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INFORMATION ANALYSIS AND SYSTEMATISATION OF THE STATE OF THE ART IN RESEARCH AND DEVELOPMENT OF TECHNOLOGIES FOR COMPUTER CONTROL OF GRAIN CROPS MOISTENING MODES

The global intensification of the use of land resources for agricultural purposes and the simultaneous negative dynamics of cultivated areas in Ukraine necessitate the substantiation of effective approaches and technologies for controlling critical parameters and the general condition of land resources when cultivating crops in open-field conditions. Soil moisture is one of the crucial factors in the justification and implementation of measures to increase soil productivity and improve crop stress resistance. Effective control of soil moisture prevents soil erosion and improves the regularity of river flow, which has a significant environmental and economic effect in the course of open-field crop production. The aim of the research is to substantiate the requirements for the creation of computer technologies for the predictive control of soil moistening modes in order to improve the efficiency of agrotechnical measures for the cultivation of grain crops through a comprehensive information analysis and systematisation of modern applied information and computer technologies. The object of the research is information processes of detection, network exchange and predictive processing of a set of distributed data on the modes of moistening of grain crops. The subject of the research is models, methods and hardware and software means of creating computer technologies for the predictive control of grain crop moistening modes. General trends in agricultural activities for growing grain crops at the national and global level have been analysed; functional and technological features, as well as models, methods and means of computerised intelligent control of soil moistening modes in the process of growing grain crops, have been analysed in detail; world experience in the creation and utilisation of software and hardware for the computerised intelligent control systems of soil moisture has been analysed and systematised; the necessity of further research on the development of effective approaches to optimising the modes of growing of grain crops through the creation and implementation of computer technologies for the predictive control of the state of agricultural objects of the open-field crop production has been proved.
Keywords: computer technology, predictive control, moisture, soil, grain crops.

ДЯЧЕНКО ГРИГОРІЙ, КРЕМНЬОВ ВОЛОДИМИР, КОВАЛЬ ВАЛЕРІЙ, ЄВСТРАТЬЄВ МИХАЙЛО
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ІНФОРМАЦІЙНИЙ АНАЛІЗ І УЗАГАЛЬНЕННЯ СУЧАСНОГО СТАНУ ДОСЛІДЖЕНЬ І РОЗРОБОК ТЕХНОЛОГІЙ КОМП'ЮТЕРНОГО КОНТРОЛЮ РЕЖИМІВ ЗВОЛОЖЕННЯ ЗЕРНОВИХ КУЛЬТУР

Світова інтенсифікація використання земельних ресурсів для сільськогосподарських цілей та одночасна негативна динаміка сільськогосподарських територій в Україні обумовлюють необхідність обґрунтування ефективних технологій та механізмів контролю критичних параметрів та загального стану земельних ресурсів під час вирощування польових агрокультур в умовах відкритого ґрунту. Вологість ґрунту є одним із вирішальних факторів під час обґрунтування і реалізації заходів щодо підвищення продуктивності ґрунту та покращення стресостійкості агрокультур. Ефективний контроль вологості ґрунту дозволяє запобігти ерозії ґрунту та покращити регулярність річкового стоку, що обумовлює значний екологічний та економічний ефект під час провадження сільськогосподарської діяльності рослинництва відкритого ґрунту. Основна мета статті полягає в обґрунтуванні вимог до створення комп'ютерних технологій прогнозного контролю режимів зволоження ґрунту для підвищення ефективності агротехнічних заходів під час вирощування зернових культур на основі комплексного аналізу та узагальнення інформації щодо сучасних прикладних інформаційних і комп'ютерних технологій. Об'єктом дослідження є інформаційні процеси збору, мережевого обміну та предикативної обробки сукупності розподілених даних щодо режимів зволоження зернових культур. Предметом дослідження є моделі, методи та апаратно-програмні компоненти побудови комп'ютерних технологій прогнозного контролю режимів зволоження зернових культур. Проаналізовано загальні тенденції провадження сільськогосподарської діяльності з вирощування зернових культур у національному та світовому масштабах; детально проаналізовано функціональні і технологічні особливості, а також застосовувані моделі, методи і засоби комп'ютерного інтелектуального контролю режимів зволоження ґрунту в процесі вирощування зернових культур; проаналізовано та систематизовано світовий досвід щодо створення та використання програмно-апаратного забезпечення систем комп'ютерного інтелектуального контролю режимів зволоження аграрних територій; доведено необхідність проведення подальших досліджень із розробки ефективних підходів до оптимізації режимів вирощування зернових культур шляхом створення і впровадження комп'ютерних технологій предикативного контролю стану аграрних об'єктів рослинництва відкритого ґрунту.
Ключові слова: комп'ютерна технологія, предикативний контроль, вологість, ґрунт, зернові культури.

1. Introduction

Current global environmental and social problems (world population growth, wars, instability of logistics chains for transporting agricultural products, adverse climate change and others) pose significant difficulties and challenges in agricultural production at both global and national levels. Despite considerable progress in plant breeding, it is worth noting that the rate of increase in specific crop yields is not showing a sustainable positive dynamic. At the global level, this is due to the erosion of agricultural land and the decline in groundwater levels because of drought and overuse [1]. In Ukraine, in addition to the above-mentioned challenges, the negative dynamics of the condition of agricultural areas is also caused by the war, which has led to the pollution of water and soil and the reduction of land resources intended for agricultural use. As land resources for horizontal scaling of crops become increasingly scarce, there is a growing need to intensify the use of land resources without reducing agricultural production. A graphical interpretation of the dynamics of harvested agricultural areas in global and national formats is shown in Fig. 1. The global experience of a large number of countries with developed agricultural production proves that the development and implementation of effective approaches to monitoring and controlling the state of land resources can have to a positive impact on sustainable agricultural development in both the short and long term.

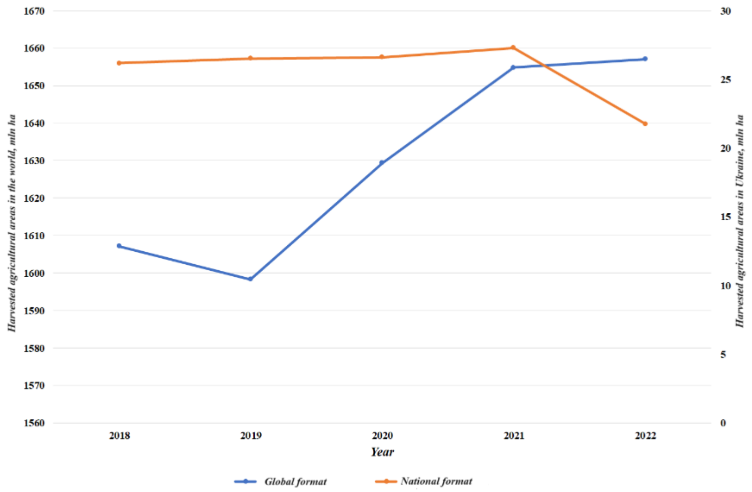
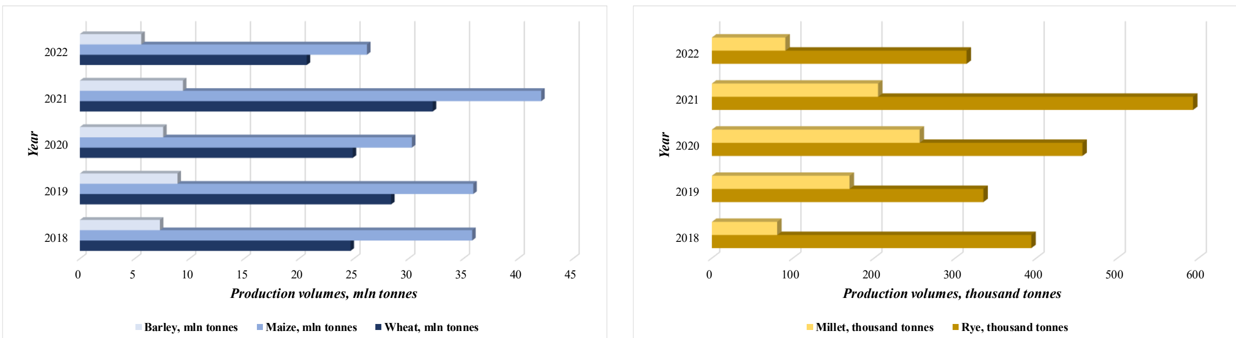


Fig. 1. Statistical indicators of the dynamics of harvested agricultural areas according to FAO (Data retrieved from [2])

It is worth emphasising that soil moisture is one of the crucial factors in justifying and implementing measures to increase soil productivity and improve crop stress resistance. In turn, effective control of soil moisture prevents soil erosion and improves the regularity of river flow, which leads to a significant environmental and economic effect in the course of agricultural activities in open-field crop production [1].

In Ukraine, the most popular and strategically important cereals for the formation of national food security are wheat, maize, barley, millet and rye [2, 3]. Statistical indicators of the dynamics of production volumes of these crops in Ukraine in the period from 2018 to 2022 are shown in Fig. 2.

Therefore, the scientific and applied task of substantiating and implementing effective approaches to optimising the use of land and material resources, including water, in the course of agrotechnical activities for growing grain crops in the field is relevant both in Ukraine and in the world. To date, several analytical and scientific studies have been conducted to establish recommended soil moisture levels for growing grain crops, depending on agroclimatic conditions and growth stages. For instance, scientific studies [4, 5] have established a time trend in the total consumption of water resources used for agricultural production in the world. This trend is shown graphically in Fig. 3.



a) barley, maize and wheat b) millet and rye

Fig. 2. Grain production statistics in Ukraine in the period from 2018 to 2022

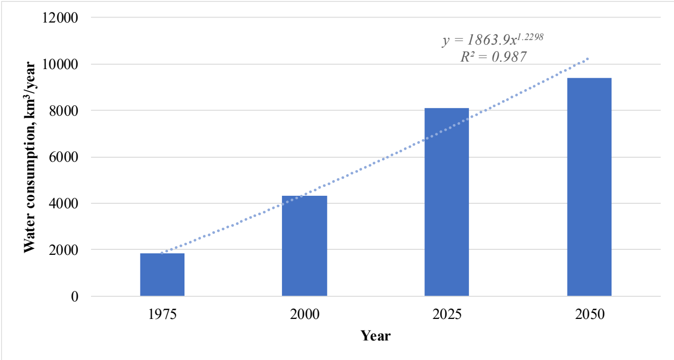


Fig. 3. Estimated values of global water consumption for agricultural production

An important factor that must be considered when developing and researching methods and means for computerised collection and processing of soil moisture data is the agroclimatic conditions under which certain types of crops are grown. At present, Ukraine has three main agroclimatic zones, namely [6, 7]:

– Steppe (southern and northern): estimated annual precipitation ranges from 350 mm to 540 mm with a probability of drought varying from 40 % to 70 %;

– Forest-steppe: estimated annual precipitation ranges from 575 mm to 650 mm with a probability of drought ranging from 15 % to 40 %;

– Polissya: estimated annual precipitation ranges from 596 mm to 760 mm with a probability of drought ranging from 0 % to 10 %.

The most informative factor determining the appropriate agroclimatic zoning of the territory of Ukraine is the ratio of moisture and heat resources, which, in turn, is determined by the climatic parameters of temperature (air and soil) and precipitation, which determine the current level of soil moisture.

Therefore, the scientific substantiation and practical implementation of effective approaches to the optimisation of agrotechnical procedures and resources used during the full cycle of the open-field grain crop cultivation, including through the creation, research and utilisation of computer technologies for the predictive control of the state of the physical and biological environments of agricultural facilities, is a relevant scientific and applied task.

2. Aim, object and subject of the research

The main aim of the article is to substantiate the requirements for the creation of computer technologies for the predictive control of soil moistening modes to increase the efficiency of agrotechnical measures for growing grain crops through a comprehensive information analysis and systematisation of modern applied information and computer technologies. The object of the research is information processes of detection, network exchange and processing of a set of distributed data on the modes of moistening of grain crops. The subject of the research is models, methods, hardware and software for the creation of computer technologies for the predictive control of grain crop moistening modes.

3. Analysis of technologies and methods of computer control of soil moistening modes.

The main aim of developing and implementing irrigation systems based on adaptive computer control algorithms is to optimise agrotechnical procedures, considering the criteria of minimising labour and resource requirements, as well as maximising the volume and quality of crop production [8]. The effectiveness of the use of software and hardware models and computer control means depends on the types and design of the irrigation technologies and systems used, considering the time and duration of soil irrigation, the optimal amount of water and the possibility of increasing energy efficiency. When developing software and hardware means for computer control of irrigation systems, the following factors have to be considered: types and vegetation stages of crops, climatic conditions, shapes and sizes of fields, degree of mechanisation and automation and others [9, 10]. All these factors lead to a significant technological diversity of agricultural irrigation systems in use. A detailed interpretation of technical solutions for soil irrigation, which have become popular in the world and domestic agrotechnical practice in the course of agricultural crop production in the open-field conditions, is shown in Fig. 4 [11]. In order to optimise the utilisation of resources, primarily water, in agrotechnical procedures for growing grain crops, it is necessary to constantly monitor a number of parameters and factors that determine the quality and volume of agricultural production. Computer control of adaptive soil irrigation involves the collection, accumulation and processing of actual measured data on the condition of plants and soil, as well as climatic conditions, using modern information, sensor, communication and computer technologies, as shown in Fig. 5 [12].

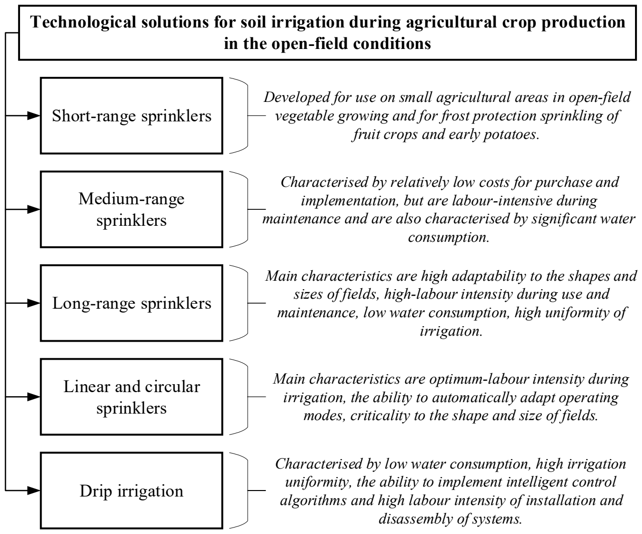


Fig. 4. Soil irrigation technologies for growing crops in the open-field conditions

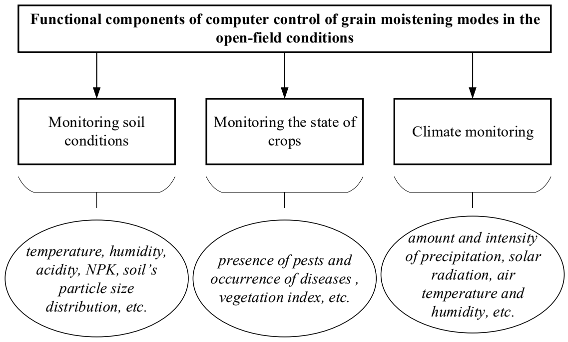


Fig. 5. Functional components of computer control of the integral state of agricultural objects during optimisation of soil irrigation modes

In turn, the functional and algorithmic basis for the implementation of software and hardware means for computer control of agricultural irrigation modes is non-destructive zonal (at different depths and locations in the field) moisture monitoring in real time. Since soil moisture is a dynamic quantity, both in time and space, it is a prerequisite of monitoring it continuously, taking into account destabilising factors (see Fig. 5). To date, a significant number of methods and means for precision online soil moisture monitoring has been developed in scientific and technical practice around the world.

Globally, these methods can be divided into two large groups: laboratory (direct) – soil moisture is estimated as the difference between the mass of wet and dry soil; indirect (field, remote) – soil moisture is estimated on the basis of data on changes in any physical or chemical parameter associated with it [13–17]. A graphical representation of the results of the analysis and systematisation of the known methods of non-destructive soil moisture monitoring is shown in Fig. 6.

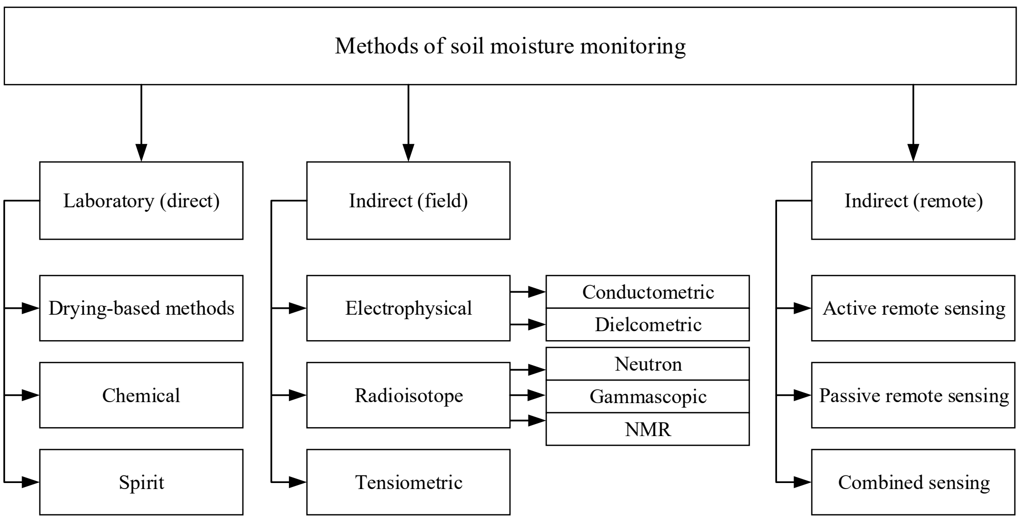


Fig. 6. Existing methods of soil moisture monitoring

Based on the information analysis of the data shown in Fig. 6, it was established that a significant number of soil moisture control methods have been developed due to a wide range of objectives for the corresponding analysis. Taking into account the need for software and hardware integration of soil moisture monitoring methods into computer technology for real-time control of the moistening modes of grain crops in the open-field conditions, it is worth noting the following: the most appropriate methods for open-field control based on the results of preliminary analysis of a priori data are conductometric and/or dielcometric (capacitive) methods. This is due to the possibility of implementing scalable zonal (by the depth and field location) computer control of soil moisture in real time, as well as software and hardware compatibility with the technical solutions used for soil irrigation.

4. Analysis of mathematical models of computer control of soil moistening modes.

As noted above, conductometric and dielcometric (capacitive) methods of soil analysis are indirect and therefore require the establishment of functional relationships between directly measured physical or chemical parameters (resistivity or dielectric constant, respectively) and relative soil moisture. The analysis of known theoretical models describing these functional relationships has been therefore carried out. The results of the analysis, according to the types of models (static and dynamic), are presented in Tables 1 and 2.

Table 1

The results of the analysis of static soil moisture control models

Mathematical basis	References
$W = 34.23 \cdot V^2 - 182.24 \cdot V + 249.45,$ where W is soil moisture, %; V is sensor output voltage, V.	[18]
$W = \frac{(4.7 \cdot V^3 - 6.4 \cdot V^2 + 6.4 \cdot V + 1.07) - 1.6}{8.4},$ where W is soil moisture, %; V is sensor output voltage, V.	[19]
$W_A = \frac{W_S}{(a \cdot EC^2 + b \cdot EC + c)} + \frac{W_S}{(b \cdot T^2 + e \cdot T + f)},$ where W_A is the actual volume moisture content, %; W_S is the measured value of the volume moisture content, %; EC is the electrical conductivity of saturated soil solution, S/m; T is the current soil temperature, °C; *a, b, c, d, e, f* are constants determined by the soil type.	[20]
$E = 0.1 \cdot W_C \cdot Y_C,$ where E is the total moisture consumption during the growing season, m^3/ha; W_C is the water consumption coefficient (depending on the types of crops grown), m^3/tonnes; Y_C is the programmed yield, quintal/ha. $I_R = \frac{100 \cdot h \cdot V \cdot (V_H - V_F)}{W_U},$ where I_R is the irrigation rate, m^3/ha; h is the depth of the soil layer to be wetted, m; V is the soil mass (volume) for the analysed layer h, g/cm^3; V_H is the limit value of the field moisture capacity for soil layer h, % of the dry weight of the soil; V_F is the actual moisture content of the analysed soil layer h before irrigation, % of the dry weight of the soil; W_U is the moisture utilization factor (depends on weather conditions, irrigation technology and physical and chemical soil's characteristics).	[21]

Table 2

The results of the analysis of dynamic models of soil moisture control

Mathematical basis	References
$\frac{\partial W(x,t)}{\partial t} = \frac{\partial}{\partial x}\left(k(h)\frac{\partial h}{\partial x} - k_T\frac{\partial T}{\partial x}\right) - \frac{\partial k(h)}{\partial x} - S(x,t,h),$ where W is absolute soil moisture; h is pressure; T is soil temperature; k is soil hydraulic conductivity; k_T is the thermal component of soil hydraulic conductivity; S is the root absorption capacity of plants grown under the analysed conditions; x is the distance coordinate; t is time.	[22]
$\frac{\partial W}{\partial t} = \frac{\partial}{\partial x}\left(K\frac{\partial W}{\partial x}\right) + \frac{\partial}{\partial z}\left(K\frac{\partial W}{\partial z}\right),$ where W is the volume moisture content in the soil; K is the hydraulic conductivity of the soil; *x, z* are the coordinates of moisture distribution; t is time.	[23]
$W(t) = ir(t) + cr(t) + rf(t) - et(t) - ro(t) - dp(t),$ where W is the soil moisture in the root zone of plants; ir is the amount of moisture supplied by irrigation; cr is the amount of moisture supplied by capillary rise of groundwater; rf is the amount of moisture supplied by precipitation; et is the amount of moisture evaporated; ro is the moisture loss rate due to runoff; dp is the moisture loss rate due to absorption; t is time.	[24]
$\frac{\partial W_i}{\partial t} = \frac{1}{D_i}\left(Q_i(W_i, W_{i+1}) - \frac{T}{3\rho_W}\right),\ \forall i = 2 \ldots N-1,$ where W_i is the volumetric soil moisture in each analysed layer; D_i is the thickness of the analysed soil layer; Q_i is the water flow between the analysed soil layers; T is the transpiration rate from the vegetation cover; ρ_W is the water density; N is a number of analysed soil layers; t is time.	[25, 26]
$ET_0 = \frac{0{,}408\Delta(R_n) + \frac{900}{T+273}\gamma U_2(e_2)}{\Delta + (1 + 0{,}34U_2)\gamma},$ $ET_C = ET_0 \cdot K_C,$ where ET_0 is the reference value of evapotranspiration, mm/h; R_n is the shortwave radiation index, W/m^2; Δ is the angular slope of the saturated vapor pressure curve, kPa/°C; T is the air temperature, °C; U_2 is the average daily/hourly wind speed at a height of 2 m, m/s; e_2 is the saturated vapor flow pressure, kPa; γ is the coefficient responsible for the evaporation rate, kPa/°C; ET_C is the actual value of evapotranspiration, mm/h; K_C is the coefficient responsible for the type of crop.	[27]

When analysing well-known methods of computer control of soil moistening modes and related technologies, special attention should be paid to those based on intelligent algorithms for processing measurement data. This fact is connected with their high efficiency when integrating them into edge computerised computing devices in the form of embedded software to control various physical and chemical processes, including predictive control of soil moisture. The systematised results of the analysis of methods and models of intelligent soil moisture control are shown in Table 3.

Table 3

The known results of the developments of soil moisture control systems based on intelligent algorithms

Characteristics of the model	Functional and logical basis	References
A model for monitoring the condition of soil and crops that determines the necessary irrigation parameters based on online monitoring data on soil moisture, air temperature and humidity, irrigation schedules, as well as current weather conditions has been developed.	A rule base based on fuzzy logic has been developed. The input variables are soil moisture and air temperature, while the output variable is irrigation intensity.	[28]
A model based on the IoT and AI has been developed for adaptive irrigation control, taking into account the objective function of maximising crop yields and minimising water consumption, by the conceptual principles of Agriculture 4.0.	Software based on machine learning methods has been developed, namely: KNN (K-Nearest Neighbors), SVM (Support Vector Machine), NB (Naive Bayes). The input variables are soil moisture, temperature, and air humidity. The output variable is irrigation pump control signals.	[29]
A nonlinear predictive model for optimal irrigation of crops in greenhouse conditions has been proposed and studied. The system based on the developed model implements online detection of soil physical and chemical characteristics and estimates the predicted value of the next irrigation cycle	Software based on machine learning methods, namely: LSTM (Long Short-Term Memory), RNN (Recurrent Neural Network), GRU (Gated Recurrent Unit). The input variables are soil temperature and humidity, air temperature and humidity, light intensity and precipitation. The output variable is a predicted value of the next watering time.	[30]
A computer method for intelligent control of irrigation modes of greenhouse crops, taking into account their stages of vegetation and destabilising effects of greenhouse microclimate factors, has been developed.	A computer model for adaptive control of an irrigation pump based on fuzzy logic has been developed and studied. The input parameters are soil moisture, day after planting (depth of the crop root system). The output variable is pulse width modulated (PWM) irrigation pump control signals.	[31–33]

From the analysis of typical research results devoted to the development of models and methods for the intelligent predictive control of soil moisture during crop cultivation (see Table 3), it can be observed that machine learning and fuzzy logic algorithms have become the most popular. The analysed results of well-known studies [28–33] prove the high efficiency of intelligent algorithms compared to conventional ones in implementing functional components of processing measurement data on the current physical and chemical state of the soil to optimise the moistening modes of crops grown in different agroclimatic zones. Such algorithms allow programmatic implementation of the principles of the predictive adaptive control of soil moisture, taking into account a significant number of informative characteristics and parameters of computer control objects and destabilising factors.

5. Analysis of software and hardware for detecting, transmitting and processing data on soil moistening modes

In the present scientific and technical practice, the conceptual approaches of the Internet of Things (IoT) and Industry 4.0 have been employed to address the issues associated with the development and utilisation of computer technologies for intelligent control and monitoring of a diverse range of production processes, including those in the agricultural sector. The systems and technologies that implement the aforementioned conceptual directions are, in the majority of cases, networked multilevel software and hardware organisations that should function as a complete service with automated decision-making capabilities [34, 35].

In turn, such concepts have contributed to the advancement of various agricultural practices including Precision Agriculture, Smart Agriculture, Agriculture 4.0, Digital Agriculture and others [36–38]. In system and network solutions for agrotechnical control and monitoring based on IoT, biological (plants and animals) and physical (soil, agrotechnical mechanisms, devices, machinery and others) objects should be equipped with devices for detecting parameters and characteristics of processes and phenomena. Furthermore, these objects should be connected using appropriate technologies and protocols for large-scale data exchange, including via the Internet. This approach is intended for the practical implementation of adaptive digital identification and control of objects and processes associated with agricultural activities [39, 40].

A significant number of developments in algorithms, systems and technologies for the intelligent, adaptive and predictive control of field crop moistening modes have been made at the global scientific and technical level. The results of a critical analysis of the main developments are presented in Table 4.

Table 4

The results of a critical analysis of existing research on the development of technologies for computer control of crops moistening modes

The object of research	The result of research	References
A model for identifying input and output parameters of predictive zonal control of the agrohydrological state of agricultural areas.	A dynamic model of soil moisture control, represented by partial differential equations and taking into account the need to maintain soil moisture within acceptable limits, has been developed and subjected to analysis.	[41]
A simulation model for the efficient use of water resources for farms.	A model for predictive control of soil moisture at the scale of a farm is proposed and validated. The model incorporates data on soil moisture, operational constraints, economic indicators and characteristics of soil moisture dynamics.	[25, 26]
A predictive model for controlling the agrohydrological state of soil based on neural network algorithms.	A dynamic model for controlling the agrohydrological state of soil based on a two-layer neural network has been developed and studied. The proposed model implements multi-zone moisture monitoring in the root zone of the soil, as well as linear correction of the predicting error.	[42]
A predictive model and computer system for optimising irrigation modes for crops.	A computer model for predictive control of soil moisture using microcomputer technologies based on Raspberry Pi has been developed and validated in Matlab & Simulink.	[27]
Processes of automated control of moisture availability of field crops using intelligent technologies.	The models and methods of intelligent control of crop moisture supply with the use of neural and fuzzy-neural network algorithms have been developed.	[43]
Methods and means of computerized control of soil moisture in greenhouse conditions.	An information and measurement technology for computerised real-time control of greenhouse soil moisture with compensation for destabilising effects has been developed and studied.	[44]
Structure, functional algorithms and component base of automatic irrigation systems.	The structure and algorithms of the cyber-physical system for remote automatic irrigation of plants have been developed and substantiated.	[45]
Structural and algorithmic structure of the automated plant irrigation system.	The structural and algorithmic structure and simulation model of the automated irrigation system based on the microprocessor platform Arduino have been developed and tested.	[46]
Algorithms and hardware and software implementation of a soil moisture control system in a parking area.	The hardware and software development of soil moisture control in the parking area based on the PLC SIMATIC S7-300 has been created and studied.	[47]
Robust machine learning algorithms for estimating and predicting the water quality index.	The theory of robust control has been elaborated in the construction of models for analysing soil moisture content at different depths based on remote sensing and machine learning.	[48]
Methods and algorithms for reliable statistical processing of time series data to predict soil moisture content.	A statistical model for predicting soil moisture content based on field data on air temperature and precipitation has been developed and studied.	[49]
Methods and systems of smart irrigation in drought areas.	Conventional and intelligent methods and technologies for planning irrigation of agricultural areas have been analysed. The benefits of integrating machine learning and artificial intelligence algorithms into the technologies for planning and implementing agrotechnical soil irrigation procedures have been identified.	[50]

Based on the analysis of existing research findings on the development and testing of computer technologies for computer control of crop moistening modes (see Table 4), the following provisional conclusions have been made:

– from the point of view of the use of ground control hardware, the most prevalent are as follows: wireless sensor networks equipped with microprocessor (Arduino) and microcomputer (Raspberry Pi) platforms;

– in terms of software and computing technologies used, the most popular and effective are the following: predictive control models, artificial neural networks, fuzzy logic, fog- and edge-computing followed by information exchange with a remote (cloud) server;

– a client-server architecture is the basis of hardware and software solutions for applied agricultural control;

– the technical and functional characteristics of computer control systems for moistening field crops are sensitive to specific agroclimatic and soil conditions.

This underscores the relevance and importance of researching the development of theoretical and applied provisions for the creation, improvement, validation and utilization of computer technologies for the predictive control of crop moistening modes.

6. Discussion and further research directions

Based on the results of the research, it can be noted that there are certain limitations in the scientific and practical elaboration of the following issues related to the creation and implementation of computer models, methods and technologies for predicting the moisture content of agricultural areas, namely:

– insufficient results with regard to the development of the software and hardware structure of computer technologies for soil moistening, taking into account the criteria of control accuracy and reliability of network interaction of the components of the studied technologies;

– limited results of research on the effectiveness of integrating algorithms for comprehensive processing of soil and climatic data for the predictive control of crop moistening modes into the edge level of computer technologies deployed and operating in the open-field conditions;

– insufficient results of research on automated support-decision for optimisation of crop moistening modes, taking into account the integral effect of informative parameters and destabilising processes and factors in the remote mode.

It is also worth noting that the majority of existing systems and technologies fail to consider the following factors: the specific types and periods of vegetation of grain crops that are typical of the agroclimatic conditions of Ukraine; the physical and chemical properties of the soil; the technological and functional aspects of agricultural activities related to grain crop production in the open-field conditions.

Therefore, the research problem of further development of theoretical and practical approaches and developments to the creation, improvement and use of computer technologies for remote predictive control of crop moistening modes, taking into account the specific agroclimatic conditions of Ukrainian agricultural enterprises, physical and chemical properties of the soil, types of crops grown, as well as the technological and functional base of agricultural activities in open-field conditions, is relevant. The following research directions and tasks are therefore worthy of further investigation:

– substantiation of the structural and algorithmic provision of the studied computer technology, taking into account the criteria of accurate zonal collection, robust edge processing, as well as reliable network interaction of functional components of the technology;

– development of information and mathematical models of the studied computer technology to substantiate the technical and functional requirements for its hardware and software components;

– development of methods and models for creating hardware and software of the studied computer technology to evaluate its main characteristics and parameters;

– creation and validation of a prototype of the computer technology for controlling the moistening modes of grain crops to substantiate recommendations for its further implementation and use in open-field conditions.

7. Conclusions

This article presents the following findings of a comprehensive analysis of the current developments of technologies for computer control of grain crop moistening modes, namely:

1. An informational analysis of global trends in agricultural activities related to the cultivation of grain crops has been carried out, which allowed for establishing the characteristic features of water consumption on national and world scales. Based on this analysis, the principal grain crops that are important for the conditions of economic development and food security of Ukraine, as well as the specific factors that affect the efficiency of their cultivation in the relevant agroclimatic conditions, have been identified.

2. The software and technological features, as well as the models, means and methods used for computer control of soil moistening modes during grain crop cultivation, have been analysed in detail. This has enabled the substantiation of the basic methods and hardware and software components that can serve as the structural and algorithmic basis for the development and research of computer technology for the predictive control of crop moistening modes.

3. The world experience in terms of the development and utilisation of software and hardware for computer control systems of agricultural moistening modes has been analysed and summarised. This has facilitated the localisation of the basic architectural solutions and approaches to the construction of applied systems for the control of agrotechnological processes, which, in turn, necessitate further advancement.

4. The necessity of carrying out scientific and applied research to substantiate effective approaches to optimising agrotechnical practices during the full cycle of growing crops through the creation and implementation of information and computer technologies for predictive control of the state of biological and physical environments of agricultural facilities of the open-field crop production has been established.

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