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Impact of mineral fertilisers on soil acidification indices

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Acidification of soil is one of the reasons for the chemical degradation process in soil. Liming is the most effective and universal means for the improvement of acid soils. In Lithuania, before intensive liming in 1963 to 1967, there were 40.7% soils affected to different extent by soil acidity. Of them, 11.9% were very acidic (pH 4.5 or less), 15.8% were of average acidity (pH 4.6 to 5.0), and only 13.0% had a low acidity (pH 5.1 to 5.5). About two thirds of severely affected soils were in West Lithuania. Due to intensive liming the area of severely affected soils was reduced, especially those of very high to average acidity. According to data collected between 1981 and 1993, the area under acidic soils reduced to 18% only. Of then, 1.5% were very acidic, 7.0% of average acidity and 10.2% had a low acidity. Results of the field experiments carried out at Lithuanian Institute Agriculture in 1988 through 1998 showed that in the absence of liming soil acidification decreased by 0.1 pH units every year. As a result of this process, an increase in the content of elements such as Al, Zn and Cu and a decrease in the content of bases in the soil were observed (Baginskas, 1964). Ten years after liming the soil pH decreased from 5.4 to 4.4 with a concomitant increase in soil acidity. To prevent the acidification of soils, it is recommended to lime them to pH 5.2 every 4 years in sandy soils and every 8 years in sandy loam soils (Antanaitis, Mažvila, 1984). To follow this recommendation, we should have to lime about 118 thousand hectare every year.

Key words: liming, acid soils, nutritive matter

INTRODUCTION

The Lithuanian Centre of Agrochemistry was established in 1985 with the objective of working mainly on acid soils. Soils with pH 5.5 or less occupies an area of around 80% in East and Southeast Lithuania and around 50% in West Lithuania (Maþvila, 1998). The plants growing on acid soils experiences deficiencies of many elements. In acid soils the microbiological activity and mineralisation of nutrients are affected. Aluminium and manganese may become harmful to plants. The yields of wheat, barley, clover and beet have been reported to be low in these soils as compared to normal ones. In Vëþaièiai it has been established that after liming of soils the pH increased from 4.4 to 6.5, the yield of barley increased from 0.46 to 4.44 t/ha (Èiuberkienë, 1998). The decrease in acidity due to liming depends upon the dose, the way and course of liming, the physical properties of soil, precipitation, the amount and nature of mineral fertilisers (Eþerinskas, 1998). Soil acidification was fixed after the second year of liming (Èiuberkienë, 1998; Veitienë, 1996). Liming of the soil is recommended every 5 to 7 years. The dose of lime depends upon the time of the previous liming. The acidification of soil is one of the reasons for soil degradation. Soil acidification and the related changes in its chemical indices were termed as Chemical Time Bombs (Blake et al., 1984; Goulding, Blake, 1997). In addition to aluminium, soil acidification affects also zinc, manganese and some other elements. In acid soils therefore there exits a danger of accumulation of these elements to the toxic levels in soil and plants (Veitienë, 1998). The process of acidification can be restricted by liming as well as by avoiding acid-producing fertilisers and addition of optimum amounts of organic matter to the soil.

The main objectives of the present study were:

ž to observe the process of soil acidification

ž to elucidate the influence of soil acidification on the content of chemical elements in the soil.

ž to highlight the effect of soil acidification on the yield of crops.

The aim of increasing the soil productivity either by liming or by applying mineral fertilisers is through decreasing the process of acidification and increasing the mineralisation of nutrients.

MATERIALS AND METHODS

Soil characteristics

The field trials were carried out in 1988 on gleyic sod podzolic light loam soil (JP_1^V). The topsoil chemical characteristics are presented in Table 1.

Table 1. **Chemical characteristics of the soil studied**

Agrochemical indices	1988	1989
pH_{KCl}	4.05–4.60	5.2–5.4
Hydrolytic soil acidity, m-ekv./kg	41.6–55.0	24.0–35.1
Content of bases, m-ekv./kg	28.7–44.5	71.3–93.7
Exchangeable soil acidity, m-ekv./kg	3.6–8.7	0.3–0.7
Mobile aluminium, mg/kg	29.0–75.9	0.2–2.2
P_2O_5, mg/kg	105.0–125.0	127.0–152.0
K_2O, mg/kg	238.0–262.0	268.0–297.0
Total N, %	0.12–0.14	0.10–0.13
Humus, %	0.85–2.89	–
Ca, mg/kg	505–649	–
B, mg/kg	0.25–0.44	0.25–0.44
Cu, mg/kg	1.16–1.47	0.97–1.17
Zn, mg/kg	0.54–1.07	1.10–1.79

The composition of the soil showed that the original non-limed soil was more acidic. It contained less amounts of bases. Al content was close to the toxic limits. The soil contained average amounts of phosphorus and very high amounts of potassium, as well as low levels of microelements. After the first year of liming the acidity as well as aluminium content of soils decreased. The hydrolytic soil acidity decreased and that of bases increased after liming.

Methods of analysis

Soil pH was measured with an electrometer and a glass electrode; hydrolytic soil acidity was determined according to Kappen, exchangeable soil acidity and mobile aluminium according to Sokolov, the amount of bases according to Kappen–Hilcovic, mobile potassium and phosphorus according to AI; total nitrogen by the Kjeldal method; boron was extracted in hot water and estimated colorimetrically, copper in 1N HCl extract, zinc in 1 N KCl extract; calcium in ammonium acetate extracts were estimated on an atomic absorption spectrophotometer; humus was estimated according to Turin (ISO/DIS..., 1992; Methods..., 1982).

Climatic conditions

Climatic conditions, especially the amount of precipitation, greatly influence the process of soil acidification and the accessibility of nutrients to plants. In dry conditions the amount of accessible elements is considerably lower than in humid conditions.

The many-year data (Table 2) showed that the average precipitation was more than 800 mm. A higher rainfall was recorded in 1989, 1990, 1994 and 1998 and below normal in 1988 and 1996. June of 1992 and July of 1994 were dry months when the amount of precipitation was rather low. August of 1989, July of 1990, June of 1995 and May of 1996 were especially humid months with the highest rainfall. Large amounts of precipi-

Table 2. **Amount of precipitation (mm) in the period of study**

Month	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Average 1947–1998
January	–	37	122	59	70	106	111	106	19	31	105	64
February	–	72	51	47	79	65	33	74	43	67	76	44
March	–	92	75	35	65	46	124	63	10	36	59	46
April	–	46	11	62	94	15	72	42	18	68	41	45
May	–	21	50	48	49	39	35	48	**147**	76	44	46
June	–	79	96	66	**7**	74	49	**108**	35	68	87	62
July	134	73	**109**	53	41	88	**0**	56	91	51	80	86
August	58	**198**	72	74	69	101	80	53	41	**18**	**168**	91
September	82	32	**163**	83	88	92	118	120	37	134	71	95
October	43	109	130	90	87	57	134	70	85	201	198	93
November	107	99	179	171	146	22	73	93	84	47	63	91
December	112	85	58	84	58	106	102	55	85	78	57	80
Total	537	943	1117	872	844	810	931	888	695	875	1049	843

tation increase the leaching of bases and nutrients to the subsoil and speeds up the acidification of soil.

RESULTS

Impact of soil acidification on changes of chemical elements

Table 3. **Changes in soil reaction (pH_{KCl}) at Vëþaièiai over the study period**

Treatments	$x \pm Sx$ 1989	1994	1998
Without microelements	5.4 ± 0.13	5.2 ± 0.08	4.6 ± 0.13
B once during rotation into soil	5.3 ± 0.20	5.1 ± 0.12	4.6 ± 0.16
B every year onto plants	5.4 ± 0.19	5.1 ± 0.10	4.6 ± 0.11
B every year into soil and onto plants	5.3 ± 0.19	5.1 ± 0.12	4.6 ± 0.16
Cu once during rotation into soil	5.2 ± 0.09	5.1 ± 0.04	4.4 ± 0.11
Cu every year onto plants	5.4 ± 0.09	5.2 ± 0.14	4.7 ± 0.18
Cu every year into soil and onto plants	5.3 ± 0.25	5.0 ± 0.14	4.6 ± 0.14
Zn once during rotation into soil	5.2 ± 0.20	5.0 ± 0.18	4.6 ± 0.19
Zn every year onto plants	5.2 ± 0.13	5.2 ± 0.10	4.6 ± 0.12
Zn every year into soil and onto plants	5.4 ± 0.13	5.2 ± 0.13	4.6 ± 0.13
Mo every year onto plants	5.3 ± 0.20	5.1 ± 0.15	4.6 ± 0.15
Mo every year into soil and onto plants	5.2 ± 0.16	5.0 ± 0.12	4.5 ± 0.14

x – average data, *Sx* – standard deviation.

Chemical analysis of soil showed that its pH, which was in the range of 5.2 to 5.4 after liming in 1989, decreased to 4.5–4.7 after a period of ten years (in 1998). The average decrease in pH was observed to be 0.1 units per year (Table 3).

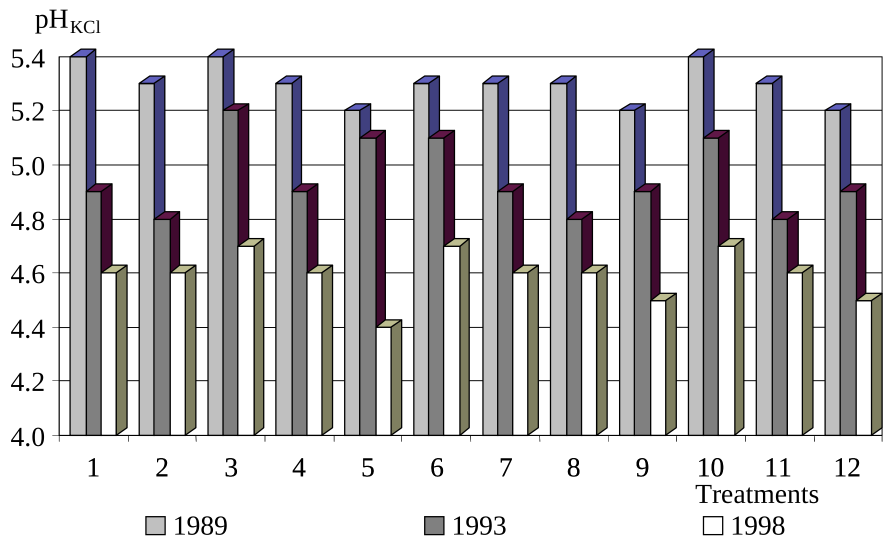
Acidification of soil in the first five years was not intensive. The pH decreased by about 0.2 units from 1989 through 1994. Acidification was more intensive during the last five-year period (from 1994 to 1998) when the pH decreased by 0.4 to 0.6 units, probably be due to effect the higher of liming in the first four years and leaching of $CaCO_3$ into the subsoil in the later period when the acidification of soil was noticeable again. The reaction of the soil seems to be sufficiently stable. The deviation of about 0.12–0.16 pH_{KCl} from the average data showed that the diversity of field trials in respect of soil acidity is low.

Data in Fig. 1 show that the use of microelements did not influence much the soil reaction. The highest effect of soil acidification was observed after dressing with copper one time per crop rotation, but the effect was not statistically significant.

The content of mobile aluminium in the soil is directly related to soil reaction (Table 4).

As reported in the previous section, the Al content in non-limed soil varied from 29 to 76 mg/kg and decreased to 0.3–2.2 mg/kg after liming. However, over the period of 10 years, as the acidity of the soil increased, Al content also increased to 14–34 mg/kg. The wide variation in the deviation from the average values showed that aluminium was not a stable element.

The content of mobile phosphorus decreased with soil acidification after liming the soil (Table 5). In spite of annual fertilisation, the average decrease of 20% over the period from 1989 to 1998 showed that soil acidification degraded the soil with respect



Treatments:
1. Without microelements
2. B once during rotation into soil
3. B every year onto plants
4. B every year into soil and onto plants
5. Cu once during rotation into soil
6. Cu every year onto plants
7. Cu every year into soil and onto plants
8. Zn once during rotation into soil
9. Zn every year onto plants
10. Zn every year into soil and onto plants
11. Mo once during rotation into soil
12. Mo every year onto plants.

Fig. 1. Changes of soil reaction. Vëþaièiai, 1989–1998

Table 4. **Impact of soil acidification on mobile aluminium content (mg/kg)**

Treatments	*x* ± *Sx*		
	1989	1994	1998
Without microelements	0.9 ± 0.4	1.6 ± 0.6	15.9 ± 6.1
B once during rotation into soil	0.3 ± 2.7	8.9 ± 7.4	22.1 ± 10.1
B every year onto plants	0.3 ± 0.2	6.4 ± 3.7	19.9 ± 7.6
B every year into soil and onto plants	1.9 ± 1.8	5.1 ± 3.2	21.3 ± 10.1
Cu once during rotation into soil	1.4 ± 0.5	4.2 ± 1.6	33.8 ± 7.2
Cu every year onto plants	0.3 ± 0.2	4.9 ± 2.0	15.7 ± 7.8
Cu every year into soil and onto plants	1.4 ± 1.3	6.4 ± 2.5	17.2 ± 8.2
Zn once during rotation into soil	2.2 ± 0.8	12.0 ± 4.9	20.6 ± 9.9
Zn every year onto plants	0.8 ± 0.2	4.7 ± 2.1	25.8 ± 6.7
Zn every year into soil and onto plants	0.5 ± 0.2	3.3 ± 1.0	13.9 ± 6.2
Mo every year onto plants	1.0 ± 0.7	7.6 ± 2.3	18.8 ± 7.2
Mo every year into soil and onto plants	1.7 ± 1.0	5.5 ± 3.0	18.3 ± 8.0

x – average data, *Sx* – standard deviation.

Table 5. **Impact of soil acidification on mobile phosphorus content, mg/kg**

Treatments	*x* ± *Sx*		
	1989	1994	1998
Without microelements	152 ± 11	123 ± 12	105 ± 10
B once during rotation into soil	147 ± 10	127 ± 10	111 ± 6
B every year onto plants	137 ± 9	123 ± 3	112 ± 10
B every year into soil and onto plants	145 ± 7	122 ± 3	117 ± 8
Cu once during rotation into soil	129 ± 9	116 ± 5	110 ± 9
Cu every year onto plants	137 ± 11	129 ± 6	118 ± 6
Cu every year into soil and onto plants	140 ± 8	138 ± 2	106 ± 10
Zn once during rotation into soil	145 ± 12	126 ± 5	111 ± 9
Zn every year onto plants	130 ± 2	126 ± 8	112 ± 3
Zn every year into soil and onto plants	142 ± 6	126 ± 4	114 ± 9
Mo every year onto plants	145 ± 10	121 ± 5	116 ± 7
Mo every year into soil and onto plants	127 v 6	132 ± 10	113 ± 8

x – average data, *Sx* – standard deviation.

Table 6. **Impact of soil acidification on potassium content, mg/kg**

Treatments	*x* ± *Sx*		
	1989	1994	1998
Without microelements	296 ± 12	331 ± 16	343 ± 17
B once during rotation into soil	297 ± 22	326 ± 12	320 ± 7
B every year onto plants	286 ± 19	327 ± 5	319 ± 19
B every year into soil and onto plants	293 ± 12	334 ± 2	326 ± 8
Cu once during rotation into soil	270 ± 6	297 ± 10	323 ± 10
Cu every year onto plants	273 ± 15	361 ± 21	345 ± 8
Cu every year into soil and onto plants	278 ±19	308 ± 21	341 ± 25
Zn once during rotation into soil	278 ± 14	335 ± 4	314 ± 5
Zn every year onto plants	279 ± 10	338 ± 10	312 ± 10
Zn every year into soil and onto plants	287 ± 16	349 ± 10	317 ± 20
Mo every year onto plants	268 ± 11	331 ± 10	342 ± 25
Mo every year into soil and onto plants	285± 14	363 ± 24	344 ± 15

x – average data, *Sx* – standard deviation.

to available phosphorus. The deviations from average data were not large, indicating phosphorus to be a rather stable element.

The content of mobile potassium, contrary to phosphorus, increased after soil acidification. The average increase was about 15% (Table 6). In contrast to other chemical indices, the increase in potassium was quite noticeable after five years. After this period the content of K increased, but the increase was not significant.

The change of soil reaction did not influence the content of boron in the soil, and the variation of data was not considerable (Table 7). The data showed that boron is not sensitive to soil reaction. These results are at variance from the results reported by some other workers (Èiuberkienë, 1998; Maþvila, 1998).

The content of calcium, contrary to that of boron, varied rather widely. It was directly related to soil reaction. The migration of calcium to subsoil due to soil acidification was rather fast.

Zinc is considered to be active in acid soils. There is quite a large variation in the content of zinc in soils (Table 8). Acidification of soil over a period of 10 years after liming decreased the content of zinc by 50%. The decrease of mobile zinc in acid soils contradicted the earlier studies (Maþvila, 1998). The decrease in the content of zinc in the pre-

Table 7. **Impact of soil acidification on boron and calcium content, mg/kg**

Treatments	*x* ± *Sx*		
	Boron		Calcium
	1989	1994	1998
Without microelements	0.25 ± 0.02	0.19 ± 0.01	562 ± 72
B once during rotation into soil	0.25 ± 0.03	0.26 ± 0.01	569 ± 107
B every year onto plants	0.25 ± 0.04	0.25 ± 0.03	597 ± 58
B every year into soil and onto plants	0.31 ± 0.03	0.24 ± 0.04	508 ± 89
Cu once during rotation into soil	0.32 ± 0.05	0.18 ± 0.02	497 ± 72
Cu every year onto plants	0.27 ± 0.04	0.21 ± 0.01	555 ± 38
Cu every year into soil and onto plants	0.31 ± 0.01	0.20 ± 0.01	577 ± 61
Zn once during rotation into soil	0.42 ± 0.05	0.25 ± 0.02	566 ± 99
Zn every year onto plants	0.44 ± 0.05	0.23 ± 0.04	520 ±77
Zn every year into soil and onto plants	0.38 ± 0.04	0.26 ± 0.04	606 ± 39
Mo every year onto plants	0.32 ± 0.06	0.26 ± 0.02	585 ± 67
Mo every year into soil and onto plants	0.28 ± 0.05	0.26 ± 0.03	558 ± 69

x – average data, *Sx* – standard deviation.

the yield of fodder beets. Boron application increased their yield by 7.8 t/ha (23%) as compared to control.

Microelements, especially molybdenum and zinc, increased the yield of perennial grasses in both crop rotations. The use of microelements in the beginning of crop rotation gave 1.92 and 1.06 t/ha of additional hay yield. The annual use of microelements increased the yield of hay by 0.94 and 1.05 t/ha. Increase in soil acidity decreased the efficiency of microelements. Fertilisation with microelements gave no increase in the yield of fodder beets and corn.

Table 8. **Impact of soil acidification on copper and zinc content, mg/kg**

Treatments	*x* ± *Sx*			
	Copper		Zinc	
	1989	1996	1989	1996
Without microelements	1.07 ± 0.11	1.27 ± 0.24	1.10 ± 0.08	1.00 ± 0.20
B once during rotation into soil	1.17 ± 0.08	1.77 ± 0.30	1.56 ± 0.04	0.80 ± 0.14
B every year onto plants	1.07 ± 0.08	1.47 ± 0.08	1.44 ± 0.17	1.12 ± 0.22
B every year into soil and onto plants	1.12 ± 0.07	1.67 ± 0.20	1.61 ± 0.10	0.70 ± 0.13
Cu once during rotation into soil	0.97 ± 0.02	1.40 ± 0.27	1.79 ± 0.41	0.65 ± 0.13
Cu every year onto plants	1.12 ± 0.11	1.37 ± 0.19	1.42 ± 0.27	0.65 ± 0.14
Cu every year into soil and onto plants	1.10 ± 0.20	1.50 ± 0.22	1.36 ± 0.16	0.67 ± 0.14
Zn once during rotation into soil	1.02 ± 0.08	1.57 ± 0.32	1.64 ± 0.10	0.55 ± 0.12
Zn every year onto plants	1.05 ± 0.05	1.35 ± 0.20	1.42 ± 0.22	0.90 ± 0.33
Zn every year into soil and onto plants	1.05 ± 0.05	1.50 ± 0.24	1.19 ± 0.19	0.77 ± 0.11
Mo every year onto plants	1.02 ± 0.02	1.40 ± 0.10	1.28 ± 0.07	0.60 ± 0.17
Mo every year into soil and onto plants	1.12 ± 0.13	1.12 ± 0.14	1.37 ± 0.21	0.67 ± 0.18

x – average data, *Sx* – standard deviation.

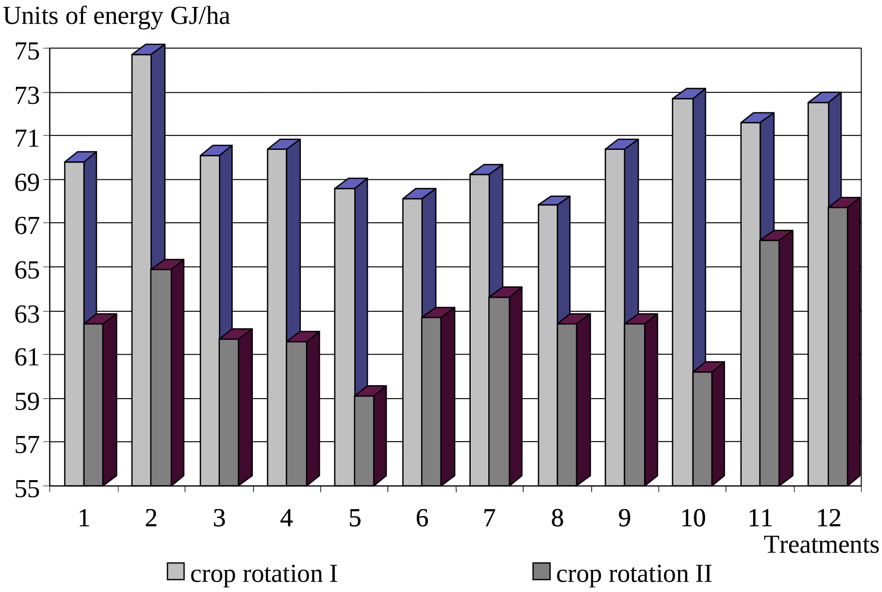
sent study may due to its removal by crops as higher crop yields were obtained after liming the soil.

The content of copper in acid soils increased by about 27% and data variation in acid soils was quite large as compared to limed soils (Table 8).

Impact of soil acidification on crop yield

Figure 2 shows the effect of soil acidification on the yield of crops and the efficiency of microelements. Among the micronutrients applied, boron and molybdenum showed the most pronounced effect on the yields of crops. Application of boron in the beginning of a crop rotation had a lasting effect on

The efficiency of fertilisers is also related to soil acidity. The increased content of aluminium due to soil acidity decreased the content of phosphorus in the soil. The total yield of the second crop rotation decreased from 70.5 GJ/ha to 62.9 GJ/ha. Soil acidification can be regarded as one of the reasons for its chemical degradation. Acidification changes the balance of nutrients in soil. Some of the elements, such as Al, may become toxic whereas other elements, such as Ca and P, may become deficient.



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9. Zn every year onto plants
10. Zn every year into soil and onto plants
11. Mo once during rotation into soil
12. Mo every year onto plants.

Fig. 2. Accumulation of units of energy in crop rotations, GJ/ha. Vëþaièiai, 1989–1998

DISCUSSION

Soil acidification is one of the reasons for the chemical degradation of soils. The chemical degradation of soil decreases the productivity of crop rotation due to the increasing contents of elements such as Al, Zn, and Cu in the soil. Soil acidification also causes irreversible chemical processes.

The aim to increase soil productivity either by liming or mineral fertilisation can be achieved by decreasing the process of acidification and increasing the mineralisation of nutrients. This aim therefore can easily be achieved by paying more attention to the marginally affected soils as compared to totally degraded soils.

Activity of chemical elements under soil acidification varies in the following order K > Ca > Al > > P > Zn > Cu > B. This arrangement of nutrients does not contradict the metal activity rules. Soil acidification is a natural process governed by inherent chemical laws. However, it should not be allowed to proceed to extreme ends. On the marginal fields, cultivation of plants tolerant to acidic soils is recommended. A reasonably high productivity on acid soils can be ensured by liming them, using non-acidifying fertilisers and an ample use of organic matter, which increases the content of humus in the soil.

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Rima Veitienë

MINERALINIØ TRÀÐØ ÁTAKA RÛGÐTËJANÈIO DIRVOÞEMIO CHEMINIAMS RODIKLIAMS

S a n t r a u k a

Intensyvinant þemës ûká á dirvoþemá su makrotràðomis nepatenka mikroelementø. Menkai naudojamos organinës tràðos taip pat nepapildo mikroelementø atsargø dirvoþemyje. Dirvoþemá kalkinant, daugelis mikroelementø tampa augalams neprieinami. Dël kalkinimo kinta ir makroelementø kiekis. Tai gali turëti átakos ne tik derlingumui, bet ir mikroelementø efektyvumui. Dël mikroelementø trûkumo dirvoþemyje gaunamas maþesnis ir prastesnës kokybës þemës ûkio augalø derlius.

Reikliausi boro trûkumui - dviskilèiai augalai. Boro tràðø efektyvumas priklauso nuo daugelio veiksniø, ypaè nuo dirvoþemio rûgðtumo. Boro kiekis dirvoþemyje priklauso nuo dirvoþemio granuliometrinës sudëties, mineraliniø tràðø, patenkanèiø á dirvà, kiekio. Molibdenas, atvirkðèiai negu kiti mikroelementai, judresnis neutralios reakcijos dirvoþemyje, o vario kiekis labiau priklauso nuo granuliometrinës sudëties, organinës medþiagos, sorbuotø baziø kiekio. Taèiau ðis elementas maþiau jautrus ávairiems aplinkos veiksniams ir jo kiekis kinta neþymiai. Tuo tarpu cinkas - chemiðkai aktyvus elementas. Jo kiekis þenkliai kinta nuo kalkinimo bei nuo ávairiø kitø dirvoþemio reakcijà keièianèiø priemoniø, t. y. kalkinimo, organinio bei mineralinio træðimo.

Tyrimai rodo, kad dirvoþemiui rûgðtëjant, jame vyksta negráþtami cheminiai procesai, maþinantys dirvoþemio derlingumà. Dirvoþemiui parûgðtëjus nuo pH_{KCl} 5,4 iki 4,4, sëjomainos augalø produktyvumas sumaþëjo nuo 70,5 iki 62,96 J/ha.

Raktaþodþiai: mikroelementai, dirvoþemio reakcija, sëjomaina