Digital precision farming technologies

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Abstract. A systematic approach to the use of digital technologies in precision farming is proposed. The scientifically grounded transition to digitalization of production processes in crop production includes two stages. The first is the formation of comprehensive data on terrestrial and space factors in the production of agroecosystems. The natural potential of the Northern Trans-Urals (1.6 - 2.2) has been established, which indicates satisfactory soil and climatic conditions for growing crops. The biopotential of agrocenoses was calculated for photosynthetic active radiation (PAR). The potential yield of spring wheat is 13.75 t / ha. In long-term experiments (1977-2020), the really possible crop yield was determined. The mathematical model of the formation of soil fertility parameters shows the intensity of growth or decline in the productivity of agroecosystems. At the second stage, in order to optimize life-supporting factors, innovative technologies for growing crops using space systems are being developed. The practical implementation of digital technologies begins with the digitization of fields, monitoring of soil fertility in elementary areas with reference to geographic coordinates. The use of precise technologies for sowing, differentiated application of fertilizers, pesticides, and yield mapping made it possible to reduce the cost of grain by 140 rubles / c and increase the profitability of its production by 24%.

1. Introduction

Digital technologies ensure the automation of production processes in the cultivation of crops. The direction is new in the agricultural sector and is gaining momentum. Digital Farming uses all available information on the state of agroecosystems, technical parameters of mechanisms for the development of innovative technologies for growing crops using satellite navigation systems [1 - 4]. In combination with the subject matter and data management of the bank, precision farming increases the accuracy of operations and makes it possible to control the variability of fertility parameters within the field [5 - 8]. As a result, optimal production conditions are formed for agroecosystems.

High intelligence technologies are based on the use of "smart" machines, which are able to receive, generate and export data with the operational setting of the operating mode of agricultural units. The data of the factors of growth and development of crops, their processing with the help of a software product of electronic carriers, allow us to develop algorithms for solutions for the entire production chain of innovative technologies for growing crops.

Digitalization is a new vector of development of the agro-industrial complex and requires specialists of the appropriate level, their understanding of the information and analytical system, its purpose in the system of precision farming. The formulation of digital technologies is often interpreted narrowly, displaying only the representation of signals in discrete analog level strips, and not in the form of a continuous sector. We propose a systematic approach to digital crop cultivation solutions that have two important stages. The first is the formation of comprehensive information about objects.
and items involved in production processes (creation of a data bank). The second is the transition to innovative technologies for growing crops using space systems. This system of digital technologies for the cultivation of agricultural crops is implemented in precision farming. According to our formulation, precision farming is a system for optimizing the links of farming and the resource base, based on GIS technologies [9].

Purpose of research: development of a digital technology system for precision farming in the northern Trans-Urals of the Ural Federal District.

2. Conditions and methods of research

The formation of a databank of space and terrestrial factors of the production of agrocenoses was carried out on the basis of the results of long-term experiments that have been carried out since 1977. Research was carried out in the subtaiga zone, northern and southern forest-steppe on chernozems, dark gray and gray forest soils of the Tyumen region. The calculation of the bioclimatic potential is carried out on the basis of the methodological approach of S.A. Sapozhnikova (1963), A.V. Gordeev et al. (2006). Monitoring of agrophysical, agrochemical and biological indicators of soil fertility was carried out according to generally accepted methods.

The development of a mathematical model for the formation of the productivity of agrocenoses, depending on the state of the parameters of soil fertility, was carried out using the mathematical apparatus proposed by A.M. Ryabchikov (1968), M.K. Kayumov (1977), T.I. Safronova, V.I. Stepanov (2012) and etc.

At the stage of digitalization of production processes, the location of agricultural land was established with a geographic reference to coordinates in the program "Google Earth" Planet Earth. To create electronic maps of fields, an onboard navigation computer (BNC), a vehicle, a personal computer (laptop), tools GIS software package MapInfo, Excel spreadsheets, a graphic editor Adobe Photoshop, and raster photography were used [15]. Precision farming technologies were carried out in accordance with the scientific and methodological base developed by us by order of the Ministry of Agriculture of the Russian Federation in conjunction with LLC "Flight Technical Center Aerosoyuz", Novosibirsk.

3. Research results and discussion

Digitalization of production processes is based on the information platform of the habitat of cultivated plants. The most important moment of the first stage of the transition to digital technologies is the determination of the bioclimatic potential (BCP), the calculation of which makes it possible to create a scientifically grounded system of precision farming. An integral quantitative and qualitative assessment of the climate, soil conditions, and the growth rate of the productivity of agrocenoses indicates satisfactory conditions for growing agricultural crops in the Northern Trans-Urals. The relative value of the bioclimatic potential in the zones of the Tyumen region is in the range of 1.6 - 2.2, which also indicates the most favorable natural conditions for animal husbandry.

The next step in the formation of the databank of the production of agroecosystems was to establish the potential crop yield. The calculation of the maximum possible productivity of agricultural plants was based on photosynthetic active radiation (PAR) - a part of solar radiation with a wavelength of 380-710 nm, within which photosynthesis is carried out. Within the northern forest-steppe of the Tyumen region, with an increase in the PAR coefficient up to 3% due to innovative technologies of crop cultivation, optimal environmental conditions, the potential yield of spring wheat is 13.75 t / ha. At the same time, the total radiation for the growing season was estimated at 20766 gJ / ha, of which the photosynthetic active radiation was 8610 gJ / ha. The planned average grain yield by the agrarians of the Tyumen region of 2.5 t / ha is only 18.2% of the potential productivity of agrocenoses [16].

The actual possible yield (TLV) of crops was determined close to the real conditions for the production of agroecosystems. For the northern forest-steppe, one of the main factors limiting the growth of crop productivity is moisture availability. Evenly falling precipitation during the growing season, satisfactory heat supply can ensure the receipt of the TLD of spring wheat 8.2 t / ha.
The temperature regime of the growing season is also limiting for obtaining good crop yields. Indeed, the possible yield of spring wheat under favorable biohydrothermal conditions in the Northern Trans-Urals reaches 8.38 t/ha.

We have formed a model of soil fertility for the growth and development of crops. For example, the maximum productivity of spring wheat (100% purity and 14% grain moisture) - 5.96 t/ha was obtained with a bulk density of leached chernozem 1.18-1.22 g/cm³ in a layer of 0-30 cm, the content of agronomically valuable aggregates 65-71%, their water resistance 60-65%, the content of N-NO₃ 15-20 mg/kg, humus 8-10%, with a productive moisture content during the growing season in a meter layer of 120-150 mm, at a pH of arable layer 6.2-6.8.

Using the mathematical apparatus, a model of the soil-forming process has been developed. It shows the relationship between the factors of soil fertility and the yield of spring wheat, which is expressed mathematically:

\[
y = -2.59 + 0.47x_1 + 0.74 \times \exp(-3.2x_1) + 1.27 \times \exp(-0.005x_2) = \\
\times x_{30.16} \times x_{40.07} \times x_{50.05} \times x_{60.06} \times x_{60.16} + 1.48 \times \exp(-0.03x_7) + 0.82 \times \exp(-0.018) \tag{1}
\]

where \( y \) – is the yield of spring wheat, t/ha;
\( x_1 \) – soil density, g/cm³;
\( x_2 \) – reserves of productive moisture in the meter layer, mm;
\( x_3 \) – water resistant structure, %;
\( x_4 \) – nitrate nitrogen, mg/kg soil;
\( x_5 \) – mobile phosphorus, mg/kg;
\( x_6 \) – exchangeable potassium, mg/kg;
\( x_7 \) – air-dry weight of weeds, g/m²;
\( x_8 \) – root rot, %;
\( R \) – the coefficient of determination;
\( S \) – the standard deviation of the model.

Having formed a databank of the optimal parameters of the external environment for the production of agroecosystems, we proceed to the second stage - the development of precision farming technologies as a mechanism for achieving the maximum possible, economically and environmentally viable crop yield. This stage also has a certain sequence of operations based on GIS technologies.

First, it is necessary to digitize agricultural land and adjust the crop rotation schemes. Monitoring the state of soil fertility with a breakdown into elementary plots makes it possible to reveal the spatial variability of soil fertility in terms of the content of N, P, K, pH, humus, etc. Detailed agrochemical cartograms are the basis for differentiated fertilization using satellite navigation systems. Research and production experiments have shown that the operation of units with an on-board navigation computer reduces the overexpenditure of seeds of grain and mineral fertilizers on an area of 551.1 m²/ha. Savings of spring wheat seeds amounted to 13 kg/ha, ammonium nitrate - 6 kg/ha, diesel fuel 0.39 l/ha. In 2020 prices, the cost of growing cereals decreased by 161.1 rubles/ha.

The automatic control mode of the herbicide working fluid supply eliminated the burn of cultivated plants by 9-12%, reduced the consumption of pesticides by 24%, ensured the possibility of working at night and increased the productivity of the unit up to 27%.

The use of a full cycle of digital technologies in plant growing of the Kalininsky agricultural enterprise in the Sverdlovsk region on an area of 7.7 thousand hectares contributed to an increase in the yield of spring wheat in 2017-2019. compared with previous 2013-2016. by 1.63 t/ha, barley - by 1.19 t/ha, oats - by 1.50 t/ha. The profitability of grain production is still low - 8.3-13.5%, which is due to large investments in the formation of the material and technical base of the economy.

4. Conclusion
A system of digital technologies in crop production in the Ural Federal District has been developed, which includes two stages. The first is the formation of a databank on terrestrial and space factors in the production of agroecosystems. The second is the transition to innovative technologies for the
cultivation of agricultural crops using satellite navigation systems to optimize the life-supporting properties of the environment.

Calculated bioclimatic potential for agroclimatic zones of the Northern Trans-Urals - 1.6-2.2. The level of potential yield of agricultural crops was determined (for spring wheat, 13.75 t / ha). Really possible yield in terms of moisture supply is 8.20 t / ha, in terms of thermal resources - 8.38 t / ha. A mathematical model of the dependence of the productivity of agroecoses on the state of environmental parameters is proposed. The digitalization of crop cultivation technologies using space systems reduces the overconsumption of seeds and fertilizers on an area of 551.1 m2 / ha, saving them 13 kg / ha and 6 kg / ha, respectively, diesel fuel - 0.39 l / ha, reducing the cost of grain by 140 rub / c and increase the profitability of its production by 24%.

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