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USE OF ARTIFICIAL NEURAL NETWORKS IN PREDICTING DIRECT NITROUS OXIDE EMISSIONS FROM AGRICULTURAL SOILS

ZASTOSOWANIE SZTUCZNYCH SIECI NEURONOWYCH W PRZEWIDYWANIU BEZPOŚREDNICH EMISJI PODTLENKU AZOTU Z GLEB ROLNYCH

Abstract: Agricultural greenhouse gases emissions are mainly produced in direct emissions from plant and animal production as well as those associated with land use changes. Agriculture is a major source of atmospheric nitrous oxide (N_2O). N_2O emissions from agricultural production has the source primarily in soil fertilized by mineral and organic fertilizers. In Poland, agricultural soils are responsible for 77.1% of emissions. Emissions associated with the animal manner farming amount 22.8%. Studies attempt to modeling and predicting of N_2O emissions from Direct Soil Emissions in relation to the use of crops and livestock population. In the analysis an artificial neural networks were used. The best values showing the quality of neural regression model were obtained by multilayer perceptrons MLP. Based on the sensitivity analysis, attempts were taken to determine the extent of the contribution of each selected variables on the estimate of the direct emissions of N_2O from agricultural soils. The sensitivity analysis of designed network on the structure MLP 9-4-1 shows that the amount of nitrogen fertilizer consumption has the biggest share in the shaping of N_2O emissions from Direct Soil Emissions. The sensitivity analysis of network on the structure MLP 16-5-1 pointed to participate cattle and pigs as the most important in the formation of N_2O emissions from Direct Soil Emissions. Among the crops in Poland, which may affect the release of N_2O stands out rapeseed and rye. The study was conducted using the statistical package Statistica v. 10.0.

Keywords: greenhouse gases, nitrous oxide, Direct Soil Emissions, modeling, predicting, artificial neural network, livestock production, crops

Introduction

Agriculture is a major source of atmospheric nitrous oxide (N_2O) [1], one of the three most important greenhouse gases [2]. In agriculture, its emissions have increased mainly due to increased efficiency of processes of nitrification and denitrification [3-6]. Agricultural soils have been identified to contribute at present about 60% to the global anthropogenic nitrous oxide emissions [7]. Magnitude of N_2O production depending

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significantly on the availability of N in the plant-soil system [8]. As a result direct and indirect emissions of N_2O can be distinguished. Direct emission sources include: the use of nitrogen fertilizers, organic nitrogen emissions in animal faeces, land management and storage of sewage sludge. Indirect emissions come mainly from the evaporation of precipitation, surface runoff and leaching of nitrogen into groundwater and surface water [9, 10].

N_2O emissions from agricultural production has the main source in soil fertilized by mineral and organic fertilizers [11, 12]. Since 1970, N_2O emissions have grown mainly as a result of increased use of mineral fertilizers worldwide [13, 14]. Its consumption will continue to increase to meet the food requirements of the increasing world population [15, 16].

In Poland, agricultural soils are responsible for 77.1% of emissions. Emissions associated with the animal manner farming amount 22.8%. The smallest share of N_2O emissions comes from combustion plant residues - 0.1% [17]. The total area of agricultural land in good agricultural condition was 83.3% in 2011, while it was accounted for 68.5% of the area under sowing. The structure was dominated by cereal crops - 73.8% of the total sown area, 10.0% of the total crop area was occupied by industrial crops and 9.6% by fodder crops [18].

Application of N fertilizers and animal production accounts for about 60% of the global N_2O emissions from agriculture. Studies showed that emissions from animal waste can be significant [19-21]. Potential sources of N_2O emissions from animal production are: animal emissions, emissions from animal waste, waste emissions from closed animals and emissions left on the soil during grazing [22]. Emissions released with the use of manure as a fertilizer (excluding emissions from grazing animals) are considered to be direct N_2O emissions from agricultural soils [23]. Because of their content and availability of minerals natural fertilizers are an important yielding factor for plants [24].

Changes in greenhouse gas emissions from agriculture, nitrous oxide among others, are dependent on many factors, including the of livestock population, the composition of the feed used, methods of fertilization and others [25].

World applied models of NO_x emissions from soils are used for the global inventory of N_2O emissions, although none of them is used throughout the world [5]. Research should also take into account other parameters such as the climate, cultivation characteristics and other conditions prevailing in the specific country. All the information complementary to the knowledge in the field of emissions released from the agricultural sector is a valuable source of knowledge.

The aim of the study

The undertaken scientific problem has been resolved to formulate answers for the following questions:

1. What kind of neural topology is suitable for modeling of N_2O emissions from Direct Soil Emissions in relation to the use of crops and livestock population?
2. To what extent the selected representative variables affect the efficiency of the generated neural model to the forecast of the production level of N_2O emissions from Direct Soil Emissions?

Methodology research

Using classical statistical methods is indicated at variable linear dependency. However, many phenomena are characterized by non-linear nature which precludes the possibility of the use of traditional methods. In such cases artificial neural networks can be applied. They combine a set of input variables with a set of output variables.

The study was conducted using the statistical package Statistica v. 10.0. Regression problems in the Statistica Neural Networks can be solved by various types of networks: multilayer perceptrons MLP, radial networks (Bayesian networks), regression networks and linear networks [26]. One of the well-known methods commonly used for network learning is algorithm of back-propagation errors [27]. The automatic designer of ANN is searching simultaneously many types of networks. The designer tries to maintain a balance between a network error and its diversity, what means he seeks to keep the representatives of different networks, despite the fact that they will not be the most perfect networks. The analyzed set was divided into three subsets (In scale: learning 2: validation 1: test 1). There were generated hundreds of neural networks with different numbers of neurons in the hidden layers, which were learnt by algorithm of back-propagation errors. Models have been tested and verified by the way "in back", consisting in the issue of forecasts by the network, which coincide with the real results. In the analyzed cases, models shall be considered as correct and suitable for forecasting parameters "forward" on the basis of set, new input variables.

Modeling was performed on the two sets of data. The first set of data included the following input variables: arable land and permanent crops, permanent meadows and pastures, nitrogen fertilizers use, and animal population: cattle, horses, pigs, sheeps, goats and poultry and the output variable direct N_2O emissions from soils. The results of the sensitivity analysis indicating a high share of nitrogen fertilizers use (the main source) in N_2O emissions and arable land and permanent crops have affected the shape of the emission of the second data set.

On the basis of the second model it was intended to analyze the extent to which the size of crops and livestock can shape the size of N_2O emissions from Direct Soil Emissions. The second data set consisted of independent variables in the form of major crops in Poland: wheat, barley, triticale, rye, maize, sugar beet, rapeseed, oats, potatoes; also permanent meadows and permanent pasture, animal population as above and the dependent variable as a Direct Soil Emissions. Data (the last two decades) were obtained from databases: Food and Agriculture Organization of the United Nations (FAO) [28], International Fertilizer Industry Association (IFA) [29] and the United Nations Framework Convention on Climate Change (UNFCCC) [30].

The results of research

The best values showing the quality of neural regression model were obtained by multilayer perceptrons MLP. Based on the sensitivity analysis, attempts were taken to determine the extent of the contribution of each selected variables (input variables to the model) on the estimate of the direct emissions of N_2O from agricultural soils (variable output). Hundreds of neural networks with different numbers of neurons in the hidden layers were tested.

Using the first set of data, the best prediction of the effectiveness obtained a three-layer MLP network with a 9-th neurons in the first layer, 4-th in the hidden layer and 1 output layer. Parameters which indicate the quality of the network are the prediction errors for a group of learning, testing and validation cases. Similar values for validation and testing errors testify that the network well generalizes acquired knowledge [31, 32] (Table 1).

Table 1

MLP 9-4-1 Network characteristic

Type of network	**MLP 9-4-1**
Quality (learning)	0.997732
Quality (testing)	0.999987
Quality (validation)	0.984152
Error (learning)	0.000003
Error (testing)	0.000005
Error (validation)	0.000004
Algorithm of learning	BFGS 24

On the basis of the sensitivity analysis it was found that for the forecasted N_2O emissions the greatest impact has the amount of nitrogen fertilizer used and the smallest one - the goats population. A significant impact on emissions has cattle and horses population and the area of arable land. All input variables are significant (Table 2).

Table 2

Sensitivity analysis of the neural network MLP 9-4-1

Nitrogen fertilizer use	184.4643
Cattle	48.1976
Horses	22.4219
Arable land and permanent crops	6.7279
Poultry	4.718
Sheeps	4.1374
Permanent meadow and pasture	4.0869
Pigs	2.4548
Goats	2.4069

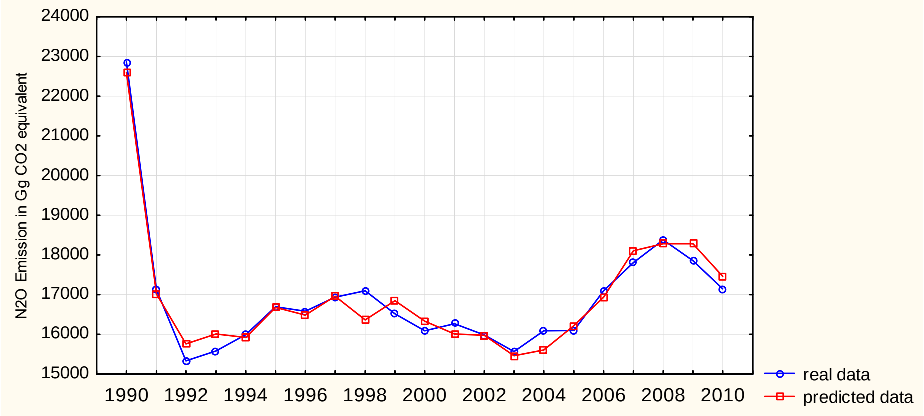

Fig. 1. The N_2O emission values of the real and modeled

The real data were compared with the projected ones. Forecasted courses of changes of the variable coincide very closely with the actual data, which means a high model fit to the data (Fig. 1).

Below predictive capabilities of model MLP 9-4-1 are presented. It was assumed theoretically the variability (reduction and growth) of nitrogen fertilizers used in subsequent years by 1%. Figure 2 shows forecasted N_2O emissions. According to the predictions, the reduction of fertilizer use by 10% would reduce N_2O emissions from the current level (about 12,200 Gg N_2O emission in CO_2 equivalent) to approximately 10,100 Gg N_2O emission in CO_2 equivalent, and in the following years expected to approximately 9350 Gg N_2O emission in CO_2 equivalent.

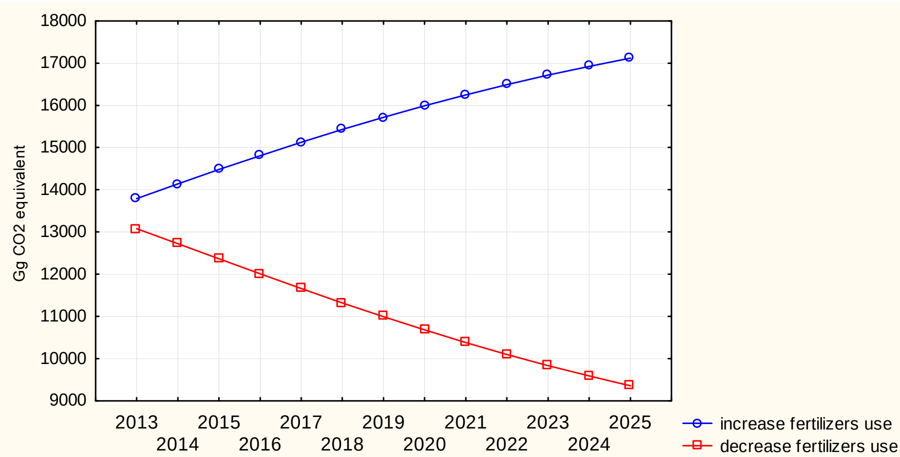

Fig. 2. Forecasted N_2O emissions with projected reductions and increase in fertilizer consumption by 1% in the following years

In the second case study one has resigned from the variable of nitrogen fertilizer use (highly correlated with N_2O emissions), and its impact on emissions has been attempted to estimate through the use of real crops. In place of the variable - arable land and permanent crops have been fixed by more important areas of harvest crops. Several hundred networks with the number of neurons in the hidden layers from 4 to 16 have been tested. The analysis of parameters has shown that the best network model was obtained for the MLP 16-5-1 (Table 3).

Table 3

MLP 9-4-1 Network characteristics

Type of network	**MLP 16-5-1**
Quality (learning)	0.980232
Quality (testing)	0.985379
Quality (validation)	0.999961
Error (learning)	0.000034
Error (testing)	0.000019
Error (validation)	0.000026
Algorithm of learning	BFGS 22

Carried out sensitivity analysis of network on the output variable indicates the importance of livestock, mainly cattle and pigs, and among the crops dominant importance have rapeseed and rye. Other input variables are also important. The smallest influence on N_2O emission was observed for triticale and barley.

Table 4

Analysis of the neural network sensitivity MLP 16-5-1

Cattle	8.8297
Pigs	8.5501
Rapeseed	7.0464
Rye	6.0892
Oats	4.9539
Permanent meadow and pasture	4.6531
Horses	4.0586
Patatos	3.5325
Sheeps	3.3481
Mize	2.8543
Wheat	2.4599
Goats	2.3808
Sugar beet	2.3343
Poultry	2.2153
Barley	1.9479
Triticale	1.9027

A significant share in the production of N_2O is cattle population [24]. The largest amount of nitrogen is released from the cattle faeces (dairy cows 70 kg/pcs/year, other cattle 50 kg/pcs/year) [33]. In the pigs case, this value is 20 kg/pcs/year and even though it is lower for the goats or horses, because of the size of pig production in Poland (*eg* pig approximately 14.860 million pcs, horses approximately 291 thousand pcs, goats approximately 122 thousand pcs), it remains very important. Significant rapeseed influence on the N_2O emissions from Direct Soil Emissions may be found in requirements of the intensive fertilization.

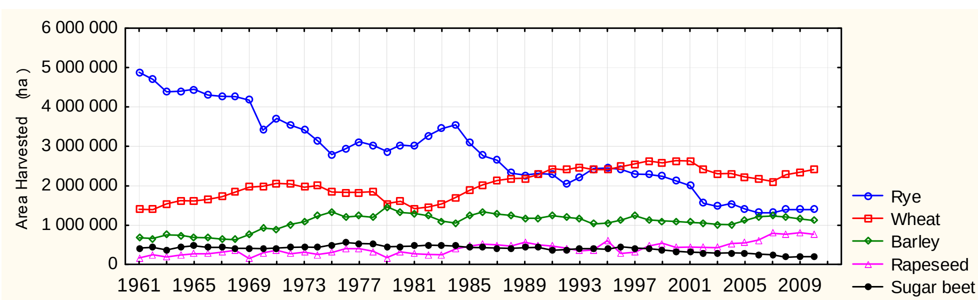

Fig. 3. The size of the areas leading crops in Poland at the turn of 1961-2010 (FAO)

In Poland, mainly winter oilseed rape is grown. Among the agronomic factors determining the rapeseed yield, the nitrogen fertilization is the most important [34]. Oilseed rape has very high requirements for nutrients and fertilizers [35] and already in the autumn retrieves considerable amounts of nutrients, mainly nitrogen (50 kg N ha) and potassium (up to 70 kg K per hectare). Among the crops considered important significance was also achieved for rye. Its importance indicates the surface area. At the turn of a few decades, rye was the main grain cultivated in Poland. Its significance successively has decreased in recent years (Fig. 3). Rye yielding potential takes place with a high mineral fertilizer, particularly nitrogen.

The use of the model to forecast indicates its high predictive capabilities, as evidenced by the coincide results with the real values (Fig. 4).

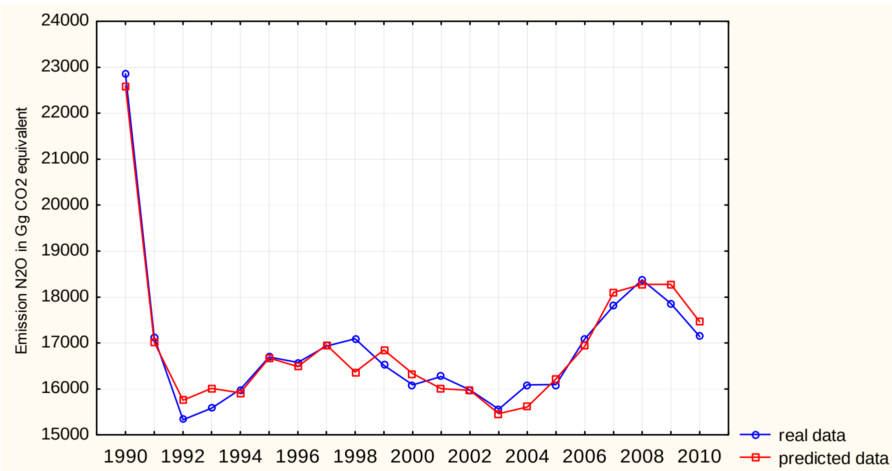

Fig. 4. The N_2O emission values of the real and modeled

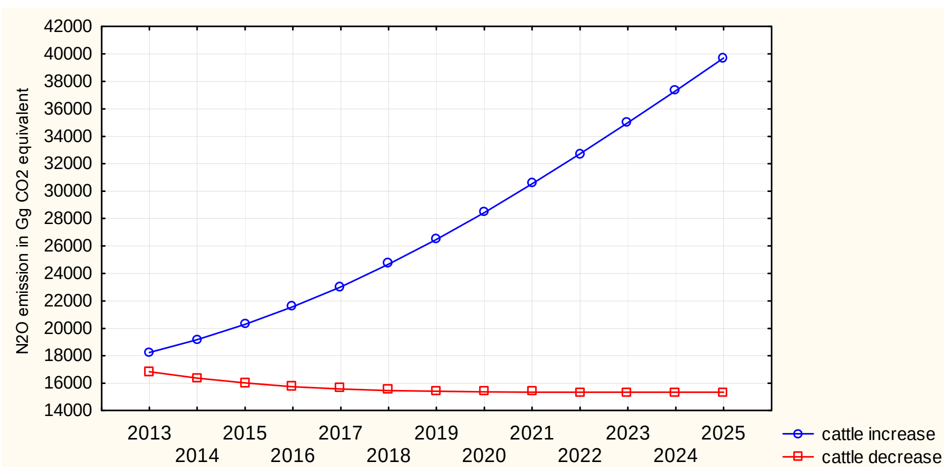

Fig. 5. Forecasted N_2O emissions with projected reductions and increase in cattle population by 1% in the following years

The selected neural model, based on previously acquired knowledge, has been used to predict the value of N_2O, taking into account the most significant variable obtained by the sensitivity analysis. The sensitivity of variable of cattle is depicted by the forecast carried out (Fig. 5). The assumed growth and decline of cattle stock by 1% in the following years and the impact on the output variable was observed. Predictions of N_2O emissions showed that the increase in the number of cattle by 1% results in the increase of emissions in the initial years an average of about 1,100 Gg N_2O emission in CO_2 equivalent, and in subsequent years of cattle increase to an average of about 2200 to even about 2350 Gg N_2O emission in CO_2 equivalent in the last forecasted year. Other trends in shaping the N_2O emissions were observed at the drop of cattle stock. With a decrease the reduction is observed but at a much slower rate and time-interval (Fig. 5).

Conclusions

Artificial neural networks are currently one of the most dynamically developing branch of artificial intelligence. They are used to solve problems that standard algorithms cannot cope with. They have the capability to adapt to the generalization namely the ability of the neural network to the approximation of the value of a function of several variables.

The presented study developed hundreds of networks models, which have been verified. The coefficient values quality of learning networks entitle to determine that the designed networks (multilayer perceptron MLP structure 9-4-1 and 16-5-1) allow a prognosis and are an effective tool to predict direct N_2O emissions from agricultural land on the basis of input variables implemented.

The sensitivity analysis of designed network on the structure MLP 9-4-1 shows that the amount of nitrogen fertilizer consumption has the biggest share in the shaping of N_2O emissions from Direct Soil Emissions.

The sensitivity analysis of network on the structure MLP 16-5-1 pointed to participate cattle and pigs as the most important in the formation of N_2O emissions from Direct Soil Emissions. Among the crops in Poland, which may affect the release of N_2O stands out rapeseed and rye.

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ZASTOSOWANIE SZTUCZNYCH SIECI NEURONOWYCH W PRZEWIDYWANIU BEZPOŚREDNICH EMISJI PODTLENKU AZOTU Z GLEB ROLNYCH

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Abstrakt: Emisje rolnicze głównych gazów cieplarnianych to głównie bezpośrednie emisje wytwarzane w produkcji roślinnej i zwierzęcej, jak również te związane ze zmianami w sposobie użytkowania gruntów. Rolnictwo jest głównym źródłem atmosferycznego podtlenku azotu (N_2O). Emisja N_2O z produkcji rolniczej ma źródło przede wszystkim w glebie nawożonej nawozami mineralnymi i organicznymi. W Polsce gleby rolne odpowiedzialne są za 77,1% emisji N_2O. Emisja związana z gospodarką odchodami zwierząt wynosi 22,8%. W badaniach podjęto próby modelowania i przewidywania bezpośrednich emisji N_2O z gleb w odniesieniu do wielkości upraw i pogłowia zwierząt hodowlanych. W analizach posłużono się sztucznymi sieciami neuronowymi. Najlepsze wartości parametrów mówiących o jakości neuronowego modelu regresyjnego uzyskały perceptrony wielowarstwowe MLP. Na podstawie analizy wrażliwości zaprojektowanego modelu sztucznej sieci neuronowej podjęto próbę ustalenia stopnia udziału poszczególnych wybranych zmiennych na prognozowaną wielkość bezpośrednich emisji N_2O z gleb rolnych. Analiza wrażliwości zaprojektowanej sieci MLP o strukturze 9-4-1 wykazała, że poziom zużycia nawozów azotowych ma największy udział w kształtowaniu emisji N_2O z gleb rolnych. Analiza wrażliwości sieci MLP o strukturze 16-5-1 wskazała na udział bydła i trzody chlewnej jako najistotniejszy w kształtowaniu emisji N_2O. Wśród upraw w Polsce, które mogą wpływać na wielkość uwalnianych emisji N_2O, wyróżnia się rzepak oraz żyto. Badanie przeprowadzono z wykorzystaniem pakietu statystycznego Statistica v. 10.0.

Słowa kluczowe: gazy cieplarniane, podtlenek azotu, bezpośrednie emisje z gleb, modelowanie, prognozowanie, sztuczne sieci neuronowe, zwierzęta hodowlane, uprawy