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ATTEMPT AT AN APPLICATION OF NEURAL NETWORKS FOR ASSESSMENT OF THE NITROGEN CONTENT IN MEADOW SWARD ON THE BASIS OF LONG-TERM FERTILIZER EXPERIMENTS

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Abstract

On the basis of long-term fertilizer experiment, conducted since 1968, an attempt was made to verify the nitrogen content with the use of a neural network, in terms of yields from subsequent cuts. The experiment is located at Czarny Potok village near Krynica (20°54′ E; 49°24′ N) on the altitude of about 720 m a.s.l., at the foot of Jaworzyna Krynicka Mt., in the south-eastern Beskid Sądecki mountain range, on a slope with 7° inclination and NNE aspect. The experiment was set up in 1968 on a natural type of mountain meadow of mat-grass (*Nardus stricta* L.) and red fescue (*Festuca rubra* L.) with a large share of dicotyledonous plants. The soil was classified to acid brown soils developed from the Magura sandstone with the texture of light silt loam. Since autumn 1985, the experiment has been conducted in two series, with the same level of fertilization: without liming (0 Ca) and limed (+Ca). Liming was repeated in 1995. The first liming was conducted with a dose calculated on the basis of 0.5 Hh value, the second one was established according to the total hydrolytic acidity. Mineral fertilization was discontinued in 1974 - 1975 and in 1993 - 1994, when the experiment was limited to an assessment of the sward yield and its chemical composition. The experiment comprises 8 treatments with five replications, receiving either nitrogen or phosphorus fertilization (90 kg N or 39.24 kg P ha^{-1}) and (39.24 kg P ha^{-1} and 124.5 kg K ha^{-1}) against the PK background, nitrogen in two forms (ammonium nitrate and urea) and two doses (90 and 180 N ha^{-1}). In 1968-1980, phosphorous and potassium fertilizers were sown in autumn and since 1981 – in spring. However, potassium (1/2 of the dose) was supplemented in summer after I cut. In 1968 - 1973, thermophosphate was applied, but triple superphosphate has been used since 1976. Over the whole period of the experiment, nitrogen fertilizers have been sown at two dates: 2/3 of the annual dose in the spring at the onset of plant growth and 1/3 of the dose several days after the first cut. A single regenerative treatment with copper (10 kg kg^{-1}) and magnesium (8 kg ha^{-1}) was applied once in 1994. Foliar nutrition (2 dm^3 ha^{-1} applied twice) with the microelement fertilizer Mikrovit-1 has been used since 2000. The microelement fertilizer contains (per 1 dm^3): 23.3 g Mg; 2.3 g Fe; 2.5 g Cu; 2.7 g Mn; 1.8 g Zn; 0.15 g B and 0.1 g Mo. The model was compared with a regression analysis. Statistical analysis was applied for two data sets: the whole data set, i.e. 43 years and 8 treatments, 2 cuts and 2 series – data of the 1st set (n = 1376), and a narrow data set, comprising

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exclusively fertilization 90 kg N ha^{-1}, irrespective of the form against the background of PK – 43 years and 2 objects, 2 cuts and 2 series – data of the 2^{nd} set (*n* = 344). A neural network can be applied in the assessment of the nitrogen content on the basis of yield including subsequent years of nitrogen fertilization and cuts. Neural networks including quantitative and qualitative features are useful for modelling the element content.

Key words: neural networks, nitrogen, sword.

INTRODUCTION

Long-term fertilizer experiments are ascribed a number of aims justifying a need for their continuation. One of these is creating data resources for elaborating and testing simulation models allowing for assessing the influence of agrotechnical factors on soil and plants, and providing practical information for farmers about the ways of improving farming systems and observe sustainability (Bakker et al. 2002, Grzebisz et al. 2010). Due to a number of diverse factors simultaneously affecting the results of an experiment, these problems are difficult to asses unanimously and use in practice. Even experiments on monocultures are susceptible to changeability of the weather conditions. Synthetic indicators of e.g. rainfall in natural conditions are not always strictly related to the yield.

Because of botanic diversification and fluctuation of meadow community species, long-term investigations of grasslands have their own specific character. An attempt at the assessment based on regression in these experiments is usually not unanimous. Seeking an explanation of processes occurring in the environment, also important from the practical point of view, may lead to the application of non-linear solutions based on neural networks (Stastny et al. 2011). The results demonstrated that the neural network model is capable of sugar beet leaf nitrogen estimation with reasonable accuracy (Moghaddam et al. 2010). The new integrated approach (continuum-removed absorption features, the REP and a neural network) could explain 60% of the variation in savanna grass nitrogen concentration on an independent test data set using airborne hyperspectral data (Mutanga, Skidmore 2004).

In practice neural networks require an introduction of verified input and output layer of dependent variable. This requires experimental data and the long term experiment allows to create data bases and fulfil statistical assumptions.

On the basis of long-term fertilizer experiment in Czarny Potok, conducted since 1968, an attempt was made to verify the nitrogen content basing on a neural network considering yields of subsequent cuts. The model was compared with regression analysis.

MATERIALS AND METHODS

The experiment (Mazur, Mazur 1972) is located in Czarny Potok near Krynica (Poland, 20°54′53″ E; 49°24′35″ N) at an altitude of about 720 m a.s.l. at the foot Jaworzyna Krynicka Mt. in the south-eastern massif of the Beskid Sądecki Mts. on aslope with 7° inclination and NNE aspect. The experiment was set up in 1968 on a natural mountain meadow of *Nardus stricta* L. and *Festuca rubra* L. type with a considerable share of the dicotyledonous. The soil from the experimental area was classified to acid brown soils developed from the Magura sandstone with granulometric composition of light silt loam (the following % of fractions: 1-0.1 mm – 40; 0.1-0.02 mm – 37; > 0.02 mm – 23) and characteristic three genetic horizons: AhA (0-20 cm – humus horizon), ABr (21-46 cm – browning horizon) and BbrC (47-75 cm parent rock). Detailed experiment data were presented in the previous papers (Kopeć 2000), in Table 1 and Figure 1.

The one factorial experiments experiment, carried on in 5 replications included 8 fertilizer treatments (Table 2).

Since autumn 1985 the experiment, at the same doses of NPK fertilizers, has been conducted in two series, without liming and with lime application. In 1995 and 2005 liming was repeated. In 1985 and 2005 years the dose of

Table 1

Soil properties before the experiment outset

Layer (cm)	pH_{H_2O}	pH_{KCl}	Hh	Hw	P	K	Exchangeable ions (mg kg^{-1} soil)			
			(cmol (+) kg^{-1} soil)		(mg kg^{-1}soil)		Ca	Mg	Na	K
0-10	5.20	4.38	4.42	0.46	4.8	112.0	680	38.0	20.0	69.0
10-20	5.58	4.48	4.04	0.65	2.6	23.3	540	28.0	18.0	61.0

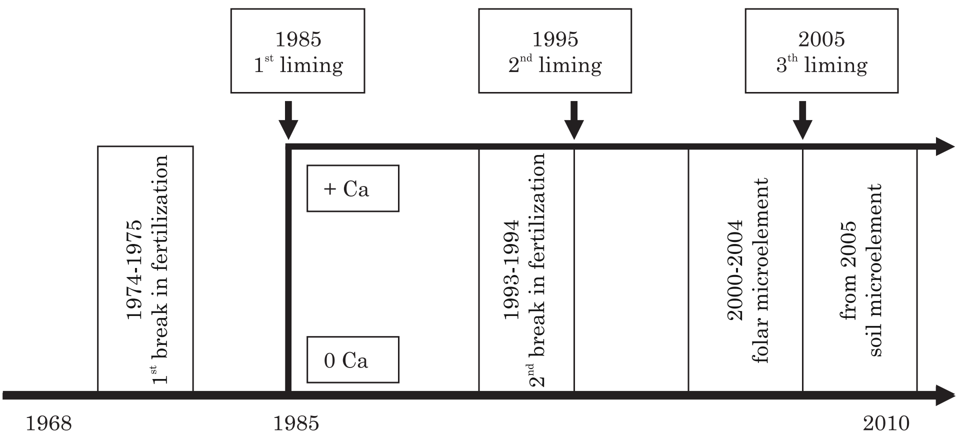

Fig. 1. Scheme of modification of cultivation measures in the experiment

Table 2

Fertilization scheme in the static experiment in Czarny Potok

Fertilizer objects	Annual dose (1985, 1995, 2005) of the element in series 0 Ca and +Ca (kg ha^{-1})			Nitrogenfertilizer	Microelements
	P	K	N		
„0"	-	-	-		B, Cu, Zn, Mn, Co, Mo
N_1	-	-	90	ammonium nitrate	B, Cu, Zn, Mn, Co, Mo
P	39.24	-	-		B, Cu, Zn, Mn, Co, Mo
PK	39.24	124.5	-		B, Cu, Zn, Mn, Co, Mo
PK +N_{1an}	39.24	124.5	90	ammonium nitrate	B, Cu, Zn, Mn, Co, Mo
PK+$N_{1u/an}$	39.24	124.5	90	urea to 2004/ ammonium nitrate from 2005	0 mikroel.*
PK+N_{2an}	39.24	124.5	180	ammonium nitrate	B, Cu, Zn, Mn, Co, Mo
PK+$N_{2u/an}$	39.24	124.5	180	urea to 2004/ ammonium nitrate from 2005	0 mikroel.

* 0 mikroel. – without microelements; P = 90 kg P_2O_5, K = 150 kg K_2O; a.n. – ammonium nitrate; u. – urea; 0 Ca unlimed series; + Ca limed series

limestone was calculated according to 0.5 Hh and in 1995 according to 1 Hh. In the years 1974-1975 and 1993-1994 no mineral fertilization was applied, and the research was limited to determining the sward yield and its chemical composition.

In 1968-1980 phosphorus and potassium fertilizers were applied in autumn. Since 1981 phosphorus fertilizers have been applied in spring, and potassium fertilizers in half dose in spring and half in summer, after the 1st cut. Phosphorus in the years 1968-1973 was in form of calcium thermophosphate (superthomasine) in the years 1975-1992 as triple superphosphate (46%) and since 2005 as enriched superphosphate (40%). In the whole period of the experiment 2/3 of the nitrogen fertilizers annual dose has been in spring at the beginning of vegetation and 1/3 of the dose about two weeks after 1st cut. In 1994, a single dose of 10 kg Cu and 8 kg Mg ha^{-1} in solid fertilizers were applied. In the years 2000-2004 foliar fertilization was conducted (twice 2 dm^3 ha^{-1}) using Mikrovit-1 fertilizer. The fertilizer contained in 1 dm^3: 23.3 g Mg; 2.3 g Fe; 2.5 g Cu; 2.7 g Mn; 1.8 g Zn; 0.15 g B and 0.1 g Mo. In the 2005-2007 periods, 0.5 g B ha^{-1} was supplied to the soil every year, whereas in the spring, 2008, 5 kg Cu, Zn and Mn ha^{-1} and 0.5 kg of Co and Mo ha^{-1} were added.

Vegetation period in the experimental area lasts from April to September (150-190 days). The weather conditions (Table 3) indicate a considerable rainfall variability.

Yields of sward fresh masses were harvested from each plot twice a year (at the turn of June and July and in September), in the initial period from the area of 42 m^2 and when liming was introduced from a 21 m^2 plot. After dry mass determination yield, samples were converted into t d.m. ha^{-1}.

During over a 40-year period of the experiment various aims were set and research hypotheses were put forward. For the sake of presentation, the whole period of research (42 years) was divided into several-year stages (Table 4) according to the applied cultivation measures. The stages cover the year of the measure application as the subsequent years i.e. its direct and residual effect.

Table 3

Statistical characteristics of precipitation and temperatures for the period 1968-2008

Parametr	Precipitation (mm)		Temperature (°C)	
	I–XII	IV–IX	I–XII	IV–IX
Arithmetical mean	876.4	568.5	5.86	12.19
Standard deviation	198.7	138.0	0.87	0.77
Range 25-75% of cases	733.2-990.0	461.5-658.2	5.35-6.30	11.7-12.7

Table 4

Stages of the experiment (Kopeć, Mazur 2011)

Stage No.	Period	Description of the stage
1	1968-1970	3-year period of introducing fertilization
2	1971-1973	3-year period of experiment continuation
3	1974-1976	1st break in fertilization (for two years) and the year of fertilization resumption
4	1977-1980	4-year period after resumption of fertilization
5	1981-1984	4-year period of fertilization continuation
6	1985-1988	4-year period of fertilization continuation after introduction of liming
7	1989-1992	4-year period of fertilization continuation
8	1993-1995	2nd break (2 years), introduction of a single grazing, the year of NPK resumption, Cu and Mg application and repetition of liming
9	1996-1999	4 year of fertilization continuation
10	2000-2004	5-year period of fertilization continuation with annual twofold application of foliar microelement fertilization
11	2005-2007	3-year period of fertilization continuation, replacement of urea by ammonium nitrate, fertilization B applied every year
12	2008-2010	3 year period of fertilization continuation with a single soil treatment with Cu, Zn, Mn, Co and Mo

In the first period, which covered the years 1968-1975, the research focused on the effect of various levels of fertilization on the yield and quality of grassland sward established as a result of natural turfing of abandoned arable land. It was the period of fertilizer industry development in Poland. The agricultural usefulness of ammonium nitrate and urea as a new fertilizer in Poland, has been compared. Nutrient doses were comparatively high; however, plant nutrient requirements for a potential yield were taken into account. At that time agriculture in mountain conditions was rather extensive and intensification process pursued only slowly. Therefore, in the period 1974-1975 fertilization was ceased, assuming a residue effect of applied nutrients. Two years later fertilization was resumed on the same level at the native treatments. The former researches show diversification of botanical composition and soil properties, which indicated a necessity sward liming. After seventeen years, fertilization with sodium carbonate was applied, assuming an improvement in soil pH and supplementing sodium content in the sward. Since 1985, the experiment was conducted in two series: without liming and with limestone application (Figure 1) in 10-year cycles.

Economic transformation, which took place in Poland in the nineties of the 20th century caused a dramatic decline in fertilizer's consumption in the whole country. It has been decided to mimic these changes on the scale of the experiment. Therefore, another break in fertilization for two years was administered. Another change was to include the single sheep grazing in the experiment. The liming was repeated in 10-year cycles (1995, 2005). While seeking possibilities of restoring yield forming potential in the subsequent years attention was focused on magnesium and microelement deficiencies. Magnesium and copper were supplied once to the soil and then foliar application of the multi microelements fertilizer was used for five years. In 2005, boron was added to the soil and then a set of basic microelements in doses, which should have improved their bioavailability previously limited by a systematic removal of these elements with the yield. The main aim of all agronomic measures was maintaining the grassland productive potential, by their influence on the quality of sward and the soil properties has been analyzed as well. The polygon of the experiment was also used in research on nutrient leaching, changes in humus content, microbial and enthomofauna activity and to determine heavy-metal cycling in agrocenosis.

A module of Statistica 9.0 application (licence for University of Agriculture) was used in statistical analysis (StatSoft, Inc. 2009).

The nitrogen content was considered as the output data for constructing the neural network and regression analysis, whereas dry mass yield was regarded as the quantitative input data and the subsequent years of the experiment, treatments, series and cuts were used as qualitative input data.

RESULTS AND DISCUSSION

In practice there is a need for fast assessment of e.g. protein in animal feed. Protein equivalent is nitrogen and its amount limits the crop yield and its quality (Kacorzyk, Kasperczyk 2006, Grzebisz et al. 2008, Kulik 2009, Bojarszczuk et al. 2011).

Statistical analysis was applied for two data sets – the whole data set, i.e. 43 years and 8 treatments, 2 cuts and 2 series – data of the1st set (n = 1376) and narrow data set comprising exclusively fertilization 90 kg N, irrespective of the form against the background of PK – 43 years and 2 objects, 2 cuts and 2 series – data of the 2nd set (n = 344).

Despite slight changes in the level of nitrogen content, set of dependencies shown in Figure 2 does not differ significantly for both cuts. With years, nitrogen content was increasing until half of the period of investigations and then was decreasing slightly. In case of lower yields, nitrogen content is higher. Especially in 2nd set biomass increment dilutes nitrogen content.

Linear regression analysis of quantitative features, i.e. nitrogen content in the sward and crop yield describes a small number of cases. Table 5 presents values of the analysis for both data sets.

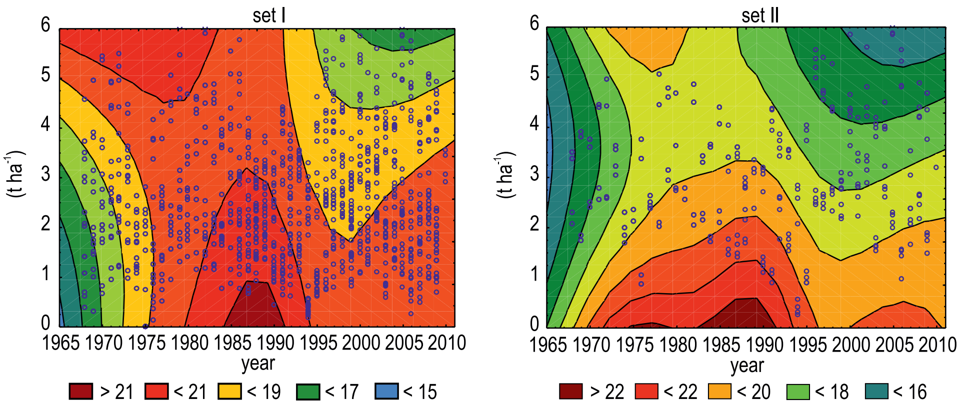

Fig. 2. Nitrogen content in meadow sward (g kg^{-1}) of both series and cuts depending on experiment years and yield for data sets I and II

The ranges of neural networks for both sets were approximate (Tables 5 and 6). Following the analysis, a network called MLP 57-10-1 was selected on the basis of learning coefficients (0.960659) quality, testing quality (0.840155) and validation quality (0.807017).The network was ascribed learning algorithm BFGS 83 with SOS error function and hidden layer initial exponential activation.

Factor sensitivity analysis had the following values: cut – 19.434, years of the experiment – 19.238, treatment – 9.021, series – 2.368, yield – 2.055.

Table 5

Parameters of regression analysis of nitrogen content in sward dependent on crop yield for two data sets

Specification	b^*	St. error. - b^*	b	St. error - b	t	p
Data 1st set	summing up regression of dependent variable: $R = 0.01628$; $R^2 = 0.00026$ $F(1.1343) = 0.35605$ p					
Intercept			19.29367	0.185594	103.9565	0.000000
Yield	-0.016280	0.027284	-0.03765	0.063098	-0.5967	0.550809
Data 2nd set	summing up regression of dependent variable: $R = 0.32071$; $R^2 = 0.10285$ $F(1.324) = 37.146$ p					
Intercept			20.67828	0.407949	50.68839	0.000000
Yield	-0.320710	0.052621	-0.76824	0.126050	-6.09472	0.000000

Table 6

Statistics of data area in neural network

Specification	Test - Learning		Test -Validation		Whole data	
	range	mean/SD	range	mean/SD	range	mean/SD
Set I						
Yield (t ha^{-1}) – quantitative input	0.13-6.09	2.52/1.27	0.38-6.10	2.60/1.44	0.13-6.10	2.53/1.26
Content of N (g kg^{-1}) – quantitative input	10.62-31.40	19.08/3.29	13.00-29.30	19.16/3.04	10.62-31.40	19.10/3.21
Set II – (90 kg N + PK treatments)						
Yield (t ha^{-1}) – quantitative input	2.60-6.09	2.99/1.23	1.10-5.86	3.10/1.12	0.26-6.09	3.02/1.16
Content of N (g kg^{-1}) – quantitative input	10.61-31.40	18.37/2.87	11.12-24.20	18.65/2.69	10.62-31.4	18.37/2.83

The data above show a significant effect of cut and subsequent years of the experiment on nitrogen content. This dependence should be explained by changes in the botanical composition, both regarding the succession registered during the experiment and seasonality of 1st and 2nd data sets. Intensification of fertilization is another factor important for determining nitrogen content. The discussed factor is less conditioned by liming and crop yield.

The network called MLP 49-4-15 was selected for narrow data set on the basis of learning quality coefficients (0.952972), testing quality (0.81568) and validation quality (0.884061). The training algorithm BFGS37 with SOS error function and hidden layer initial linear activation was ascribed to the network.

Factor sensitivity analysis had the following values: years of the experiment – 17.549, cut – 11.603, series – 1.762, yield – 1.339.

The data above evidence a considerable effect of subsequent years of the experiment and cut on nitrogen concentrations. An inversion of sensitive features occurred and diversification of sensitivity level. A difference in botanical composition is less diversified at the same dose than with extreme fertilization considered in 1st set. The sensitivity of liming effect and crop yields look analogously as in case of 1st data set.

Neural networks proved to be particularly good not only for elaboration of short term results (Boniecki 2005), but also in the context of time as an element of data interpretation. Progress in predicting productivity, spatial modelling and spatial-and-time forecasting has been made recently regarding the interpretation of long-term experiment results. Application of neural networks makes possible a deeper analysis, particularly while solving non-linear regressions, forecasting and classification.

CONCLUSIONS

1. Application of a neural network for assessment of nitrogen content on the basis of yield is possible taking into account subsequent years of nitrogen fertilization level and cut.

2. Neural networks are useful for modelling the element content at the application of descriptive quantitative and qualitative features.

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