Effect of NPK Fertilization on the Yield and Mineral Element Content of an Established All-grass

P. RAGÁLYI and I. KÁDÁR

Research Institute for Soil Science and Agricultural Chemistry (RISSAC) of the Hungarian Academy of Sciences, Budapest

Introduction

As VOISIN (1965) stated: "Mineral fertilizers are one of the most important of the discoveries of modern chemistry. Well applied they maintain and even raise soil fertility, increase crop yields, and improve the feeding value of agricultural produce. Without mineral fertilizers agriculture would never have been able to quadruple its yields in fifty years and thus earn its place as one of the principal factors in the higher standard of living of civilized countries."

If unwisely used, however, this marvellous tool can become greatly dangerous, by destroying soil fertility, reducing yields and impairing the feeding value of agricultural products, seriously and adversely affecting both animal and human health. Grass alone requires high rates of N in order to maximize production or to equal yields of grass–legume combinations. In New Zealand (DOW et al., 1980) up to 600 lb N/acre were required on grass pasture to equal the yield of grass–clover pasture receiving no N fertilizer. N over-fertilization at the same time leads to elevated nitrate content in feed or forage, which is toxic to animals. The critical range starts from 0.25% NO_3-N in D.M. for forage, where it is the only source of feed (TUCKER et al., 1961; CHAPMAN, 1966; BARCSÁK, 2004).

The application of K may considerably increase responses to N or P fertilizers when a progressive depletion of soil K occurs. Although grasses have a greater ability to extract K or P from the soil than many other crops, restrictions of growth caused by deficiencies in these elements are not uncommon in Hungary, particularly when high yields are obtained with high N levels and the herbage is regularly cut and removed rather than grazed. This appears mainly on sandy soils poor in K (ANTAL et al., 1966).

The long-term effect of N, P and K fertilizers on soil and crop is still not well understood. As a consequence of dressings of P fertilizers available Zn "disappears" from the soil. The effect is marked when the soil is relatively low in available Zn and the crop is susceptible to Zn deficiency, as in the case of corn. This effect of P is cumulative. At present, therefore, in traditional maize-growing regions Zn defi-

Correspondence to: PÉTER RAGÁLYI, Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences, H-1022 Budapest, Herman Ottó út 15. Hungary. *E-mail:* ragalyi@rissac.hu

ciency is becoming more frequent following decades of heavy and often excessive application of P (KÁDÁR, 1992; KÁDÁR et al., 2000).

The antagonistic effect of K on the uptake of Ca, Mg, Na, B etc. elements has been recognized for many decades. The synergetic effects of N on the element uptake of the main major nutrients are also well known (FINCK, 1982; GEISLER, 1988). The interactions among N×P, N×K and P×K supply levels, however, are not well understood, their effect on yield and element uptake has not been revealed yet. This type of field study needs a complicated research program with a large number of plots. The present work aimed to evaluate the effect of different N, P and K supply levels and their combinations on the development, yield and mineral composition of an established all-grass sward in the 28^{th} year of a long-term fertilization trial set up on a calcareous chernozem soil. Details of this experiment were summarized earlier by KÁDÁR (2005a,b).

Material and Methods

The calcareous chernozem soil of the growing site contained around 3% humus, 3–5% $CaCO_3$, 20–22% clay in the ploughed layer and was originally supplied moderately well with available K, Mg, Mn, Cu and poorly with P and Zn. The trial included 4N×4P×4K= 64 treatments in 2 replications, giving a total of 128 plots. The applied fertilizers were Ca-ammonium nitrate, superphosphate and potassium chloride. The area was drought sensitive with the groundwater table at a depth of 13–15 m and negative water balance of about 100 mm/yr. The grass was established on 21 September, 2000. Treatments and the soluble PK contents of the soil's ploughed layer are given in Table 1.

During the thirty years of the experiment 0–9000 kg N, 0–4500 kg P_2O_5 and 0–7500 kg K_2O nutrients were applied per hectare. N doses were divided into two halves, one was applied in autumn and the other in spring. The experimental plots represent low, moderate, high and very high supply levels and all of their combina-

Table 1

Treatments and their effects on the soluble PK content in the ploughed layer of the calcareous chernozem soil

Fertilization and soil analysis	Treatments or fertilization levels				$LSD_{5\%}$	Mean
	0	1	2	3		
Applied amount of fertilizer						
N kg/ha/ yr	0	100	200	300	–	150
N kg/ha/30 yrs	0	3000	6000	9000	–	4500
P_2O_5 kg/ha/30 yrs	0	1500	3000	4500	–	2250
K_2O kg/ha/30 yrs	0	2500	5000	7500	–	3750
Ammonium lactate soluble P and K content of soil (EGNÉR et al., 1960)						
AL-P_2O_5, mg/kg	66	153	333	542	42	274
AL-K_2O, mg/kg	135	193	279	390	32	249

tions, which may possibly be found elsewhere in arable fields or are probable to develop in the future. Until 2000 several arable crops were grown in free crop rotations. In 2001–2003 grass was grown on the whole experimental area. The mixture of 8 grass species (Meadow fescue *(Festuca pratensis)*, Tall fescue *(Festuca arundinacea)*, Perennial ryegrass *(Lolium perenne)*, Agropyron *(Agropyron cristatum)*, Red fescue *(Festuca rubra)*, Timothy *(Phleum pratense)*, Reed canarygrass *(Phalaris arundinacea)*, Cocksfoot *(Dactylis glomerata)* was sown in autumn 2000. The dominant species was the meadow fescue with a 25% application rate.

The grass herbage had a very favourable wet year in 2001 with more than 700 mm rainfall during the total vegetation period and resulted in 2 cuts. Cuts were made before the flowering stage of meadow fescue. Composite plant samples from 20 subsamples per plot, as well as soil composite samples from the ploughed layer out of 20 cores per plot were taken at harvest time for laboratory analyses.

Plant samples were dried, milled and analyzed for 20–25 elements with cc. HNO_3 + cc. H_2O_2 digestion and using ICP technique. After drying and milling of the soil samples, their NH_4-acetate+EDTA soluble element contents were determined with the LAKANEN and ERVIÖ (1971) method, as well as their NH_4-lactate soluble PK content according to EGNER et al. (1960). The layout and method of the trial was published elsewhere (KÁDÁR, 2005a).

Results and Discussion

The 1st cut took place on 23 May, 2001. The effect of N was moderate in the 1st cut, giving around 2 t/ha hay surpluses on the average, and the maximum yield responses were obtained in the N_1 (100 kg N/ha/yr) treatment. The yield of the 2nd cut (9 October, 2001) showed increased N responses, the yields were basically determined only by N fertilization. The highest hay surpluses were obtained in the N_3 (300 kg N/ha/yr) treatment, making out about 3 t/ha. There was a 4-fold increment in hay yield due to the applied N (Table 2).

The „moderate" supply levels (135 mg/kg AL-K_2O and 153 mg/kg AL-P_2O_5) basically satisfied the P and K demands of grass. An increasing trend was observable, however, in hay yields with the higher P supply levels. Without a satisfactory P supply the efficiency of N fertilization is much lower and vice versa. N, P or K over-fertilization did not cause a significant depression, though the higher P levels reduced yield on the N control plots in both the 1st and 2nd cut. There were no P responses any more at the later harvesting date (9 October) even on the P_1 (low) supply level, with 66 mg/kg AL-P_2O_5 value (Table 2).

The differences are much more enhanced considering the unfertilized control plots ($N_0P_0K_0$) and the balanced rising NPK treatments. In the 1st and 2nd cuts the hay yield of the $N_0P_0K_0$ plots was 1.7 and 1.2 t/ha, while the highest ($N_3P_3K_3$) treatment gave 8.8 t/ha and 4.2 t/ha, respectively. NPK fertilization increased the air-dry hay yield from 3 t/ha to 13 t/ha (1st+2nd cuts together) in the 1st year of the trial (Table 3).

Table 2
Effect of N×P supply levels on the air-dry hay yield in 2001, t/ha

AL-P_2O_5 mg/kg	Yearly N fertilization rates, kg N/ha/yr				$LSD_{5\%}$	Means
	0	100	200	300		
	1st cut (23 May)					
66	3.3	3.9	3.8	4.8		4.0
153	5.5	7.2	7.6	6.9	1.0	6.8
333	5.8	7.9	7.4	7.4		7.1
542	4.9	8.1	7.9	8.1		7.2
Mean	4.9	6.8	6.7	6.8	0.5	6.3
	2nd cut (9 October)					
66	1.4	2.7	3.5	3.6		2.8
153	0.8	2.1	3.5	4.0	0.4	2.6
333	1.0	2.3	3.4	4.0		2.7
542	0.9	2.1	3.4	3.9		2.7
Mean	1.0	2.3	3.4	3.9	0.2	2.7

Note: Data are given as a mean of K treatments

The optimum N content in the hay, leading to maximum yield, amounted to 2% and 2.5–3.0% in the 1st and 2nd cut. As a consequence of the applied N the air-dry content decreased from 33% to 31% in the 1st cut, and from 27% to 21% in the 2nd. In the 1st cut hay the optimum K content was around 2% and more, where the highest hay yields were obtained. Here the K/P ratio was about 10 and the N/K ratio around 1.0. It should be emphasized that these optima are or may be valid for grass species mixture without legume crops, similar to these described conditions, and for the 1st cut hay.

As a function of N fertilization the element content of hay in the 1st cut usually increased, except for Al and Mo, which showed dilution effects. The rise in element concentration was 25–50% for K, Ca, Mg, Mn, P, Sr, B and Ni; 60–70% for S and Co, two-fold for N and Cu; five-fold for NO_3-N and Na as compared to the N control (Table 4).

Table 3
Effect of different NPK supply levels on the air-dry hay yield of the 1st and 2nd cut, t/ha

Date of cut	NPK supply levels or combinations					$LSD_{5\%}$
	$N_0P_0K_0$	$N_1P_0K_0$	$N_1P_1K_1$	$N_2P_2K_2$	$N_3P_3K_3$	
23 May, 2001	1.7	3.5	7.8	7.9	8.8	2.0
9 Oct., 2001	1.2	2.0	2.6	3.7	4.2	0.8
Together	3.0	5.5	10.4	11.6	13.0	2.4

Note: For applied fertilizer amounts: See Table 1

Table 4

Effect of N fertilization on the mineral element content of the air-dry hay on 23 May, 2001

Measured elements and units		N-fertilization, kg N/ha/yr				$LSD_{5\%}$	Mean
		0	100	200	300		
K	%	1.86	2.37	2.26	2.38	0.09	2.22
N	%	1.10	1.87	2.09	2.39	0.16	1.86
Ca	%	0.48	0.56	0.58	0.62	0.03	0.56
S	%	0.15	0.25	0.26	0.26	0.01	0.23
P	%	0.17	0.22	0.22	0.23	0.01	0.21
Mg	%	0.12	0.17	0.18	0.18	0.01	0.16
NO_3-N	%	0.06	0.10	0.22	0.34	0.03	0.18
Na	mg/kg	109	488	574	535	62	426
Mn	mg/kg	83	106	114	118	5	105
Al	mg/kg	102	93	80	78	23	88
Sr	mg/kg	13	16	16	17	1	15
B	mg/kg	4.4	5.4	5.3	5.4	0.4	5.1
Cu	mg/kg	2.1	3.8	4.4	4.7	0.3	3.8
Ni	mg/kg	0.90	1.01	1.10	1.12	0.16	1.03
Mo	mg/kg	0.21	0.20	0.18	0.16	0.02	0.19
Co	mg/kg	0.05	0.07	0.07	0.08	0.02	0.07

Note: As, Hg, Cd, Pb and Se are usually below the 0.1 mg/kg detection limit. Data are given as means of PK treatments

As it can be seen in Table 5, P fertilization stimulated the uptake of Mn and Mg by 10–20%; S, NO_3-N and Co by 40-50%, Na and Sr by 60–70%, P by 90%; while it inhibited the uptake of Zn and Co by 20–40%, Al and Fe by 50–60%, Mo by 70% in comparison to the P control. The reduced Fe content has no considerable effect on grass quality, but the decline in Zn content in fodder may cause disturbances in some protein synthesis. The optimal P/Zn rate is assumed to be between 50 and 150 (KÁDÁR, 1992). The P/Zn ratio in the P control soil showed optimal values of 118, while in the soil with high P supply this ratio was 278, indicating Zn deficiency.

K fertilization had a marked effect on the mineral element composition of the 1st cut. So, due to the rising K levels K, Ba and N increased in the hay, while the uptake of all other measured elements was depressed. It is worth mentioning that not only the uptake of metal cations was hindered, but also that of B and Mo, which are generally in anion form in the soil solution (Table 6).

The soil P×K levels show negative interactions with the Fe, Al, Mo and Cr content of the 1st cut hay (Table 7). The applied PK fertilizers were not sources of these elements, so the changes in element concentrations were induced. In the case of the highest PK levels Fe, Al and Cr contents dropped to 1/3 of the control values. The hay's Mo content, however, decreased by an order of magnitude, thus PK prevalence is probable to induce Mo deficiency in this soil. This phenomenon cannot be revealed by soil analysis but by plant analysis with diagnostic purposes (BERGMAN, 1992). Data in Table 7 are given as means of N treatments.

Table 5
Effect of soil P supply on the mineral element content of the air-dry hay on 23 May, 2001

Measured elements and units		Ammonium lactate soluble P_2O_5, mg/kg				$LSD_{5\%}$	Mean
		66	153	333	542		
S	%	0.17	0.24	0.26	0.25	0.01	0.23
P	%	0.13	0.20	0.24	0.25	0.01	0.21
Mg	%	0.14	0.16	0.17	0.17	0.01	0.16
NO_3-N	%	0.14	0.20	0.19	0.20	0.03	0.18
Na	mg/kg	298	448	486	474	62	426
Mn	mg/kg	95	111	112	103	5	105
Al	mg/kg	147	65	73	67	23	88
Fe	mg/kg	204	119	119	107	38	137
Sr	mg/kg	11	14	17	19	1	15
Zn	mg/kg	11	9	9	9	1	10
Ni	mg/kg	0.87	1.03	1.10	1.13	0.16	1.03
Mo	mg/kg	0.32	0.16	0.14	0.12	0.02	0.19
Co	mg/kg	0.08	0.07	0.06	0.05	0.02	0.07

Note: As, Hg, Cd, Pb and Se are below the 0.1 mg/kg detection limit. Data are given as means of NK treatments

Table 6
Effect of soil K supply on the element content of the air-dry hay on 23 May, 2001

Measured elements and units		Ammonium lactate soluble K_2O, mg/kg				$LSD_{5\%}$	Mean
		135	193	279	390		
K	%	1.89	2.18	2.35	2.45	0.09	2.22
N	%	1.76	1.79	1.86	2.04	0.16	1.86
Ca	%	0.62	0.56	0.54	0.52	0.03	0.56
Mg	%	0.19	0.16	0.15	0.15	0.01	0.16
Al	mg/kg	103	87	91	71	23	88
Fe	mg/kg	163	137	134	115	38	137
Sr	mg/kg	16	15	15	14	1	15
Ba	mg/kg	6.3	6.7	8.3	9.0	0.6	7.6
B	mg/kg	6.0	5.1	4.8	4.6	0.4	5.1
Cu	mg/kg	4.0	3.6	3.8	3.6	0.3	3.8
Ni	mg/kg	1.30	1.01	1.14	0.68	0.16	1.03
Mo	mg/kg	0.23	0.21	0.19	0.12	0.02	0.19
Co	mg/kg	0.08	0.06	0.06	0.06	0.02	0.07

Note: As, Hg, Cd, Pb and Se are below the 0.1 mg/kg detection limit. Data are given as means of NP treatments

Table 7
Effect of P×K supply levels on Fe, Al, Mo, Cr contents of air-dry hay on 23 May, 2001

AL-K_2O mg/kg	Ammonium lactate soluble (AL) P_2O_5, mg/kg				$LSD_{5\%}$	Mean
	66	153	333	542		
			Fe, mg/kg			
135	307	119	127	101		163
193	175	149	115	107	76	137
279	197	104	118	116		134
390	140	103	114	105		115
Mean	204	119	119	107	38	137
			Al, mg/kg			
135	206	72	73	63		103
193	139	71	72	67	46	87
279	148	59	76	80		91
390	97	60	69	60		71
Mean	147	65	73	67	23	88
			Mo, mg/kg			
135	0.44	0.18	0.15	0.15		0.23
193	0.30	0.16	0.17	0.15	0.04	0.19
279	0.34	0.20	0.15	0.15		0.21
390	0.24	0.09	0.09	0.05		0.12
Mean	0.33	0.16	0.14	0.12	0.02	0.19
			Cr, mg/kg			
135	0.33	0.14	0.17	0.10		0.19
193	0.20	0.14	0.16	0.17	0.08	0.17
279	0.20	0.12	0.13	0.14		0.15
390	0.14	0.12	0.14	0.13		0.13
Mean	0.22	0.13	0.15	0.13	0.04	0.16

Note: data are given as means of N treatments

According to Table 8, the N×K interactions resulted in a dramatic increase in the N content of the 1st cut hay from 0.96% measured in the NK control up to 2.72% in the highest NK level. In the case of K the increase was from 1.71 to 2.79%. N fertilization had a stimulating, while K fertilization a depressing effect on the Ca, Mg and Zn uptake in hay. For assessing the nutrient status of crops information is also needed about the ratios of measured elements in plant tissues. As a function of N×K supply the ratios of K/Ca varied between 5–7, that of K/Mg between 10–18, that of K/Ni was around 10–40 thousand.

The N×K levels have extreme effects on the Na content of hay (Table 9). Generally, the Na content of hay was increased several times by N fertilization, while K fertilization caused a similar rate decrease, counterbalancing each others influence. Indeed, the source of Na was the K fertilizer in soil. However, the K–Na antagonism and N–Na synergism were of crucial importance for plant uptake.

Table 8
Effect of N×K supply levels on the N, K, Ca, Mg and Ni contents of the air-dry hay on 23 May, 2001

AL-K_2O mg/kg	N fertilization, kg N/ha/yr 0	100	200	300	$LSD_{5\%}$	Mean
			N %			
135	0.96	1.80	2.00	2.30		1.76
193	1.10	1.84	1.94	2.28	0.31	1.79
279	1.14	1.90	2.15	2.26		1.86
390	1.21	1.94	2.29	2.72		2.04
Mean	1.10	1.87	2.09	2.39	0.16	1.86
			K %			
135	1.71	2.03	1.82	2.02		1.89
193	1.81	2.44	2.31	2.15	0.19	2.18
279	2.00	2.49	2.35	2.56		2.35
390	1.94	2.52	2.55	2.79		2.45
Mean	1.86	2.37	2.26	2.38	0.09	2.22
			Ca %			
135	0.48	0.62	0.66	0.70		0.62
193	0.46	0.59	0.59	0.59	0.06	0.56
279	0.49	0.52	0.55	0.59		0.54
390	0.46	0.52	0.52	0.59		0.52
Mean	0.48	0.56	0.58	062	0.03	0.56
			Mg %			
135	0.12	0.20	0.21	0.21		0.19
193	0.12	0.18	0.19	0.18	0.02	0.16
279	0.12	0.16	0.17	0.17		0.15
390	0.11	0.15	0.16	0.17		0.15
Mean	0.12	0.17	0.18	0.18	0.01	0.16
			Ni, mg/kg			
135	1.23	1.30	1.29	1.38		1.30
193	0.82	1.10	1.13	1.01	0.32	1.01
279	0.80	1.05	1.19	1.31		1.08
390	0.56	0.60	0.80	0.76		0.68
Mean	0.85	1.01	1.10	1.12	0.16	1.02

Note: Ammonium lactate soluble K_2O (mg/kg) in the ploughed layer. Data are given as means of P treatments.

The hay of the 2nd cut contained about 20% more N, K, Ca, Mg and Na, 40% more Cu, 70–80% more S and Mn, 90% more Fe and P, 140% more Al and nearly 5-times more Mo. There was no change in the B content, while NO_3-N dropped by 40%. Contents of As, Hg, Cd, Pb and Se were usually below the 0.1 mg/kg detection limit, but in the 2nd cut hay Cd was measurable in the aging plant herbage. The Cu/Mo ratio was 2.6 in the N control soil, while in the soil heavily fertilized with N

Table 9
Effect of soil N×K supply on the Na content of the air-dry hay in the 1st and 2nd cut, mg/kg

N supply, kg N/ha/yr	Ammonium lactate soluble K_2O, mg/kg				$LSD_{5\%}$	Mean
	153	193	279	390		
23 May, 2001						
0	115	114	111	96		109
100	447	512	471	521	124	488
200	554	531	557	652		574
300	600	480	490	569		535
Mean	429	409	407	459	62	426
9 October, 2001						
0	100	105	69	56		82
100	702	252	292	332	260	395
200	1189	596	524	682		748
300	1198	708	656	807		842
Mean	798	415	385	469	130	517

its value was 7.8. The P/Zn ratio indicated an optimal value of 150 in the P control soil, while its value was 269 in the soil over-fertilized with P. So, the P-induced Zn deficiency was also provable in the hay of the 2nd cut, while the Cu-induced Mo deficiency disappeared.

Summary

The grass herbage had a very favourable wet year in 2001 with more than 700 mm rainfall during the total vegetation period. The hay yield of the unfertilized control plots was 1.7 and 1.2 t/ha in the 1st and 2nd cut, while the $N_3P_3K_3$ treatment produced 8.8 and 4.2 t/ha yields, resp. NPK fertilization increased the air-dry hay yield from 3 to 13 t/ha (1st+2nd cuts together). The N requirement of the young grass was moderate, while the P response significant in the 1st cut. The optimum P supply was 150 mg/kg ammonium lactate soluble AL-P_2O_5 in the ploughed layer. No K responses were observed on the soil with 135 mg/kg AL-K_2O values. There were no P responses by the 2nd cut even on the soil with low P supply (66 mg/kg AL-P_2O_5 value), while the applied N caused a 4-fold increase in hay yield. The optimum N content in the hay, leading to maximum yield, amounted to 2% in the 1st cut and 2.5–3.0% in the 2nd. The applied N decreased the air-dry content of the 1st cut from 33% to 31%, and that of the 2nd cut from 27% to 21%.

Summarizing the above, it can be stated that long-term fertilization can drastically change (in some cases with an order of magnitude) the concentrations and ratios of elements built in hay through synergetic or antagonistic effects. In the hay of the 1st cut, for example, the minima–maxima contents of measured elements varied in air-dry hay as follows: N 0.90–3.02, Ca 0.4–0.7, S 0.14–0.32, P 0.12–

0.30, Mg 0.10–0.24%; Na 70–700, Fe 100–288, Al 45–250, Mn 71–130, Sr 10–22, Zn 7–14, Ba 6–11, B 3.6–8.1, Ni 0.3–1.6, Cr 0.1–0.4, Mo 0.04–0.44, Co 0.04–0.12 mg/kg.

Key words: NPK fertilization, established all-grass, hay yield, mineral element content of hay yield

References

ANTAL, J., EGERSZEGI, S. & PENYIGEI, D., 1966. Plant Production on Sand. (In Hungarian) Mezőgazdasági Kiadó. Budapest.

BARCSÁK, Z., 2004. Bio Grass Management. (In Hungarian) Mezőgazda Kiadó. Budapest.

BERGMANN, W., 1992. Nutritional Disorders of Plants. Gustav Fischer Verlag. Jena-Stuttgart–New York.

CHAPMAN, H. D. (Ed.), 1966. Diagnostic Criteria for Plants and Soils. Quality Printing Co., Inc. Riverside, CA.

DOW, A. I. et al., 1980. Effects of N fertilization on yield, N recovery, nutrient content and quality of three irrigated pasture grasses. Bulletin 0893. College of Agriculture, Research Centre. Washington State University. USA.

EGNÉR, H., RIEHM, H. & DOMINGO, W. R., 1960. Untersuchungen über die chemische Bodenanalyse als Grundlage für die Beurteilung des Nährstoffzustandes der Böden. II. K. Lantbr. Högsk. Ann. **26.** 199–215.

FINCK, A., 1982. Fertilizers and Fertilization. Verlag Chemie. Deerfield Beach, Florida–Basel.

GEISLER, G., 1988. Pflanzenbau. 2. Auflage. Paul Parey. Berlin–Hamburg.

KÁDÁR, I., 1992. Principles and Methods of Plant Nutrition. (In Hungarian) MTA Talajtani és Agrokémiai Kutató Intézete. Budapest.

KÁDÁR, I., 2005a. Effect of fertilization on the yield and N uptake of an established all-grass sward. 1. (In Hungarian) Gyepgazd. Közl. **2.** 36–45.

KÁDÁR, I., 2005b. Effect of fertilization on the mineral element content of an established all-grass sward. 3. (In Hungarian) Gyepgazd. Közl. **2.** 57–66.

KÁDÁR, I. et al., 2000. Mineral nutrition of maize *(Zea mays* L.) on chernozem soil I. (In Hungarian) Növénytermelés. **49.** 371–388.

LAKANEN, E. & ERVIÖ, R., 1971. A comparison of eight extractants for the determination of plant available microelements in soils. Acta Agr. Fenn. **123.** 223–232.

TUCKER, J. M. et al., 1961. Nitrate Poisoning in Livestock. Circular No. 506. Calif. Agr. Exp. Sta. CA.

VOISIN, A., 1965. Fertilizer Application. Soil, Plant, Animal. Crosby Lockwood. London.