melon crops, and open ground vegetables.

If W_s^d is the yield of agricultural crop d for year s, $d=\overline{1,h}$. $\hat{W}_{s+\pi}^d$ is the forecast of the yield of agricultural crop d with the period π, i.e. for the year (s+π), then the real value of the yield of crop d in the year (s+π)

Table 1

Yield of basic agricultural crops in the Republic of Kazakhstan (hundreds per hectare)

Year	Cereals (incl. rice) and legumes	Oil-seeds	Sunflower seeds	Potato	Vegetables in open soil	Gourds	Sugar beet
1900	12.2	No data	9.2	113.0	154.0	84.0	239.0
1991	5.3		4.9	99.0	121.0	79.0	148.0
1992	13.2		3.3	104.0	114.0	72.0	136.0
1993	9.7		3.2	94.0	106.0	69.0	123.0
1994	7.9		3.4	94.0	104.0	59.0	77.0
1995	5.0		2.9	84.0	101.0	59.0	91.0
1996	6.5		1.9	88.0	96.0	58.0	105.0
1997	8.7		2.8	84.0	101.0	67.0	116.0
1998	5.6		4.2	77.0	114.0	78.0	143.0
1999	13.0	4.9	4.9	108.0	134.0	97.0	172.0
2000	9.4	3.9	4.0	106.0	153.0	119.0	154.0
2001	12.2	5.7	6.0	133.0	166.0	127.0	173.0
2002	11.5	6.3	5.9	139.0	172.0	135.0	207.0
2003	10.8	7.1	6.8	139.0	177.0	144.5	210.4
2004	8.8	6.2	5.9	134.0	186.0	153.2	197.4
2005	10.0	7.0	6.3	150.0	196.0	159.3	209.2
2006	11.7	6.6	5.9	153.6	201.0	167.1	240.8
2007	13.3	7.2	5.9	155.8	211.0	171.7	248.9
2008	10.1	5.5	4.1	143.7	204.0	158.9	204.3
2009	12.6	6.5	5.7	160.0	218.7	161.1	182.9
2010	8.0	5.0	4.4	143.0	214.4	177.0	174.3
2011	16.9	6.7	4.6	167.2	222.9	186.1	188.2
2012	8.6	6.1	5.9	165.9	234.0	206.8	168.2
2013	11.6	8.0	7.0	181.5	238.7	212.4	267.7
2014	11.7	7.8	6.7	184.3	243.0	217.1	240.6
2015	12.7	8.1	7.6	185.5	245.8	221.0	232.5
2016	13.5	9.6	9.3	190.4	250.0	221.4	285.5
2017	13.4	9.7	10.2	194.2	253.7	224.2	274.4
2018	13.5	9.7	10.0	197.9	257.3	224.2	305.3
2019	12.3	9.3	10.3	203.4	260.5	234.6	324.5
2020	12.8	9.5	11.3	206.7	265.9	238.8	323.2
2021	10.4	8.3	11.0	207.4	268.0	252.7	275.5
2022	13.8	9.1	12.0	205.4	271.3	255.6	341.4

Table 2

Gross indicators of activity (USD million) of agricultural enterprises on average in the Republic of Kazakhstan

Indicator \ Year	2018	2019	2020	2021	2022
Gross output of crop production	1657.8	1976.9	2746.9	3009.6	4778.8
Gross output of livestock products	685.4	805.2	939.1	1168.6	1354.4
Services in the field of agriculture	27.0	31.1	22.0	24.9	31.4

is determined as $W^d_{s+\pi}$. Since the yield forecast takes into account all factors, in addition to the use of smart technologies, and the yield was obtained with the use of smart technologies, then we shall consider the increase in productivity as an assessment of the effectiveness of the use of precision farming technologies in the activities of agricultural enterprises.

An estimate was built on the basis of yield indicators for 2022. Taking into account the growing trend in the share of enterprises using elements of precision agriculture, we shall consider 2022 as the year with the maximum use of elements of precision agriculture in the activities of agricultural enterprises. The efficiency of using precision farming technologies is determined by the formula:

$$E^d = \frac{W^d_{2022} - \hat{W}^d_{2022}}{W^d_{2022}} \cdot 100\,\%, \tag{5}$$

where E^d is the efficiency of using precision agriculture technologies in 2022.

The estimate of the average efficiency of the use of precision agriculture technologies for 4 years (the period from 2019 to 2022) is calculated according to the formula:

$$\overline{E}^d = \frac{1}{4}\sum_{\pi=1}^{4} \frac{W^d_{2022+\pi} - \hat{W}^d_{2022+\pi}}{W^d_{2022+\pi}} \cdot 100\,\%, \tag{6}$$

where $\overline{E}^d$ is the efficiency of using precision farming technologies for the period from 2019 to 2022 in percent.

The overall assessment of the effectiveness of the use of precision agriculture technologies E is calculated as the arithmetic average of the effectiveness for all crops according to the formula:

$$E = \frac{1}{h} \cdot \sum_{d=1}^{h} E^d. \tag{7}$$

The results of efficiency calculations are given in Table 3.

Table 3

Effectiveness of using precision farming technologies in the Republic of Kazakhstan for various agricultural crops

Agricultural crop	Performance in 2022 (%)	Average performance for the period from 2019 to 2022 (%)
Sugar beet	16.41	9.83
Melons	12.64	8.98
Open ground vegetables	6.47	4.93
Potato	5.43	5.83
Sunflower seeds	19.46	13.94
Oilseeds	–4.42	–4.77
Cereals (incl. rice) and legumes	3.23	–9.30
Average	8.46	4.21

Therefore, it can be concluded that the efficiency of using precision farming technologies in the activities of agricultural enterprises in the Republic of Kazakhstan in 2022 reached 8.46 %, and the average efficiency for the period 2019–2022 was 4.21 %.

An example of the application of technology transfer in precision agriculture is the activity of the company “Pilot farm of oil plants” LTD. (Republic of Kazakhstan, East Kazakhstan region, Ust-Kamenogorsk) [20]. For optimal management of agricultural land and optimization of all processes, the company uses automated smart systems. In order to preserve moisture and prevent erosion, soil cultivation in this company is shallow, to a depth of 22–25 cm. The company has not used plowing on its land for three years. Most of the area is cultivated with minimal technology, and 15 % uses direct seeding in order to convert all areas to zero technology. The implementation of elements of precision agriculture helps achieve this. Differentiated application of fertilizers, creation of a yield map, etc. are also used from the elements of precision agriculture and digitization. The Cropio system has been implemented in the farm, which allows one to monitor the course of vegetation. The performance indicators of this enterprise for 2021–2023 are given in Table 4.

Table 4

Performance indicators of the enterprise «Pilot farm of oil plants» LTD

Indicator \ Year	2021	2022	2023
Corporate income tax, USD thousand	79.3	134.7	149.0
Taxes, USD thousand	639.8	717.0	926.2
Annual income, USD million	54.6	73.9	75.9
Average yield of crops, tons/ha	30	32	34

As can be seen from our data, the application of precision farming technologies and digitalization tools in the activities of the subjects from the agro-industrial sector makes it possible to enable a constant growth trend of both the revenue part of the enterprise and the overall productivity of finished products.

6. Discussion of evaluations of the effectiveness of using precision farming technologies in the activities of agricultural enterprises

From Table 3, it can be concluded that the efficiency of using precision farming technologies in the activities of agricultural enterprises in the Republic of Kazakhstan in 2022 reached 8.46 %. The average efficiency for the period 2019–2022 was 4.21 %. Efficiency was calculated according to formulas (1) to (3). Analysis shows that oilseeds and grain crops, unlike others, show a negative increase in productivity. This indicates that the study did not take into account all the factors that affect the productivity and for these crops there are factors that prevail over the introduction of precision farming technologies and require additional study.

Taking into account the growing trend of enterprises that use the transfer of precision farming technologies in their activities, it can be assumed that the percentage will grow in the near future. Our evaluations of the effectiveness of the use of precision farming technologies confirm the hypothesis that technology transfer in agriculture, in particular precision farming technologies, makes it possible to increase productivity and, accordingly, the profitability of agricultural enterprises. In particular, the results are confirmed by statistical data on the growth of the total gross output of agricultural products in the part of crop production from USD 1,657.8 million in 2018 to USD 4,778.8 million in 2022 in general for the Republic of Kazakhstan (Table 2).

Work [2] describes the calculation of costs for growing agricultural crops based on the set of Agricultural 5.0

technologies. The evaluation of the effectiveness of the use of precision agriculture technologies, which is described in the current paper, allows us to study the change in the yield of agricultural crops before and after the introduction of elements of precision agriculture. However, cultivation costs are not calculated since the use of elements of precision agriculture by agricultural enterprises is considered in general without specifying specific means, etc.

The study shows that the use of the transfer of precision farming technologies is a key component in improving the efficiency of agricultural enterprises in the Republic of Kazakhstan, which includes increasing the yield of agricultural crops and enhancing the profitability of the enterprise. Although the agricultural sector of any country is a combination of agriculture, processing of agricultural products, and manufacture of agricultural machinery. This study examined the efficiency of agricultural enterprises in terms of growing agricultural crops. Other components of the agro-industrial sector were not considered, and this may be the subject of further research.

Our research has inherent limitations arising from the constraints of the linear weighted moving average method for yield forecasting. The method considered does not take into account seasonal changes, which can be caused, in particular, by the cycle of solar activity. The limitations of the study include the use of averaged data for the Republic of Kazakhstan. The use of data from individual enterprises or districts would make it possible to more accurately assess the impact of the transfer of precision farming technologies.

The shortcomings of the study include the lack of a cause-and-effect analysis of the impact of the transfer of precision agriculture technologies in certain industries. The development of this research may consist in a closer integration of precision farming technologies into the activities of agricultural enterprises. It is also advisable to conduct controlled experiments on the cultivation of agricultural crops to directly measure effectiveness of the use of precision agriculture technologies.

The main difficulties of the experimental nature of further research are the activities of agricultural enterprises under conditions of environmental uncertainty. These conditions make it difficult to separate the influence of weather factors on yield from the effects of technology transfer and significantly reduce the repeatability of experiments.

7. Conclusions

1. The state of development of agricultural production, in particular crop production in the Republic of Kazakhstan, was studied; the share of agricultural enterprises that use precision farming technologies in their activities was determined. It was established that since 2019, the use of precision farming technologies in the activities of agricultural enterprises in the Republic of Kazakhstan has intensified. At the same time, from 60 to 75 % of enterprises already use elements of precision farming technologies in their activities. The given numerical indicators testify to the relevance and demand for the development of technology transfer in this area; it is connected with the growth of the gross output of agricultural products and, accordingly, growth in the profits of enterprises.

2. A procedure for determining the efficiency of the use of precision farming technologies by agro-enterprises in the Republic of Kazakhstan based on forecasting yield indicators using the linear-weighted moving average method based on crop yield data for the past 32 years has been devised. It was found that the proposed procedure made it possible to evaluate the efficiency of using precision farming technologies in the activities of agricultural enterprises in the Republic of Kazakhstan, which in 2022 reached 8.46 %, and the average efficiency for the period 2019 2022 was 4.21 %. Therefore, the use of precision farming technologies makes it possible to improve the validity of decisions on the management of an agricultural enterprise and to obtain a higher profit from the sale of produced agricultural products.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

Funding

The paper was written within the state order for the implementation of the scientific program under the budget program in the Republic of Kazakhstan 217 “Development of Science”, subprogram 101 “Program-targeted funding of the scientific and/or technical activity at the expense of the national budget” on the theme: AP19678730 Development of precision farming information technology for agricultural management using “The Internet of Things”.

Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Schauberger, B., Jägermeyr, J., Gornott, C. (2020). A systematic review of local to regional yield forecasting approaches and frequently used data resources. European Journal of Agronomy, 120, 126153. https://doi.org/10.1016/j.eja.2020.126153
2. Saiz-Rubio, V., Rovira-Más, F. (2020). From Smart Farming towards Agriculture 5.0: A Review on Crop Data Management. Agronomy, 10 (2), 207. https://doi.org/10.3390/agronomy10020207
3. Romanovska, P., Schauberger, B., Gornott, C. (2023). Wheat yields in Kazakhstan can successfully be forecasted using a statistical crop model. European Journal of Agronomy, 147, 126843. https://doi.org/10.1016/j.eja.2023.126843
4. Sadenova, M. A., Beisekenov, N. A., Rakhymberdina, M. Y., Varbanov, P. S., Klemeš, J. J. (2021). Mathematical modelling in crop production to predict crop yields. Chemical Engineering Transactions, 88, 1225–1230. https://doi.org/10.3303/CET2188204

5. Beisekenov, N. A., Sadenova, M. A., Varbanov, P. S. (2021). Mathematical Optimization as A Tool for the Development of "Smart" Agriculture in Kazakhstan. Chemical Engineering Transactions, 88, 1219–1224. https://doi.org/10.3303/CET2188203
6. Cai, Y., Guan, K., Lobell, D., Potgieter, A. B., Wang, S., Peng, J. et al. (2019). Integrating satellite and climate data to predict wheat yield in Australia using machine learning approaches. Agricultural and Forest Meteorology, 274, 144–159. https://doi.org/10.1016/j.agrformet.2019.03.010
7. Mimenbayeva, A., Yessen, A., Nurbekova, A., Suleimenova, R., Ospanova, T., Kasymova, A., Niyazova, R. (2023). Development of a linear regression model based on vegetation indices of agricultural crops. Scientific Journal of Astana IT University, 15 (15), 101–110. https://doi.org/10.37943/15emub4283
8. Ji, C., Andrashko, Y., Biloshchytska, S., Tsiutsiura, S. (2021). Conceptual Research Model of Developing the Decision Support System for Agriculture Under Uncertainty. 2021 IEEE International Conference on Smart Information Systems and Technologies (SIST). https://doi.org/10.1109/sist50301.2021.9465888
9. Chunmei, J. (2022). Risk management for the functionality component of an agricultural enterprise's decision-making support information system. Management of Development of Complex Systems, 52, 35–38. https://doi.org/10.32347/2412-9933.2022.52.35-38
10. Xue, J., Su, B. (2017). Significant Remote Sensing Vegetation Indices: A Review of Developments and Applications. Journal of Sensors, 2017, 1–17. https://doi.org/10.1155/2017/1353691
11. Mutanga, O., Masenyama, A., Sibanda, M. (2023). Spectral saturation in the remote sensing of high-density vegetation traits: A systematic review of progress, challenges, and prospects. ISPRS Journal of Photogrammetry and Remote Sensing, 198, 297–309. https://doi.org/10.1016/j.isprsjprs.2023.03.010
12. Aharon-Rotman, Y., McEvoy, J., Zhaoju, Z., Yu, H., Wang, X., Si, Y. et al. (2017). Water level affects availability of optimal feeding habitats for threatened migratory waterbirds. Ecology and Evolution, 7 (23), 10440–10450. https://doi.org/10.1002/ece3.3566
13. Boyko, R., Shumyhai, D., Gladka, M. (2016). Concept, Definition and Use of an Agent in the Multi-agent Information Management Systems at the Objects of Various Nature. Advances in Intelligent Systems and Computing, 59–63. https://doi.org/10.1007/978-3-319-48923-0_8
14. Kuchansky, A., Biloshchytskyi, A., Andrashko, Y., Biloshchytska, S., Honcharenko, T., Nikolenko, V. (2019). Fractal Time Series Analysis in Non-Stationary Environment. 2019 IEEE International Scientific-Practical Conference Problems of Infocommunications, Science and Technology (PIC S&T). https://doi.org/10.1109/picst47496.2019.9061554
15. Kuchansky, A., Biloshchytskyi, A., Andrashko, Y., Biloshchytska, S., Shabala, Y., Myronov, O. (2018). Development of adaptive combined models for predicting time series based on similarity identification. Eastern-European Journal of Enterprise Technologies, 1 (4 (91)), 32–42. https://doi.org/10.15587/1729-4061.2018.121620
16. Aubakirova, G., Ivel, V., Gerassimova, Y., Moldakhmetov, S., Petrov, P. (2022). Application of artificial neural network for wheat yield forecasting. Eastern-European Journal of Enterprise Technologies, 3 (4 (117)), 31–39. https://doi.org/10.15587/1729-4061.2022.259653
17. Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan. Available at: https://www.gov.kz/memleket/entities/stat?lang=en
18. Aerospace committee of the Ministry of Digital Development, Innovations and Aerospace Industry of the Republic of Kazakhstan. Available at: https://www.gov.kz/memleket/entities/kazcosmos/press/article/details/1502?lang=ru
19. Transfer and adaptation of precision farming technologies in crop production on the principle of "demonstration farms (polygons)" in Akmola region. Report on research work. LLP "A.I. Baraev Scientific and Production Center of Grain Farming" (2020). Shortandy, 240.
20. Pilot farm of oil plants. Available at: https://eldala.kz/dannye/kompanii/346-opytnoe-hozyajstvo-maslichnyh-kultur