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Residual effect of superphosphate on a calcareous chernozem soil

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Abstract

A P exhaustion long-term field experiment, with initial P_2O_5 doses of 0, 40, 80, 120, 240, 360, 480, 600 and 720 kg/ha, was established in autumn 1972 on a loamy calcareous chernozem soil containing about 3% humus, 5% $CaCO_3$, with moderate supplies of N, S and K, and low available P-content in plow-layer (Olsen-P_2O_5 = 15-20 mg/kg, AL-P_2O_5 = 70-80 mg/kg). The trial, i.e. P-aftereffect lasted for 20 years.

Studying the long-term effects of superphosphate in field experiment on a calcareous chernozem soil, it could be demonstrated that the „half life time" of residual P was 5-7 years compared to the fresh given.

Key words: nutrient balances, fertilization, P-residual effect, field trial

Introduction

In comparison to other plant nutrients the mobility of P in soil is low because of the generally low solubility of phosphate compounds and the strong P-binding capacity of soil components. On the other hand, residual effect of previous P application is more long lasting than that of potassium, and especially than that of nitrogen. For providing the P requirement of crops, soils need a sufficient pool of plant-available P (Sarkadi and Kádár 1974; Füleky, 2006; Sárdy et al., 2006; Ragályi and Kádár, 2006; Csathó et al., 2006).

Phosphorus is considered as the second most important macronutrient in Hungary, following nitrogen. The magnitude of responses to P application is influenced not only by the available P levels in soil, but by the crops as well. Wheat is considered as a phosphorus-demanding crop. Having strongly negative P balances since 1990, Hungarian agriculture is still living on the residues of previous P (and K) applications, but these reserves are becoming smaller and smaller. It is essential to know how long the previous P application provides adequate P for crops as a function of residual effects (Table 1).

Material and methods

The P-exhaustion field trial with superphosphate containing 0, 40, 80, 120, 240, 360, 480, 600, and 720 kg ha^{-1} initial build-up P_2O_2 doses was established in the autumn of 1972, on a light loamy calcareous Mollisol, originally poorly supplied with P (Kádár 1992).

Following that every second year, starting on the initial 0 level in autumn 1974, continuing on the initial 40 kg ha^{-1} P_2O_2 level in autumn 1976, on the initial 160 kg ha^{-1} P_2O_2 level in autumn 1978, on the initial 240 kg ha^{-1} P_2O_2 level in autumn 1980, etc., fresh 0, 40, 80, and 120 kg ha^{-1} P_2O_2 doses were applied in order to compare the effect of fresh superphosphate P to residual effect of "older" and "older" previous P application, based on the P balances.

The test crops were the following: in the first 8 years winter wheat, in the 9^{th} year millet, in the 10 to 12^{th} year alfalafa, in 13^{th} year spring barley and in the 14 to 22^{nd} years winter wheat again (Table 2).

Table 1. Nutrient balances in Hungarian Agriculure, kg/ha (Agricultural area, 1900-2000) (In: Kádár, 2007)

Turnover	1900-50	1960-64	1971-75	1984-86	1991-2000
		N-Balance			
Uptaken by yield	40	47	72	96	83
Returned by					
Manures	6	7	8	8	7
Fertilizers	-	16	68	91	35
By-products	-	-	7	8	7
Total*	7	23	84	107	55
Balance sheet	-33	-24	+12	+11	-28
Returned/Uptaken, %	18	49	117	111	66
		P_2O_5-Balance			
Uptaken by yield	15	18	27	38	32
Returned by					
Manures	7	7	8	8	7
Fertilizers	1	12	50	57	5
By-products	-	-	4	3	3
Total	8	19	62	68	15
Balance sheet	-7	+1	+35	+30	-16
**Returned/Uptaken, %	53	106	230	179	47
		K_2O-Balance			
Uptaken by yield	38	48	68	84	79
Returned by					
Manures	16	18	20	20	13
Fertilizers	-	7	64	69	6
By-products	-	-	21	24	20
Total	16	25	105	113	39
Balance sheet	-22	-23	+37	+29	-40
Returned/Uptaken, %	42	52	154	135	49

By-products: stalks of corn and sunflower, straw of wheat mainly. *Including Legumes, 5 kg/ha. **Quotient showing the replacement of the uptaken nutrients

Table 2. Experimental plan of build-up (old-P applied in 1972) and maintenance (fresh-P applied between 1974-1990) kg ha^{-1}

Build-up P_2O_5 kg ha^{-1}, 1972	Maintenance P-application (fresh-P) P_2O_5 kg ha^{-1}				Year of application
0	0	40	80	120	1974
40	0	40	80	120	1976
80	0	40	80	120	1978
120	0	40	80	120	1980
240	0	40	80	120	1982
360	0	40	80	120	1984
480	0	40	80	120	1986
600	0	40	80	120	1988
720	0	40	80	120	1990

Remark: Build-up treatments were established in 12 replications giving a total of 108 plots. Maintenance treatments were applied in 3-3 replications on old-P levels.

Results and discussion

Changes in ammonium-lactate (Egner et al., 1960) soluble P_2O_5 contents as a function of time are shown in Table 3. Following build-up fertilization, ammonium lactate soluble P contents diminished strongly for 4 years, then a 3-year equilibrium was observed in this light loamy calcareous Mollisol, not strongly fixing phosphorus. This was followed by another 3-year fixing period. However, this time the P fixation was not as strong as it was in the first 4 years. Then another 6 years equilibrium period vas observed. Difference in AL-P_2O_5 contents of the highest 720 kg ha^{-1} build-up dose and the P control plots was 190 mg kg^{-1} in the first year and it diminished to 130 kg ha^{-1} in the second year, to 110 mg kg^{-1} in the third year, to 40 to 50 mg kg^{-1} in the 4th to 9th years and to 10 to 20 mg kg^{-1} from the 10th year of the trial (Table 3).

Table 3. Changes in the ammonium lactate (AL) soluble P_2O_5 content in plowlayer. Residual-effect experiment (1972-1990).

P_2O_5 kg/ha	Ammoniumlactate (AL) soluble P_2O_5 mg/kg							
in 1972	1972*	1973	1974	1975	1976	1980	1986	1990
0	70	80	71	82	79	86	80	82
120	68	105	87	90	76	94	82	84
240	75	137	104	106	89	98	80	80
480	70	206	124	140	101	114	90	90
720	71	284	199	180	128	131	94	94
$LSD_{5\%}$	9	30	27	12	8	10	6	6

*Remark: 1972 before application

Residual effect of the initial build-up 240 kg P_2O_5 ha^{-1} provided adequate P for winter wheat for 4 years, of the 480 kg P_2O_5 ha^{-1} dose for 6 years, of the 720 kg P_2O_5 ha^{-1} dose for 8 years (1.4 to 1.5 t ha^{-1} grain yield surpluses). Although in lower and lower yield levels, P residual effects were detectable even in the 9th to 20th years: 0.1 to 0.2 t ha^{-1} surpluses in the 240 kg P_2O_5 ha^{-1}, 0.4 to 0.5 t ha^{-1} surpluses in the 480 kg P_2O_5 ha^{-1} and 0.6 to 0.7 t ha^{-1} surpluses in the 720 kg P_2O_5 ha^{-1} initial dose. In the 21st and 22nd years however, no P residual effect was observed on this loamy calcareous chernozem soil, originally poorly supplied with P, not strongly fixing phosphorus (Table 4).

Millet did not show residual P effects in the 9th year (0.1 to 0.2 t ha^{-1} surpluses). Residual effects in alfalfa in the 10th to 12th were as much as 1.5 t ha^{-1} hay yield surpluses. Spring barley in the 13th year shoved only slight 0.3 t ha^{-1} surplus as residual P effect. As a function of time 4 years average main yield levels in the P exhaustion trial were 4.4 t ha^{-1}; 4.2 t ha^{-1}; 3.1 t ha^{-1}; 2.5 t ha^{-1}; 3.0 t ha^{-1} and 1.9 t ha^{-1} cereal units, indicating the worsening P supply in the P exhaustion trial. Fresh 0, 40, 80 and 120 kg P_2O_5 ha^{-1} application given every second year, once on one build-up P dose, resulted in 1.0 to 1.5 t ha^{-1} winter wheat grain yield surpluses, 2.0 to 2.5 t ha^{-1} alfalfa hay yield surpluses and 1.5 t ha^{-1} spring barley grain yield surpluses. The effect of fresh P application on millet grain yield surpluses was minimal: 0.2 t ha^{-1} (Table 4).

The fresh P equivalence of previously added initial P was expressed in surpluses in main yields. As time passed the fresh P equivalency of previously added build-up P doses diminished significantly. In case of 2 years older P the residual effect reached 126% of the fresh P effects. The four years older P application referred to 61%, the six years older to 37%, while the eight years older to 33% of the fresh effect. Later on the residual P effects seemed to stabilize on a very low level: the residual effect of 10 to 20 years older P only reached 5 to 17% of fresh P application, as compared to the mutual P balance intervals. Under temperate continental climate the decrease in the residual effect of previously added P fertilizers can be explained by crop P uptake and P fixation. However even the 19th to 20th year residual effect of the initial build-up 720 kg P_2O_5 ha^{-1} application is still significant on the grain yields (0.6 to 0.7 t ha^{-1}), as can be seen in Table 4.

Table 4. Comparison of the residual effect of build-up P application and the effect of fresh P application at the mutual P-balance intervals. 2 year average surpluses, 1973-1990.

Fresh P	Residual P	Year	Crop	Average grain/hay surpluses			
Year	Year	of the trial		t ha^{-1}		%	
				Fresh P	Residual P	Fresh P	Residual P
1-2	-	1973-74	w. wheat	0.50	-	100	-
1-2	3-4	1975-76	w. wheat	1.18	1.49	100	126
1-2	5-6	1977-78	w. wheat	0.98	0.60	100	61
1-2	7-8	1979-80	w. wheat	1.14	0.42	100	37
1-2	9-10	1981-82	millet/alfalfa	0.20	0.06	100	33
1-2	11-12	1983-84	alfalfa	1.27	0.22	100	17
1-2	13-14	1985-86	s.barley/w.wheat	0.98	0.10	100	10
1-2	15-16	1987-88	w. wheat	0.70	0.06	100	9
1-2	17-18	1989-90	w. wheat	0.50	0.03	100	6
1-2	19-20	1991-92	w. wheat	0.87	0.04	100	5

Conclusions

Soil P-test (Olsen and AL) values sharply decreased in the first 4 years, after which an equilibrium was reached.

On this soil, originally poorly supplied with P, the 317 kg/ha initial P rate provided satisfactory yield levels of cereals for 8 years, 211 kg for 6 years, and 106 kg for 4 years. The residual effect of build-up P rates was measurable even 20 years after application.

The effectiveness of the initial "old" P doses previously added dropped by 50% every 5-6 years compared with "fresh" superphosphate-P, given every second year. This thus represents the half-life of the P remaining in this soils, which is not strongly fixing.

It seems possible to recover as much as 50% of the earlier applied P, but with decreasing yield.

Concerning the nutrient balance of the Hungarian agriculture one can state that since 1990, Hungarian agriculture is still living on the residues of previous P (and K) applications, but these reserves are becoming smaller and smaller.

The comparison of old and new P responses was made on the basis of equivalent P balances, i.e. the old P levels represented the amount of P left in the soil after plant uptake.

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