Sustainable Land Use and Mineral Fertilizers on Meadow Chernozem Soil

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One of the most important factors of environmental economics is that all elements of agrotechnics must be evaluated after careful consideration of their favourable and unfavourable economical and environmental effects.

Up to the late '80-s one of the main elements of intensive agricultural technologies was the high rate application of mineral fertilizers. However, the application of fertilizers was carried out in an over-uniformed system without taking the viewpoint of environmental effects into account. In this way mineral fertilizers were considered by public opinion as the main environmental pollutants.

For a realistic judgement of the ecological effects of mineral fertilizers, the evaluation of the results of long-term fertilizer experiments gives a good opportunity. In Hungary most of the long-term fertilization experiments go back to the sixties of this century. Among others, KOZÁK et al. (1983), GYŐRI and KISFALUSI (1983), DEBRECEZNI and BORSAVÖLGYI (1983), TATÁR and TATÁR (1983), SZALKAI et al. (1989), FÜLEKY and DEBRECEZNI (1991), BLASKÓ (1983, 1990), NYIRI (1987), HOLLÓ (1990) and KRISZTIÁN and KADLICSKÓ (1992) published the results and measurement data of different long-term field experiments on the acidification processes caused by mineral fertilizers.

MURÁNYI and RÉDLY (1986, 1987) reported on the experimental results obtained with samples representing the most important soil types of Hungary. Based on these data and taking into account the buffer characteristics VÁRALLYAY et al. (1989) developed a category system for the acid tolerance of soils.

The possibilities of N-leaching out, the main factors influencing this process on different Hungarian soils were investigated among others by DEBRECZENI and DEBRECZENI (1983), SZIKI and PAPP (1987), TÓTH (1984), RÉZHEGYI and HELTAI (1984), KISSEVICH (1989), BLASKÓ and JUHÁSZ (1991), NÉMETH et al. (1987), PEPÓ (1990) and KÁDÁR (1992). KÁDÁR (1992) published a wideranging survey on the potential heavy metal and other pollutant accumulation caused by mineral fertilizers.

The experiments of which the main results will be reviewed here were established in 1967 as part of the uniform national fertilization experimental network. The evaluation of the environmental effects of mineral fertilization was done in the framework of the project OTKA 519, entitled "Loadability limits of different soils".

The design of the trials was as follows:

The doses of N fertilizer were 50, 100, 150, 200 and 250 kg N/ha, the phosphate fertilizer doses were 0, 50, 100, 150 and 200 kg P_2O_5/ha and those of potassium fertilizer were 0 and 100 kg K_2O/ha.

There were two types of crop rotations with winter wheat, maize, maize and peas in rotation A and a winter wheat, maize, maize, winter wheat biculture in rotation B.

Table 1

Chemical and physical properties of the investigated soil profile (0-100 cm)

Depth, cm	pH (H_2O)	pH (KCl)	y_1	$CaCO_3$ %	Na_2CO_3 %	K_A	Salt content,%
0-10	6.39	5.10	15.2	-	-	44	0.04
10-20	6.20	4.75	16.1	-	-	45	0.04
20-30	6.46	4.91	14.6	-	-	45	0.03
30-40	7.03	5.61	8.0	-	-	47	0.03
40-50	8.14	6.94	-	1.2	-	46	0.04
50-60	8.41	7.26	-	6.9	0.026	50	0.04
60-70	8.49	7.37	-	8.5	0.036	50	0.04
70-80	8.52	7.45	-	10.7	0.041	53	0.04
80-90	8.63	7.46	-	12.3	0.056	55	0.04
90-100	8.69	7.50	-	14.4	0.051	52	0.04

Depth, cm	Humus content, %	AL-Ca	AL-Mg	AL-P_2O_5	AL-K_2O	NO_3^-
		mg/100 g		ppm		
0-10	2.53	346	46.8	26	233	1.8
10-20	2.68	358	47.5	16	226	2.7
20-30	2.47	367	44.3	3	216	2.7
30-40	2.27	434	51.2	11	213	3.1
40-50	1.96	929	62.0	25	201	3.7
50-60	1.67	3510	99.3	11	187	3.1
60-70	1.53	4132	120.3	11	172	3.4
70-80	1.27	4970	152.6	8	166	4.0
80-90	1.18	5538	201.9	3	167	4.9
90-100	1.18	6012	234.3	6	158	3.9

In the period of 1967-1987 N was applied in autumn in the first and third repetitions, while in the second and fourth repetitions 50% of N was spread in autumn and 50% in spring. In 1987 split N application was used in all four repetitions.

The main soil properties of the experimental field can be seen in Table 1.

According to the Hungarian nomenclature it is a meadow chernozem, that is a chernozem soil with some hydromorphic characteristics. The parent material is infusion loess, with a greater clay content than in the case of a typical loess. The parent material originally contained $CaCO_3$, but as a consequence of leaching processes the $CaCO_3$ can only be found in the deeper layers. The pH value of the top layers is slightly acidic, besides which a relatively high potential acidity value can be observed. On the other hand some Na and Mg salt accumulation, even Na_2CO_3 can be observed in the deeper layers.

The main features of the precipitation data can be seen in Table 2.

Results

In the following an attempt will be made to summarize the main experimental results from the viewpoint of sustainable land use.

In Table 3 the 25-year average yields of winter wheat and maize can be seen. It is obvious from the data that a certain low level of production is possible even for a long term without any fertilization. But this kind of production cannot be economical. The money equivalent of the yield is less than the expenses of tillage and harvesting operations.

Another problem is the very big yearly fluctuation in the yields of the control plots, which is indicated by the relatively high values of the coefficient of variance (Table 3). Fertilizer effect curves computed from the average yield data of the long-term experiment (Figures 1 and 2) allow certain conclusions to be drawn from the viewpoint of sustainable land use.

Firstly: A steep increase in yields can be observed as the N fertilizer rate rises from 1-100 kg.

Secondly: In the case of unbalanced fertilization (in this case Na fertilization without P) there is virtually no yield increase due to the effect of N fertilizers. This is not only a production or economical problem, but also a major ecological problem, because, as will be seen later, that part of the N which is not incorporated into the plant or the yield, accumulates in the deeper soil layer.

Thirdly: If a comparison is made between the yields of the two crop rotations, it can be seen that the yields of winter wheat almost doubled in the crop rotation with peas, or a yield of 5 t/ha can be produced by using 120 kg/ha of N fertilizer in the maize-winter wheat rotation, and the same output of yield can be produced with 30-50 kg/ha of N fertilizer in the case of a crop rotation with peas.

Table 2

Monthly precipitation (mm) (Karcag, 1979-1991)

Month	Years													Aver-age	50-yr aver-age
	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991		
Jan.	70.4	28.0	13.2	40.1	22.2	71.3	16.6	42.8	67.6	37.6	10.5	16.8	9.5	34.4	24.0
Feb.	34.8	19.1	15.3	11.8	28.9	10.2	15.4	52.0	17.7	39.5	27.4	23.1	32.0	25.2	27.0
Mar.	45.6	49.8	35.9	25.9	17.8	15.5	53.5	21.6	49.8	79.0	33.0	12.4	15.6	35.0	32.0
Apr.	34.7	57.1	11.6	51.0	37.9	17.8	29.7	15.1	52.2	9.2	82.3	38.0	60.8	38.3	43.0
May	28.0	89.9	23.0	33.4	40.3	82.7	112.7	87.4	110.8	54.8	39.0	17.3	82.1	61.6	54.0
Jun.	49.6	88.7	34.0	57.7	52.7	56.8	31.0	33.3	61.7	76.7	100.2	34.0	17.3	53.4	68.0
Jul.	54.9	103.8	88.6	98.5	30.3	12.6	59.1	68.4	29.3	32.1	27.2	35.4	130.8	59.3	56.0
Aug.	35.8	66.2	28.2	26.5	36.1	33.3	41.6	50.1	30.7	38.1	54.6	14.5	64.0	40.0	52.0
Sept.	2.3	9.6	41.2	51.2	57.6	113.5	17.9	0.0	32.2	63.3	40.9	44.2	13.4	37.5	42.0
Oct.	21.0	38.5	24.1	15.6	32.3	22.6	7.3	11.6	31.5	10.8	18.2	50.4	110.7	30.4	48.0
Nov.	42.7	86.8	6.8	21.6	26.6	38.7	84.2	4.4	61.8	10.3	46.1	39.5	34.3	38.8	45.0
Dec.	29.8	18.0	113.2	26.9	3.2	37.2	39.1	37.7	28.7	47.6	5.3	50.3	32.4	36.1	36.0
Summer half year	205.3	415.3	226.6	318.3	254.9	316.7	292.0	254.3	316.9	274.2	344.2	183.4	368.4	290.1	315.0
Winter half year	244.3	240.2	208.5	141.9	131.0	195.5	216.1	170.1	257.1	224.8	140.5	192.5	234.5	199.9	212.0
Total mm/yr	449.6	655.5	435.1	460.2	385.9	512.2	508.1	424.4	574.0	499.0	484.7	375.9	602.9	490.0	527.0

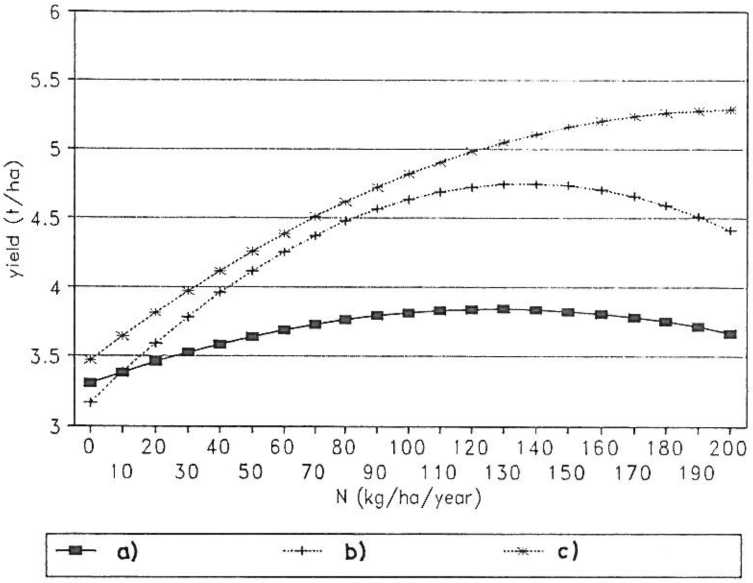

Figure 1
Effect of N fertilizer on winter wheat yields at different P fertilizer levels after maize
a) 0 kg; b) 50 kg; c) 100 kg P_2O_5/ha

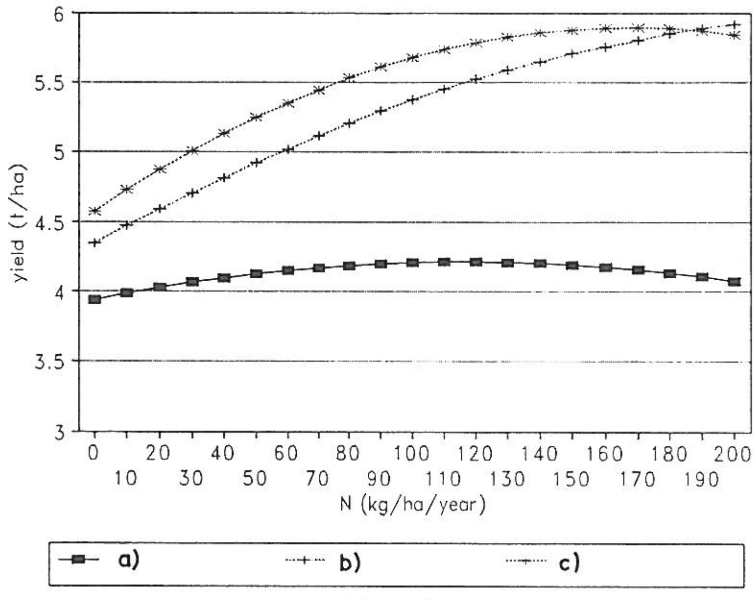

Figure 2
Effect of N fertilizer on winter wheat yields at different P fertilizer levels after peas
a) 0 kg; b) 50 kg; c) 100 kg P_2O_5/ha

Table 3

Average yields of winter wheat and maize and their coefficients of variance for each treatment

Treatment codes	Treat-ments	Winter wheat		Maize	
		Yield*, t/ha	CV %	Yield**, t/ha	CV %
1.	$N_0P_0K_0$	2.85	24.1	5.50	27.8
2.	$N_1P_0K_0$	3.81	15.1	7.26	17.9
3.	$N_1P_1K_0$	4.04	9.5	7.00	19.9
4.	$N_1P_2K_0$	4.18	15.1	7.11	20.1
5.	$N_2P_0K_0$	3.64	17.1	6.87	15.6
6.	$N_2P_1K_0$	4.70	15.0	7.93	16.0
7.	$N_2P_2K_0$	4.51	20.2	7.53	20.8
8.	$N_3P_0K_0$	4.00	21.5	7.11	17.5
9.	$N_3P_1K_0$	4.76	20.3	8.00	16.5
10.	$N_3P_2K_0$	5.11	19.2	8.02	15.5
11.	$N_1P_0K_1$	3.50	21.9	6.89	18.6
12.	$N_1P_1K_1$	4.05	9.7	6.97	18.5
13.	$N_1P_2K_1$	3.92	15.8	6.74	21.5
14.	$N_2P_0K_1$	3.76	19.4	7.44	15.8
15.	$N_2P_1K_1$	4.54	14.8	7.59	19.4
16.	$N_2P_2K_1$	4.51	17.2	7.41	21.4
17.	$N_3P_0K_1$	4.20	25.1	7.78	18.3
18.	$N_3P_1K_1$	4.74	17.6	8.05	17.5
19.	$N_3P_2K_1$	4.98	12.2	7.79	19.7
20.	$N_4P_3K_2$	5.09	18.4	7.75	22.6

Note: * = 10 year average; ** = 9 year average

A well-known harmful effect of mineral fertilization, particularly N fertilizers, is the acidification of the soil. The acidification process could be observed in the present experiment, too (Figure 3). But there was a surprising result: a very steeply decreasing pH curve could also be observed in the top soil layer of the control plots.

The decrease in pH probably caused by other factors was even greater than that caused by mineral fertilizers. But the acidification effect of N fertilizers, especially in the case of higher rates, is a demonstrable fact.

Studying the time function of the pH-curve, various sections can be observed. In the first phase the curve runs down steeply. In the second phase there is virtually no change. This can be explained partly by the buffer curve of the investigated soil; the changes are probably bigger in the zone between the inflexion points. In the third phase an abrupt pH increase was caused by liming, while after liming a new pH decreasing period began. The practical consequence of this process is that liming is an indispensable element of sustainable land use.

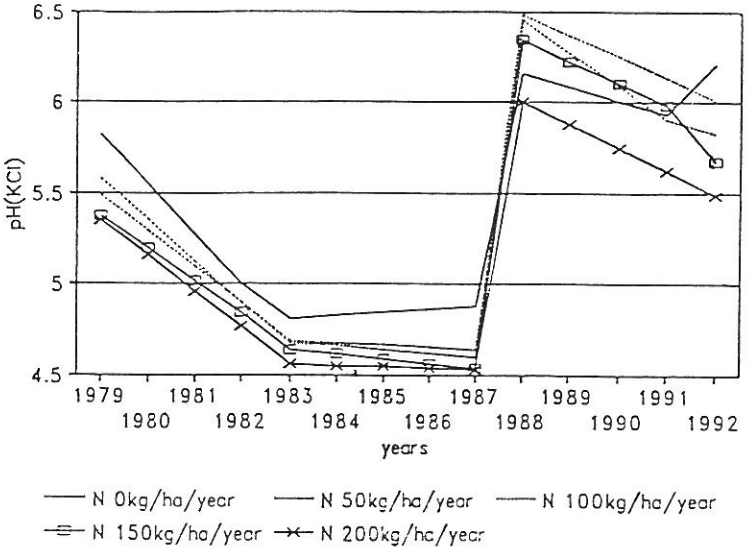

Figure 3
Changes in soil pH (KCl)

But there are some dangers in this process. If lime is used a certain decrease in organic material accumulation can be observed as a consequence of faster mineralization processes (Figures 4-7). The organic material content did not change significantly under the influence of fertilization, but as a consequence of the acidification process, the quality of humus material changed for the worse. (The K-value is the ratio of the Ca-saturated and the other relatively small water-soluble Na and H-saturated organic material.)

Liming may improve the humus quality, but at the same time a decrease in humus content might be expected. The practical consequence of this process is that in the case of liming on acidified soils a positive organic material balance is necessary as well.

The NO_3 nitrogen content of the soil profile was investigated to a depth of 3 m. A typical N accumulation zone could be observed beginning at 60 cm depth, showing a maximum between 80-180 cm, while a decreasing amount of accumulated N could be observed till a depth of 250 cm (Figure 8). The depth of the N accumulation maximum does not depend in practice on the amount of applied N, but there are very big differences in the amounts of accumulated N depending on the N fertilization rates. Some N accumulation is unavoidable even in the case of low fertilizer rates, but it must be taken into account, that the amount of N accumulated in the deeper layers is not in direct proportion to the amount of applied N. The relationship between the applied N and the N

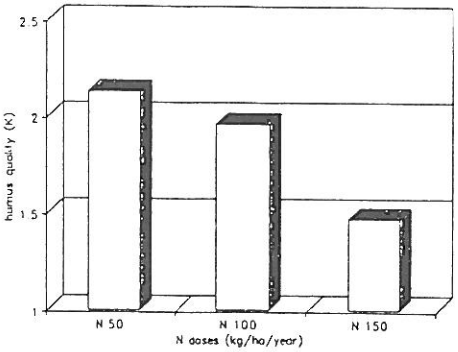

Figure 4
Effect of N fertilizer on humus quality

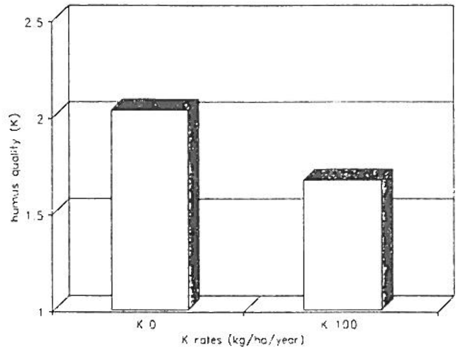

Figure 5
Effect of K fertilizer on humus quality

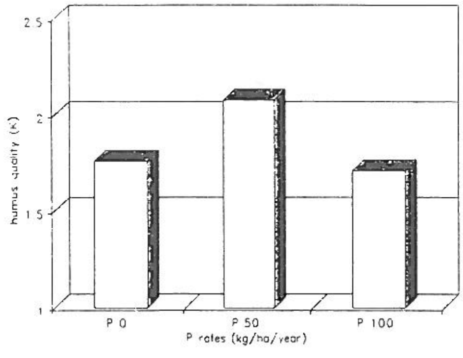

Figure 6
Effect of P fertilizer on humus quality

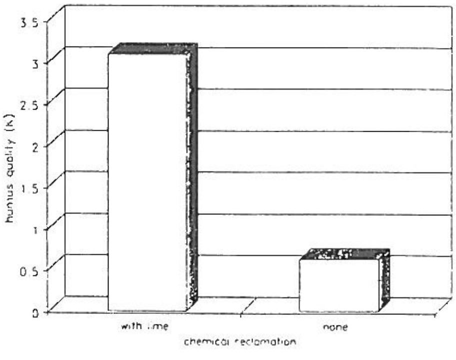

Figure 7
Effect of chemical land reclamation on humus quality

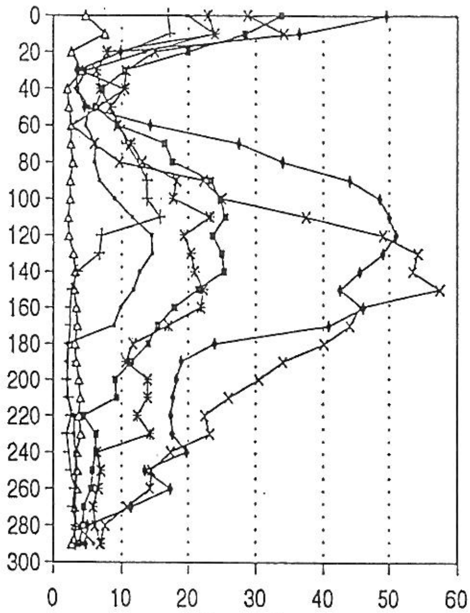

Figure 8

Effect of different N rates on the NO_3-N content of the soil profile. Horizontal axis: NO_3-N content, ppm. Vertical axis: Depth, cm. Note: 1: N 100% in autumn, 2: N 50% in autumn, 50% in spring.

· $N_1P_0K_0$ 1; + $N_1P_0K_0$ 2; x $N_2P_0K_0$ 1; ■ $N_2P_0K_0$ 2; x $N_3P_0K_0$ 1; +$N_3P_0K_0$ 2; Δ $N_0P_0K_0$

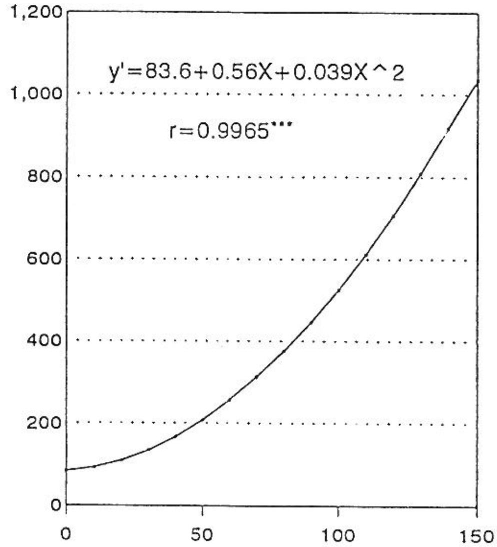

Figure 9

Relationship between the N doses and NO_3 accumulation in the 60-300 cm layer
Vertical axis: NO_3 content, kg/ha. Horizontal axis: N doses, kg/ha/year

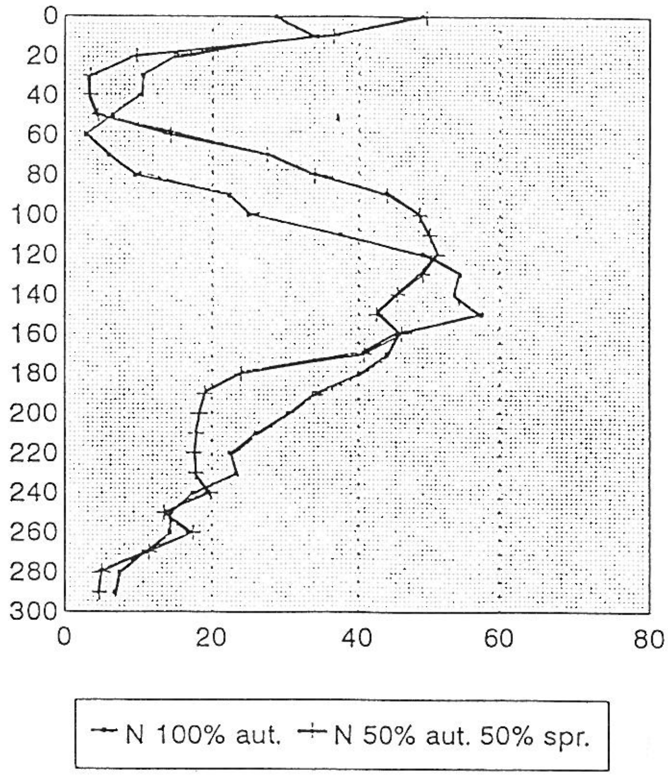

Figure 10

The effect of split application of N fertilizers on the NO_3 content of the soil profile (Karcag, 1992) Vertical axis: Depth, cm. Horizontal axis: NO_3-N content, ppm

leaching-loss is parabolic (Figure 9). The effect of the split application of N fertilizer was also investigated. In two replications of the experimental plots the whole amount of N fertilizer was applied in autumn. In two replications the N fertilizer was split: half of the N was applied in autumn and the other half in spring. As a consequence of split application there was hardly any difference in the amount of N stored in the deeper layers, so this does not seem to be a promising way of decreasing N leaching (Figure 10). Another possible way of using the accumulated N might be the planting of crops with a deeper root system, but in this experiment this investigation was not possible.

A third possible negative effect of the long-term use of mineral fertilization is the accumulation of heavy metals and other contaminants.

The soil profile was investigated down to 3 m, but no detrimental accumulation has been found up till now (Table 4).

Table 4

0.5 *M* HNO_3-soluble microelements in the $N_0P_0K_0$ (1) and $N_3P_2K_1$ (2) treatments of the long-term field experiment (25th year) (ppm)

Depth cm	Co		Cd		Pb		Ni		Cr	
	1.	2.	1.	2.	1.	2.	1.	2.	1.	2.
0-10	2.5	2.8	0.3	0.2	6.5	6.3	13.0	13.1	2.3	2.3
10-20	2.7	2.7	0.3	0.2	6.5	6.7	13.0	13.4	2.4	2.4
20-30	2.6	2.7	0.3	0.2	6.2	5.9	10.8	13.2	2.6	2.5
30-40	2.8	2.7	0.4	0.2	6.0	5.4	12.5	12.6	2.7	2.9
40-50	2.6	2.9	0.4	0.2	5.9	5.3	11.0	11.2	2.9	3.1
50-60	2.4	2.9	0.5	0.2	7.5	5.7	8.0	10.2	3.3	3.1
60-70	2.1	2.3	0.5	0.3	7.9	7.1	8.7	9.1	3.4	3.6
70-80	2.0	2.2	0.5	0.3	8.8	7.4	8.2	8.5	3.6	3.7
80-90	2.1	1.9	0.5	0.4	9.2	8.2	7.8	8.2	3.2	3.8
90-100	2.2	1.8	0.6	0.6	9.2	9.2	7.8	7.7	3.3	3.4
100-110	2.1	2.0	0.6	0.5	9.5	9.0	7.6	7.9	3.4	3.2
110-120	2.1	2.1	0.6	0.5	10.0	9.7	7.2	7.6	3.7	3.5
120-130	1.9	1.8	0.6	0.5	9.8	9.8	7.5	7.6	3.6	3.4
130-140	2.1	2.2	0.5	0.5	10.0	9.3	7.3	7.2	3.4	3.3
140-150	2.2	2.3	0.5	0.4	10.0	9.8	7.0	7.0	3.1	3.3
150-160	2.4	2.0	0.5	0.4	10.2	9.5	7.2	6.7	3.1	3.0
160-170	2.3	2.3	0.4	0.4	9.7	10.0	6.9	6.2	3.0	3.0
170-180	2.3	2.2	0.4	0.4	9.7	9.1	7.2	6.1	3.2	3.0
180-190	2.1	2.2	0.3	0.3	9.1	9.9	6.4	6.2	2.9	3.0
190-200	2.7	2.2	0.5	0.4	9.4	9.1	7.1	6.4	2.7	2.5
200-210	2.7	2.1	0.4	0.4	9.4	8.4	6.6	6.2	2.6	2.4
210-220	2.4	2.1	0.3	0.3	8.1	8.4	6.0	6.0	2.5	2.5
220-230	2.8	2.1	0.4	0.4	8.7	8.6	6.7	6.2	2.7	2.6
230-240	2.7	2.1	0.3	0.4	8.4	8.6	6.7	6.4	2.7	2.9
240-250	2.6	2.8	0.3	0.4	8.4	9.2	6.5	7.1	2.9	3.3
250-260	2.3	3.0	0.4	0.4	8.3	9.2	7.2	8.0	3.3	3.5
260-270	5.2	3.6	0.4	0.4	12.1	9.3	9.1	7.5	3.6	3.3
270-280	3.8	4.2	0.4	0.4	11.1	9.4	10.0	7.1	3.9	3.2
280-290	3.2	5.4	0.4	0.5	11.5	11.1	10.4	7.8	4.1	3.8
290-300	3.6	2.6	0.5	0.6	11.6	9.3	9.6	9.4	3.6	4.6

Conclusions

An evaluation of yield outputs leads to the conclusion that from the viewpoint of stable, economic yields an adequate nutrient supply is an indispensable precondition for plant production.

The unfavourable side-effects of mineral fertilizers can be moderated first of all by the use of adequate rates and the split application of N fertilizers, and by liming balanced to the fertilizer rates.

In spite of these agrotechnical means, some N accumulation in the deeper layers is unavoidable. Crops with a deep root system are recommended for the utilization of the accumulated N.

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