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PRECISION AGRICULTURE IN THE NORTH OF KAZAKHSTAN

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ABSTRACT. The precision farming system has been used in the North of Kazakhstan where specialized landfill on an area of 3000 ha was formed. In the fields of the landfill, detailed agrochemical survey (accuracy) of soil samples of the southern carbonate chernozem for grid cells 1 ha and 5 ha of fieldnet treatments with were conducted. Further differentiated fertilization was carried out both with the help of Amazone ZA-M and with the use of the Bourgault sowing complex. Monitoring of the state of the soil, plant development and work performed was carried out both by traditional methods and using modern remote sensing data. After the introduction of precision farming technologies in the North Kazakhstan from 2019 precision farming technologies has been used. As a result of the work carried out only from the introduction of one element of precision farming – differentiated rationing of fertilizer application, an increase in the yield of spring wheat 'Astana' by 9.6–19.2% to the standard economic technology was established. Research results have shown that the share contribution with a high yield of 2000 kg ha^{-1} was significant for a sampling grid cells 1 ha of fieldnet (40–47%) and less significant for a sampling grid cells 5 ha of fieldnet (15–20%). Hence it follows that the choice of a fieldnet with grid cells 1 ha is more preferable. Due to the use of a differentiated application system the savings from reducing the consumption of mineral fertilizers for the unit of the relay have had 69.26 EUR. Our novel research has shown that for characterizing the state of plants an assessment is given which was performed using test sites 1 and 5 ha grid cells of fieldnet treatments. In this case, we have used the vegetation indices NDVI – Normalized Difference Vegetation Index. At the same time, this index has changed relatively synchronously with the results of the yield of the spring wheat.

Introduction

It is known that wheat grown in Kazakhstan is the main crop for the republics of Central and Central Asia. The main wheat producer in this the region is Kazakhstan, which currently ranks 9th in production and 7th place in the export of wheat in the world (Fehér *et al.*, 2019). Other Asian countries, including Afghanistan, are the largest importers of Kazakhstan's wheat. Moreover, since 2004 imports in these countries have more than doubled. In countries such as Tajikistan and Kyrgyzstan, wheat accounts for over 60% of daily calorie intake (Satybaldin, 1997). Thus, food price surges are one of the main sources of food insecurity in Tajikistan and other republics (Morgounov *et al.*, 2018) in Asia.

Thus, wheat production in Kazakhstan serves as the food base for all of Asia. Moreover, the increase in yield and product quality is very relevant not only for Kazakhstan but also for many other countries (Abdullaev *et al.*, 2019).

One of the main ways to increase wheat productivity in Kazakhstan is the transition from extensive to highly intelligent farming systems. This path has already established itself all over the world where highly intelligent farming systems including farming technologies are being developed and introduced into production. However, before moving on to the introduction of precision farming technologies their adoption to new conditions is required (Irmulatov *et al.*, 2019; Truflyak *et al.*, 2017).

For the conditions of Kazakhstan, a very urgent task is the first stage of the introduction of high-intensity technologies of precision farming and precision plant growing aimed at increasing yields to 2000–2500 kg ha^{-1} which is the main task of the work of agricultural produces and scientists. Rational use of soil resources reproduction of soil fertility is the main condition for ensuring the stable development of an agro-industrial complex of the country and the most important source of expansion of agricultural production (Shortan, 2014). One of the main tasks of agriculture in North Kazakhstan is the realization of the productivity potential of arable soils at the level of productivity within above-mentioned yields of grain (first stage) and will reduce energy costs per unit of production (Agribusiness, 2020). The technology of precision farming and precision plant growing is a continuation of those innovative scientific and technological research that was carried out in the agro-industrial complex of Kazakhstan starting from the stage of "Virgin Land Upturned" and adaptive resource-saving production which lay down by A.I. Baraev and other scientists and production workers (Abdullaev, 2018).

The presented work was performed within the framework of the state program of Kazakhstan: "Transfer and adaptation of technologies for precision farming in the crop production on the principle of demonstration farms (polygons)". In this regard, our goal was to conduct this study.

Material and methods

For the introduction of new farming systems in Kazakhstan, it was necessary to develop new methodological foundations adapted to the conditions of the arid climate. For these purposes, the program "Transfer and adaptation of technologies for precision farming in the production of crop production according to the principle of demonstration farms (polygons)" was formed. The studies were carried out in the conditions of northern Kazakhstan (N51° 32'51.77"; E71° 03'27.50") since 2017 on the land use of non-profit institution LLP (Abdullaev, 2018)

To solve these problems a specialized test site on an area of 3000 ha was organized. The necessary equipment and agricultural machinery to carry out the work specialized for the precision farming system was purchased. All hardware and technical support were preliminarily adjusted, tested and adapted to production conditions. Equipping the test site with the necessary instruments, agricultural machinery and equipment made it possible to deploy precision research at the test site using both ground-based survey and Earth remote sensing (ERS) data (Komarov *et al.*, 2018). The following were carried out: agrochemical assessment of the field, application of fertilizers and fertilizing, sowing, caring for crops, harvesting, methodological approaches of the precision farming system was used (Yakushev, 2016). To clarify the heterogeneity of the supply of nutrients to the soils of the landfill, a detailed agrochemical survey of the landfill territory concerning soil samples per 1 ha and 5 ha with grid cells of fieldnet was carried out. The sampling of soil samples was carried out by an automated sampler based on a car with a GPS reference in the sub-zones of dark chestnut soils and southern carbonate chernozems which is typical for the above-mentioned region.

Fertilization was carried out in two ways: pre-sowing when fertilizers were applied together with sowing seeds in rows. This application was carried out using a Bourgault seeding complex equipped with a device (controller). Another method of fertilizing was spread surface. It was produced using an Amazone ZA-M solid bulk fertilizer spreader. At the same time, with the mineral fertilization 30 kg ha^{-1} of nitrogen and 20 kg ha^{-1} of phosphorus. Doses of nitrogen ranged from 0 to 60 kg, phosphorus – from 0 up to 50 kg. Potassium was not added, it is already in excess. An electronic operational map of fertilization (they were not evenly applied across the field) was in the memory of the on-board computer, which regulated the fertilization. Both complexes were equipped with on-board electronics and GPS receivers. Earth remote sensing (ERS) data were used in the assessment of orthophoto maps and the formation of a relief model, which was carried out using unmanned aerial vehicles (UAVs). So, field research, carried out using ground-based research and remote sensing, made it possible to develop a digital elevation model (DEM). It was a mathematical description of the earth's surface using a set of points located on it, connections between them, as well as a method for determining the heights of arbitrary points belonging to the modelling area by their plane coordinates. Complex display of ortho-mosaics shown in Fig. 1.

To assess the state of plants during the period of their growth and development, we used space images from satellites of the Sentinel 2 group. Using these images, it was possible to assess the change in the characteristics of large field objects (100 ha and more). The images were acquired in real-time using the Land Viewer service. It is generally known that Land Viewer provides free global satellite images and high resolutions satellite images. In our case, we used the vegetation indices NDVI – Normalized Difference Vegetation Index. This index described first time by B.J. Rose (1973) which as a simple indicator of the amount of photosynthetically active biomass (Sawyer, 1994). This is one of the most common and used indices for solving problems using quantitative estimates of vegetation cover. NDVI most correctly differentiates different types of vegetation according to optical characteristics (NASA, 2000). It is common knowledge that moderate values represent shrub and grassland (0.2–0.3), while high values are for tropical rainforests (0.6–0.8). The values of the index are also influenced by the species composition of vegetation, its closeness, condition, exposure and angle of inclination of the surface, and the colour of the soil under sparse vegetation. The index is moderately sensitive to changes in the soil background, except for cases when the vegetation density is below 30%. Based on a detailed assessment of various vegetation indices, the most informative indicators with a spatial resolution of 30 m were previously identified which were used in further studies (Komarov *et al.,* 2018). The need to analyze a digital elevation model for agricultural monitoring is associated with the possibility of taking into account the features of the relief, namely, taking into account slopes of different steepness (length, shape, exposure, and soil cover structure), height difference and detection of ravines, logs, watersheds (Fig. 1).

The obtained indicators were used in the implementation of a precision farming system at the landfill since the differentiated application of chemicalization agents should be based not only on the data of a detailed agrochemical survey with the preparation of maps of the agrochemical heterogeneity of the field but also take into account the relief features, characteristics of the agricultural landscape and the activity of watercourses, as well as the peculiarities of soils and ways of their transformation. This was the first time it was implemented in experimental fields.

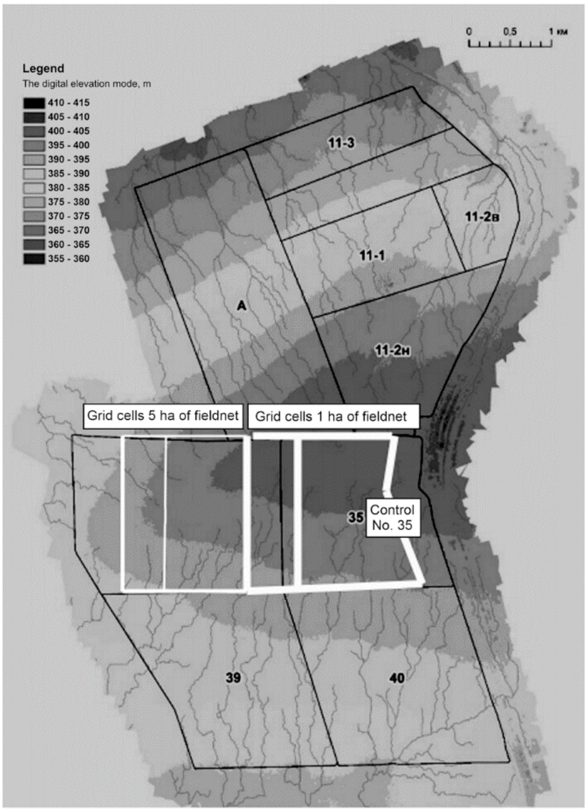

Figure 1. Value in numerals model of relief with streams and with corresponding highlighted fields, where field No. 35 is a control which represents as a control case with old extensive technology. Others numbers of the field are also represented as auxiliary experimental fields which are do not meet the objectives of this study

Statistical analysis was performed using the Stat and Microsoft Excel 2010 standard software packages. The reliability of the results of field experiments was assessed by the t-test.

Results

The results of the agrochemical characteristics of the precision farming landfill are shown in Table 1. It is noted that according to the sampling grid cells 5 ha of fieldnet, the reaction of the soil environment is moderately alkaline and the content of mobile potassium is high. The variation is also high, mostly for treatment grid cells 5 ha of fieldnet. The content of available phosphorus ranges from low to medium levels with an average of 28.6 mg kg^{-1} (LSD$_{05}$ = 4.5 mg kg^{-1}) which is substantially higher compared with treatment grid cells 1 ha of fieldnet.

Table 1. Results of agrochemical characteristics of the soils in the arable horizon of the southern carbonate chernozem at a precision farming landfill

Treatments, *i.e.* grid cells of fieldnet, ha	Indices	Number of samples, n	Mean value of indices, mg kg^{-1}	LSD$_{05,}$ mg kg^{-1}
1	N-NO$_3$	318	15.2	1.1
1	P$_2$O$_5$	159	27.2	1.1
1	K$_2$O	159	733	23.9
1	pH	159	8.56	0.01
5	N-NO$_3$	122	13.1	1.9
5	P$_2$O$_5$	61	28.6	4.5
5	K$_2$O	61	793	38.4
5	pH	61	8.55	0.02

The results of the vegetation index (NDVI) for a precision farming landfill in comparison with control is shown (Fig. 2). At the same time, to assess the in the homogeneity of the state of the fields by the vegetation index, the method of dividing the fields by contrast zones into sectors was applied.

Vegetation indices for fields with different cell sizes show that the smaller the cell size, the more accurately the data is displayed. So, in a field with a cell size of 1 ha of fieldnet, the difference in the distribution of the vegetation index over the field is visible. The image with fieldnet a grid cells size of 5 ha of fieldnet shows a less contrasting distribution of the vegetation index. On the control field No. 35 indicators of the vegetation index are even more even and contrasting spots of heterogeneity are smoothed out.

Vegetation indices for fields with different grid cells sizes of fieldnet show that the smaller the grid cells size, the more accurately the data is displayed. So, in a field with a grid cells size 1 ha of fieldnet, the difference in the distribution of the vegetation index over the field is visible. The image with grid cell 5 ha of fieldnet size shows a less contrasting distribution of the vegetation index. On the control, field No. 35 indicators of the vegetation index are even more even and contrasting spots of heterogeneity are smoothed out.

Assessment of the state of the vegetation cover for each sector allows using cluster analysis to identify in more detail the zones of heterogeneity by the vegetation index. This, in turn, makes it possible to identify not only zones of heterogeneity, but also to determine the share (distribution) of the predicted yield in different parts of the field. As seen in Fig. 2 in the first sector, the predominant level of NDVI 0.5–0.6 occupies 46.00% of the sector's territory. The higher level of NDVI 0.6–0.7 is only 13.55%, while NDVI 0.7–0.8 accounts for only 0.56%. In sector 2, NDVI 0.5–0.6 covers 43.75 %. And a higher NDVI level of 0.6–0.7 covers a more significant area – 21.12%. There is an increase in the vegetation index and a higher significance. Thus, according to the NDVI indicator, it is seen that sector 1 has significantly lower indicators than sector 2. Even more significant differences in the vegetation index are recorded for sectors No. 3 and 4. However, evaluating the relationship between the distribution of vegetation index and yield the NDVI has changed relatively synchronously with the results of the yield of the spring wheat.

Concerning evaluating the yield data obtained using an electronic map (Fig. 3) it can be seen that there are zones in the field with both low and higher yield and this heterogeneity in yield practically coincides with the previously obtained data (Abdulaev *et al.*, 2019; Irmulatov *et al.*, 2019).

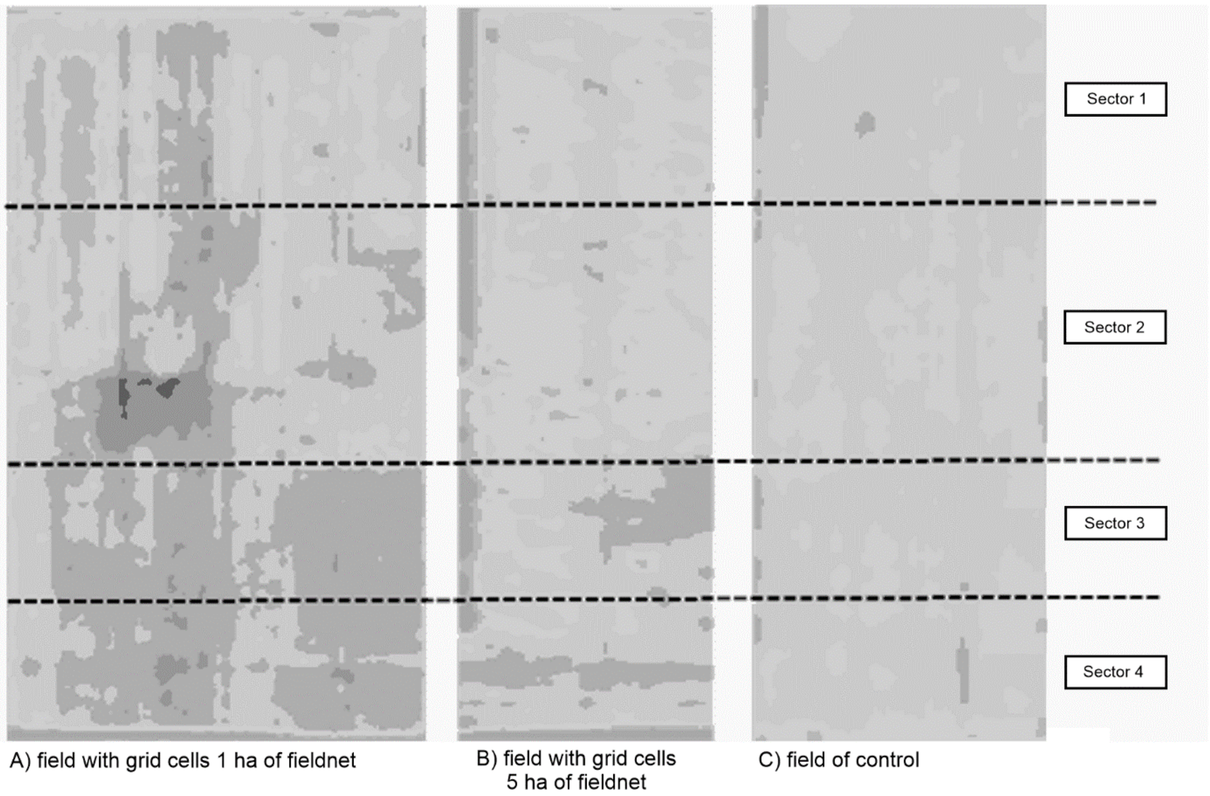

Figure 2. Distribution of the vegetation index (NDVI) over the territory of fields with different grid cells of fieldnet sizes and selected sectors of heterogeneity in the distribution of NDVI (comment: the order of the treatments is different compared to the order in Fig. 1 since this order of treatments was established depending on the intensity of changes of the NDVI. Moreover, the control is at number 35 of treatment).

The yield map data show (Fig. 3) that the applied elements of precision farming (differential fertilization) did not work to their full extent. According to the sampling grid cells 5 ha of fieldnet, the variation in yield indicators was in the range of 1000–2000 kg ha^{-1}, and according to the sampling grid cells1 ha of fieldnet, from 1000 kg ha^{-1} to 2500 kg ha^{-1} (Table 2). At the same time, the share participation of the minimum yield was significant both for the selection grid cells 1 ha of fieldnet (amounting to 30–37%), and with grid cells 5 ha of fieldnet – almost twice as much (70–75%). The share contribution with a high yield of 2000 kg ha^{-1} was significant for a sampling grid cells 1 ha of fieldnet (40–47%) and less significant for a sampling grid cells 5 ha of fieldnet (15–20%). Thus, an element of precision farming technology – differentiated fertilization – in the first year of the experiment provided an increase in yields not as much as expected. On the sampling grid cells 5 ha of fieldnet, the increase was 140 kg ha^{-1} or 9.6%, and on the sampling grid cells 1 ha of fieldnet, 280 kg ha^{-1} or 19.2%.

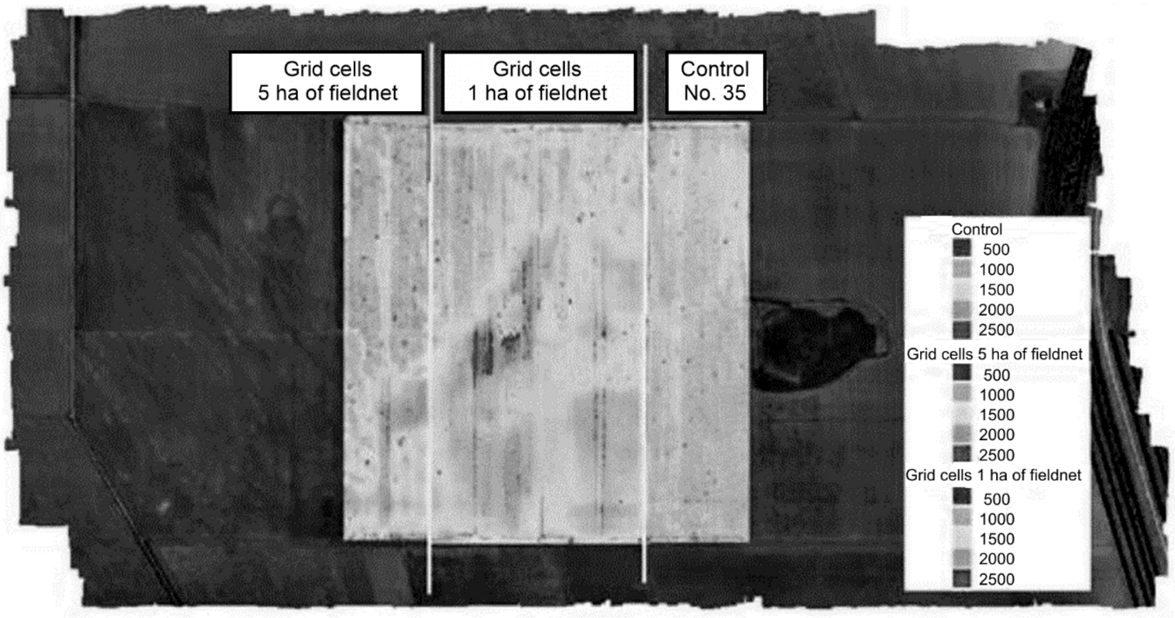

Figure 3. Yield map for the treatments under consideration

Table 2. The yield of spring wheat 'Astana' on the landfill of precision farming

Treatments, *i.e.* also elementary area of grid cells of fieldnet, ha	Sown area, ha	Yield, kg ha^{-1}	LSD$_{05}$ kg ha^{-1}
1	174.4	1742	295
5	68.3	1596	254
Control	82.9	1463	349

Discussion

When comparing with grid cells 1 and 5 ha of fieldnet, there is low variability in pH and potassium (Table 1). The coefficients of variation for these parameters (pH and K_2O) between the elementary areas are comparable this was observed on a 5 ha with grid cells of fieldnet that with it, although according to some parameters the content of nutrients in the soil (P_2O_5 and K_2O) was higher, this difference was not statistically significant. In this case, one should take into account the fact that the coefficient of use of mineral fertilizers is important. This indicator (Smirnov *et al.*, 2014) depending on the type of fertilizer, has values for Northern Kazakhstan at N (0.55), at P_2O_5 (0.10) and K_2O (0.40). But yet indeed, it seems to us that such a potassium content is K_2O = 733–793 mg kg^{-1} in the soil not incorrect. There is no error regarding the potassium content in the soil because this content is typical in carbonate chernozems. There is an effusion regime (moisture evaporates and pulls salt through the pores), and not a flushing one, as we usually do (Haliniarz *et al.*, 2018). Therefore, salts in the conditions of Northern Kazakhstan do not go down the profile like we do, but accumulate at the top. Hence the high content of potassium, magnesium, calcium, and other alkaline elements in soils. Therefore, the pH in the soil is alkaline, more than 8.0 (Table 1). In general, taking into account the sufficient supply of nutrients in soils and their insignificant variability in the field, it was problematic to expect high efficiency from the introduction of the differentiated application of mineral fertilizers in precision farming technology.

Based on the analysis of the results of the experiment on the introduction of individual elements of precision farming in the conditions of Northern Kazakhstan, a positive effect from the introduction of technologies is noted (Table 2). Taking into account the possibility of further growth in yields from the differentiation of fertilization, as well as the use of other elements of precision farming, the introduction of a farming system in Kazakhstan is very promising.

It should also be especially emphasized that the prospects for wheat production in Kazakhstan are due to favourable natural and climatic conditions for the cultivation of cereals and leguminous crops and, first of all, food wheat with a high gluten content (Lu, 2017), which is in high demand in world markets (Bora *et al.*, 2014). In this regard, grain production is one of the strategic sectors of the republic, from the state of which food security of the country, income and employment of the population, development-related industries (livestock, poultry, food and processing industry).

Typical technologies for the cultivation of spring wheat using extensive technologies on southern carbonate chernozems showed a low (1460–1700 kg ha^{-1}) yield in the context of the variety 'Astana' (Table 2). At the same time, the variation in yield depended on the prevailing weather and climatic conditions and some other indicators (Meng *et al.*, 2017). At the same time, it is generally known that the Northern Kazakhstan stand is located in an arid climate zone were 220–350 mm of rainfall per year. There were 17 (42%) medium dry years, and only 12 years (30%) were there favorable conditions for grain production (Satybaldin, 1997).

In any case, extensive technology limited the growth of wheat productivity. To obtain high and sustainable yields required a transition from extensive to new technologies capable of increasing yields. These could be the precision technologies of precision farming, which have proven themselves all over the world.

The transition from extensive technologies to precision farming technology ensured a significant increase in productivity while reducing (due to differentiated rational use) doses of fertilizers applied by 10–30%.

We completely agree that the economic importance of cereals including spring wheat particularly arises from their role in the food industry and thus in ensuring national food security (Haliniarz *et al.*, 2018). At the same time, it is important to introduce new methods of a highly intelligent farming system and elements of farming systems used in agricultural practice (Anselin *et al.*, 2004).

As shown in the conditions of the Leningrad region of the Russian Federation (Matvejenko *et al.*, 2020), this task is quite feasible. It is also shown that by introducing new elements of precision farming, the yield of spring wheat can increase from 2500 up to 4000–4500 kg ha^{-1} and more. At the same time, due to the introduction of elements of precision farming, the grain of 2–3 classes was obtained for the first time in the North-West region of the Russian Federation. So, the main limiting factor in crop production in an arid climate (for example, for Kazakhstan) is lack of moisture (less than 300 mm per season), with an excess of solar radiation and high temperatures leading to drought.

With the achievement of cost savings per 1 standard relay of 69.26 EUR from the introduction of the system of differentiated fertilization, the return on investment of 2553.63 EUR is achieved with the production of about 36 standard relays.

In the structure of costs for the implementation of technological operations of sowing, the cost of a machine operator's work is about 24 EUR per standard relay. For a standard relay, fuel consumption is about 127.7 EUR. This imbalance creates conditions for excessive consumption of fuel and lubricants. The introduction of a control system for fuels and lubricants can provide savings of up to 30% of the specified cost item, which makes it possible to recoup the costs of using sensors in the first season of their use. In the structure of costs for growing wheat seeds, the share of fuels and lubricants can leave up to 14% of all direct production costs.

Saving 30% of fuel and lubricants due to the introduction of a precision farming system can be 8.42 EUR ha^{-1} or 4.0% of all production costs. In terms of a ton of products, this is 9.8% of all costs. Thus, the implementation of this system of precision farming in conditions of all Kazakhstan is very promising. Economic efficiency calculations showed that in the precision farming system, the total savings from the introduction of the automatic driving system on the Buhler Versatile 485 tractor for 1 standard relay amounted to 72.89 EUR.

Conclusions

The introduction of innovative farming systems, including precision farming technology, is very promising for the conditions of Kazakhstan. It is shown at a specialized precision farming landfill formed in North of Kazakhstan that the involvement of innovative technologies, new technology in the first year of implementation ensured the highest yield. Equipping the test site with the necessary instruments, agricultural machinery and equipment made it possible to deploy precision research at the test site using both ground-based survey and Earth remote sensing (ERS) data. We have used the vegetation indices NDVI – Normalized Difference Vegetation Index which has changed relatively synchronously with the results of the yield of the spring wheat 'Astana'. Also important is the fact that the share contribution with a high yield of 2000 kg ha^{-1} was significant for a sampling grid cells 1 ha of fieldnet within 40–47% and less significant for a sampling grid cells 5 ha of fieldnet within 15–20%. Hence the conclusion suggests itself that the choice of a field grid with cell sizes of 1 ha is more preferable Calculations of the economic efficiency of the introduction of elements of precision farming in Kazakhstan have shown their high efficiency and prospects for further developments.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publications of this paper.

Author contributions

KA – 30%, BI – 30%, AK – 30%, EN – 10% – study of the concept and design;
KA – 30%, BI – 30%, AK – 30%, EN – 10% – data collection;
KA – 15%, BI – 25%, AK – 50%, EN – 10% – analysis and interpretation of data;
KA – 15%, BI – 15%, AK – 50%, EN – 20% – writing a manuscript;
KA – 10%, BI – 10%, AK – 50%, EN – 30% – critical revision and approval of the final manuscript.

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