The Effect of Fertilization and Liming on Some Soil Chemical Properties of Eutric Gleysol

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SUMMARY

The effect of different rates of mineral and organic fertilizers, liming and two types of zeolite tuffs upon the changes in the soil chemical complex were monitored in an exact field trial set up on Eutric Gleysol near Karlovac in Central Croatia. The trial was set up according to the randomized block method with four replications. The four-year investigations revealed a significant increase in pH values in treatments with hydrated lime, as well as in variants in which special natural amendments based on zeolite tuffs were applied. The applied rates of liming materials led to a significant increase in the base saturation of the cation exchange capacity as well as in content of investigation nutrients - phosphorus and potassium. While organic fertilizers and zeolite tuffs had less effect on changes of the studied parameters, significantly greater changes of the studied parameters (pH, cation exchange capacity, content of phosphorus and potassium) were recorded in treatments in which the hydrated lime was combined with mineral fertilizers.

KEY WORDS

Liming, Fertilization, Zeolite tuffs, Soil chemical properties

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INTRODUCTION

Sustainable Land Management and Good Agricultural Practice are the priorities of the overall agricultural development of Croatia (***, 2002), since this is the development sphere in which Croatia sees its prospects for the future. Plant production in a narrow crop rotation (spring crop /maize/ - stubble crop /winter wheat/), which is unfortunately one of the current characteristics of Croatian agriculture, leads to extensive removal of calcium and to imbalance in this macronutrient availability (Bašić et al. 1990). Mineral fertilizers with low calcium levels and absolutely insufficient application of organic fertilizers have caused the trend of soil acidification (Mesić et al. 1994).

Another factor that additionally aggravates this situation is the substantial spatial participation of acid soils (Dystric Cambisol, Luvisol, Stagnic Podzoluvisols and Gleyic Podzoluvisols). It is assumed that soils of increased acidity, i.e. soils requiring liming, account for 60% of soils in the most developed part of the Republic of Croatia, where more than 80% of agricultural products are produced (Bogunović et al. 1998).

Many authors have reported the problems of acid soils and the efficiency of various lime materials and zeolite tuff for acidity reduction, and thereby also improvement of both chemical and physical soil properties (Allen and Ming 1993, Boettinger and Graham 1993, Vaněk et al. 1997, Trávník et al. 1998 and Lukin and Epplin 2003). There are literature reports pointing to the positive effect of organic matter upon changes in soil and in crop yields (Zobač 1994, Von Boguslawski 1995 and Badarudin et al. 1999).

The goal of the investigations is to determine the effects of different rates of mineral fertilizer and farmyard manure, as well as the effect of hydrated lime and special natural amendments based on zeolite tuff as liming material upon the changes in the chemical properties of the investigated soil.

MATERIALS AND METHODS

In the autumn of 1998, the trial area was selected (near Karlovac, Central Croatia – N 45^0 29^I 05^{II} – E 15^0 36^I 56^{II}) and soil samples were taken in order to determine the suitability of the area with respect to acidity parameters, as well as the so-called zero (initial) state prior to the application of agroameliorative treatments. Experimental testing of the trial area soil showed that regarding its major chemical characteristics, the soil is suitable for the intended investigations, evaluation of the effects of mineral fertilization, lime materials and zeolite tuffs for liming acid soils and raising the currently low levels of phosphorus and potassium.

As already mentioned, hydrated lime (HL) of high purity and very good physical parameters was used in the trial (Table 1). Solid farmyard manure (FYM), hydrated lime and zeolite tuffs (ZT) (Table 2) were applied only once, at the setting up of the trial. Two types of special natural amendments were used: with (ZT+SPP) and without an organic component (ZT). Zeolite tuff without the organic component contains the following mineral component: clinoptilolite with Al/Si ratio 1:5 and phillipsite with Al/Si ratio 1:3, as well as basic minerals: gismondine with Al/Si ratio 1:1 and analcime with Al/Si ratio 1:2. They can be represented by the formula: $(Me_2)_n$ x Al_2O_3 x SiO_2y where n is the number of cations, and x and y depend on zeolite type. Clinoptilolite with a very favourable degree of base saturation prevails in these investigations (Butorac et al. 2002 and 2002a). Zeolite with the organic component (besides the above-mentioned mineral component) was inoculated with *Azotobacter chrooccocum* (total microorganism count was 1.67 x 10^9 t^{-1}).

Mineral fertilizers were represented by complex mineral and single nitrogen fertilizers. During the basic autumn tillage for maize, the lower rate of 260 kg ha^{-1} ($N_1P_1K_1$) and the higher rate of 350 kg NPK 8:26:26 ($N_2P_2K_2$) were applied, accounting for 50% of complex fertilizers. The remaining 50% of

Table 1. Chemical and physical-mechanical analysis of hydrated lime and farmyard manure

Component - Hydrated lime (HL)	Content, %	Component - Farmyard manure (FYM)	Content, %
Free water –105 °C	0.13	pH/H_2O	8.27
Bound water	23.75	Dry matter	20.2
Loss by ignition	24.84	H_2O	79.9
SiO_2 + insoluble	0.51	Ignited residue (550 °C)	27.8
FeO + AlO	0.86	Loss by ignition	72.2
CaO	72.94	Organic matter	69.9
MgO	0.43	Carbon	40.4
SO_3	0.11	Total nitrogen/dry matter	2.4
CO_2	0.96	P	0.16
Residue-sieve 0.60 mm	0.00	K	0.57
Residue-sieve 0.09 mm	8.00	C/N	16.7

Table 2. Chemical and microbiological analysis of zeolite tuffs

Zeolite tuffs without organic component (ZT)	Content, %	Zeolite tuffs with organic component (ZT + SPP)	Content
SiO_2	64.93	Total microorganisms	1.6 x 10^9
Al_2O_3	13.66	Bacteria	1.33 x 10^8
Fe_2O_3	2.03	Fungi	7.0 x 10^5
K_2O	1.88	Actinomyces	1.33 x 10^6
Na_2O	3.66	Ammonifiers	1.68 x 10^8
CaO	2.99	Aerobic nitrogen fixators	89.33 %
MgO	1.10	Cellulolytic bacteria	25.33 %
Loss by ignition	9.84	Cellulolytic fungi	29.33 %
		Nitric bacteria	98.67 %
		Nitric bacteria	74.67 %

complex fertilizers (7:20:30) at the same rates (260 and 350 kg ha^{-1}) were applied with the spring pre-sowing fertilization. Sixty percent of the total nitrogen quantity was added to the soil before sowing with the said complex fertilizers while 110 kg /N_1/ and 145 kg ha^{-1} /N_2/ of nitrogen from the single nitrogen fertilizer (UREA) was applied together with the complex mineral fertilizer during the seedbed preparation. The remaining 40% of nitrogen was added in the form of CAN with two topdressings (200 kg /N_1/ and 290 kg ha^{-1} CAN /N_2/). Of the total quantity of complex mineral fertilizer for winter wheat, 2/3 was applied with the basic tillage (320 /$N_1P_1K_1$/ and 420 /$N_2P_2K_2$/ kg ha^{-1} 8:26:26). The remaining one third (160 and 210 kg ha^{-1} 8:26:26) was added in the pre-sowing soil preparation along with 30% nitrogen (15 kg /N_1/ and 22 kg ha^{-1} /N_2/ UREA). In the first and second topdressings, at the beginning of and at full tillering, 25% of total nitrogen was applied (275 kg CAN /$N_1P_1K_1$/ and 370 kg ha^{-1} CAN /$N_2P_2K_2$/). The remaining 20% of nitrogen (110 and 150 kg ha^{-1} CAN) was applied with the last topdressing at the onset of forking – towards earing.

The following treatments were set up in the trial:

1. Check (not fertilized)
2. $N_1P_1K_1$ – 145:120:145 (maize) 150:125:125 (winter wheat) kg ha^{-1} N - P_2O_5 – K_2O
3. $N_2P_2K_2$ – 200:160:195 (maize) 200:165:165 (winter wheat) kg ha^{-1} N - P_2O_5 – K_2O
4. $N_1P_1K_1$ + HL I* (4 t ha^{-1})
5. $N_1P_1K_1$ + HL II* (8 t ha^{-1})
6. $N_2P_2K_2$ + HL I
7. $N_2P_2K_2$ + HL II
8. $N_1P_1K_1$ + FYM I (15 t ha^{-1})
9. $N_2P_2K_2$ + FYM II (30 t ha^{-1})
10. $N_1P_1K_1$ + HL I + FYM I
11. $N_1P_1K_1$ + HL II + FYM II
12. ZT (3 t ha^{-1})
13. ZT + SPP (3 t ha^{-1})
14. $N_1P_1K_1$ + ZT
15. $N_1P_1K_1$ + ZT + SPP

*I = lower doses; **II = higher doses

The paper presents the results for the four investigation years, when maize (*Zea mays* L.) (1999 and 2001) and winter wheat (*Triticum aestivum* L.) (1999/00 and 2001/02) were grown on the trial field. The trial was set up according to the randomized block scheme, with four replications. The trial plot area was 10 x 5 = 50 m^2. The total area of the experiment was of 0.50 ha, including an additional area for traffic operations.

The following soil chemical properties were investigated: soil pH_{KCl}, cation exchange capacity – CEC (ISO 1994), as well as the content of phosphorus and potassium (Egner et al. 1960). Soil data were analyzed as a randomized block design using ANOVA, *F*-test procedure and the t-test, correlation and regression techniques (Petersen 1994).

RESULTS AND DISCUSSION

The soil type under study is Eutric Gleysol (FAO 1990). Excessive moistening is due to the high groundwater level (two kilometers from the experimental field flows one of the biggest Croatian river - Kupa), which causes problems particularly in the late autumn and early spring periods because agricultural management practices cannot be applied at the time of optimal soil moisture conditions.

As seen from Table 3, the soil texture is loam to clay loam (ISO 11727), while physical parameters indicate that this is porous soil of medium water-holding capacity with a low air capacity (Table 4). The soil shows acid reaction, very low supplies of phosphorus, moderate supplies of potassium, and high base saturation of the soil cation-exchange capacity (Table 5).

Changes in the soil chemical properties

Changes in soil chemical indicators were monitored throughout the investigation period. Soil samples were collected after crop harvests. Results of the soil chemical analyses are given in further text per years and trial treatments. The analyses include the initial state, before the trial was set up, for the said indicators

Table 3. Particle size distribution of Eutric Gleysol from experimental plots*

Soil Horizon	Depth cm	Particle size distribution, g kg^{-1}				Texture
		Coarse sand (2-0.2 mm)	Fine sand (0.2-0.02 mm)	Silt (0.02 - 0.002 mm)	Clay (< 0.002 mm)	
P	0-23	7	425	200	368	Clay Loam
G_{so}	23-41	9	436	237	318	Clay Loam
G_r	41-87	5	364	235	396	Clay Loam

*(average values of 15 data); P = anthric layer; Gso=oximorphic layer; Gr = reductomorphic layer

Table 4. Physical parameters of the soil from the plots*

Soil horizon	Depth, cm	Bulk density (ρ_b) Mg m^{-3}		Total porosity, %	Water capacity, %	Air capacity, %
P	0-23	1.46	2.55	48.89	44.09	4.80
G_{so}	23-41	1.38	2.50	48.15	44.68	3.47
G_r	41-87	1.40	2.70	47.20	44.74	2.46

*(average values of 15 data)

Table 5. Chemical properties of the soil from the plots*

Soil horizon	Depth, cm	pH - KCl	Organic matter (g kg^{-1})	Hydrolitic acidity, Y_1	V, %	P	K
						kg ha^{-1}	
P	0-23	4.86	15.5	16.1	71.32	39	335
G_{so}	23-41	4.71	6.7	15.8	74.24	24	178
G_r	41-87	5.04	-	14.3	75.28	-	-

*(average values of 15 data)

(soil pH, content of phosphorus and potassium, and only part of the soil cation exchange capacity, i.e. the degree of base saturation (V, %).

Data given in Table 6 indicate significant differences in the soil chemical properties after the first investigation year. Differences in soil reaction before the trial and after the first investigation year are displayed in Figures 1 and 2. As regards the soil reaction and base saturation of the soil cation-exchange capacity, as parameters determine a large part of chemical and, of no lesser importance, also microbiological processes in soil, and thereby also its fertility, it should be emphasized that the initial state was unfavourable for agricultural production, which was one of the basic criteria for the choice of the experimental area. As expected, the greatest changes were recorded in treatments where higher rates of liming materials were applied. No significant differences in soil reaction and base saturation of the soil cation exchange capacity were recorded in variants where a combination of

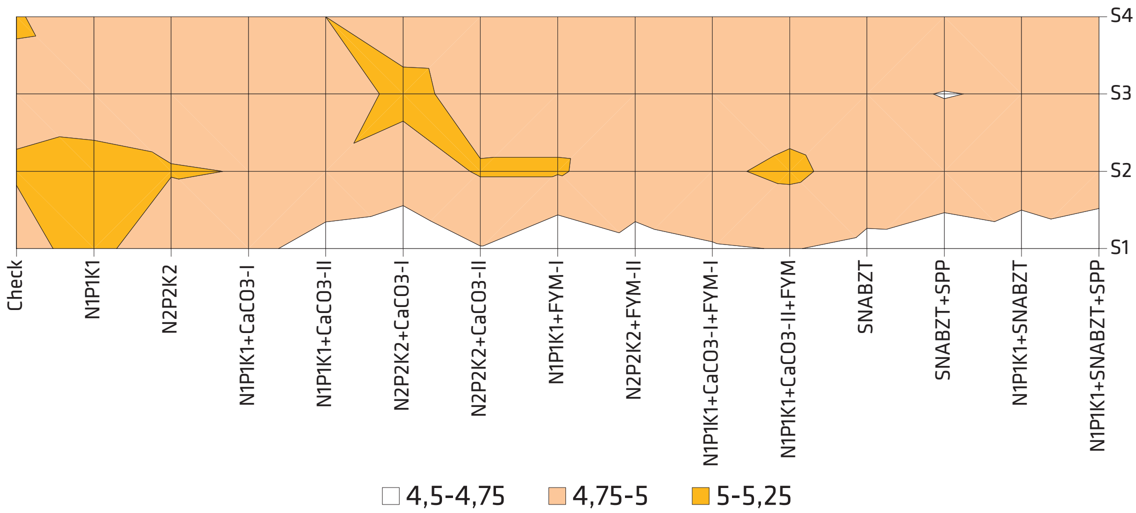

Figure 1. Soil pH before of start investigation

Table 6. Changes in soil pH and the degree of base saturation (V, %)

Treatments	Initial state - autumn 1998		1st year - autumn 1999		2nd year - summer 2000		3td year - autumn 2001		4th year – summer 2002	
	pH	V, %	pH	V, %	pH	V, %	pH	V, %	pH	V, %
1. Check (not fertilized)	4.98	71.9	5.03	72.6	5.15	70.2	5.18	72.5	5.22	72.1
2. $N_1P_1K_1$	4.98	71.7	4.96	75.0	5.13	70.3	5.08	72.1	5.21	73.8
3. $N_2P_2K_2$	4.90	71.5	4.85	73.2	5.05	68.5	4.91	71.2	5.11	73.8
4. $N_1P_1K_1$ + HL I (4 t ha^{-1})	4.87	71.7	5.37	81.0	5.40	75.7	5.26	78.6	5.55	78.3
5. $N_1P_1K_1$ + HL II (8 t ha $^{-1}$)	4.86	71.3	5.62	88.4	5.55	78.9	5.60	83.7	5.51	80.7
6. $N_2P_2K_2$ + HL I	4.85	71.1	5.38	80.1	5.45	75.9	5.27	77.7	5.35	76.0
7. $N_2P_2K_2$ + HL II	4.88	72.4	5.69	88.2	5.53	77.9	5.48	79.7	5.51	79.2
8. $N_1P_1K_1$ + FYM_1 (15 t ha^{-1})	4.87	71.6	4.91	74.3	5.08	68.6	5.00	72.4	5.16	73.1
9. $N_2P_2K_2$ + FYM_2 (30 t ha^{-1})	4.82	70.6	4.92	73.5	5.10	66.9	4.96	70.4	5.16	75.1
10. $N_1P_1K_1$ + HL I + FYM_1	4.85	71.4	5.31	81.5	5.40	77.0	5.30	79.0	5.49	79.7
11. $N_1P_1K_1$ + HL II + FYM_2	4.88	70.4	5.42	83.7	5.40	75.9	5.58	83.3	5.52	80.4
12. ZT 3 t ha $^{-1}$	4.83	72.1	5.31	81.1	5.35	75.8	5.18	77.5	5.35	76.3
13. ZT + SPP 3 t ha $^{-1}$	4.82	70.1	5.31	80.9	5.30	75.1	5.35	78.4	5.31	76.6
14. $N_1P_1K_1$ + ZT	4.80	70.5	5.38	81.0	5.43	78.3	5.19	76.5	5.27	76.9
15. $N_1P_1K_1$ +ZT + SPP	4.81	71.4	5.22	78.8	5.33	75.9	5.28	76.8	5.23	76.6
$t_{5\%}$*	n.s.		0.28	4.79	0.16	4.79	0.23	3.91	0.24	3.37
$t_{1\%}$**			0.39	6.67	0.22	6.67	0.32	5.44	0.33	4.69

mineral fertilizers and farmyard manure was applied. As part of calcium and other nutrients is removed from soil with the plant mass each year, a drop in soil reaction will occur in the future, as evidenced by the research done by Von Boguslavski (1995) and Šimek et al. (1999). Also, no significant differences were recorded in variants with a combination of lower doses of mineral fertilizers and zeolite tuff with SPP.

In the second investigation year, pH was not so much changed by comparison with the preceding year. Changes in the soil cation-exchange capacity correspond to the soil reaction changes. The greatest changes were recorded in variants involving both doses of liming rates and zeolite tuffs, while no significant changes in soil saturation with bases were determined in variants where only mineral fertilizer and organic manure were applied. Similar results were obtained by Alley (1981), Farina and Channon (1991), Kubát and Lipavský (1996) and Vaněk et al. (1997). Although organic matter in soil, among others, influences also the base Exchange capacity: Donahue et al. (1990), Kubat and Lipavsky (1996) and Ragasits and Kismanyoky (2000) and can bind a certain amount of aluminium as well (Hern et al. 1988). No appreciable effect of organic matter on chemical changes in soil was recorded in the second and the following investigation years. No changes in pH values that would point to certain regularities or trends were recorded in the control treatment, and neither in the variants of only mineral or mineral and organic fertilization, which is accountable by the relatively short investigation period.

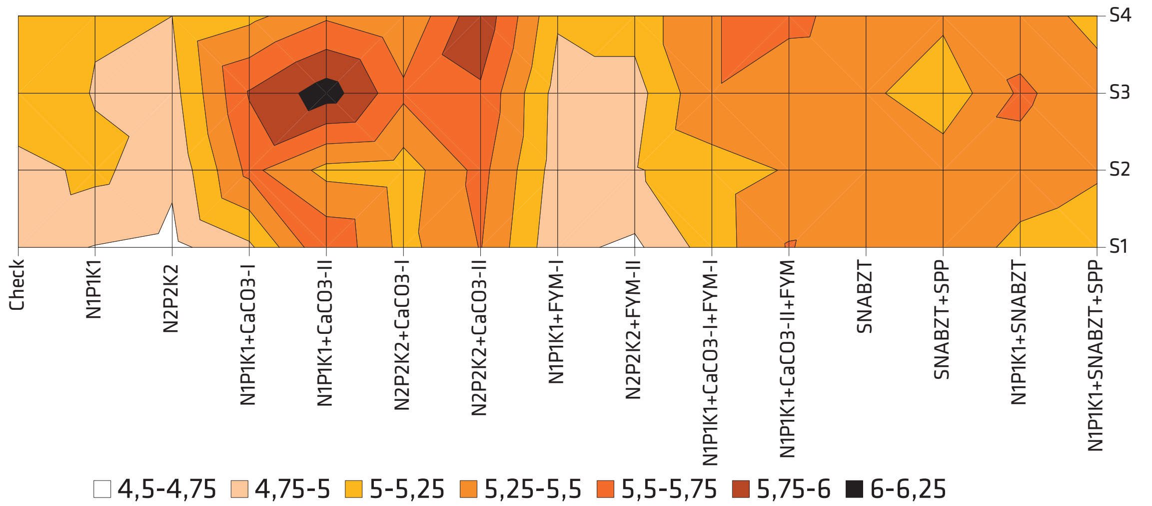

Figure 2. Soil pH after first year of investigation

Table 7. Changes in phosphorus and potassium

Treatments	Initial state - autumn 1998		1st year - autumn 1999		2nd year - summer 2000		3td year - autumn 2001		4th year – summer 2002	
	P	K	P	K	P	K	P	K	P	K
	kg ha^{-1}									
1. Check (not fertilized)	35	322	44	328	38	316	42	305	32	300
2. $N_1P_1K_1$	47	358	45	414	44	406	60	423	50	431
3. $N_2P_2K_2$	44	356	42	406	60	428	69	431	65	434
4. $N_1P_1K_1$ + HL I (4 t ha^{-1})	39	339	53	440	50	412	60	426	59	431
5. $N_1P_1K_1$ + HL II (8 t ha^{-1})	41	347	83	518	44	423	74	406	65	437
6. $N_2P_2K_2$ + HL I	38	305	39	395	53	400	102	409	82	423
7. $N_2P_2K_2$ + HL II	41	316	63	428	50	406	90	484	86	456
8. $N_1P_1K_1$ + FYM_1 (15 t ha^{-1})	35	328	47	428	42	406	75	412	75	412
9. $N_2P_2K_2$ + FYM_2 (30 t ha^{-1})	30	308	50	414	47	414	93	459	90	451
10. $N_1P_1K_1$ + HL I + FYM_1	35	342	74	420	59	420	63	428	64	431
11. $N_1P_1K_1$ + HL II + FYM_2	38	322	59	414	59	420	68	409	65	409
12. ZT 3 t ha^{-1}	42	350	42	412	45	442	45	403	44	395
13. ZT + SPP 3 t ha^{-1}	39	342	39	400	47	431	42	400	43	389
14. $N_1P_1K_1$ + ZT	42	356	56	423	53	440	48	423	49	412
15. $N_1P_1K_1$ +ZT + SPP	45	361	54	440	39	462	53	442	51	403
$t_{5\%}$*	n.s.		n.s.		n.s.		25.2	35.3	7.8	34.4
$t_{1\%}$**							35.2	49.0	10.8	48.1

Changes in the cation-exchange capacity follow the changes of soil reaction in the second trial year. It can be seen from Table 6 that there were no significant changes in the cation-exchange capacity only in treatments where mineral fertilizer was combined with organic fertilizer. Similar results were obtained by Kadar et al. (1999) and Whalen et al. (2000). In all other variants, significant differences were recorded in the values of the degree of base saturation.

In the third trial year, significant differences in soil reaction were recorded only in the variants in which the higher rate of lime material was applied in combination with mineral fertilizer (lower level) or in combination of higher rates of all the three materials studied, at the 5% level, as well as in variants in which only the higher rate of mineral fertilizers was applied or their combination with higher rates of organic fertilizer and hydrated lime.

A significant difference in soil reaction was recorded in the fourth year in variants where hydrated lime was applied in combination with mineral fertilizer, or in combination with mineral and organic fertilizers. No significant differences in soil reaction were recorded in the third and fourth years in variants in which zeolite tuffs were applied.

Contents of phosphorus and potassium indicate that there were no significant differences between the initial state and after the two investigation years (Table 7). During the third trial year, significantly higher levels of phosphorus were recorded in variants in which the higher mineral fertilizer rate was applied, or the combination of mineral, organic and lime materials. No significant differences in phosphorus were determined in variants in which zeolite tuff was applied. Compared to the control treatment, all other variants had a significantly higher content of potassium.

An identical situation was recorded in the last trial year. All variants had significantly higher contents of phosphorus and potassium compared to the control. Better efficiency of mineral and organic fertilization, with mandatory liming, was also confirmed by the research done by Zobač (1994), Šimek et al. (1999) and Vrkoč et al. (2002).

Comparison of the fluctuation of the effective soil acidity during the fourth investigation years reveals differences in the efficiency of particular materials if applied at higher or lower rates. A higher effective acidity reduction was recorded in variants where hydrated lime was applied than in variants where it was not applied or in variants where combinations of mineral fertilizer and farmyard manure or zeolite tuffs were used.

CONCLUSION

The four-year investigation results point to the following conclusions:

Application of hydrated lime influenced changes in the soil chemical properties, notably in terms of correcting excessive acidity. A certain drop in the efficiency of lime materials was recorded after the four trial years, which indicates that this treatment should be repeated after five or six years. Mineral fertilization had a positive effect on the contents of phosphorus and potassium in soil; however, no significant differences in these nutrients were recorded in the first two investigation years, whereas significant differences in the contents of the studied nutrients were recorded in the third and fourth year.

In the first two trial years, special natural amendments with zeolite tuffs caused changes in soil reaction, but not so pronounced as in the case of hydrated lime application. In the third and fourth years, the response to zeolites was still weaker than to hydrated lime; pH values decreased compared to the initial ones, indicating their short-time and relatively weak efficiency for controlling excess soil acidity. Since the mechanism of the action of special natural amendments is based on the processes of intensified ion exchange, it is obvious that the applied doses of this material were insufficient for an appreciable change of soil reaction.

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