METHOD OF FORECASTING THE AGRO-ECOLOGICAL STATE OF SOILS ON THE EXAMPLE OF THE SOUTH OF UKRAINE

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ABSTRACT

Land resources are the main means of production and a factor of socio-economic development and ecological sustainability of environment[1]. The condition of soils is one of the main indicators of the ecological state of the territories, because of the direct impacts from internal factors, which are caused by the use of soils in agricultural production[2] and external influences caused by anthropogenic activities[3]. Unsatisfactory condition of the soil cover in Ukraine, which is confirmed in scientific works of the leading Ukrainian scientists, determines necessity of soil fertility forecasting, which in its term will allow to identify risk zones with the most unfavorable conditions for agricultural activity and to determine the optimal reclamation measures to improve the qualitative state of degraded soil[4]. Forecasting the agro-ecological state of soils makes it possible to establish the spatial-temporal patterns of its changes under the influence of anthropogenic and natural factors. The complexity of the forecasting processes is determined by the multifactorial and temporal conditionality of the destruction of the natural properties of soil fertility[5]. The use of traditional statistical methods to forecast the corresponding complex stochastic and dynamic processes significantly reduces the reliability of the obtained results. The article uses the method of artificial neural networks, which provides the possibility of nonlinear interpretation of large arrays of input data, interactive adaptation of created models to new information, with high accuracy interpret retrospective arrays of data and highly accurate forecasting the nonlinear processes[6]. Using the Statistics Neural Networks (SNN) module, neuromodels of the three-layer perceptron's architecture were created to forecast soil fertility in South of Ukraine in the soil layer 0...20 cm for the main agrochemical parameters[7].

Keywords: artificial neural networks, Statistics Neural Networks (SNN), soil fertility, forecasting, agrochemical parameters.

INTRODUCTION

Intensive agriculture, in particular, increasing the rates of industrial and agricultural load on natural complexes, improper utilization of wastes, causes significant technogenic transformation of the soil cover, which sometimes exceeds the rates of the soil-forming process. Forecasting the risk of contamination and soil fertility reducing in areas where soil sampling has not actually been carried out is crucial to determine the agro-ecological state of the soils, and their further improvement[8]. However, the accuracy of risk assessment depends on many factors, including the methodology used. Therefore, it is proposed to use the artificial neural network method to analyze soil monitoring data. The most important feature of neural networks is their ability to learn basing the environmental data and, as a result, to increase their productivity. Increasing of productivity occurs over the time in accordance with certain rules. The learning process of the neural network proceeds by means of an interactive process of correction of synaptic weights and thresholds. Ideally, the neural network receives knowledge about the environment at each iteration of the learning process[9].

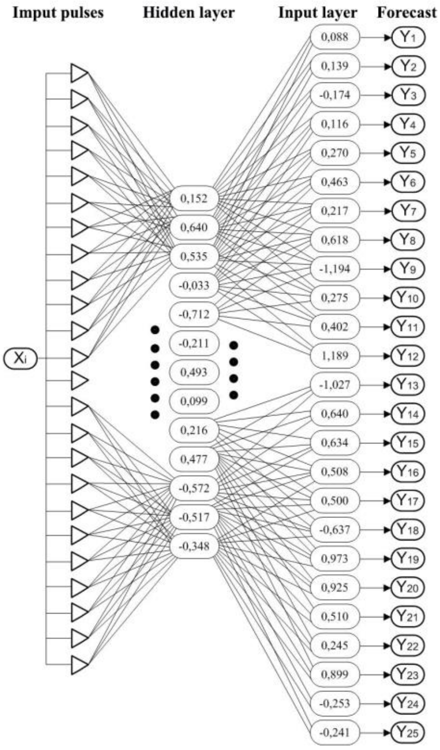
DATA AND METHODS

During the analyzing of approaches to the design of neural networks, their architecture and learning methods, it was decided in the software product to implement a neural network with architecture – a multilayer perceptron, with the ability to adjust the number of layers. An error correction with an algorithm of backtracking the error is selected as the training rule. Since the selected network configuration is suitable for pattern recognition, the corresponding training vectors for the network were selected. Considering the network configuration and the tasks it has to solve, sinusoid-hyperbolic tangent was chosen as the activation function for the neuron[10].

For forecasting the approximated neural models (NM), in particular:

1) humus content - NM with thirteen neurons in the hidden layer, learning method: inverse distribution (100 epochs) and associated gradients (355 epochs), matrix of NM includes 2275 weight coefficients (Figure 1).

Architecture and thresholds of neurons activation:



Network response function:

$$y_i(t) = f(\sum_{j=1}^{13} w_j^{(2)}(t) f(\sum_{n=1}^{150} w_n^{(1)}(t) x_n^{(t)})), \partial e\ i = \overline{1,25}$$

Weight coefficients correction function:

$$E(w(t)) = \frac{1}{2}(\sum_{i=1}^{25}(f(\sum_{j=1}^{13} w_j^{(2)}(t) f(\sum_{n=1}^{150} w_n^{(1)}(t) x_n^{(t)})) - d_i^{(t)})^2)$$

NM learning algorithm:

$$w_{ni}(t+1) = 0{,}02\delta_i x_n(t) + 0{,}7(w_{ni}(t) - w_{ni}(t-1))$$

Neuronal activation function:
sinusoid-hyperbolic tangent
Error of learning and testing network:

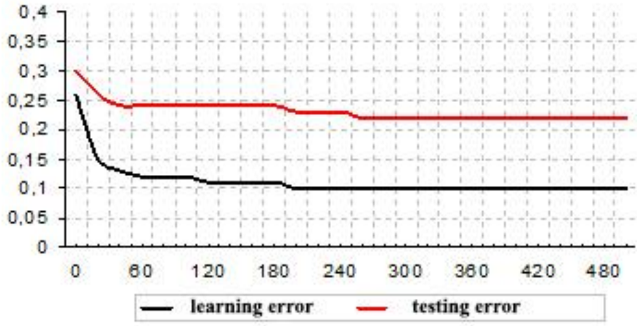


Figure 1 Mathematical implementation of neuron model for the forecasting of humus content in soils

Multilayer NMs have provided the opportunity to approximate correctly the data that was not used in the learning process and to forecast with high accuracy the subsequent changes in soil fertility[8]. The statistical parameters of the reliability of the NM implementation in the training and test samples are presented in Table 1.

The reliability of approximation models and forecasting was determined based on the division of time series into two subsets of 0.7 and 0.3: learning (70% – 28 years) and test (30% – 12 years). The reliability of the models in the test samples was 83–94%, which confirms the high level of approximation of the model, respectively, obtaining the reliable results of the time projection to 2025.

Table 1 Statistical parameters of learning the NM for forecasting changes in agrochemical properties in soils of South of Ukraine

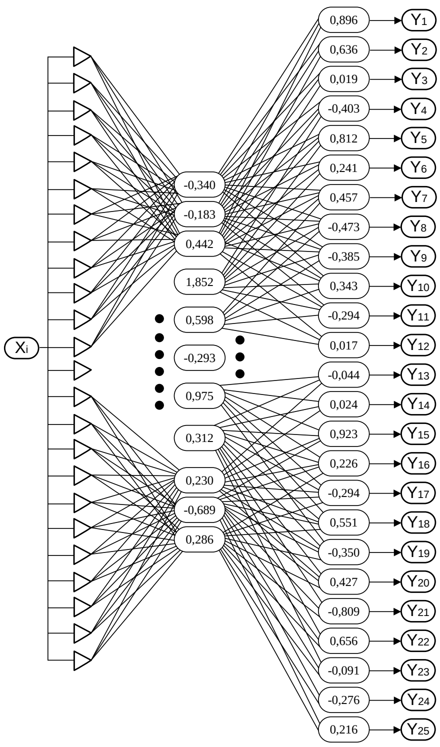
Statistical parameters	Training sample	Test sample
Humus content		
Mathematical expectation of error	0.0009	0.02103
Standard deviation of the error	0.0398	0.06521
Mathematical expectation of absolute error	0.0273	0.05521
Correlation	0.988	0.95408
Moving phosphorus content		
Mathematical expectation of error	0.2014	1.4581
Standard deviation of the error	2.4651	4.0256
Mathematical expectation of absolute error	2.0142	3.9854
Correlation	0.945	0.911
Exchangeable potassium content		
Mathematical expectation of error	0.1904	2.21884
Standard deviation of the error	3.8366	4.26292
Mathematical expectation of absolute error	3.0439	4.03400
Correlation	0.969	0.92887

It is established that under the current conditions of farming it is forecasted: maintaining the tendency of dehumidification of arable soils in the layer of 0...20 cm, on non-irrigated lands its speed will be 0.01% per year, irrigated lands – 0.03% per year; reduction of nitrogen content, on non-irrigated lands – 0.04 mg per year, irrigated – 0.06 mg per year; decrease in the content of movable phosphorus, on non-irrigated – 0.16 mg per year, irrigated – 0.18 mg per year; decrease in the content of exchangeable potassium, on non-irrigated lands – 1.9 mg per year, irrigated – 3.1 mg per year.

Based on data (n = 256) of the spatial distribution of nitrogen and exchangeable potassium, a logarithmic relationship is established between them. This made it possible to determine the trend of NO_3 content in the soils of the South of Ukraine based on P_2O_2. It is forecasted NO_3 reduction - on non-irrigated lands – by 0.04 mg/year, irrigated lands – by 0.06 mg/year.

2) content of moving phosphorus - NM with eleven neurons in the hidden layer, learning method: backward distribution (100 epochs) and related gradients (20 and 472 epochs), matrix of NM includes 1650 weight coefficients (Figure 2).

Architecture and thresholds of neurons activation:



Network response function:

$$y_i(t) = f(\sum_{j=1}^{11} w_j^{(2)}(t) f(\sum_{n=1}^{125} w_n^{(1)}(t) x_n^{(t)})), \partial e \ i = \overline{1,25}$$

Weight coefficients correction function:

$$E(w(t)) = \frac{1}{2}(\sum_{i=1}^{25}(f(\sum_{j=1}^{11} w_j^{(2)}(t) f(\sum_{n=1}^{125} w_n^{(1)}(t) x_n^{(t)})) - d_i^{(t)})^2)$$

NM learning algorithm:

$$w_{ni}(t+1) = 0{,}05\delta_i x_n(t) + 0{,}6(w_{ni}(t) - w_{ni}(t-1))$$

Neuronal activation function:
sinusoid-hyperbolic tangent

Error of learning and testing network:

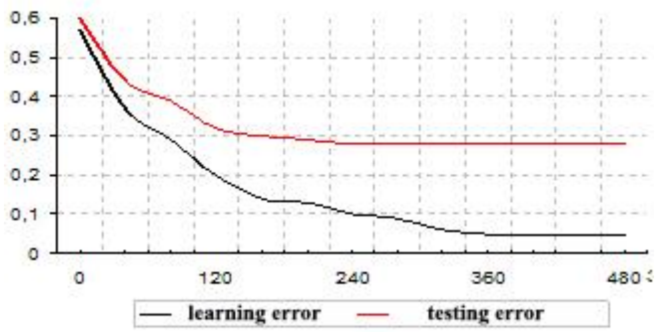


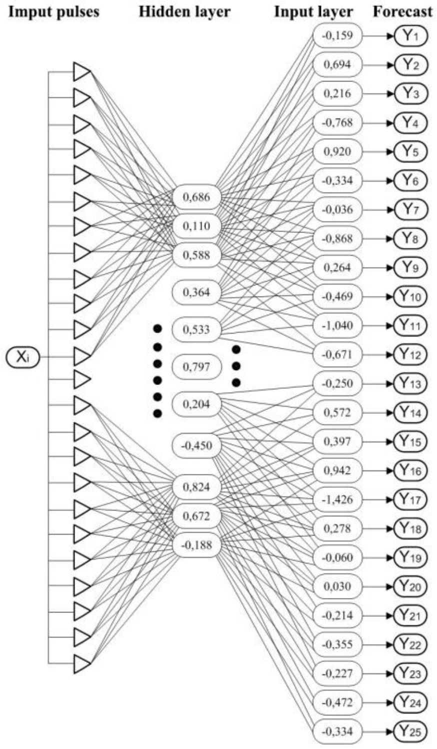
Figure 2 Mathematical implementation of neuron model for the forecasting of moving phosphorus content in soils

Under conditions of saving the 15-year (2005–2020) trend, it is forecasted an annual increasing on non-irrigated lands on average: Mn by 7.40%, Cu by 0.04%, Zn by 0.12%, Cd by 1.40%, Pb - 0.19%; on irrigated lands, the reduction of moving trace elements on average: Mn by 1.50%, Cu - 0.02%, Zn - 0.15% and the increase of metals on average: Cd by 0.18%, Pb - 0.005%.

As a result of spatio-temporal modeling of the agro-ecological state of soils of the Kherson region, it is established that under the conditions of preservation of traditional agriculture the tendency of degradation of the fertile soil layer on non-irrigated and irrigated agricultural lands will be preserved. This will lead to a deterioration in the quality of agricultural products.

3) content of exchangeable potassium - NM with twelve neurons in the hidden layer, learning method: backward distribution (100 epochs) and related gradients (20 and 596 epochs), matrix of NM includes 1800 weight coefficients (Figure 3).

Architecture and thresholds of neurons activation:



Network response function:

$$y_i(t) = f\left(\sum_{j=1}^{12} w_j^{(2)}(t) f\left(\sum_{n=1}^{125} w_n^{(1)}(t) x_n^{(t)}\right)\right), \partial e\ i = \overline{1,25}$$

Weight coefficients correction function:

$$E(w(t)) = \frac{1}{2}\left(\sum_{i=1}^{25}\left(f\left(\sum_{j=1}^{12} w_j^{(2)}(t) f\left(\sum_{n=1}^{125} w_n^{(1)}(t) x_n^{(t)}\right)\right) - d_i^{(t)}\right)^2\right)$$

NM learning algorithm:

$$w_{ni}(t+1) = 0{,}2\delta_i x_n(t) + 0{,}5(w_{ni}(t) - w_{ni}(t-1))$$

Neuronal activation function:
sinusoid-hyperbolic tangent

Error of learning and testing network:

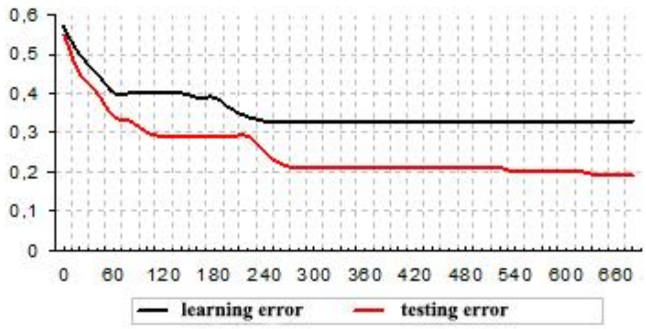


Figure 3 Mathematical implementation of neuron model for the forecasting of exchangeable potassium content in soils

CONCLUSION

Extensive use of agricultural land, disturbances of crop rotations have led to a significant deterioration of the natural properties of soil in the South of Ukraine during the last 47 years by the main agrochemical parameters: humus content in the layer of 0…20 cm of soil decreased by an average of 16.0%, nitrogen of 26.92% , moving phosphorus by 34.84%, exchangeable potassium by 25.52%. Under the conditions of continuing the current farming model, it is predicted that the trend of arable soil dehumidification will continue, its rate will be in the range of 0.01% - 0.03% per year, reduction of nitrogen content from 0.04 mg to 0.06 mg per year, content of moving phosphorus by 0.16-0.18 mg per year, the content of exchangeable potassium by 1.9-3.1 mg per year.

There is a tendency to increase the content of moving trace elements and heavy metals, especially on non-irrigated lands on average: Mn by 10 mg / kg, Cu - 0.07 mg / kg, Zn - 0.4 mg / kg, Cd - 0.15 mg / kg, Pb - 0.35 mg / kg. On irrigated lands there is a decrease in Mn by an average of 2 mg / kg, Cu - 0.03 mg / kg, Zn - 0.5 mg / kg, but there is a slight accumulation of the content of heavy metals: Cd - 0.06 mg / kg, Pb - 0.01 mg / kg.

The forecast of average increase of the trace elements on the non-irrigated lands: Mn by 7.40%, Cu - 0.04%, Zn - 0.12%, Cd - 1.40%, Pb - 0.19%; on irrigated lands, the reduction of moving trace elements on average: Mn by 1.50%, Cu - 0.02%, Zn - 0.15% and the increase in heavy metals on average: Cd by 0.18%, Pb - 0.005%. This trend is a confirmation of the need to implement national and regional environmental policies and appropriate programs for the protection, rational use, reproduction of land resources.

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