The Effect of Liming and Fertilization on Yields of Maize and Winter Wheat

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SUMMARY

Effect of different rates of hydrated lime and zeolite tuffs, as lime materials, mineral and organic fertilizers upon the yield of maize and winter wheat grain was studied in an exact field trial set up on Eutric Gleysol, near Karlovac, Central Croatia. The following crops were cultivated during the study period: 1999 and 2001 – maize, 1999/00 and 2001/02 – winter wheat. In the first investigation year, the highest yield of maize grain of 9.78 t ha^{-1} was achieved with the combination of the higher mineral fertilizer rate and the higher rate of farmyard manure. In the following year, the highest yield of winter wheat grain of 5.85 t ha^{-1} was achieved with the combination of the higher mineral fertilizer rate and the higher rate of hydrated lime. In the third and fourth investigation years, the highest yields of maize grain (10.05 t ha^{-1}) and wheat (5.48 t ha^{-1}) were recorded for the combination of the higher rates of mineral fertilizers and hydrated lime. The foregoing allows the conclusion that mineral and organic fertilization combined with hydrated lime is the optimal solution for increasing the yields of test crops.

KEY WORDS

Fertilization, Liming, Yield, Maize, Winter wheat

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INTRODUCTION

Unfavourable chemical properties of very acid soils restrict the growth and development of cultural plants, often to the extent of justification of using such soils in field production. The pH of the soil plant–root zone influences the ability of plants to acquire essential nutrients from the soil. If the soil pH declines below a critical level, the solubility of aluminium and manganese ions increases, resulting in toxicity and lower yields. Increased acidity of soil solution does not only impede root development but has also an adverse effect on its physical-chemical properties, development of root mass, and thereby also its penetrability, thus impairing plant uptake of nutrients both from the soil and all types of fertilizers.

Acidification of soils over time is a consequence of the removal of base elements with harvested crops and the application of nitrogen fertilizers. Harvested crops contain base elements such as potassium, magnesium and calcium. For example, 10-15 kg of calcium is lost per year in a cereal yield of one tonne (Lukin and Eplin 2003) and leaching about 150 – 450 kg ha^{-1} of calcium (Butorac 1999). If we know content of calcium in the soil, it is not difficult to estimate when all calcium will be taken out of the soil with harvests and leaching. Naturally, unless calcium deficiency is compensated by liming.

There are literature reports pointing to the positive effect of organic matter upon changes in soil and in crop yields: Zobač (1994), Panse et al. (1995), Vaněk et al. (1997) and Badarudin et al. (1999). With respect to the foregoing, investigations on Eutric Gleysol (FAO 1990) were undertaken in 1998. Efficiency of fertilization with organic and mineral fertilizers and of different liming rates and zeolite tuffs is investigated in a field fertilization trial.

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 zeolite tuffs as liming materials upon the yield of crops grown (wheat and maize). Investigation results will serve to recommend the optimal fertilization for maize and wheat on the studied acid soil.

MATERIALS AND METHODS

The materials and methods linked with these investigations have been described in detail in our previous paper – Kisić et al. (2005). 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. $N_1P_1K_1$ + (Hydrated lime – 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. $N_1P_1K_1$ + (Farmyard manure – 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 (Zeolite tuffs without organic components - 3 t ha^{-1})
13. ZT + SPP (Zeolite tuffs with organic components - 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. Yield and some yield components 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

For a better understanding of the efficiency of the applied materials, the climatic conditions prevailing during the trial should be described, since in some years they may have a decisive influence on the activity of the applied materials, as well as on yields of the crops grown. According to the long-term mean, there is no water deficiency in the studied area, which also holds for 1999 (Table 1). In 2000, precipitation deficiency was recorded as early as in April, while the total water deficiency in the summer months amounted to 245 mm. This deficiency was most probably slightly reflected on the achieved yields of winter wheat. In 2001, precipitation deficiency of 100 mm was recorded in August. It seems likely that this deficiency reduced yields of maize grain proportionally in all trial variants. No precipitation deficiency was recorded in the last investigation year.

As seen from Table 2 the soil shows acid reaction, very low supplies of phosphorus, moderate supplies of potassium, and high base saturation of the soil cation-exchange capacity.

Yields and yield components of test crops

Based on the four-year results, the yields of test crops grown in that period are presented in Table 3 (maize) and Table 4 (winter wheat). The highest yield of maize (9.78 t ha^{-1}) was recorded in the variant with the higher mineral fertilizer rate in combination with the higher rate of solid farmyard manure. A significantly lower yield was recorded in the check treatment,

Table 1. Average monthly temperatures (^{0}C) and monthly sums of precipitation (mm)

Month	Average monthly temperatures, °C					Average sum of monthly precipitation, mm				
	30-year, average, 1970-99	1999	2000	2001	2002	30-year, average, 1970-99	1999	2000	2001	2002
I	-0.5	0.5	-2.7	3.6	0.1	62	50	21	135	33
II	2.5	1.2	4.2	4.0	5.6	65	94	33	39	98
III	6.7	8.4	7.8	10.1	7.9	89	44	78	119	23
IV	10.9	12.5	13.9	10.1	9.5	91	98	36	137	242
V	15.8	17.1	17.4	17.4	17.3	97	104	46	90	101
VI	19.4	20.0	21.6	17.5	20.6	98	110	42	133	66
VII	21.1	21.3	21.3	21.2	21.1	99	210	85	40	201
VIII	19.8	20.6	22.4	21.5	20.8	116	64	7	16	120
IX	16.2	18.1	16.5	14.0	14.1	95	117	73	302	127
X	11.0	11.3	13.1	13.8	10.9	96	80	182	10	113
XI	5.7	2.9	9.3	3.3	9.2	117	111	131	113	99
XII	1.0	0.3	5.1	-3.1	1.6	98	101	139	57	119
$\bar{x}/\sum$	10.8	11.2	12.5	11.1	11.5	1123	1183	872	1191	1343

Table 2. 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)

Table 3. Yield and some yield components of maize

Treatments	Maize, 1999				Maize, 2001.			
	Grain yield, t ha^{-1}	1000 grains mass, g	Hectolitre mass, kg	Total nit-rogen in grain, %	Grain yield, t ha^{-1}	1000 grains mass, g	Hectolitre mass, kg	Total nit-rogen in grain, %
1. Check (not fertilized)	3.17	328.0	61.60	0.97	3.25	294.8	64.25	0.90
2. $N_1P_1K_1$	7.99	376.0	72.70	1.35	7.94	316.5	69.15	1.39
3. $N_2P_2K_2$	8.22	386.8	73.30	1.43	9.02	310.0	67.45	1.48
4. $N_1P_1K_1$ + HL I (4 t ha^{-1})	8.52	382.5	72.75	1.33	9.35	350.5	69.35	1.39
5. $N_1P_1K_1$ + HL II (8 t ha^{-1})	8.97	374.5	72.30	1.37	9.69	351.0	70.70	1.44
6. $N_2P_2K_2$ + HL I	9.04	389.3	73.15	1.45	9.74	334.5	68.05	1.52
7. $N_2P_2K_2$ + HL II	9.38	378.3	72.70	1.45	10.05	360.0	71.45	1.50
8. $N_1P_1K_1$ + FYM_1 (15 t ha^{-1})	8.68	384.3	72.50	1.37	8.88	307.5	70.30	1.45
9. $N_2P_2K_2$ + FYM_2 (30 t ha^{-1})	9.78	399.5	72.35	1.44	9.46	313.0	70.90	1.50
10. $N_1P_1K_1$ + HL I + FYM_1	9.24	367.3	72.65	1.38	9.67	323.8	67.90	1.47
11. $N_1P_1K_1$ + HL II + FYM_2	9.32	384.0	73.00	1.39	9.97	338.0	71.30	1.45
12. ZT 3 t ha^{-1}	6.92	358.0	72.10	1.34	6.53	319.0	67.50	1.43
13. ZT + SPP 3 t ha^{-1}	7.21	368.0	72.20	1.39	6.95	312.8	68.40	1.48
14. $N_1P_1K_1$ + ZT	8.08	381.0	72.65	1.43	8.23	316.1	67.75	1.50
15. $N_1P_1K_1$ +ZT + SPP	8.25	383.3	72.10	1.42	8.30	313.3	67.60	1.49
$t_{5\%}$*	0.87	20.3	58.0	0.10	0.89	27.3	33.2	0.09
$t_{1\%}$**	1.18	28.2	80.8	0.13	1.20	38.1	46.3	0.13

and a significantly higher yield was recorded in the variant with the higher mineral fertilizer rate in combination with higher doses of hydrated lime, as well as in variants in which a combination of the lower mineral fertilizer rate and the higher dose of hydrated lime and organic fertilizer was applied. In the variant where the lower and higher mineral fertilizer rates in combination with the lower and higher rates of liming materials and zeolite tuffs were applied, the yield was significantly higher compared

Table 4. Yield and some yield components of winter wheat

Treatments	Winter wheat, 1999/00				Winter wheat, 2001/02			
	Grain yield, t ha^{-1}	1000 grains mass, g	Hectolitre mass, kg	Total nitrogen in grain, %	Grain yield, t ha^{-1}	1000 grains mass, g	Hectolitre mass, kg	Total nitrogen in grain, %
1. Check (not fertilized)	1.99**	33.38*	73.25**	1.76**	2.05**	35.45	72.55*	1.70**
2. $N_1P_1K_1$	4.64	34.75	76.15	1.95	4.27	36.98	74.76	1.97
3. $N_2P_2K_2$	5.68**	35.33	76.00	2.19**	4.71	37.20	76.56	2.26**
4. $N_1P_1K_1$ + HL I (4 t ha^{-1})	4.88	35.90	76.70	2.00	4.67	37.13	74.81	2.07*
5. $N_1P_1K_1$ + HL II (8 t ha^{-1})	5.12	35.30	76.35	2.02	4.85*	36.88	75.50	2.05*
6. $N_2P_2K_2$ + HL I	5.68**	35.45	76.25	2.16**	5.29**	37.25	75.80	2.24**
7. $N_2P_2K_2$ + HL II	5.85**	34.75	77.25*	2.29**	5.48**	36.25	75.05	2.35**
8. $N_1P_1K_1$ + FYM_1 (15 t ha^{-1})	5.05	35.25	77.00	1.99	5.00**	36.00	76.45	2.06*
9. $N_2P_2K_2$ + FYM_2 (30 t ha^{-1})	5.75**	35.13	76.00	2.13**	5.35**	37.20	75.50	2.17**
10. $N_1P_1K_1$ + HL I + FYM_1	5.19	34.95	76.40	2.04*	5.02**	37.13	74.70	2.09**
11. $N_1P_1K_1$ + HL II + FYM_2	5.29*	34.83	76.65	2.04	5.26**	35.73	76.10	2.10**
12. ZT 3 t ha^{-1}	3.05**	34.63	76.30	1.89**	3.15**	35.10*	75.10	1.95
13. ZT + SPP 3 t ha^{-1}	2.79**	34.98	77.05	1.82	3.36**	34.90*	74.60	1.89**
14. $N_1P_1K_1$ + ZT	5.17	34.98	77.20*	1.90	4.51	36.73	75.50	1.97
15. $N_1P_1K_1$ +ZT + SPP	5.05	35.33	76.45	1.83**	4.68	36.28	74.80	1.91**
$t_{5\%}$*	0.64	1.20	0.93	0.08	0.62	1.49	2.12	0.08
$t_{1\%}$**	0.86	1.67	1.30	0.11	0.84	2.07	2.95	0.11

to mineral fertilization alone. The foregoing points to the conclusion that the level of maize yield in variants involving the combination of mineral fertilization and liming materials was conditioned by the interaction of mineral fertilization and liming. This, partly, helps explain the relatively small differences in maize yields between variants involving combinations of higher and lower rates of hydrated lime and mineral fertilizers.

A significantly lower of the hectoliter and 1000 grain mass was recorded in the check treatment as compared to the lower mineral fertilizer rate. As regards the nitrogen content of maize grain (Table 3), it is notable that significantly lower nitrogen content was recorded only in the check variant, and also in the variant with higher mineral fertilizer rates combined with the higher or lower lime doses.

Correlation between the phosphorus (Figure 1) and potassium (Figure 2) and the achieved yield of maize grain indicates their weak and medium correlation after first year of investigation. As shown in our preceding paper (Kisić et al. 2005), in this year there was no significant difference between the studied parameters (phosphorus and potassium). A relatively low correlation between yields and nutrients was therefore expectable. Although the drought in the final stages of wheat development had an adverse effect on the yield, the trial is significant and the differences between variants indicate different efficiency of the applied materials in the second investigation year (Table 4). It might be assumed that the relatively small differences in winter wheat yields between variants would have been bigger if no drought had occurred. The highest yield of wheat grain of 5.85 t ha^{-1} was recorded in the combination of the higher mineral fertilizer rate and the higher rate of hydrated lime. Compared to the lower mineral fertilizer rate, significantly lower yields were recorded in the check treatment and in variants in which only zeolite materials were applied. In all variants with the higher mineral fertilizer rate significantly higher yields were achieved compared to the lower mineral fertilizer rate. Higher yield of wheat grain was also recorded in the treatment involving a combination of lower doses of mineral fertilizers and higher doses of liming materials and organic manure. Still, it can be seen from the data in Table 4 that, in the second trial year, mineral fertilization had a stronger effect on yield than liming. This might be due to the substantial drought that occurred in the final stages of winter wheat development (Table 1). We think that the very poor effects of solid farmyard manure and zeolite tuffs were due to the same reason. As the year in question was expressly dry, it is likely that expected mineralization of organic matter failed to occur.

Nitrogen content of wheat grain was significantly lower in the check treatment compared to the lower mineral fertilizer rate and higher in all variants in which the higher mineral fertilizer rate was applied. Also, significantly higher nitrogen content was determined in the variant in which mineral zeolite was applied, and in the combination of the lower mineral fertilizer rate with organic zeolite tuff.

The 1000-grain mass, at the 5% level, was significantly lower in the check treatment compared to the lower

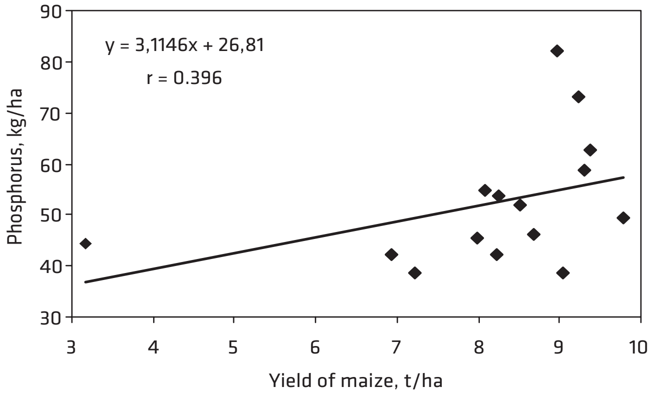

Figure 1. Correlation between phosphorus and yield of maize after first year of investigation

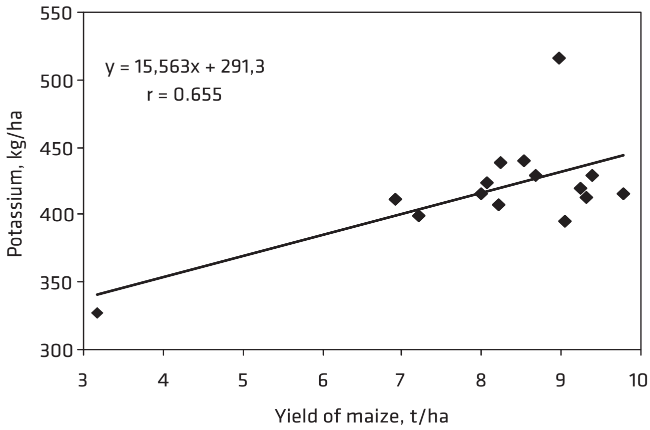

Figure 2. Correlation between potassium and yield of maize after first year of investigation

mineral fertilizer rate. Compared to the same variant, the hectoliter mass was significantly lower in the check treatment and higher at the 5% level in variants with the higher rate of mineral fertilizer and hydrated lime, as well as in the combination of mineral fertilization and mineral zeolite.

Similar results of applying different liming materials were attained by Karabinova et al. (1995), Vaněk et al. (1997), Trávník et al. (1998), Kadar et al. (1999), Pepo (2002) and Kovačević and Josipović (2003).

During the third investigation year, the highest yield of maize (10.05 t ha^{-1}) was recorded in the variant with the higher mineral fertilizer rate in combination with higher doses of hydrated lime (Table 3). Compared to the lower mineral fertilizer rate, a significantly lower yield was recorded in the check treatment. It was only in the variants in which the lower mineral fertilizer rate was applied in combination with mineral and organic zeolites that no significant difference in the yield of wheat grain was recorded compared to the lower mineral fertilizer rate, whereas significant differences in yields, were recorded in all the other variants.

As regards the nitrogen content of maize grain (Table 3), it is notable that the check treatment had a significantly lower nitrogen content (compared to the lower mineral fertilizer rate), and at the 5% level in variants with higher mineral fertilizer rates in combination with the higher and lower lime doses. Also, in variants with the higher rates of mineral and organic fertilizers, as well as in variants where zeolite materials (except for mineral zeolite) were applied, a significantly higher nitrogen content in maize grain was recorded compared to the lower mineral fertilizer rate. Higher yields of maize grain with the application of mineral and organic fertilizers, along with liming, were reported by Balík et al. (1995), Bogdan (1999) and Antunović et al. (2002).

Compared to the lower mineral fertilizer rate, a significantly higher 1000-grain mass was recorded in the variant with higher rates of mineral fertilizer and hydrated lime, while a significantly lower hectoliter mass was recorded in the check treatment only.

Like in the preceding year so also in the last investigation year, the highest yield of wheat grain of 5.48 t ha^{-1} was recorded in the combination of the higher mineral fertilizer rate and the higher dose of hydrated lime (Table 4). The relatively low yields in all variants are attributed to the expressly rainy autumn, when seedbed preparations and sowing of this crop were carried out. Also, precipitation of 242 mm was recorded in April of 2002 (Table 1), accounting for 1/5 of that year's precipitation. This amount of precipitation, with very bad permeability of this soil, had an adverse effect on the yields, which were proportionally reduced in all trial variants. Compared to the lower mineral fertilizer rate, a significantly lower yield was recorded in the check treatment. No significant differences in yields were determined in variants in which the higher mineral fertilizer rate was applied with the lower lime dose, or the lower mineral fertilizer rate in combination with both zeolite materials. In all other variants, a significantly higher yield of wheat grain was achieved compared to the lower mineral fertilizer rate.

Nitrogen content in wheat grain was significantly lower in the check treatment compared to the lower mineral fertilizer rate. No differences in nitrogen contents of wheat grain were recorded in variants in which mineral zeolite was applied. In all other variants, a significantly higher nitrogen content compared to the lower mineral fertilizer rate was recorded.

Nagy (1997), Kovac (1998), Schmidt et al. (2000), Barzegar et al. (2002) and Szalay et al. (2003) also reported that the highest grain yields of winter wheat were achieved with the combination of mineral and organic fertilization with liming as an ameliorative measure. Significant differences between the

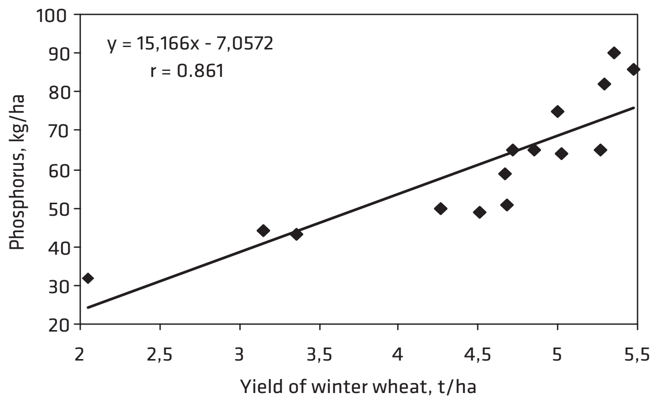

Figure 3. Correlation between phosphorus and yield of winter wheat after four years of investigation

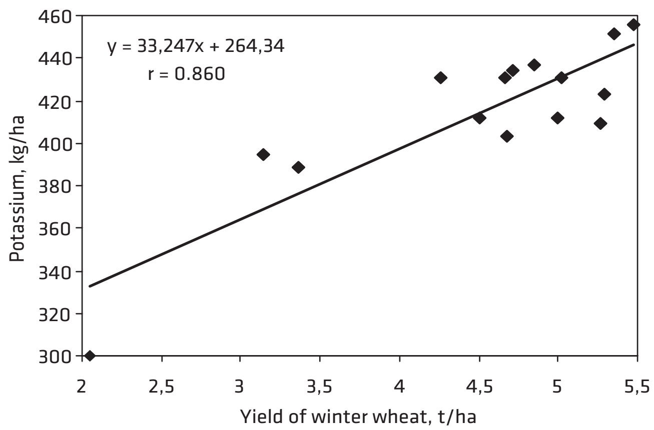

Figure 4. Correlation between potassium and yield of winter wheat after four years of investigation

phosphorus and potassium contents in the studied variants (Kisić et al. 2003) confirm the complete correlation between the phosphorus (Figure 3) and a very strong correlation for potassium (Figure 4) on the end of investigation.

As regards 1000-grain mass, it was only in the variant in which zeolite materials alone were applied that a significant increase at the 5% level was recorded compared to the lower mineral fertilizer rate, while a significantly lower hectoliter mass was determined in the check treatment only.

CONCLUSION

Results presented in this paper indicate that the downward trend of effective soil fertility, notably in humid regions, was primarily caused by the reduced soil content of calcium. Calcium deficiency led to degradation of the physical, chemical and biological properties of soil, and thereby also of soil fertility (Trávník et al. 1998, Šimek et al. 1999, Schmidt et al. 2000 and Tang et al. 2003).

The achieved yields of test crops, as well as the changes that took place in soil (Kisić et al. 2003) indicate that liming should not be the "missing link" in the soil fertilization chain, and that it should be applied on a regular basis on arable areas.

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

Combinations of higher mineral fertilizer rates and higher rates of hydrated lime rendered particularly good results. In the first investigation year, the highest yield of maize grain of 9.78 t ha^{-1} was achieved by the combination of the higher mineral fertilizer rate and the higher rate of farmyard manure. The highest yield of winter wheat grain of 5.85 t ha^{-1} was achieved with the combination of the higher mineral fertilizer rate and the higher rate of lime in the second investigation year. That variant was also the best in the subsequent investigation years. Yields of 10.05 t ha^{-1} of maize grain and 5.48 t ha^{-1} of wheat were achieved in the variant with the higher rate of mineral fertilizers combined with the higher lime dose.

The results indicate that mineral fertilization had a stronger influence on nitrogen content in wheat grain compared to its content in maize grain.

As regards the action of zeolite materials, it was found that they had a stronger influence on the yields of test crops than on the changes in soil. The foregoing findings allow the conclusion that mineral and organic fertilization combined with liming is the optimal solution for increasing yields of test crops on the investigated soil type.

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