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STUDY OF THE pH VARIABILITY IN PERMANENT MEADOW SOILS RESULTING FROM NITROGEN FERTILIZATION AND AFTER-EFFECT OF LIMING

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A b s t r a c t. Investigations on the acidification dynamics of grassland soil not limed (acidification) and renewed acidification after soil liming (reacidification) related to ammonium nitrate (AN) and calcium nitrate (CN) fertilisation in three long-term grassland experiments (started in 1981) have been performed. The experiments were set up in randomised blocks in 4 repetitions in 1981, and were localised in the Mazowieckie voivodeship. The soils under the experiments differed in their physical and chemical properties. Lime ($CaCO_3$) was used once directly on the sward, at the beginning of the experiments in doses related to hydrolytic acidity levels 1 Hh and 2 Hh. Two doses of nitrogen (N_1 - 120, N_2 - 240 kg/ha) in the AN form, and since spring 1992 in CN form were used. Phosphorus and potassium were applied at constant doses. The pH_{KCl} level of each 5 cm soil layer down to 25 cm depth from each fertilising treatment was measured. The recognition of specific dynamic of acidification and reacidification in the separate 5 cm layers, on the background of different soil properties, doses and forms of nitrogen fertilisers can be helpful in characterising the N transformation processes as well as nutrient consumption by the herbage, the roots mass of which is contained mostly in 0-15 cm upper soil layer.

K e y w o r d s: meadow soil, long-term experiment, pH, liming, nitrogen fertilisation.

INTRODUCTION

The organic matter mineralization as well as nitrogen fertilisation, particularly with ammonium nitrate induces continual acidification of soil surface layers in grassland soils [3,6,10,11]. Acidifying effect connected with soil processes, and with atmospheric deposition on non-manured grassland was observed also in course of time [5]. The thickness of soil layer undergoing acidification can differ considerably depending upon the intensity of this process, stimulated by the soil, climatic and anthropogenic factors [8-10] Applying calcium fertilizers, besides the neutralisation effects, favours simultaneously the nitrification and consequently the release of protons and renewed soil acidification [4,7,11].

The aim of this paper was to investigate and estimate acidification dynamics of grassland soil not limed (acidification) and renewed acidification after soil liming (reacidification) in relation to ammonium nitrate (AN) and calcium nitrate (CN) fertilisation on three long-term grassland experiments.

MATERIALS AND METHODS

The experiments set up in the randomised blocks in 4 repetition in 1981, were localised in Mazowieckie voivodship in villages Baniocha (B), Janki (J) and Laszczki (L). The soils under the experiments differed in physical and chemical properties (Table 1). Lime ($CaCO_3$) was applied once, directly on the sward, at the start of experiment in the doses according to hydrolytic acidity 1 Hh (Ca_1 - 5.7 (B); 2.3 (J); 3.6 (L) t CaO ha^{-1}) and 2 Hh (Ca_2 - double doses). Two doses of nitrogen in the form of ammonium nitrate (AN) (N_1 - 120, N_2 - 240 kg ha^{-1}) and constant phosphorus (P_2O_5 - 80 kg ha^{-1}) and potassium doses (K_2O - 150, from 1992 -180 kg ha^{-1}) were used. Since spring 1992, the plots (50 m^2 surface) were divided in two parts. One part was fertilised with AN and on the second - calcium nitrate (CN) was applied in the same nitrogen doses. The pH_{KCl} of each 5 cm soil layer down to 25 cm depth from each fertilising treatment (Ca_0N_1, Ca_0N_2, Ca_1N_1, Ca_1N_2, Ca_2N_1, Ca_2N_2) in 4 repetitions was measured every year during 1982-1986, every two years in 1986-1992 and every three years in 1992-1998. The results were elaborated by the analysis of variation method with a Student--Neuman-Keuls test. Three crops were harvested during subsequent years. Mean values of precipitation in 1980-1996 were 521.5 mm - annually and 327.8 mm - during the vegetation season.

RESULTS

The changes of soil pH after thirteen (B experiment), seventeen (J experiment) and sixteen (L experiment) years from the lime application are presented below. From three experiments started in 1981 one - in Baniocha was cancelled in 1995 from the economical and organisational reasons.

Dynamics of pH in soil microprofile

The dynamics of pH in the soil microprofiles (down to 25 cm depth) from the plots fertilised with AN is presented in Figs 1-3. In the case of not limed soil from

3 experiments an increase of pH, particularly in 0-5 and 5-10 cm layers, was observed from the beginning of investigation up to about 1984-1985 (Figs 1-3). This effect was more intensive in N_2 treatments. Later on, the decrease of pH values, higher in N_2 treatments, started. The most intensive acidification took place in J experiment, in the soil with low carbon content and CEC_{tot} value (Table 1, Fig. 2). The weakest dynamics of pH in 0-25 cm layer was observed in B experiment, in the soil with very low clay and calcium content (Table 1, Fig.1). The pH values measured every year (1982-1986) showed certain variation - increasing or decreasing, particularly in the 0-10 cm soil layer (Figs 1-3). The highest pH values in the layer 20-25 cm appeared in L experiment, in soil rich in calcium content (Fig. 3). Noteworthy, pH changes in the microprofiles of not limed soil were displaced parallel (Figs 1-3).

Table 1. Soil characteristics before the start of experiments (0-10 cm layer)

Soil properties	Experiments		
	Baniocha (B) (light loamy sand)	Janki (J) (hevy loamy sand)	Laszczki (L) (light silty loam)
pH_{KCl}	4.5	4.5	4.3
Content:			
C_{org}, %	2.5	1.9	3.8
N_{tot}, %	0.173	0.150	0.315
Ca_{tot}, %	0.034	1.144	0.258
Bulk density, Mg m^{-3}	1.40	1.48	1.27
Particles < 0.02 mm, %	9.0	18.4	22.4
CEC_{tot}, cmol (+)kg^{-1}	14.5	7.5	23.8

The dynamics of soil pH after liming differed depending on the kind of soil, lime doses and especially on nitrogen doses (Figs 1-3). The increasing pH of soil surface layer 0-5 cm during the first 2-3 years after liming was confirmed. During elapse of the time of experiments, pH below the layer 0-5 cm increased down to 25 cm depth, stronger on double dose of lime. Just as in the case of the not limed soil, the most intensive dynamics of pH changes, particularly in the 0-5 and 5-10 cm soil layers was observed in J experiment (Fig. 2). In these layers, the decreasing of pH was observed, in 0-5 cm layer almost from the year 1984 on N_2 and from 1986 on N_1 treatment. On the Ca_2 plots, reacidification took place mostly after applying the double dose of nitrogen in J experiment. In L experiment, on the soil with higher clay as well as carbon and calcium content, the most intensive reacidification of 0-5 and 5-10 cm layers was observed on lower lime dose - Ca_1

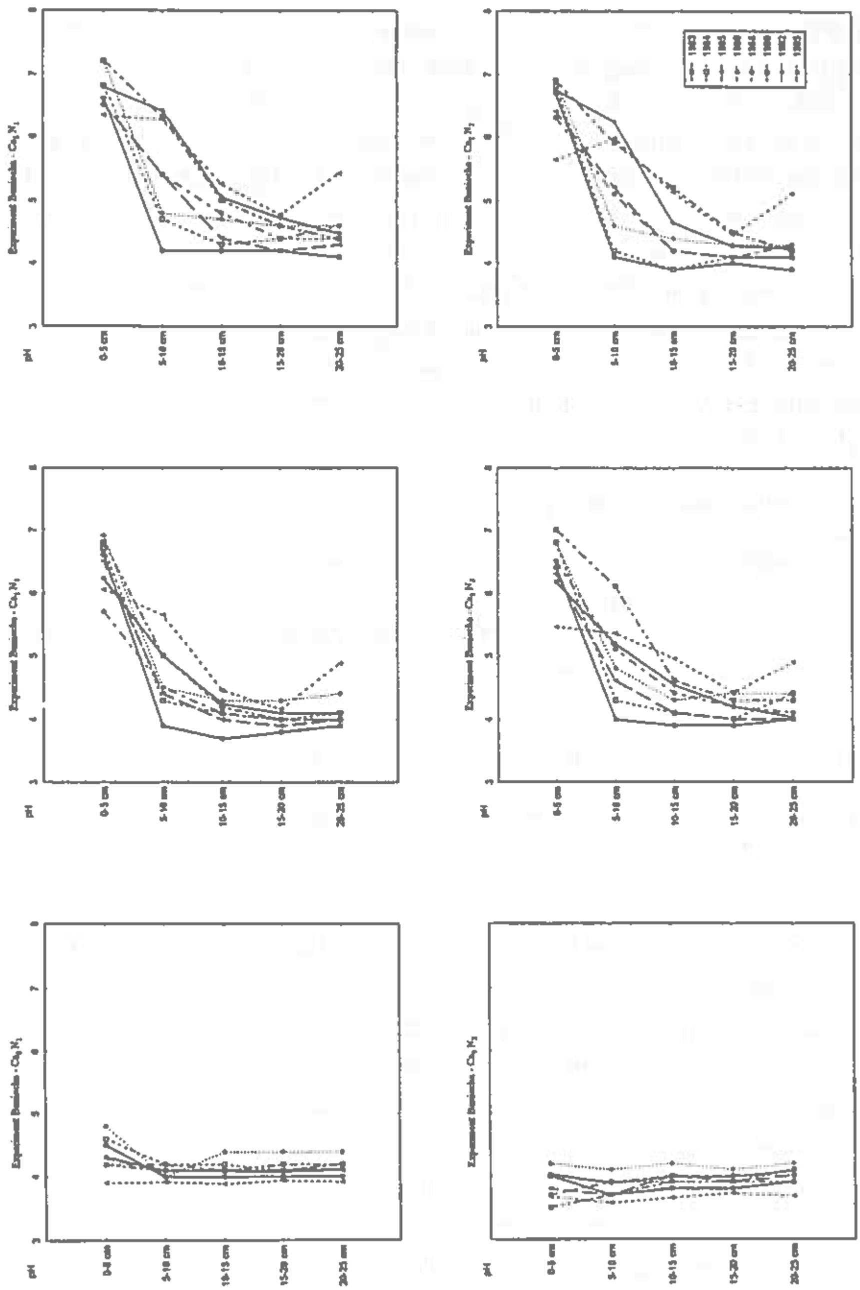

Fig. 1. Dynamics of pH in 5 cm soil layers (down to 25 cm depth) from Baniocha experiment during 1983 - 1995 after ammonium nitrate fertilization; N_1 - 120 kg N ha^{-1}, N_2 - 240 kg N ha^{-1}; Ca_0 - not limed treatment, Ca_1 - lime dose according to 1 Hh hydrolytic acidity, Ca_2 - double dose.

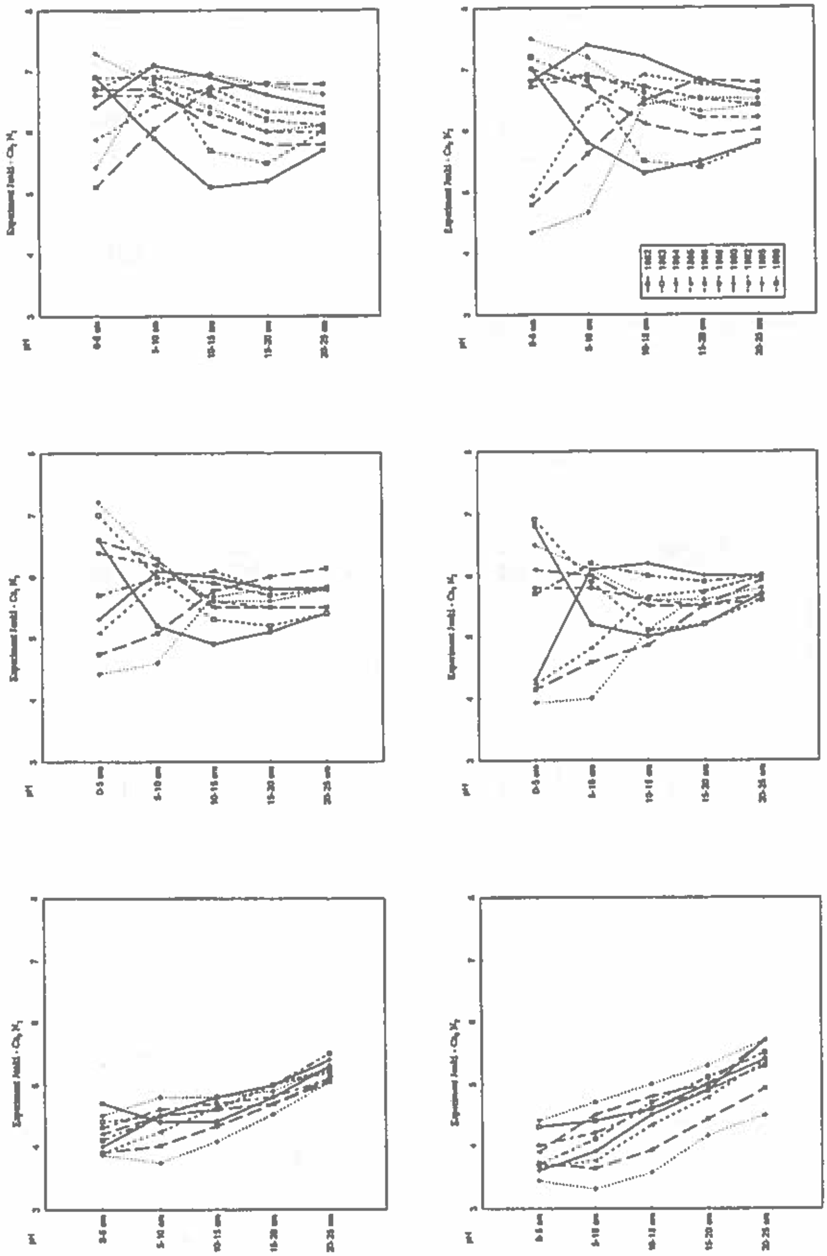

Fig. 2. Dynamics of pH in 5 cm soil layers (down to 25 cm depth) from Janki experiment during 1982 - 1998 after ammonium nitrate fertilization; N_1 - 120 kg N ha^{-1}, N_2 - 240 kg N ha^{-1}; Ca_0 - not limed treatment, Ca_1- lime dose according to 1 Hh hydrolytic acidity, Ca_2 - double dose.

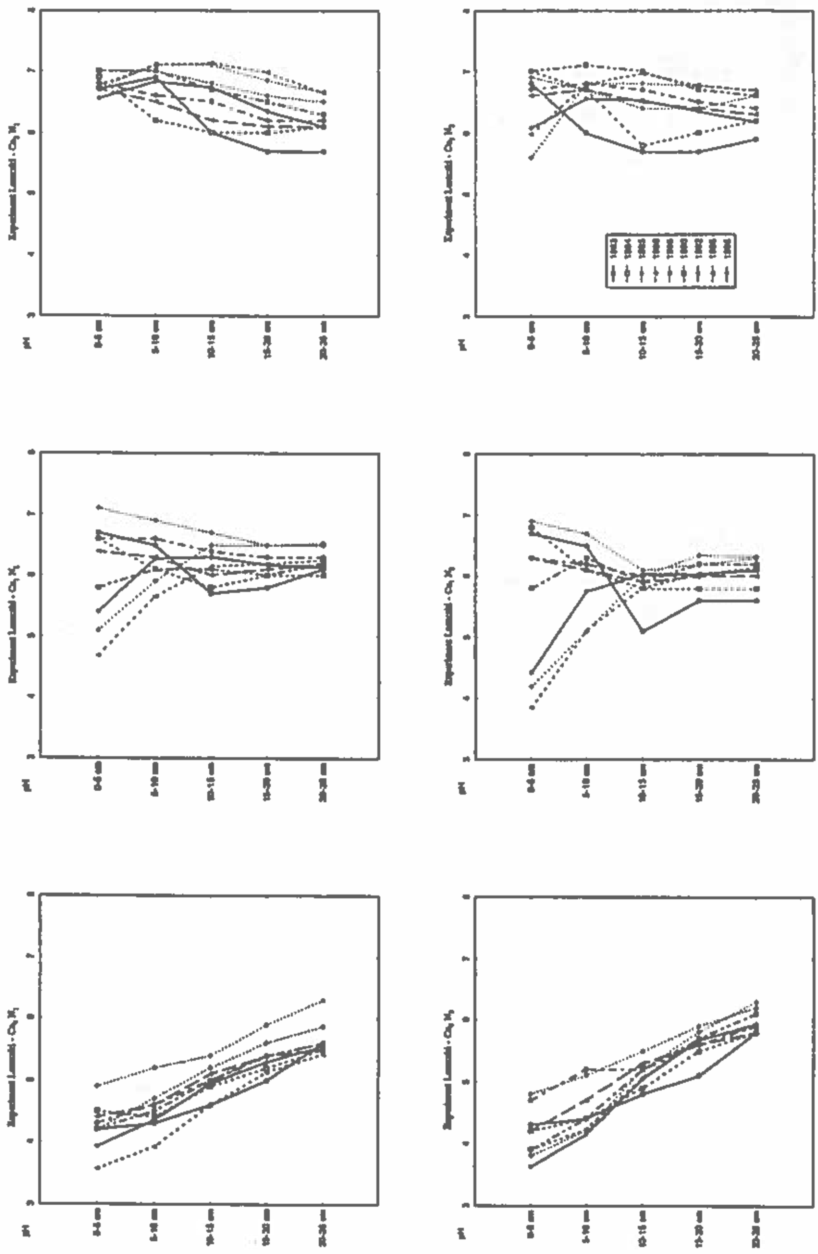

Fig. 3. Dynamics of pH in 5 cm soil layers (down to 25 cm depth) from Laszczki experiment during 1983 - 1998 after ammonium nitrate fertilization; N_1 - 120 kg N ha^{-1}, N_2 - 240 kg N ha^{-1}; Ca_0 - not limed treatment, Ca_1 - lime dose according to 1 Hh hydrolytic acidity, Ca_2 - double dose.

(Fig. 3). In this experiment, the renewed decreasing of soil pH appeared practically only in 5-10 cm layer in Ca_1N_1 and in 0-5 cm layer in Ca_2N_2 treatments.

The mean pH values of investigated soils, calculated for the whole 0-25 cm soil layer showed quite different picture of the pH changes after lime use as well as in the function of time (Fig. 4). In the case of single dose of nitrogen (120 kg ha^{-1}), the increase of soil pH after liming with the higher dose of lime in B experiment, and more intensive in J experiment was only confirmed. The effect of lime dose in L experiment, as well as the effect of double nitrogen dose in B experiment on soil pH were not observed. Like in the investigation of separate soil layers, the highest acidification as well as reacidification process was observed in J experiment.

Changes of pH in relation to fertiliser factors and soil layer

An interaction between fertiliser treatments (A factor) and soil layers (B factor) has proved the results from J and L experiments for each of two saltpetre forms (AN and CN) after 16-17 years of experiments. Significant differences between the pH values of soils from six treatments for each 5 cm layer down to 25 cm depth as well as between the separate layers at the same treatment have been estimated (Tables 2-3).

In J experiment, pH of 0-5 cm layer of soil fertilised with AN, not limed and limed, differed significantly 17 years after liming. The highest values of pH in this layer (5.1) was in the soil fertilised with lower dose of nitrogen and limed with double dose of lime (Ca_2N_1). After CN use, the difference of pH appeared also in the case of two lime doses, regardless on nitrogen doses (Table 2). In L experiment, in the same layer of soil fertilised with AN, the dose of lime differentiated significantly soil pH after 16 years of experiment. The highest pH values appeared in the Ca_2N_1 treatment. The higher nitrogen dose resulted in decreasing of soil pH in this layer. After CN use in this experiment, no significant effect of higher nitrogen dose (N_2) on pH in 0-5 cm soil layer was observed, even on limed plots (Table 3). In both experiments, in the deeper layers of not limed soil, below 5 cm down to 25 cm, a clear tendency of lowering pH appeared after higher nitrogen dose application. However, significant differences between the pH values were not proved, also in the case of CN use (Tables 2-3).

In the J experiment after AN used, the 5-10 and 10-15 soil layers are the most sensitive to the after-effect of liming as well as different nitrogen doses. In the 15-20 cm layer the lime doses still differentiated soil pH, but in 20-25 cm layer the effect of lime was only proved. In the case of CN used, the significant effect of

T a b l e 2. Comparison of pH of soil layers after fertilization with ammonium nitrite (AN) and calcium nitrate (CN)[1/] and an effect of fertilizer treatments on Janki experiment after 17 years from liming (1998)

Layer (cm)	Fertilizer treatments											
	Ca_0N_1		Ca_0N_2		Ca_1N_1		Ca_1N_2		Ca_2N_1		Ca_2N_2	
	AN	CN	AN	CN	AN	CN	AN	CN	AN	CN	AN	CN
0-5	a 3.90ab	a 47.8a	a 3.71ab	a 5.01a	a 4.73abc	a 5.77b	a 4.14abc	a 5.56b	a 5.10c	a 6.64c	a 4.78abc	a 6.72c
5-10	a 4.00ab	a 4.63a	a 3.62a	a 4.71a	a 5.07bc	ab 5.90b	a 4.58b	b 5.91b	b 6.05c	b 7.03c	b 5.62c	b 7.06c
10-15	a 4.32a	a 47.3a	a 3.92a	a 4.51a	b 5.76bc	b 6.25b	a 4.86a	b 6.02b	c 6.96c	b 7.16c	c 6.47bc	b 7.21c
15-20	ab 4.68a	a 5.01a	b 4.43a	a 4.85a	b 6.06b	ab 6.17b	b 5.51b	b 6.29b	c 6.80c	b 7.14c	c 6.82c	ab 7.09c
20-25	bc 5.05a	b 5.36a	c 4.93a	b 5.37a	b 6.14b	ab 6.17b	b 5.92b	bc 6.39b	c 6.78b	b 7.10c	c 6.77b	ab 7.10c

1/ Calcium nitrate used from 1992.

Significant of mean factors variability and their interaction: A factor - fertilizer treatments; B factor - layers. For AN: interaction (AxB) - ** (empirical F for α = 0.01 - 2.559); for CN: interaction (AxB) - ** (empirical F for α = 0.01 - 1.75); comparison of mean values of A factor on the same level of B factor - the letters on right side; comparison of mean values of B factor on the same level of A factor - the letters on left side; the same letters - not significant differences.

Table 3. Comparison of pH of soil layers after fertilization with ammonium nitrate (AN) and calcium nitrate (CN)[1/] and an effect of fertilizer treatments on Laszczki experiment after 16 years from liming (1998)

Layer (cm)	Fertilizer treatments											
	Ca_0N_1		Ca_0N_2		Ca_1N_1		Ca_1N_2		Ca_2N_1		Ca_2N_2	
	AN	CN	AN	CN	AN	CN	AN	CN	AN	CN	AN	CN
0-5	a 4.23ab	a 4.89a	a 3.84a	a 5.16a	a 5.13b	a 6.03b	a 4.20a	a 5.96b	a 6.74c	ab 6.86c	a 5.61b	a 7.15c
5-10	b 4.71a	a 4.87a	a 4.24a	a 4.85a	b 5.94b	a 6.26b	b 5.07b	b 6.38b	a 7.08c	a 7.18c	b 6.76c	a 7.32c
10-15	c 5.22a	a 5.15a	b 5.15a	b 5.48a	c 6.49b	a 6.39b	c 6.04b	b 6.41b	a 7.06bc	a 7.10c	b 6.81bc	a 7.29c
15-20	ab 4.68a	b 5.55a	c 5.81a	c 5.80a	c 6.49b	a 6.42b	c 6.35ab	b 6.45b	a 6.85bc	b 6.84b	b 6.76bc	a 7.15b
20-25	c 5.87a	c 5.92a	d 6.29a	d 6.16a	c 6.52a	a 6.46ab	c 6.33a	b 6.53ab	a 6.65a	b 6.66b	b 6.68a	a 6.98b

1/ Calcium nitrate used from 1992.

Significant of mean factors variability and their interaction: A factor - fertilizer treatments; B factor - layers. For AN: interaction (AxB) - ** (empirical F for $\alpha = 0.01$ - 10.81); for CN: interaction (AxB) - ** (empirical F for $\alpha = 0.01$ - 7.220); comparison of mean values of A factor on the same level of B factor - the letters on right side; comparison of mean values of B factor on the same level of A factor - the letters on left side; the same letters - not significant differences.

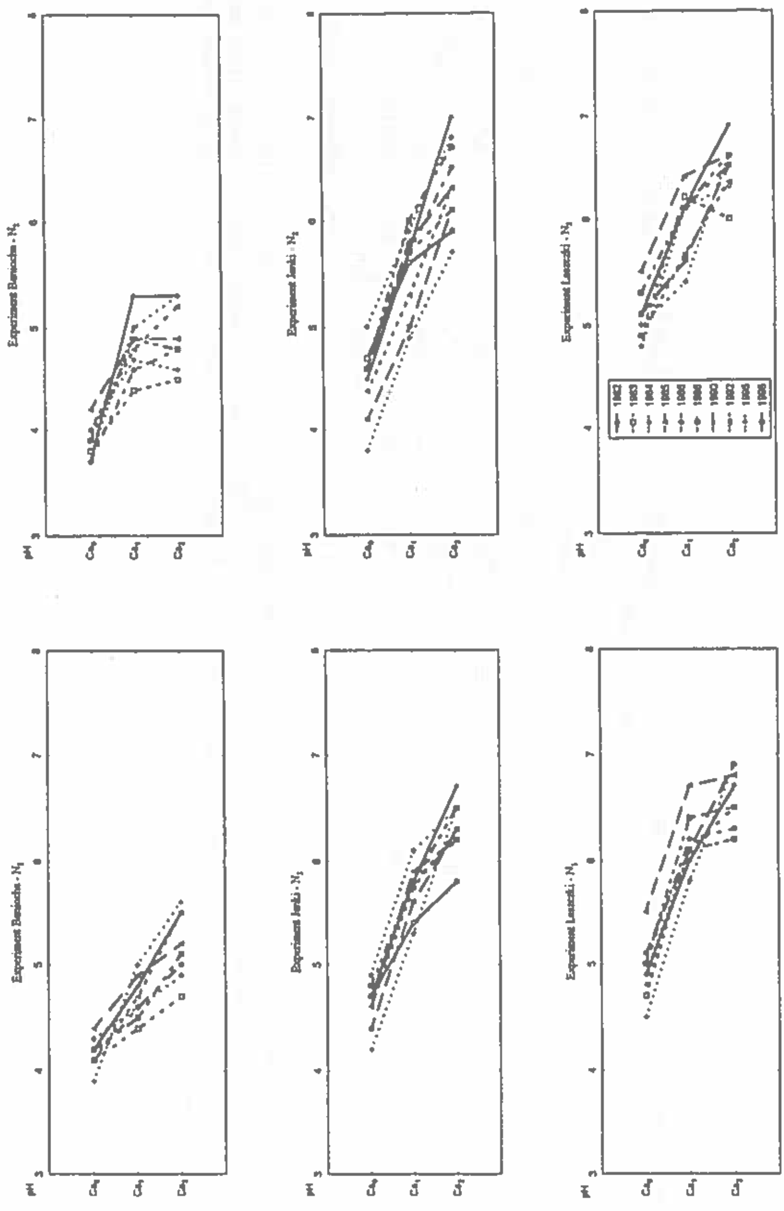

Fig. 4. Dynamics of pH calculated for 0-25 cm soil layer from three grassland experiments - Baniocha (during 1983-1995), Janki (during 1982-1998) and Laszczki (during 1983-1998) after ammonium nitrate fertilization; N_1 - 120 kg N ha^{-1}, N_2 - 240 kg N ha^{-1}; Ca_0 - not limed treatment, Ca_1- lime dose according to 1 Hh hydrolytic acidity, Ca_2 - double dose.

double dose of nitrogen on pH of not limed and limed soil in the layers down to 25 cm depth did not appeared (Table 2). In the L experiment after AN use, a differences between soil pH resulting from the liming appeared only to the 20 cm depth. This effect after CN use can also be observed in 20-25 cm soil layer (Table 3).

A lack of significant differences between pH of analysed soil layers down to 20 cm depth in the soil not limed was proved in the case of CN use in J experiment regardless of nitrogen doses (Table 2). In the soil of L experiment, much higher variability of pH after CN as well as AN use was observed (Table 3). In J experiment, in the case of AN and CN use, considerable differentiation of pH between the layers in 25 cm microprofile of limed soil were found (Table 2). On the contrary, in L experiment on soil fertilised with AN and limed with double dose of lime no significant differences ware observed in soil pH down to 25 cm depth at lower nitrogen dose (N_1) and in the layers below 0-5 cm, at N_2 dose. After CN use, similarly to the case of AN, the lack of differentiation of pH in the whole 25 cm soil layer was noted in Ca_1N_1 and Ca_2N_2 treatments (Table 3).

Effect of different saltpetre forms, lime and nitrogen fertilisation on soil pH

The significant interaction between the fertiliser factors and saltpetre forms have been proved in 0-5 cm soil layer in J and L experiments (Table 4). Significant effect of saltpetre form on soil pH for each treatment was shown in J experiment. The CN fertilisation resulted in increasing pH value of this soil layer. Lime stimulated this effect. The effect of nitrogen doses was not observed. In L experiment, the differences between the soil pH after AN and CN fertilisation appeared only on plots with higher nitrogen dose regardless of liming.

Significantly higher mean values of pH in the deeper soil layers, down to 25 cm, with CN use were recorded in J experiment but only in 5-10 cm soil layer in L experiment (Tables 5-6). In J experiment, besides the differences between AN and CN effect on soil pH, an effect of liming in the deeper soil layers was also demonstrated. Significant effect of nitrogen doses appeared only in 10-15 cm layer in the case of AN use (Table 5). In the 5-10 cm soil layer in L experiment, beside the effect of saltpetre forms, the effect of liming was shown. In the soil fertilised with CN, no significant differences due to nitrogen dose was found (Table 6). Noteworthy, given soil pH on AN treated plots is a result of fertiliser impact during 17 (Janki) and 16 (Laszczki) years, but on CN treated plots - during 7 years.

Table 4. Comparison of the effect of saltpetre forms (ammonium nitrate - AN and calcium nitrate - CN[1/]) on the pH of 0-5 cm soil layer in grassland experiments after 17 (Janki) and 16 (Laszczki) years from liming

Saltpetre form	Fertilizer treatments					
	Ca_0N_1	Ca_0N_2	Ca_1N_1	Ca_1N_2	Ca_2N_1	Ca_2N_2
			Janki			
AN	a 3.90	a 3.71	b 4.73	a 4.14	c 5.10	b 4.78
CN	b 4.78	b 5.01	c 5.77	c 5.56	d 6.64	d 6.72
			Laszczki			
AN	a 4.23	a 3.84	b 5.13	a 4.20	cb 6.74	b 5.61
CN	a 4.89	b 5.16	b 6.03	b 5.96	c 6.86	c 7.15

1/ Calcium nitrate used from 1992. A factor - fertilizer treatments (Ca - liming, N - nitrogen fertilization); D - saltpetre form (AN, CN). Significance of main factors variability and theirs interaction. For Janki experiment: interaction (DxA) - * (empirical F values with $\alpha = 0.01$ - 2.681); for Laszczki experiment: interaction (DxA) - * (empirical F values with $\alpha = 0.01$ - 2.716). Comparison of mean values of D factor on the same level of A factor - the letters on left side. The same letters - not significant differences.

DISCUSSION

The results allow for answering the following questions: (1) why the temporal variations of pH in grassland soils have to be investigated? (2) why the investigation of pH in separate layers (down to 25 cm depth) of grassland soils is needed? (3) which layers of not limed and limed soils show the greatest temporal dynamics of pH changes? (4) does the saltpetre form affect the dynamics of pH changes in 25 cm surface layer of grassland soils ?

Conyers *et al.* [3], among others, considered the importance of temporal variation of soil pH. These variations (up to 0.45 pH units depending on the site, soil depth and weather conditions) were attributed by authors to variable responses of crops and pastures to liming, that had been observed on acidic soils in south-eastern Australia.

The temporal variations of pH in 5 cm soil layers down to 25 cm depth in the same experiments as in this paper, were observed earlier, in the years 1982/83-1986 [9]. During this time, two phases of pH changes were observed in the not limed and limed soil. In the first phase (I), about 2-3 years from the start of experiments, the increase of pH was observed. This effect in the soil of not limed plots could resulted from the release of bases after the fertiliser use. In the next phase (II), the gradual pH decrease took place [9]. The character of phase of pH changes

T a b l e 5. Comparison of the effect of fertilizer treatments (Ca and N) and saltpetre form on the pH of soil layers after fertilization with ammonium nitrate (AN) and calcium nitrate (CN)[1/] on Janki experiment after 17 years from liming (1998)

Layer (cm)	Fertilizer treatments											
	Ca_0N_1		Ca_0N_2		Ca_1N_1		Ca_1N_2		Ca_2N_1		Ca_2N_2	
	AN	CN	AN	CN	AN	CN	AN	CN	AN	CN	AN	CN
0-5[2/]	3 811	4.89a	4.44b	5.67b	4.94c	6.68c	4.58a	5.73a	4.21b	5.77a	4.40	5.75
5-10	a 3.82a	b 4.67a	b 4.83b	c 5.91b	c 5.84c	d 7.05c	a 5.04a	a 5.86a	a 4.61a	a 5.90a	a 4.83	b 5.88
10-15	a 4.13a	b 4.62a	c 5.31b	d 6.14b	d 6.58c	e 7.19c	a 5.59a	a 6.05a	b 5.09b	c 5.92a	a 5.34	b 5.98
15-20	a 4.56a	a 4.93a	b 5.79b	b 6.24b	c 6.81c	c 7.12c	a 5.85a	a 6.12a	a 5.59a	a 6.08a	a 5.72	b 6.10
20-25	a 4.99a	a 5.37a	b 6.03b	bc 6.28b	cd 6.77c	d 7.10c	a 5.99a	a 6.21a	a 5.87a	a 6.29a	a 5.93	b 6.25
Mean	4.26	4.90	5.28	6.05	6.19	7.03	5.41	5.99	5.07	5.99	5.24	5.98

1/ Calcium nitrate used from 1992.

Significant of mean factors variability and theirs interaction: A factor - fertilizer treatments; B factor - layers. For AN: interaction (AxB) - ** (empirical F for $\alpha = 0.01$ - 10.81); for CN: interaction (AxB) - ** (empirical F for $\alpha = 0.01$ - 7.220); comparison of mean values of A factor on the same level of B factor - the letters on right side; comparison of mean values of B factor on the same level of A factor - the letters on left side; the same letters - not significant differences.

T a b l e 6. Comparison of the effect of fertilizer treatments (Ca and N) and saltpetre form on the pH of soil layers after fertilization with ammonium nitrate (AN) and calcium nitrate (CN)[1/] on Laszczki experiment after 16 years from liming (1998)

Layer (cm)	Fertilizer treatments											
	Ca_0N_1		Ca_0N_2		Ca_1N_1		Ca_1N_2		Ca_2N_1		Ca_2N_2	
	AN	CN	AN	CN	AN	CN	AN	CN	AN	CN	AN	CN
0-5[2/]	4.04a	5.03a	4.67b	6.00b	6.18c	7.01c	5.37a	5.93a	4.55b	6.09a	4.96	6.01
5-10	a 4.48a	a 4.86a	b 5.51b	c 6.32b	d 6.92c	d 7.26c	a 5.91a	a 6.11a	a 5.36b	a 6.19a	a 5.64	b 6.15
10-15	a 5.19a	a 5.32a	b 6.26b	b 6.40b	c 6.94c	c 7.19c	a 6.26a	a 6.21a	a 6.00a	a 6.19a	a 6.13	a 6.26
15-20	a 5.71a	a 5.68a	b 6.42b	b 6.43b	b 6.81b	b 7.00c	a 6.32a	a 6.27a	a 6.31a	a 6.47a	a 6.31	a 6.37
20-25	a 6.08a	a 6.04a	a 6.43a	a 6.50ab	a 6.70a	a 6.82b	a 6.04a	a 6.35a	a 5.73a	a 6.56a	a 6.20	a 6.45
Mean	5.10	5.39	5.28	6.35	6.70	7.05	6.04	6.17	5.73	6.34	5.85	6.25

1/ Calcium nitrate used from 1992.

Significant of mean factors variability and theirs interaction: A factor - fertilizer treatments; B factor - layers. For AN: interaction (AxB) - ** (empirical F for $\alpha = 0.01$ - 10.81); for CN: interaction (AxB) - ** (empirical F for $\alpha = 0.01$ - 7.220); comparison of mean values of A factor on the same level of B factor - the letters on right side; comparison of mean values of B factor on the same level of A factor - the letters on left side; the same letters - not significant differences.

in the soil was confirmed by the mean values of annual rate of pH changes (Δ pH yr^{-1}) during the investigations in the years 1982/83-1995 [8]. In these studies, three phases of pH changes could be distinguished. In the II phase, the pH variability presented certain specific stability in the soil layers below 5 cm. Intensive acidification, especially reacidification, was demonstrated in the third phase (III) [8]. In the present paper, the dynamics of soil pH changes confirmed previous observations (Figs 1-4). The results of Wheeler [11] presented also two phases in lime effect in his 8 years investigations. After the use of lower lime dose (5 t ha^{-1}), pH of 0-7.5 cm soil layer changed from 5.27 to 6.22 during the first 3 years and decreased to 5.84 in eighth year of experiment.

Wheeler [11] showed greater reacidification at higher lime dose (0.083 pH units yr^{-1} with 5 t ha^{-1} and 0.117 pH units yr^{-1} with double dose). In the present paper as formerly [8], the increase of reacidification efficiency with the increased lime dose depending on the kind of soil was proved. This effect, expressed by the differences between the soil pH at the start of experiment and 17 years later, appeared chiefly in the soil with low carbon content and CEC_{tot} value, in J experiment (Figs 1-3). But the reacidification exceeded acidification of the soil in all three experiments. In spite of recidification process, the effect of lime use (lime doses from 2.3-11.4 t CaO ha^{-1}) could be confirmed in the soil of 3 experiments, even after 16-17 years in L and J experiment (Figs 1-4). Wheeler [11] observed the lime effect on acid soils (increase of pH above that in the soil not limed) after applying the doses of lime between 1.25 -10 t ha^{-1} during about 11 to 12 years.

Wheeler [11] presented the effect of surface lime applications (5 t ha^{-1} initially and 2.5 t ha^{-1} a year later) on soil properties, including pH, in four soil layers (0-5, 5-10, 10-15 and 15-20 cm) over 15 years. The maximum increase of pH in subsequent soil layers appeared in different terms - after 2, 5, 12 years, and in 15-20 cm layer a constant increase of pH was observed. In the present paper, considerable temporal changes of pH can be observed in the soil layers down to 15 cm depth, particularly in the case of fertilisation with higher dose of nitrogen (N_2) in J and L experiments (Figs 2-3). The maximum pH values in subsequent 5 cm soil layers in three experiments depended on soil properties as well as on lime, and particularly nitrogen doses. For the most part, including limed plots, the maximum pH in 0-5 cm layers appeared after 3 years from the start of experiments. On the plots not limed, after elapse of this time, the highest pH values involved the whole 0-25 cm soil layer. In most cases, maximum of pH appeared in 15-20 and 20-25 cm soil layers after 16-17 years. The lowest variability of pH in subsequent 5 cm soil layers was noted after 7 years indicating a kind of ionic equilibrium

(Figs 2-3). In B experiment on the soil with low clay content, a tendency to increase pH with the depth of soil profile was observed after 15 years. The maximum pH was attended in 20-25 cm soil layer, the minimum in 0-5 cm soil layer on the limed plots, fertilised with N2 dose (Table 1, Fig. 1).

The highest efficiency of acidification process and connected with this phenomenon the leaching of bases, particularly lime losses, was recorded in the limed soils (reacidification) [2]. Significant differences, presented in this paper, between pH of the subsequent layers of soil fertilised with AN, chiefly in J experiment on the soil low in carbon content, confirm these observations (Tables 1-3). Chambers and Garwood [2] as well as Goulding and Annis [5] and de Klein *et al.* [7] considered the importance of humus in the acidification and reacidification processes.

In spite of CN use for only 7 years (from 1992), the different variability of pH, in separate 5 cm soil layers, connected with variable effect of saltpetre forms (AN and CN) was proved in presented investigations (Tables 4-6). The soils fertilised with AN from the 5 cm layers down to 25 cm depth, had lower pH compared to the soil fertilised with CN, regardless of the effect of fertiliser factors (Ca and N). The acidifying effect of AN - 240 kg ha^{-1} N was confirmed in the soil layers down to 15 cm depth on not limed plots after 16-17 years of experiment. No such effect was found after CN use. The previous liming of soil diminished and even removed the different effect of two forms of saltpetre. The different effect of two forms of saltpetre is connected probably with various amount of H^+ ions produced for two kinds of N inputs and N losses [7]. Cited authors showed that 0.14 kmol H^+ per kg of lost N resulted from the leaching of NO_3^- in the case of NH^+ fertilisers and there was no H^+ ions production in the case of NO_3 fertilisers. On the other hand, calcium ions from AN fertilisation could suppress the leaching process of bases by intensifying microbiological processes, and thus stimulating nitrogen immobilisation [1].

Improving measurement and understanding temporal long-term variation of soil pH as well as the dynamics of pH in the separate surface layers of grassland soils is needed [3,10]. The knowledge of these problems could help recognising the effect of lime on nitrogen mineralization [7,11] as well as the response of herbage to lime applications [3,5]. It could be supposed that the estimation of soil acidification resulting from different sources, such as soil organic matter, fertilisers and grazing [7] requires a better understanding of the temporal variation of pH in separate soil layers. The subsequent conclusions could serve as an answer to questions presented at the beginning of the discussion.

CONCLUSIONS

1. The high temporal variability of pH in the separate 5 cm soil layers down to 25 cm depth as well as the diversity in the direction and intensity of pH changes, proved in the long-term experiments on grassland soils, calls for the improving of understanding of these phenomena.

2. The recognition of specific dynamics of acidification and reacidification in the separate 5 cm layers, related to different soil properties, doses and forms of nitrogen fertilisers can be helpful in characterising the development of nitrogen transformation processes as well as of nutrient consumption by the herbage, the roots mass of which is contained mostly in 0-15 cm soil surface layer.

3. The knowledge of temporal variations of pH in separate 5 cm soil layers is needed for estimation of the acidification rate of grassland soils as well as of lime requirement and could be helpful for the calculations of reasonable lime doses on such soils.

4. The 5 cm soil layers down to 15 cm depth presented the greatest dynamics of pH and considerable temporal variability, particularly after lime application and in the case of fertilisation with higher doses of nitrogen.

5. Ammonium nitrate (AN) and calcium nitrate (CN) have a different impact on pH changes in subsequent surface layers of grassland soils. The same dose of nitrogen (240 kg ha^{-1}) in the CN form used during 7 years, in comparison to AN form used during 16-17 years, have no acidifying effect on the soil in the most sensible soil layer down to 15 cm depth.

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