THE NEED TO DEVELOP PRECISION AGRICULTURE IN THE CONTEXT OF CLIMATE CHANGE

Vasile BOTNARI[1]

Abstract. *Analysis of agricultural practices applied at different stages of development shows numerous examples when, under conditions of concentration and intensification of agricultural production, deviations of technological parameters from optimal values lead either to a sharp decrease in yield, or to a decrease in the quality of production, environmental pollution with chemical compounds associated with a decrease in soil fertility and labor productivity. In the context of climate change, the development of precision agriculture has gained wider distribution due to the performance of information technologies, high-speed Internet and the possibility of obtaining information in digital format about the condition of agricultural land and crops from a distance. Thus, precision agriculture presents a comprehensive system of high-performance agricultural management, which includes methods of rotation and positioning of agricultural crops, complete information matrices, information evaluation systems and development of technological decisions*

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1. Introduction

Vulnerability of agriculture to climate change

Despite the progress made in improving productivity and plant resistance to biotic and abiotic factors, the implementation of new varieties, efficient agricultural techniques and the improvement of plant protection systems, the level of harvests remains relatively low, with large fluctuations both at the producer (farmer) and at the branch level. This phenomenon has become particularly pronounced in the last two decades, which indicates the presence of climate change and the significant importance of climate factors in the formation of harvests.

It is known that one of the factors of these changes is caused by the progressive warming of the global climate.

[1] Dr. Hab. Eng., Principal Scientific Investigator: Resistance Genetics Laboratory Plants within Institute of Genetics, Physiology and Plant Protection of the State University of Moldova, Chisinau. Republic of Moldova. Honorary Member of the Academy of Romanian Scientists, Bucharest, Romania. E-mail: vasilebotnari52@gmail.com, vasilebotnari@yahoo.com

Currently, several forecasts are being developed based on simulation models that anticipate that with the increase in the average annual temperature in Europe, in the number of hot days [9], the intensity and duration of drought is also forecast, which may lead in the future to a worsening of the soil moisture regime and an increase in the frequency of droughts throughout the Republic of Moldova.

Due to its geographical location, the territory of the Republic of Moldova is included in the region with an insufficient humidity. The predominance of the agricultural involves the dependence of the national economy on climatic conditions. According to the international classification of arid territories, the Republic of Moldova is characterized as a subhumid - dry geographical area, with a hydrothermal coefficient of 0.50 - 0.65. [7, 8]. Insufficient or lack of long-term precipitation against the background of high temperatures leads to the intensification of the drought phenomenon, with frequent manifestations in the central and southern areas. In the North of the country, a severe drought is recorded 1-2 times in 10 years, in the Center 2-3 times, and in the South 3-4 times. Out of the last 20 years, 11 have been dried and with droughts. In the southeastern part of the country, lands with semi-arid characteristics are increasingly obviously [2].

Precipitation during the vegetation period of plants, sometimes in the form of torrential rains accompanied by hail, does not directly contribute to the accumulation of moisture reserves in the soil, and in some cases worsens the situation even more, causing floods, erosion and partial or total destruction of agricultural crops [8]. In the absence of precipitation, the harvest of cereal and rapeseed crops can be compromised on a large part of the territory of the country, which oblige some farmers to re-cultivate part of the autumn sowings and sow them with crops from the second group, corn or sunflower. Due to the poor growth and development of plants, low yields, in most cases, do not cover the costs of harvesting, in the central and southern areas, part of the areas of these crops in some years remaining unharvested.

Expectations of covering the losses caused by drought in cereal crops, even partially, with the harvest of crops from the second group, corn, sunflower, soybeans, sugar beets, are not coming true.

a. Corn **b.** Sugar beet

Fig. 1. Crops compromised by drought

On the contrary, against the backdrop of supraoptim temperatures, in the absence of humidity, these crops suffer even more, so that agricultural crops from the second group are more seriously compromised, including in the Central and Northern areas (Fig. 1). Such situations are becoming more typical year by year.

Climate change may lead to a decrease in the productivity potential of many agricultural crops, requiring at the same time some changes in the principle of homologation of varieties by geographical areas, a review of crop rotation with the determination of risk areas, a review of the spectrum of diseases and pests with the continuous updating of plant protection systems. In this context, studies on the individual role of each factor (extreme temperatures, atmospheric, pedological or hydrological drought, heat, hail, frosts during the crop growing season, etc.) are of a particular importance, as well as the analysis of different scenarios of their impact on the level of harvests and the competitiveness of the production obtained [3, 10].

The phenomenon of global warming reported in the last two centuries, especially in the last decades, represents a continuous increase in average atmospheric temperatures in the immediate vicinity of the ground, as well as of the surface of the waters. In the last century, the average air temperature near the Earth's surface has increased by 0.74 ± 0.18°C, reaching values of approximately 15°C [1].

A study of the evolution of the average temperature at a global level reconstructed and recognized by climatologists, shows that the last decade of the 20th century and the first two of the 21st century constitute the warmest period in the last 2000 years. The current era is warmer by a few tenths of a degree compared to the medieval maximum. The evolution of temperatures will continue to increase. According to the European Union Space Program Copernicus [6] July 2023 was the warmest month on record, and August was estimated to be the second warmest. In the first nine months of the year, the global average temperature was by 0.01°C lower than in 2016, the warmest year on record.

With global warming, summers are becoming increasingly hot, leading to prolonged drought. Although agriculture, especially in the South, has always been exposed to chronic water and soil moisture shortages, climate change has further amplified these problems [8, 10]. Dry soils and the lack of water resources available for irrigation, in many cases seriously affect agricultural businesses, reducing productivity potential and production quality. In addition to the afore mentioned, high temperatures can favor the emergence of new pests characteristic of other geographical areas, the much more intense spread of pests and diseases, directly affecting plant health.

Analysis of climate scenarios indicates a real probability that the following years will be just as warm, and their influence on the global average temperature may be even greater [17]. Drawing a similarity with the geographical area of Moldova, we will mention that the air temperature in the summer months in 2022-2024 recorded values of 21.3-23.9 ºC, being by 2.1-2.7 ºC higher than the multiannual average.

Possible climate scenarios for Moldova were developed using a set of General Circulation Models (GCM), applied as a research tool for studying and simulating climate [13, 16]. The results of experiments conducted using GCM and based on different greenhouse gas emission scenarios, marked A2 and B2 in the Special Report on Greenhouse Gas Emission Scenarios [14, 16] for three time periods (2010-2039; 2040-2069; 2070-2099) serve as a benchmark for extrapolation. According to both emission scenarios, average annual temperatures across the entire territory of the Republic of Moldova will increase. By the end of the century, temperature increases could average 4.1-5.4 °C. Depending on the GCM experiment, these values range from 1°C to 6°C.

With increasing temperatures, annual precipitation is also projected to decrease, especially under the A2 emissions scenario, which projects significant warming for the Republic of Moldova in winter and between seasons. By the 2080s, negative temperatures (reference -21°C) could decrease by 2 - 5.7°C, and average spring and autumn temperatures could be higher by about 4 - 5°C. Over the course of the current century, relatively more moderate warming is assumed to occur in the summer months, by 1 - 3°C. Some increase in precipitation is also projected in winter and spring, but the trends for summer and autumn are predominantly negative, decreasing by about 20-30% by the 2080s. Overall, we can expect warmer and wetter winters in the future, but warmer and drier conditions in summer and autumn. By analogy, in Moldova we could have winters like in France, Great Britain and summers like in Greece and Spain.

Climate change in the Republic of Moldova shows that all years from 2015 to 2024 were among the warmest recorded since the beginning of instrumental observations (1871), with annual average values of over 12.0°C, which is by 2°C higher than the multiannual average and which reveals a more pronounced acceleration compared to other geographical areas [5]. Greater amplitudes of this warming are observed in the southern districts of the country. In the northern part, the increasing trend includes values in the range of 1.5-1.6°C, in the southern area temperatures increase more rapidly, reaching the value of 2.3°C. The increasing trend in temperature intensifies the phenomenon of heat, the latter being more pronounced in summer (June-August).

Meteorological observations show that in recent decades, in the center and north of the country, the phenomenon of "dryness and heat" has been manifested with a duration of 3 - 7 days. Under such conditions, agricultural crops are less affected by thermal stress generated by temperatures above 25 °C and relative air humidity below 30%. In some places, in the southern districts, the phenomenon of "heat" has a greater intensity, with a duration of over 10 days [10] .

As a result of higher temperatures, evaporation will increase by 15-20% in the coming periods and approximately twice by the end of this century. More pronounced signals of climate change are expressed in the case of the A2 emissions scenario. The aridity index also denotes that the climate in the Republic of Moldova tends towards a drier one, from a state with insufficient moisture with subhumid areas, towards dry and semi-arid areas [9, 10].

Climate change is expected to make droughts considerably longer and more intense in the future. Extreme weather events are likely to become more frequent in the future [17]. Forecasts predict that temperatures of 34–35 °C, previously considered rare, could soon become the norm in summer [7].

From the point of view of aridity and dryness, the number of days with reference to the active vegetation period determines the months of May-August as a critical period for plant growth and development of the main agricultural crops. Dry days are considered those days that maintain a high thermal background (>25 °C) and a low relative air humidity (<30%), conditions with a major negative impact on plant growth and development. The maintenance of long intervals with dry days demonstrates that they have doubled in recent years compared to the first decades, which underlines the accelerated pace of climate change at the regional level.

In the context of climate change, which represents a risk for agriculture, it is necessary to review some habits rooted in agricultural practice, simultaneously with the adaptation of plant cultivation technologies capable of ensuring the maintenance, and in some cases an increase of productivity in agricultural crops. Regardless of the extent to which the effects of climate change will be felt, thanks to the genetic reserves accumulated during evolution with the contribution of plant breeding research, varieties with increased capacity to adapt to new environmental conditions have been created.

In context, thsi paper emphasize the role of precision agriculture as an important factor for increasing crop production.

2.Materials and methods

The research focused on assessing the level of scientific assistance in agriculture in the Republic of Moldova, mainly related to plant cultivation, multilateral analysis of the research methodology, technological recommendations developed for the main agricultural crops and the results of their implementation in the context of the variability of climatic factors, data from the National Bureau of Statistics on the average harvest per unit area and the level of global production, regulatory acts developed by the Ministry of Agriculture and Food Industry, as well as state policies for adapting agriculture and the environment to climate change with the implementation of organizational and technological measures to mitigate their impact on the agricultural sector.

In order to analyze the problems related to the instability of agricultural crop productivity and the processes of desertification and long-term soil degradation, to which some territories of the Republic of Moldova are prone, based on statistics and newsletters of the State Hydrometeorological Service [15] were reassessed, the climatic resources were reassessed with reference to the agroclimatic zones of the South, Center and North of the Republic of Moldova, from the perspective of sustainable development and competitiveness of agriculture.

To determine the impact of climate variability on crop productivity, the study took into account operational information and that accumulated in the databases of the automated system for monitoring climatic and agrophysical parameters within the Institute of Genetics, Physiology and Plant Protection.

Meteorological data and soil moisture reserves throughout the year (at an interval of 15 minutes) have been maintained in the database since 2016, from where they can be accessed at any time. To assess the influence of climatic factors on plant productivity, large data sets are used regarding climatic parameters with values (maximum, minimum and average of: air temperature °C, relative air humidity %, wind direction gr, wind speed in m/sec and km/h, solar and active radiation in W/m² and Mj/m², precipitation in mm), soil moisture on profiles 0-10; 20-30; 30-40; 40-60; 60-100 cm, temperature and electrolyte concentration in the superficial soil layers (0-5; 5-15 and 15-30 cm).

Physiological parameters: photosynthesis intensity, diurnal and nocturnal transpiration, microclimatic parameters, as well as the reaction of genotypes to extreme climatic conditions (superoptimal temperatures, atmospheric and pedological drought) are determined at different stages of plant development, using the RTM-48A phytomonitor [11]. The monitoring process allows for automatic measurements at certain time intervals, with the production of phytodiagrams in the form of a film, over a period of 24-72 hours.

For a thorough argumentation of the need for the development and implementation of precision agriculture, the investigations were carried out following an extensive analysis of the literature on the given topic and the approaches formulated in the consensus of the international scientific community on the current state and future scenarios of climate change, taking into account the fact that the Republic of Moldova has adhered to the most important global and European agreements to combat their possible negative effects.

3.Results and discussions

3.1.Precision agriculture – an important factor in increasing plant productivity

The concept of precision agriculture itself appeared in the 1980 s, with the appearance of the first maps for the differentiated application of fertilizers, based on the analysis of soil samples included in the cartogram of agricultural lands. However, the idea of precision agriculture has gained wider distribution in recent years, due to the development of information technologies, high-speed Internet and the possibility of obtaining information in digital format about the condition of agricultural lands and crops from a distance. In general, precision agriculture is a comprehensive system of high-performance agricultural management, which includes methods of rotation and positioning of agricultural crops, complete information matrices, systems for assessing yield and technological parameters.

The expansion of technical progress and the accelerated development of artificial intelligence have also influenced the agricultural sector. In the specialized literature of the last decades, several notions have appeared with reference to the imprint of technical progress on agriculture, such as: industrial agriculture, sustainable agriculture, conservative agriculture, organic agriculture, digital agriculture and others. In this case, we will only refer to some appreciations given to the concepts of smart agriculture and precision agriculture, defining the commonalities and differences [19].

As defined and presented by FAO at the 2010 Hague Conference, smart agriculture aims to contribute to achieving sustainable development goals by integrating the three dimensions of sustainable development (economic, social and environmental), while addressing food security in the context of climate challenges [9, 12].

In our view, precision agriculture represents the differentiated adaptation of the agricultural production process to climate change, through the efficient implementation of crop rotation and rotation, continuous monitoring of soil and environmental fertility, in order to ensure the most acceptable circumstances for the establishment and maintenance of agricultural crops, while optimizing irrigation practices and monitoring environmental conditions, harvesting and capitalizing on the production obtained.

In terms of plant cultivation**,** precision agriculture includes the establishment and maintenance of agricultural crops in accordance with plant needs in terms of moisture and nutritional level, capable of ensuring optimal technological conditions for plant growth and development, productivity and production quality, while maintaining or reducing costs under different production conditions [2].

The scientific concept of precision agriculture is based on the idea of excluding as much as possible disturbances along the entire chain of the technological process. To detect and evaluate these heterogeneities, special agricultural business management programs based on Geographic Information Systems (GIS) and Global Navigation are currently available. Satellite System (GNSS), advanced irrigation control practices equipped with equipment and sensors for measuring soil moisture and determining watering norms depending on climatic conditions and plant needs, etc. The collected and processed data are used for planning crop establishment periods, calculating fertilizer and pesticide application rates, more accurate productivity prediction and financial planning [19].

In the Republic of Moldova, the approach to the concept of adapting plant cultivation technologies to climate change and production was developed three decades ago, during which the foundations for the development of precision agriculture were laid. In 2018, the monograph “Fundamentals of managing technological processes for cultivating vegetable crops in open ground” [4] was published, where the conceptual support for the development of precision agriculture was presented, taking into account mathematical achievements in the field of simulation of crop formation processes in the “ *soil-plant-atmosphere* ” system.

The currently used crop forecasting methods and their implementation methods do not foresee and do not cover unpredictable situations caused by the instability of climatic factors. In addition, in connection with the transition to the requirements of a market economy, in addition to economic indicators, it is necessary to take into account a multitude of environmental, energy and organizational factors. This involves the processing of large amounts of information and calculations, the implementation of which, without the support of an integrated decision-making system, is difficult to achieve.

Scientific progress and experience demonstrate that solving problems related to the rational management of the process of forming the productivity of agricultural crops is possible. The situation can change only with the transition from declarative, purely experimental and empirical conclusions to quantitative, experimental-theoretical ones, based on the use of simulation models of growth, plant development and the formation of the productivity of agricultural crops, associated with expert systems and support for the adopted agronomic decisions.

The methodology for anticipating truly possible yields, based on optimizing the main factors of plant growth and development, can be accepted as an effective means of integrating theoretical and practical knowledge in the management of the production process. The experience of crop scheduling in vegetable crops demonstrates that satisfactory results can be obtained by using simulation models of agroecosystem productivity, which allow "simulating" and analyzing numerous technological versions and decision-making options with the help of information technologies [4].

Current methods of programming and technological supervision of agricultural crops are not without shortcomings. The recommendations obtained are not always well-argued, which requires the improvement and development of new methods of quantitative assessment of the conditions of growth, development and formation of the productivity of agricultural crops. Improving the methodology for continuous optimization of technological processes in agricultural activities will contribute to obtaining a pre-calculated level of productivity of agricultural crops, maintaining soil fertility while complying with environmental requirements, sanitary standards, as well as improving the concept of agronomic decision-making.

In the sense of the above, it is appropriate to develop and implement in agricultural practice methods for directing plant cultivation technologies, ensuring the differentiated application of technological decisions, in accordance with specific pedoclimatic and economic conditions. The emphasis is on the need to move from fragmented research to directed research with the identification of models for the formation of productivity and quality of plant production, the development and implementation of information technologies based on the management of technological processes, the optimization of plant density, irrigation norms and terms, fertilizer administration norms and the timing of their application, taking into account the condition of the soil, the biological peculiarities of the cultivated varieties and the intensity of climatic factors. Thus, precision agriculture includes plant cultivation technologies, specific computerization techniques and systems with the formulation of situation-specific decisions and the assessment of effects in time and space.

The implementation of such a concept provides for the large-scale application of information technologies, automated collection of data on production factors and conditions, applied technological operations, improved diagnostics of the phytosanitary situation in agroecosystems and decision-making for their implementation.

The use of precision agriculture is becoming increasingly susceptible with the development of GPS and GNSS navigation systems. Thus, currently, information technologies used in precision agriculture ensure the systematic collection and analysis of information about the state of the soil, plants, climate and other factors, which in one way or another favor or affect the growth and development of plants.

The support of navigation systems and the use of remote sensing images allow for the precise determination of the location of the study object (the occurrence of pests and outbreaks of infection) within the fields and the condition of agricultural crops [18].

As a result of data processing and specific knowledge, information systems provide agricultural producers with operational recommendations at the planning level regarding the rational management of fertilizers, watering norms and timing, soil cultivation, other operations and technological parameters in plant cultivation, which, overall, contribute to reducing costs, minimizing environmental impact, increasing the level of harvests, quality and completeness of agricultural production [19].

Some of the components that underline precision agriculture are specialized equipment and digital maps of fields, including various parameters and characteristics. Drones and information obtained from satellites help to monitor the condition of the field from a distance. Meteorological sensors and other types of equipment determine temperature, humidity, electrolyte concentration in the soil and other indices of the “ *soil - plant - atmosphere* ” system. Computers and other equipment, including mobile phones equipped with software and applications, support information analysis, documentation maintenance and proper management of the entire technological chain and business plan.

In order to carry out a more in-depth analysis of the impact of climate change on the productivity of agricultural crops, a control system of factors influencing growth and development was created within the Institute of Genetics, Physiology and Plant Protection of the Republic of Moldova, equipped with sensor equipment, a meteorological station that automatically monitors climatic and agrophysical parameters. Monitoring of climatic parameters and soil moisture reserves is carried out automatically throughout the year (Fig. 2). Meteorological data are recorded and maintained in the database, from where they can be accessed at any time. Thus, databases of climatic parameters are created with values (maximum, minimum and average of: temperature °C, relative air humidity %, wind direction gr, wind speed m/sec and km/h, solar and active radiation W/m² and Mj/m²˒ atmospheric deposition mm), soil moisture on profiles. 0 - 100 cm (Fig. 3), temperature and electrolyte concentration in the superficial soil layers (0 -30 cm).

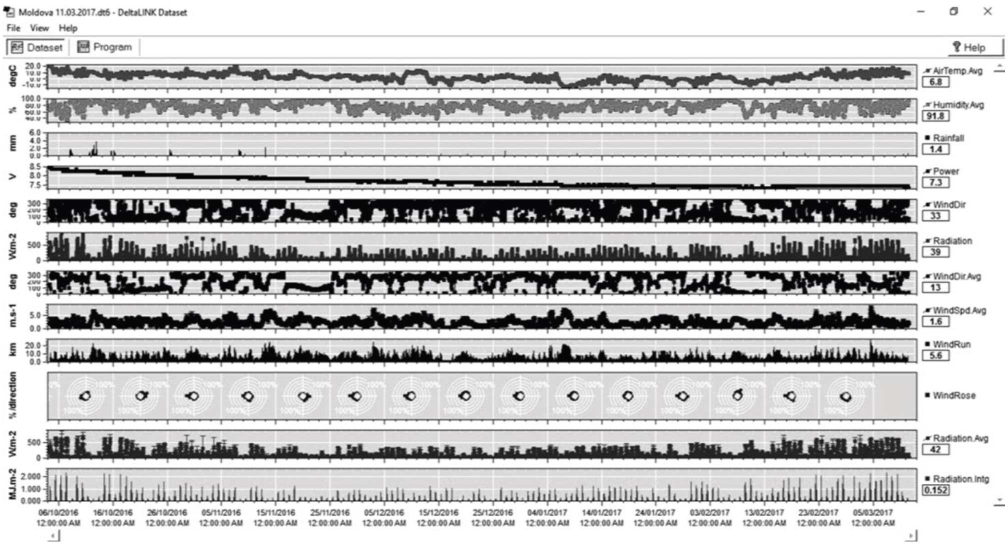

Fig. 2 Fragment of graphical representation of meteorological parameters

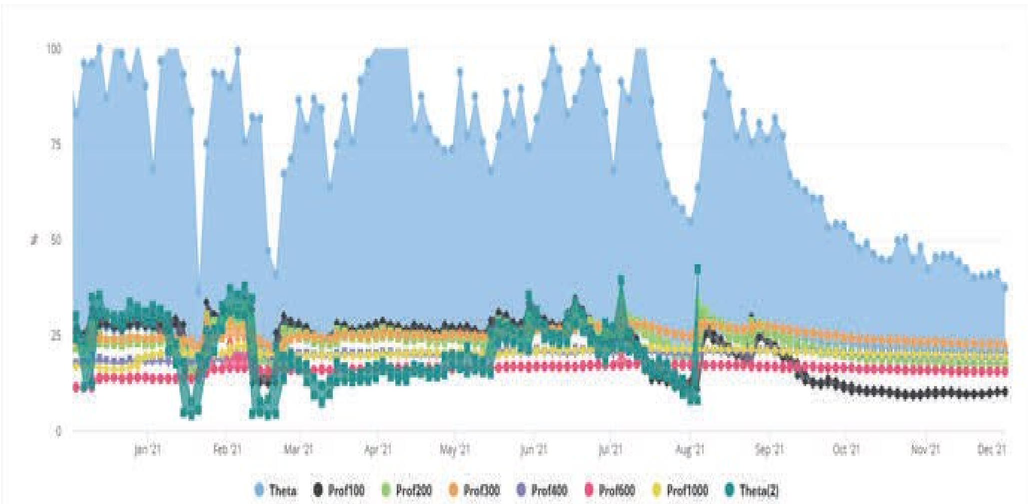

Fig. 3 Fragment of a graphical representation of soil moisture

The equipment has the ability to determine the conductivity of the pore water (ECp) and the conductivity of the water (EC) available to the plant roots. Nutrient levels are checked by monitoring the conductivity of the electrolytes and adjusting the injection of nutrients into the irrigation water. The sensor is easy to embed in the soil or substrates and in just 5 seconds indicates the water content (%), the conductivity of the pore water (ECp) and the temperature, other important indicators that characterize the condition of the root zone. In some cases, nutrients can be applied through fertilization, being administered directly into the soil with various types of fertilizers. The rate at which they are absorbed by the plant roots depends on several factors, including weather conditions and the soil moisture regime.

In cases where recycled water or water extracted from rivers with high salt levels is used for irrigation, an increase in soil salinity may occur over time, which will ultimately reduce soil fertility and crop productivity. The WET-2 sensor is convenient and effective for explicitly checking soil salinity, providing important information for taking appropriate corrective measures.

Monitoring of agro-meteorological and agro-physical parameters of the soil in field conditions with agricultural crops is carried out systematically, throughout the entire vegetation period at highlighted time intervals, according to the same measurement method with the data reading and storage device (www.deltalink-cloud.com). Subsequently, the initially displayed and analyzed readings are stored in memory and then downloaded to the computer. The information obtained and stored in the databases can be transmitted to the Excel operating system or other computing packages that perform a directed analysis with graphical representation of the results.

Physiological parameters: photosynthesis intensity, diurnal and nocturnal transpiration, microclimatic parameters, as well as the reaction of genotypes to extreme climatic conditions are determined at different stages of development, using the RTM-48A phytomonitor (Fig. 4).

Photosynthetic activity indices are monit ored by means of specific sensors in direct contact with the plant. The device automatically monitors photosynthetic activity in plants by analyzing CO_2 exchange.

The equipment is equipped with cameras for attachment to leaves. The phytomonitor's operation is based on the difference in CO_2 concentration at the outlet of the measuring chamber installed on the leaf in relation to the CO_2 concentration in the surrounding environment.

Fig.4 Phytomonitor for determining physiological indices in plants

The monitoring process allows for automatic measurements to be made at certain time intervals, with the production of phytodiagrams in the form of a film, over a period of 24-72 hours. As a result, concrete data are obtained on photosynthetic activity and the reaction of plants to extreme climatic conditions in different phases of development. A more detailed analysis of the results obtained allows for the determination of the physiological activity integrated into the light saturation curve for gross and net photosynthesis (micromol $CO_2/m^2/s$) [11].
Precision agriculture needs to be developed on the automation of processes along the entire technological chain, from land preparation for sowing to harvesting, transportation and storage of production. Current information systems allow monitoring the location and more efficient choice of traffic routes for agricultural machinery at all technological stages, including in the harvesting process, with the exclusion of unauthorized transportation of production, which will ultimately contribute to reducing losses and improving the financial situation of the enterprise.

Equipping agricultural machinery with GPS navigation systems helps to avoid overlaps and exclude missed areas when performing pre-sowing and crop establishment work, administering fertilizers and applying pesticide treatments, as well as consecutively determining soil moisture and temperature, microclimate and other parameters in different areas of the field at a certain time interval.

Agricultural machinery equipped with sensors and control systems ensures the precise distribution of seeds and other means intended for each individual area of the field. Given that the characteristics of different areas of the field vary significantly, information technologies allow identifying these areas and taking into account their characteristics when performing technological operations. This allows farmers to more efficiently use seeds and seedlings, fertilizers and plant protection products to obtain crop increases at lower costs. In such an approach, intuition based on circumstances matters less and less. At the same time, the operational system allows for the formulation and analysis of technological decisions based on multilateral calculations of the current and future situation. In addition, the rational use of material resources will lead, on the one hand, to reducing the cost of agricultural production, and, on the other hand, to protecting the environment.

Lately, farmers have been resorting to the differentiated use of fertilizers, depending on the nutrient content in different areas of the field, identified with the help of GPS receivers. In Based on an automated calculation system, fertilizer is redistributed to the advantage of areas where an increase in the administration rate is required and thus fertilizer application is differentiated, while soil fertility is also homogenized.

Recording and storing on electronic support the history of fields, crop rotations, applied works and harvest levels can contribute both to the formulation of operational decisions and to the performance of specific assessments regarding the technological cycle, which is becoming a mandatory and increasingly evident condition to ensure competitive production and sustainable agriculture.

In the context of the above, precision agriculture can be used to improve the condition of fields and agricultural management in various aspects:

(1) From an agronomic point of view, taking into account the optimization of nutritional regimes and other conditions for plant maintenance, growth and development, highlighting phenophases, earliness and determining harvest levels;

(2) From a technical point of view, better time management when carrying out work during the periods of planting, harvesting, transport and valorization of agricultural production (including directed planning of technological operations);

(3) From an environment point of view, reducing the impact of cultivation technologies and inputs on the environment (a more balanced assessment of the phytosanitary status and the needs of agricultural crops in terms of fertilizers and water to minimize the consumption of ingredients per unit of production);

(4) From an economic point of view, increasing productivity and/or reducing costs, increasing the competitiveness of agricultural production, business efficiency (including reducing costs for a production unit).

The system for controlling and maintaining technological parameters when sowing or planting agricultural crops is equipped with sensors integrated into the seeder and tractor, designed to ensure their continuous and constant monitoring. The unit has an electronic device with complex functionalities, so that the operator has exhaustive information about each coulter of the seeder or sprinkler of the spraying machine throughout the operation. In this way, the control systems ensure monitoring of technological parameters and the possibility of promptly obtaining information about possible deviations, as well as emergency elimination of malfunctions.

Sowing quality control systems ensure compliance with parameters such as seed embedment depth, row spacing, seed uniformity and seeding rate. Together with continuous monitoring of technological parameters, the system detects any deviation from specified standards and warns the operator about any deviations and problems that have arisen. This allows taking measures to correct the process in question, minimizing losses and ensuring optimal conditions for plant growth and development.

4. Conclusions

(1) Precision agriculture represents an important step in the development and efficiency of sustainable agriculture, especially in the context of climate change and the negative impact on the environment caused by the implementation of intensive agricultural practices.

(2) Information and intelligent technologies play an important role in increasing the productivity and competitiveness of agricultural production, the efficiency and sustainability of agricultural systems.

(3) In order to develop and implement precision agriculture, it is important that authorities, ministries of agriculture and environment, research institutions and agricultural associations collaborate to develop strategies for the adaptation and resilience of the agricultural sector to climate change, promoting sustainable practices in supporting farmers towards advanced and environmentally friendly agriculture.

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