Comprehensive Assessment Method of Agricultural Territories Based on Artificial Intelligence Technology in Terms of Greenhouse Effect Dynamics

D. V. Goncharov[1(✉)], O. A. Ivashchuk[1], and O. O. Ivashchuk[2]

[1] Belgorod State National Research University, 85, Pobedi, Belgorod 308005, Russia
goncharov_dv@bsu.edu.ru
[2] Caspian University of Technology and Engineering Named After Sh. Yessenov, 32, Microdistrict Street, Aktau 130000, Kazakhstan

Abstract. In this article the results of the development of integrated assessment modelling and forecasting of the agricultural areas productivity are presented depending on the technogenic and natural impacts, which include the dispersion and accumulation of greenhouse gases based on neuro-fuzzy data analysis. The digital transformation of crop production is part of a federal strategy aimed at adapting agricultural areas to climate change and obtaining a consistently high yield through the introduction of Industry 4.0 digital technologies and platform services. The software-algorithmic tools are presented to implement the method. The group of researchers considered a new approach to the adaptation of agricultural areas in the context of the greenhouse effect dynamics and proposed a new method of agro-ecological and natural-agricultural zoning of territories to increase the amount of crop yields. Practical implementation makes it possible to select evidence-based measures for zoning agricultural areas, thereby improving the efficiency of specific control actions for the adaptation of territories in terms of the greenhouse effect dynamics. Practical implementation of the approach is expected to increase the level of environmental and food security.

Keywords: Integrated assessment · Adaptation of agricultural areas · Yield enhancement · Greenhouse effect · Zoning · Assessment algorithm

1 Introduction

The current level of information technology development, mathematical, situational and computer modeling approaches and automation facilities make it possible to solve a wide range of concerns in the field of environmental situation management in various territories: organization of intelligent monitoring, implementation of estimates and forecasts, formation, evaluation and comparison of control scenarios, etc. [1]. The effectiveness of the implementation of such functions in systems for ensuring environmental safety is determined by the results of a comprehensive study of the parameters of the natural environment and the technosphere, identifying the necessary cause-and-effect relationships.

Such knowledge allows us to not only to carry out the necessary scientifically based assessments and conclusions but also to form effective recommendations for achieving the required levels of environmental safety [2].

It should be noted that man-made and natural objects as well as the processes of their interaction are characterized by high dynamism and complexity. The works of Russian and foreign researchers are represented in the scientific literature, as well as works by groups of scientists, which have shown the high efficiency of using the artificial intelligence modeling machine, particularly artificial neural networks and fuzzy logic, in solving various problems of processing environmental data and predicting the dynamics of natural environments [3]. The use of these artificial intelligence technologies is highly effective in solving problems of a comprehensive assessment of the situation, which is determined by the combined influence of the current and/or forecasted state of several components of the biotechnosphere, as well as the need to find ways to balance management, taking into account both the conservation of the natural environment and resources and ensuring a high level of technological development.

2 Relevance and Scientific Significance

Recently, increasing attention from scientists and the general public has been paid to global environmental problems that have a negative effect on the climate, which is intensified by the development of production and agricultural technologies. With the growth of production levels, the emissions of gaseous pollutants increase, which in turn increases the concentration of greenhouse gases (GHGs) in the atmosphere, primarily carbon dioxide (CO_2), which traps thermal radiation and contributes to climate change (temperature increase, ozone layer depletion, etc.). However, there is an opposite side the study; climate change caused by an increase in the concentration of GHGs in the atmosphere—the greenhouse effect (GE)—can contribute to a positive aspect in modern crop production, namely, a favorable effect on the photosynthetic activity of plants, which is necessary for the formation of high yields and maintaining the mineral soil balance [4].

Using the capabilities of artificial intelligence, a modern system for monitoring, forecasting and managing the environmental situation can scientifically justify the adaptation of agricultural territories to climate change measures by means of their effective agro-ecological and natural-agricultural zoning with reference to the dynamics of GE.

An analysis of Russian and international publications has recently shown that the main line of research is related to climate change modeling [5, 6], the calculation and forecasting of GHG concentrations from both man-made and natural sources [7, 8], the modernization of technological processes to ensure the reduction of greenhouse gas emissions into the atmosphere [8], and the use of alternative energy sources [9, 10]. However, currently, there are no methods or models for a comprehensive assessment of the possible productivity of agricultural territories based on the existing and predicted spatial and temporal distribution of GHG concentrations (their dispersion and accumulation in the surface layer of the atmosphere). At the same time, it is important to cumulatively consider the impact both on the state and characteristics of the agricultural crops themselves and the impact on the possibility of restoring the humus layer of the

soil, taking into account external influences, analysis of the technologies used and the characteristics of the territory itself. The development of a technology used for such a comprehensive assessment would offer the benefits of making it possible to expand the existing methods of data mining in the field of ensuring environmental and food security, creating a new effective approach to ensuring automated agro-ecological and natural-climatic zoning of territories, creating an appropriate methodological tool for the formation and evaluation of models of management scenarios that simultaneously contribute to reducing the negative impact on the environment and increasing the productivity of the territory, and preserving and restoring the characteristics of the quality and economic efficiency of resources.

3   Research Task

The team of authors set the scientific task of forming a method and developing appropriate algorithms and models to ensure the updating of the following decision support functions in the adaptive management of the productivity of agricultural areas in terms of GE dynamics:

- Automated comprehensive assessment of the possible productivity of the study area based on the analysis of the spatiotemporal distribution of GHGs (scattering and accumulation) in the surface layer of the atmosphere. An analysis is carried out on the cumulative state of the two most important characteristics that determine the yield of agricultural crops and closely correlate with the considered parameters of GE: photosynthetic activity of agricultural plants (conversion of atmospheric CO_2 and visible light energy into the energy of chemical bonds of organic substances, including the conversion of carbon dioxide into organic substances) and soil carbon dioxide emissions (the total production of CO_2 by soil microorganisms from the decomposition and oxidation of organic matter by soil fauna and plant root systems, as well as from high-use of soil and fertilizers in agriculture).
- Automated formation based on the results of a comprehensive assessment of models of adaptive management scenarios for changing the productivity of the study area under the conditions of GE dynamics in order to increase productivity (taking into account the characteristics of the territory, climatic and meteorological parameters, soil characteristics, etc.). Management scenarios should demonstrate the transition from the formed predicted situation to the required situation in the direction of increasing productivity in the study area based on a scientifically based choice of parameters for its zoning: agroecological (a set of measures and actions for a clear and reasonable delimitation and classification of territories according to their purpose) and natural agricultural (delimitation of territories, taking into account climatic, soil, technogenic and other conditions in relation to the agrobiological requirements of agricultural plants), as well as determining the type of agricultural crop and technological map that provide the required result.

3.1 Development of a Method and Model for Comprehensive Assessment of the State of Agricultural Territory Under the Dynamics of the Greenhouse Effect Based on an Intelligent Simulation

The key indicator of the agroecological situation in this case is the state of the considered agricultural area in terms of its productivity, which determines the yield of agricultural crops, located in the zone of influence of specific man-made and natural objects and/or processes that form specific parameters of GE. Let us introduce the corresponding linguistic variable *AtmGG*, which (taking into account and developing the approach proposed by D.A. Pospelov [2, 3, 11]) can be defined as a complex spatiotemporal assessment of a set of characteristics: the state of agricultural crops in terms of the possible basis for assessing their photosynthetic activity; the state of the soil environment, which determines the productivity of the study area; and their connections with the parameters of the technosphere and the external environment, which influence the formation of the level of environmental and food security.

Based on the general principles of situational modeling [2, 12], we introduce the following concepts:

- The current state of the agricultural territory located in the area of influence of objects and/or processes of the technosphere (we will denote it by AtmGGact when implementing the modeling process), which is determined at a given point in time;
- Full state (we will denote by AtmGGfull during the implementation of the modeling process), including:
- State AtmGGact;
- Knowledge about the state of the studied objects and/or processes of the technosphere, the state of the agricultural territory, external influences at a given time;
- Knowledge about the mechanisms and technologies for managing objects and/or processes of the technosphere, the infrastructure of the territory, about cause-and-effect relationships that determine the conditions of dynamics and the possibility of optimizing their parameters.

An elementary act of agroecological situation management in the territory under consideration can be represented on the basis of a logical transformational rule:

$$AtmGG_i^{full} : AtmGG_i^{act} \underset{U_k}{\rightarrow} AtmGG_j^{act} \tag{1}$$

where U_k—k-th is control action on any parameter of the studied object and/or process of the technosphere, the infrastructure of the territory under consideration, which determines the spatial and temporal dynamics of the agroecological situation; $k = 1, M,$ K, where K is the number of possible control options (possible impacts, the totality of which can provide the desired result).

Relation (1) demonstrates the following: if in the considered agricultural area characterized by some infrastructure parameters and located in the zone of technogenic impact, taking into account the influence of the external environment, an agroecological situation has formed, determined by the state $AtmGG_i^{act}$, and the state of the technogenic objects and processes themselves, mechanisms their implementations, the methods used and the control roadmap defined by $AtmGG_i^{full}$ allow the application of the control action U_k,

then when the latter is implemented, the current state $AtmGG_i^{act}$ is transformed into a new state $AtmGG_i^{act}$, which is associated with adaptation of the study area under the conditions of GE dynamics with a corresponding increase in its productivity and crop yields.

Based on the set-theoretic approach, we represent the linguistic variable in this way:

$$\{AtmGG, T, H, G, M\} \tag{2}$$

where $AtmGG$ = "Agroecological situation" is the name of a linguistic variable that reflects the state of the agricultural area in terms of GE dynamics, T is the corresponding base term-set ($AtmGG$ values), which can be represented as a fuzzy set on the set H (a set of numerical characteristics, for definition of T to a certain value), G are syntactic rules for the formation of new $AtmGG$ values that are not contained in the base set T, M are syntactic rules that define the membership functions of fuzzy terms formed by the syntactic rules of G.

Based on the above, the linguistic variable $AtmGG$ will be a composite:

$$AtmGG = \left(AtmGG_{absor}, AtmGG_{prod}\right) \tag{3}$$

where $AtmGG_{absor}$ is a linguistic variable that describes the state of the territory in terms of soil emissions under the conditions of GE dynamics.

$AtmGG_{prod}$—describes the state of the territory in terms of photosynthetic activity of agricultural plants in terms of GE dynamics. These variables, respectively, have the following form:

$$\{AtmGG_{absor}, T_{absor}, H_{absor}, G_{absor}, M_{absor}\},$$

$$\left\{AtmGG_{prod}, T_{prod}, H_{prod}, G_{prod}, M_{prod}\right\} \tag{4}$$

where T_{absor} and T_{prod} are the sets that determine the values of the linguistic variables $AtmGG_{absor}$ and $AtmGG_{prod}$. T_{absor} and T_{prod} are fuzzy variables on the numerical set H_{absor} and H_{prod}, which describe the level of soil emission and photosynthetic activity of agricultural plants under the conditions of GE dynamics, respectively.

Scientific studies indicate that carbon dioxide is the main anthropogenic pollutant emitted into the atmosphere as a result of various industrial processes [13, 14]. To assess the yield of agricultural crops, the dispersion and accumulation of CO_2 in the surface layer of the atmosphere are studied. The total concentration of carbon dioxide in the atmosphere compared to other GHGs (CH_4, O_3, N_2O) is the highest. Its annual increase is also due to a long lifespan; however, scientists have long proposed technologies to combat carbon—the technology of capturing and storing CO_2 in geological reservoirs (CCS technology) and the sequestration of atmospheric carbon dioxide by plants to bind with soil organic carbon. Carbon-rich soil is more fertile, which can positively affect the productivity of agricultural areas and contribute to the achievement of the goals of the Paris Agreement on climate change and the achievement of sustainable development goals and adaptation to the conditions of the dynamics of GE. This determined the specification of the set H.

To carry out a comprehensive assessment of the agricultural territory in terms of the mineralization of the humus layer of the soil, which is necessary for making decisions on the zoning of agricultural territories in terms of GE dynamics, the following terms are introduced:

$$T_{absor} = \{T_{absor1}, T_{absor2}, T_{absor3}, T_{absorp4}, T_{absor5}\} \qquad (5)$$

where $T_{absor1} =$ "most effective", such an estimate of carbon dioxide emissions from soil is given when the soil respiration rate is 35.47 ± 0.05 and 55.42 ± 0.07 mol CO_2 m^{-2} s^{-1}.

$T_{absor2} =$ "effective", such estimate of carbon dioxide emissions from soil is given when the soil respiration rate is 16.58 ± 0.05 and 35.47 ± 0.07 mol CO_2 m^{-2} s^{-1}.

$T_{absor3} =$ "moderate", this estimate of carbon dioxide emissions from the soil is given when the soil respiration rate is 6.76 ± 0.08 and 16.58 ± 0.09 mol CO_2 m^{-2} s^{-1}.

$T_{absor4} =$ "low", such estimate of carbon dioxide emissions from the soil is given when the soil respiration rate is 0.58 ± 0.08 and 6.76 ± 0.06 mol CO_2 m^{-2} s^{-1}.

$T_{absor5} =$ "not efficient", such estimate of carbon dioxide emissions from the soil is given when the soil respiration rate is 0.26 ± 0.04 and 0.58 ± 0.07 mol CO_2 m^{-2} s^{-1}.

To describe the agricultural area from the point of view of the photosynthetic activity of agricultural plants under the conditions of GE dynamics, the following terms are introduced:

$$T_{prod} = \{T_{prod1}, T_{prod2}, T_{prod3}, T_{prod4}, T_{prod5}\} \qquad (6)$$

where $T_{prod1} =$ "most effective", such estimate of the GHG concentration in the surface layer of the atmosphere is given when the CO_2 concentration is set in the range of $600 \div 700$ ppm.

$T_{prod2} =$ "effective", such estimate of the GHG concentration in the surface layer of the atmosphere is given when the CO_2 concentration is set in the range of $500 \div 600$ ppm.

$T_{prod3} =$ "moderate", such estimate of the GHG concentration in the surface layer of the atmosphere is given when the concentration of CO_2 is set in the range of $400 \div 500$ ppm.

$T_{prod4} =$ "low", such estimate of the GHG concentration in the surface layer of the atmosphere is given when the CO_2 concentration is set in the range of $300 \div 400$ ppm.

$T_{prod5} =$ "not efficient", such estimate of the GHG concentration in the surface layer of the atmosphere is given when the CO_2 concentration is set below 300 ppm.

To carry out a comprehensive assessment of the agricultural territory in relation to its productivity in terms of GE dynamics, we introduce the following terms with the resulting estimates:

$$T = \{T_1, T_2, T_3, T_4, T_5\} \qquad (7)$$

where $T_1 =$ "maximum productivity", when the assessment in terms of the effect on the level of plant photosynthesis $AtmGG_{absor} =$ "most effective", and the assessment in terms of the emission of the upper humus layer $AtmGG_{prod} =$ "most effective". With such an assessment, the agricultural area can be used for organic farming with high yields, which excludes the use of pesticides, herbicides, chemical fertilizers, various plant growth regulators, as well as genetically modified plant seed.

$T_2 =$ "high productivity" when the assessment of the level of photosynthetic activity of plants $AtmGG_{absor} =$ "effective" and the assessment in terms of emission of the upper humus layer $AtmGG_{prod} =$ "effective" or when one of the assessments is "effective" and the other assessment is "most efficient". With such an assessment, the agricultural area can be effectively used for the cultivation of cultivated plants with high yields.

$T_3 =$ "moderate productivity" when rated in terms of effect on plant photosynthesis $AtmGG_{prod} =$ "moderate" or "effective", and rated in terms of upper humus emission $AtmGG_{absor} =$ "moderate" or "effective". With such an assessment, the agricultural area can be used for the cultivation of crops with above-average yields.

$T_4 =$ "low productivity" when the rating in terms of the effect on the level of plant photosynthesis $AtmGG_{prod} =$ "moderate" or "low" and the rating in terms of the emission of the upper humus layer $AtmGG_{absor} =$ "moderate" or "low". With such an assessment, the agricultural area can be used for the cultivation of crops that are insensitive to an increase in CO_2 concentration.

$T_5 =$ "minimum productivity" when rated in terms of effect on plant photosynthesis $AtmGG_{prod} =$ "not effective" or "low", and rated in terms of upper humus emission $AtmGG_{absor} =$ "low" or "not effective". With such an assessment of the agricultural area, it is recommended to plant annual plants for the mineralization of the humus layer of the soil.

To obtain a comprehensive assessment and make a fuzzy conclusion about the state of agricultural territories regarding the concentration of greenhouse gases in the surface layer of the atmosphere, it is necessary to build the following sets of logical rules:

logical rules:

if $(AtmGG_{absor} = T_{absor1})$ and $(AtmGG_{prod} = T_{prod1})$.
or $(AtmGG_{absor} = T_{absori})$ and $(AtmGG_{prod} = T_{prodj})$.

…

then $AtmGG = T_k$,

where T_{absori}, T_{prodj} are the terms ("most effective", "efficient", "moderate", etc.) included in the base terms of the sets T_{absor}, T_{prod} with dimensions i, j. $T_k \in T$ from (7), $k = \overline{1, 5}$.

As a result of a comprehensive assessment of the agricultural area, obtained as a result of a fuzzy conclusion regarding the impact on the photosynthetic activity of the concentration of greenhouse gases and regarding the CO_2 emission of the soil—$AtmGG = T_k$.

The degree of conformity of the sets H_{prod} and H_{absor} to the terms T_{prodi} and T_{absorj} is determined by the membership functions $\mu_{Tyield\ capacityi}$ $\mu_{Tabsorj.}$, specially compiled for this case. The type and parameters of these functions are determined basing on the opinions of experts in this field regulatory documents and official statistics.

3.2   Algorithm for Forming Control Scenarios

The algorithm for generating management scenarios based on the described method for the integrated assessment of agricultural areas is shown in Fig. 1. At the beginning of

this algorithm, data are collected on the concentration of GHGs in the surface layer of the atmosphere and the level of soil emissions, and the data can be obtained as a result of field measurements or when modeling the forecast level. The next step is to update fuzzy inference systems based on the data obtained. Furthermore, based on the values of the linguistic variables $AtmGG_{absorj}$ and $AtmGG_{prodj}$, fuzzy intermediate estimates $AtmGG_{absor}$ and $AtmGG_{prod}$ are derived. Recording the results of the assessment and indicators of the concentration of greenhouse gases in the surface layer of the atmosphere in the database allows further development of scientifically based management decisions. At the subsequent stages, the final comprehensive assessment of the studied agricultural area is obtained. In the case of obtaining a comprehensive assessment of "maximum productivity", an agrotechnical plan is drawn up for the use and maintenance of the parameters of the territory for organic farming, greater accuracy in the choice of crops and the preparation of an agrotechnical plan for cultivation. If a comprehensive assessment below "maximum productivity" or "high productivity" is obtained, the assessment is also detailed, and an agricultural crop is selected that has the least response to an increased concentration of CO_2 in the surface layer of the atmosphere and an agrotechnical cultivation plan is drawn up, or a crop is selected and an agrotechnical plan is drawn up for mineralization of the humus layer of the soil. At the last stage, recommendations are formed for the adaptation of agricultural areas in the context of the dynamics of GE and visualization of the assessment results using GIS tools.

The described method, based on a situational approach, fuzzy modeling tool and GIS tools, can be effectively used to conduct a comprehensive assessment of the current and forecasted state of agricultural territories from the point of view of planting, as well as to form scientifically based decisions on zoning territories regarding the dynamics of the greenhouse effect to increase productivity [15–18].

3.3   Software Implementation of the Algorithm for Forming Control Scenarios

A software implementation of a comprehensive assessment of the state of an agricultural area has been developed in the MATLAB Fuzzy Logic Toolbox environment using the anfis m-function based on a customized fuzzy inference system. While learning the parameters of the network nodes are adjusted to minimize the standard error (RMSE)—the difference between the experimentally measured indicators e* and the network outputs e:

$$\delta = \sqrt{\frac{1}{N}\sum_{t=1}^{N}([e* - e]^2)} \rightarrow min \qquad (8)$$

where N is the number of observations in the training data set.

A hybrid learning algorithm was used to train the ANFIS network and determine the parameters of the membership functions of Sugeno-type fuzzy inference systems. The network structure is shown in Fig. 2.

The training sample contains n = 200 observations of the dynamics of greenhouse gas concentrations in the surface layer of the atmosphere and the level of carbon dioxide emissions from the soil. The initial value of step 10^{-4} in the direction of the anti-gradient of the criterion δ is set when changing the parameters of the membership functions.
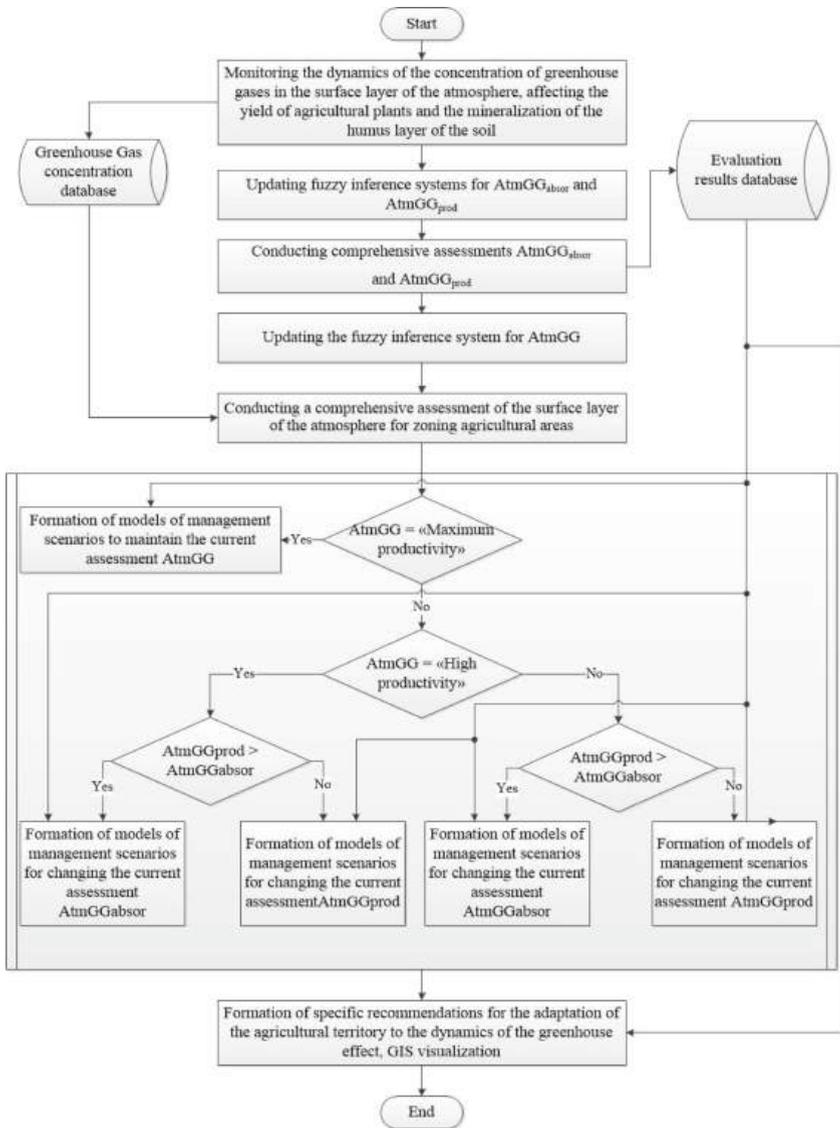
Fig. 1. Formation algorithm of a recommendation for the of agricultural areas adaptation based on the method of integrated assessment

Training set: average error—$2 * 10^{-1}$, maximum error—$4 * 10^{-2}$, recognized—95%. Test set: average error—$2,7 * 10^{-1}$, maximum error—$4,5 * 10^{-2}$, 92% recognized. The dependence of the output variable on the input values is presented as a response surface that performs the function of visualizing dependencies for experts and decision-makers (Fig. 3).
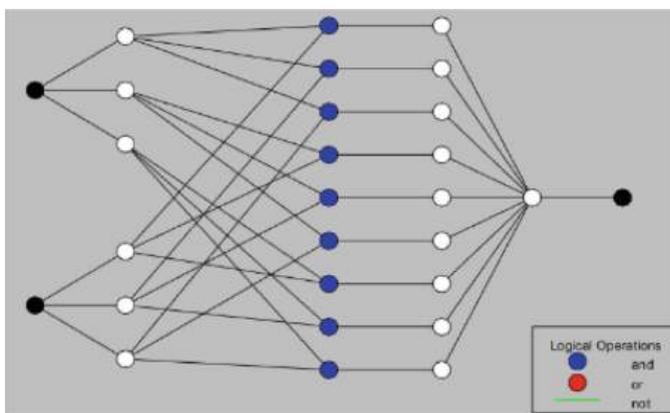
Fig. 2. Structural representation of a neuro-fuzzy network
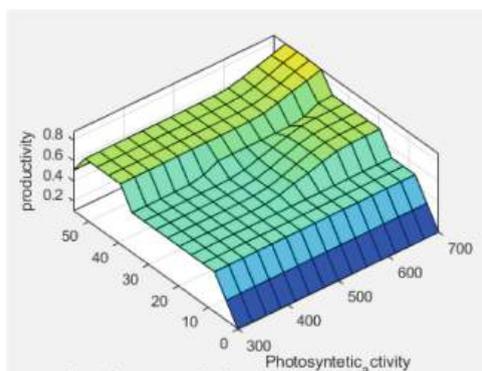
Fig. 3. Response surface

After calculating the integral assessment of the agricultural territory in relation to its productivity in the context of the dynamics of GE and the formation of management models, the question arises of the need to implement specific effective measures aimed at adapting the territories under consideration to the dynamics of GE, which is achieved through adaptive zoning of territories and the choice of agricultural crops with respect to a positive response to the current and predicted distribution of GHG concentration in the surface layer of the atmosphere.

3.4 Suggestions and Implementation Results

In real business conditions, not every agricultural enterprise has all the opportunities to implement the necessary measures to increase plant productivity. Most often, this is due to the high financial costs needed; for example, to switch from classical tillage to no-tillage technology, it will be necessary to re-equip most of the equipment. Therefore,

it seems relevant to use a decision support system that allows you to choose the best set of actions based on the results of a model assessment [19].

The research was carried out in the territory of the Belgorod region, which covers slightly more than 27 thousand square kilometers, where more than 1.5 million (one and a half million) people live. The region is one of the five leaders of the country in the agricultural sector. The experience gained in the close relationship between science, government and business has allowed the Belgorod Region to act as a platform for the creation of a scientific and educational center, the purpose of which is to ensure food independence and security. In addition, industrial enterprises operating in the territory emit approximately 15 thousand tons of gaseous pollutants into the atmosphere on average per year. The main stationary sources of emissions in the territory of Belgorod are ZAO "Belgorod Cement", OAO "Belvitamins", OAO "Belenergomash", and OOO "Belenergomash Boiler Plant". Calculations were also made indicating high emissions of greenhouse gases by motor vehicles—21.5 thousand tons (55% of the total emissions of gaseous pollutants into the atmosphere in Belgorod).

A software package was developed using the C# programming language and the Visual Studio 2022 development environment for the practical application of the described algorithm for management scenario formation and for the adaptation of agricultural territories based on the integrated assessment method, as well as the development of appropriate recommendations.

Taking into account the specifics of crop production in the Belgorod region, lists of measures were developed to increase the yield of agricultural crops—the timing of sowing and harvesting, protection from weeds and pests, crop rotation, tillage technologies, etc.

Fig. 4. Getting recommendations

Figure 4 shows a screen form that allows you to enter information about the moisture and heat supply of the considered agricultural territory, information about the mineral

indicators of the soil. The use of GMap.Net libraries allows you to interact with various GIS systems that determine the possibility of interactive selection of the territory on the map to obtain a comprehensive assessment and visualization of forecasting results.

Based on the described method and the use of the fuzzy logic tool the software solution will make it possible to form specific recommendations for the adaptation of agricultural areas in the context of GE dynamics.

3.5 Conclusion

As a result of the research, an algorithm for a comprehensive assessment of the possible productivity of agricultural territories under the conditions of GE dynamics was proposed, as well as its software implementation. The obtained estimates formed the basis for the creation of a new neuro-fuzzy technology for selecting measures for scientifically based zoning of agricultural territories, which makes it possible to increase the effectiveness of specific management decisions on the adaptation of territories under the conditions of GE dynamics in order to increase productivity, contribute to ensuring the required level of environmental and food security.

References

1. Ivashchuk, O.A., Konstantinov, I.S.: Supporting ecological safety adaptive management in industrial and transport complex. Large Syst. Manag. **25**, 96–115 (2009)
2. Ivashchuk, O.A., Fedorov, V.I., Goncharov, D.V.: Approaches to the development of an automated control system for the adaptation of agricultural areas under the changing greenhouse effect. Math. Stat. Eng. Appl. **3s2**, 948 (2022)
3. Goncharov, D.V., Ivashchuk, O.A., Reznikov, N.G.: Method for modeling and visualization of agricultural crops growth based on augmented reality technology in terms of the greenhouse effect dynamics. International Russian Smart Industry Conference (SmartIndustryCon), Sochi, Russian Federation, p. 66 (2023)
4. Priadkina, H.A.: Pigments, efficiency of photosynthesis and winter wheat productivity. Plant Var. Stud. Prot. **1**, 97–108 (2018)
5. Albegov, R.B., Gagieva, S.S.: Climate change in North Caucasus. Possible threats and countermeasures. Bull. MANEB **4**, 162 (2010)
6. Smithers, J., Blay-Palmer, A.: Technology innovation as a strategy for climate adaptation in agriculture. Appl. Geogr. **21**(2), 175–197 (2001)
7. Torres-Quezada, J., Coch, H., Isalgue, A.: Assessment of the reflectivity and emissivity impact on light metal roofs thermal behaviour, in warm and humid climate. Energy Build. **188**, 200–208 (2019)
8. Druzhinin, P.V., Shkiperova, G.T.: Ecological and economic models and forecasts in the regional management system. Forecast. Probl. **1**, 88–98 (2018)
9. Fuglestvedt, J.S., Berntsen, T.K.: Metrics of climate change: Assessing radiative forcing and emission indices. Clim. Change **58**, 267–331 (2003)

10. Pavlova, V.N., Sirotenko, O.D.: Observed climate changes and dynamics of agricultural productivity in Russia. AI Voeikova **565**, 132–151 (2012)
11. Stupina, A.A., Rozhkova, A.V., Olentsova, J.A.: Digital technologies as a tool for improving the efficiency of the agricultural sector. IOP Conf. Ser.: Earth Environ. Sci. **839**, 22092 (2021)
12. Hossain, M.S., Majumder, A.K.: Impact of climate change on agricultural production and food security: a review on coastal regions of Bangladesh. Int. J. Agric. Res., Innov. Technol. (IJARIT) **8**(2355-2020-1646), 62–69 (2018)
13. Van Meijl, H., Havlik, P., Lotze-Campen, H., Stehfest, E.: Comparing impacts of climate change and mitigation on global agriculture by 2050. Environ. Res. Lett. **13**(6), 64021 (2018)
14. Ryabov, Y., Ponkina, E.V.: Modeling the development of agricultural production: a model of partial equilibrium globiom. Anal., Model., Manag., Dev. Socio-Econ. Syst. **1**, 369–371 (2021)
15. Stehfest, E., van Zeist, W.J., Valin, H., Havlik, P., Popp, A.: Key determinants of global land-use projections. Nat. Commun. **10**(1), 2166 (2019)
16. Sadenova, M.A., Beisekenov, N.A., Rakhymberdina, M.Y.: Mathematical modelling in crop production to predict crop yields. Chem. Eng. Trans. **88**, 1225–1230 (2021)
17. Kiryushin, V.I.: Optimization of agricultural land use by impact on the climate. Earth Environ. Sci. **1**, 1–7 (2022)
18. Li, Y., Wen, W., Miao, T., Wu, S.: Automatic organ-level point cloud segmentation of maize shoots by integrating high-throughput data acquisition and deep learning. Comput. Electron. Agric. **193**, 106702 (2022)
19. Kaur, M.J., Riaz, S.: Cyber-physical cloud computing systems and internet of everything. Princ. Internet Things (IoT) Ecosyst.: Insight Parad. **1**, 201–227 (2020)