The Interaction Between Phosphorus Fertilizer Residues and Fresh Phosphate Dressings in a Chernozem Soil

J. SARKADI and I. KÁDÁR

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

It was characteristic of 'SIGMOND's comprehensive scientific research activity that he contributed notably not only to the development of theoretical soil science but, from the very beginning of his scientific carreer, he dealt also with numerous problems of applied soil science, for example with those of the P-fertilization of soils. He studied systematically P-solubility in soils. He improved the analytical methods of SCHLÖSING and in 1900 he published his method for the determination of the soils' "available" P content [14]. He was one of the first soil scientists of the world who realized and established that the quantity of phosphorus, extractable by dilute acids, is greatly dependent on different soil properties, first of all on the "alkalinity" of soils [16]. His method for the determination of the alkalinity degree and the HNO_3-soluble P content of soils is known all over the world as 'SIGMOND's method [17].

In 1906 he published his findings which are up-to-date even today, saying that the availability of different Fe-, Al-, and Ca-phosphates is greatly dependent on soil properties [15].

Naturally, in 'SIGMOND's lifetime fertilizer consumption was on a much lower level than nowadays. This was due to the fact that mineral fertilizers were more expensive as compared to the prices of agricultural products. The nutrient balance of Hungarian soils was highly negative in the first half of the century. According to the calculations of FARKAS [3], on an average the amount of 19 kg P_2O_5/ha was taken up by crops, whereas only 9 kg P_2O_5/ha was added to soils annually between 1929 and 1938. Thus the P_2O_5 content of soils decreased by 10 kg/ha/year.

In the second half of the century the mineral fertilizer consumption has increased to a great extent in Hungary. In the period between 1960 and 1964 the P balance of Hungarian soils was found to be in equilibrium, according to the calculations of GYŐRFFY [4]. In the past few years this balance was found to be positive. Between 1970–1972 25–30 kg P_2O_5/ha was taken up by crops and 45–48 kg P_2O_5/ha was added to soils annually. The average increase in the P_2O_5 content of soils was about 20 kg/ha/year.

Nowadays, in our country it is a question of topical interest to determine to what extent the P compounds, accumulated in the soil, are taken up by crops, and to what extent it is reasonable to increase the P reserve of soils.

It is known from literature that the recovery of P-residues is dependent on numerous factors, such as the quantity of the applied mineral fertilizers, soil properties, crop sequence, etc. [1, 2, 5, 7, 11, 13, 18, 19, etc.].

In the experiments carried out under different conditions the efficiency of P-residues was found to be quite different.

From the results of our long-term experiment to be discussed below, conclusions can be drawn regarding the efficiency of accumulated P residues — expressed in new P equivalents — in calcareous chernozem soils which are rather wide-spread in Hungary.

Materials and methods

The experiment was carried out in the Danube Valley on a calcareous chernozem with a 50—80 cm thick humus layer on a loess parent material. The experimental field is situated at Nagyhörcsög, 140 m above sea level. The climate is continental, the mean annual temperature is 10.9 °C (between 1962 and 1972), the average annual precipitation is 576 mm. Among the exchangeable cations Ca^{2+} ions are predominant all over the profile. The clay fraction ($<$0.002 mm) constitutes 20%, the silt fraction ($<$0.02 mm) 40—50%. In the ploughed layer pH_{H_2O} is 7.5—8.0, pH_{KCl} is 7—7.8, $CaCO_3$ amounts to 3—7%, and the total C content is between 2 and 2.3%.

The experiment, started by LATKOVICS [8] in 1961/62, was originally a factorial NPK-fertilization experiment carried out in a split-plot design in strips, in four replications with maize and wheat, changed in every four years. Different N doses (4 levels) were added to the whole plots and different P and K doses (3 levels) to the sub-plots.

Due to the influence of different amounts of P_2O_5 (0 kg/ha, 240 kg/ha, 480 kg/ha) added to the soil during eight years, there were marked differences in the easily available P contents of soils on each plot in 1969. The set up of the experiment was changed so that we could determine the interactions between the P residues and new P. To achieve this aim the same amount of NK was given to each plot and 4 new P doses (0, 40, 80, 120 kg/ha P_2O_5) to the previous sub-plots, adequately randomized. The addition of the new P doses was repeated in 1970 and 1971.

In the experiment with the changed design the effects of the following three factors were studied:

1. residual effect of previous N dressings
2. residual effect of previous P (K) dressings
3. first year's and cumulative effects of new P.

The main effects and the first order interactions were tested to that of the second order.

The test crops were "*Bezostaya 1.*" from 1966 to 1971 and, in 1972, "*Yubileynaya*" winter-wheat varieties. Superphosphate, ammonium-nitrate + limestone and KCl (40% K_2O) were added to the soil. In autumn the soil was fertilized with P, K and with half of the N quantity, while the other half of it was broadcasted in spring. The nutrient content of the grain-yield was determined after wet digestion [12]. Every year from 1969 on composite samples after stubble-stripping 20–20 subsamples were taken from the 0–20 cm soil layer from each plot. The subsamples were composed per plots. The "available" P contents of the composite samples were determined by the EGNÉR–RIEHM–DOMINGO [10] and OLSEN et al. methods [9].

Results and discussion

According to the analyses of variance not given here in detail, the main effects of the studied factors, as well as the interactions between P residues and new P were found to be significant in this period. That is the reason why in Table 1 only crop yields effected by residual and new P are given in the average of the previous N, NK treatments.

Table 1

Residual effects of previous P treatments and effects of new P doses on the average residual effects of N and NK

Year	Previous P* 1961–68	New P levels (P_2O_5 kg/ha)⁰				LSD5%	B_1^x
		0	40	80	120		
		Grain yield, q/ha (86% dry matter)					
1969/70	P_0	14.2	20.8	24.1	27.6	4.1	12.7
	P_1	25.6	28.2	31.3	33.2	4.1	6.6
	P_2	26.3	27.7	30.5	31.6	5.4	4.6
	LSD5% P_0-P_1	4.1					
	,, P_2-P_0, P_2-P_1	5.1					
1970/71	P_0	17.2	28.6	36.9	39.4	4.8	17.0
	P_1	27.4	34.9	40.4	43.0	4.8	13.0
	P_2	34.0	41.5	42.1	42.2	6.8	6.2
	LSD5% P_0-P_1	4.8					
	,, P_2-P_0, P_2-P_1	5.9					
1971/72	P_0	13.6	26.2	28.2	33.6	4.5	15.6
	P_1	21.8	30.5	34.4	38.3	4.5	13.4
	P_2	31.8	37.4	37.2	38.3	5.7	4.8
	LSD5% P_0-P_1	4.1					
	,, P_2-P_0, P_2-P_1	5.1					
Average of 3 years	P_0	15.0	25.2	29.7	33.5	3.1	15.1
	P_1	24.9	31.2	35.4	38.2	3.1	11.0
	P_2	30.7	35.5	36.6	37.4	3.8	5.2
	LSD5% P_0-P_1	2.7					
	,, P_2-P_0, P_2-P_1	3.3					

* Previous P_1 = 240 kg/ha, P_2 = 480 kg/ha P_2O_5.

⁰ NK = 1969/70, and 1970/71: 120 kg/ha N, 60 kg/ha K_2O 1971/72: 200 kg/ha N, 100 kg/ha K_2O.

^{x} B_1 = average marginal efficiency of new P (60 kg/ha/year).

The fitting of the quadratic response-functions, calculated from the crop yields effected by the new P, was found to be satisfactory, especially on P_0 and P_1 levels.

The following functions were calculated for the three years average:

$$\text{on } P_0 \text{ residue level: } y = 15.2 + 27.1\ x - 10.0\ x^2 \quad (1)$$

$$\text{on } P_1 \text{ residue level: } y = 25.0 + 17.5\ x - 5.5\ x^2 \quad (2)$$

$$\text{on } P_2 \text{ residue level: } y = 30.9 + 12.7\ x - 6.2\ x^2 \quad (3)$$

where y = grain yield, q/ha; x = added amount of new P_2O_5, kg/ha.

As the quadratic regression coefficients (b_2) did not differ significantly from each other, it may be supposed that only the slopes of the curves were different. In this case the calculated equations are as follows:

$$y = 15.6 + 24.0\ x - 7.45\ x^2 \quad (1)\text{a}$$

$$y = 24.6 + 19.9\ x - 7.45\ x^2 \quad (2)\text{a}$$

$$y = 30.8 + 14.2\ x - 7.45\ x^2 \quad (3)\text{a}$$

Both the latter, directly comparable linear regression coefficients (b_1) and the marginal efficiency (see: B_1 values in Table 1) of the average new P dose (60 kg P_2O_5/ha annually) prove that a part of the residual P is available for wheat in this calcareous chernozem. The higher the residual P content of the soil, the smaller the initial and average efficiency of new P.

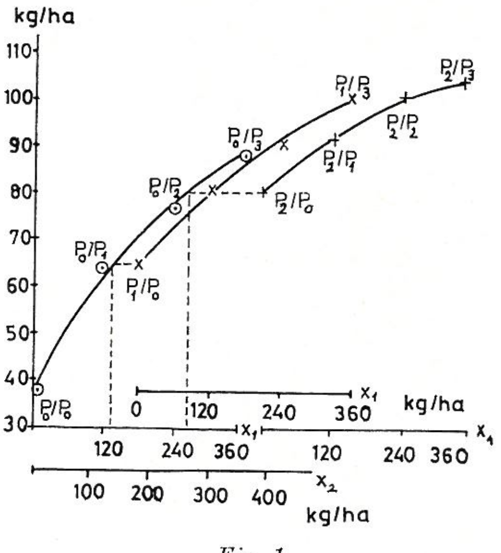

Fig. 1

The effect of P residue and new P on the P uptake by wheat. Vertical axis: P_2O_5 uptake, kg/ha, total of 3 years (1970—72). Horizontal axes: (x_1) New P_2O_5 kg/ha, total of 3 years (1970—72); (x_2) P_2O_5 residues, kg/ha, in 1969

If we solve the equation (1) at $y = 25.0$ (average grain yield as a result of previous P_1/new P_0 treatment) then $x = 43$ kg P_2O_5/ha /year. It means that in the three-year period the efficiency of 240 kg P_2O_5 residue was equal to that of 129 kg new P_2O_5, while the efficiency of 480 kg P_2O_5 residue was equal to that of $3 \times 84 = 252$ kg new P_2O_5. Owing to the deviations in the regression coefficients, there are also some deviations in these values, nevertheless linearity can be seen at the first glance.

Similar values can be obtained if the effects of new P are determined not from the grain yield but from the total P content of the crop-yield. (Figure 1 and Table 2).

Supposing in the first approximation that the efficiency of the previous P is linear, we may consider the efficiency of 100 kg P residue as equal to that of 50—

Table 2

The apparent recoveries and "equivalents" of P residues

	Years	Level of previous P doses		
		P_0	P_1	P_2
Added (A) P_2O_5 kg/ha	1961–68	—	240	480
Uptake (U) P_2O_5 kg/ha	1962–69	145	205	238
Extra uptake (dU) P_2O_5 kg/ha	1962–69	—	60	93
Balance (A–U) P_2O_5 kg/ha	1969	–145	35	242
Relative residue (R) P_2O_5 kg/ha	1969	0	180	387
A P_2O_5 kg/ha	1969–71	—	—	—
U P_2O_5 kg/ha	1970–72	38	64	80
dU P_2O_5 kg/ha	1970–72	—	26	42
U P_2O_5 kg/ha	1962–72	183	269	318
dU P_2O_5 kg/ha	1962–72	—	86	135
Apparent recovery:				
100 dU/A	1961/62–68/69		25	19
100 dU/R	1969/70–71/72		14	11
100 dU/A	1961/62–71/72		36	28
100 U/A	1961/62–68/69		85	50
100 U/R	1969/70–71/72		35	21
New P equivalents of P residues (P_e)				
Calculated from yield curve	1970–72		129	258
Calculated from P-uptake curve	1970–72		136	264
P_e of 100 kg previous P				
calculated from yield curve	1970–72		54	54
calculated from P-uptake curve	1970–72		57	55
P_e of 100 kg residue of previous P				
calculated from yield curve	1970–72		72	67
calculated from P-uptake curve	1970–72		75	68

55 kg new P. In effect, this equivalent must be higher because a certain quantity of P added to the soil in the period between 1961 and 1968 was taken up by crops. Accepting the approximative calculation — according to which the quantity of P residue in the soil can be estimated from the difference between the amounts of P added to the soil and taken up by plants — we may conclude that in 1969 on the P_1 and P_2 residue levels there was 180 and 387 kg/ha more P_2O_5, respectively, in the soil than on the P_0 level (Table 2). The efficiency of 100 kg P residue, calculated in this way, was equal to that of about 70 kg new P.

It is well-known that the actual recovery of P-fertilizers cannot be determined with our present methods. In spite of this it can be seen from Table 2 that when the apparent recovery of residual P was calculated either with the "difference method" or with the "balance method", it increased by 40–50% in

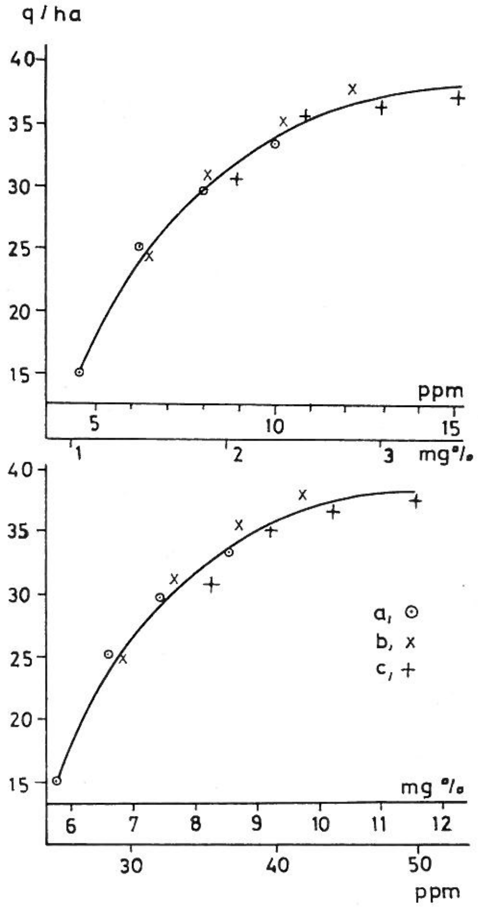

Fig. 2

Correlation between soil-P and yield. Vertical axes: grain yield, q/ha, average of 3 years (1970–72). Horizontal axes: (upper graph) $NaHCO_3$ soluble P, ppm; $NaHCO_3$ soluble P_2O_5, mg %. (lower graph) AL–P_2O_5, mg %; AL–P, ppm. (a) P_0 residue/new P_0, P_1, P_2, P_3; (b) P_1 residue/new P_0, P_1, P_2, P_3; (c) P_2 residue/new P_0, P_1, P_2, P_3

the period between 1970 and 1972 in comparison to its values calculated for 1961–1968.

The amounts of residual and new P can be determined from the analyses of the soil's soluble P content, as well. There is a close correlation ($r = 0.82, 0.76$) between the data of P balance, and the AL-soluble P content and the $NaHCO_3$-soluble P content of the plots' soils, respectively. Although the slope of the curves, indicating the effects of residual and new P changed in a statistically significant way each year, the changes, actually, were not considerable from the practical point of view. On the average of all data, 100 kg P_2O_5/ha added to the soil increased the AL-soluble P content by about 1 mg %, and the $NaHCO_3$-soluble P content by 0.5 mg % (5 ppm). There was a close correlation between the AL-soluble P content and the $NaHCO_3$-soluble P content just as it had been indicated by the experimental results of KRÁMER and FÜLEKY [6]. Figure 2 shows the relation between the AL-soluble, and the $NaHCO_3$-soluble P contents of the soil samples (taken after the harvest from each plot), and grain yields on the average of three years.

Similarly to the findings of other experiments carried out in chernozem soils, above 10–12 mg % AL-soluble P_2O_5 values and 13–16 ppm $NaHCO_3$-soluble P values, the curves indicating the crop yields level out.

Conclusion

The obtained data prove that it is advisable to take the residual P content of soils into consideration when determining the mineral fertilizer requirements of plants. Table 1 and Figure 1 show that in order to obtain similar crop yield and P uptake, on previous P_1 level one dose less (40 kg P_2O_5/ha/year), on previous P_2 level two doses less of mineral fertilizers were needed than on previous P_0 level.

Conclusions regarding the residual P content of soils can be drawn partly on the basis of P balances obtained from the data of the field register books, partly on the basis of the data of soil analyses performed every four or five years. The relationships observed in our experiments, (Figure 2) seem to indicate that if the AL-soluble P_2O_5 content of the studied chernozem soil reaches about 10 – 12 mg %, then it is sufficient to apply such a P quantity that keeps the P balance of the soil in equilibrium i.e. which is equal to the P content of the expected crop yield.

Summary

The relationships between P residues and new P doses were studied in a long-term experiment on a calcareous chernozem soil in the Danube Valley. The experiment was started in the autumn of 1961. Winter-wheat was grown on the experimental field. The total amounts of previous P were 0 kg/ha, 240 kg/ha, and 480 kg/ha P_2O_5. These quantities were added to the soil as superphosphate in an NPK factorial experiment during 8 years, in 0 kg/ha, 30 kg/ha, 60 kg/ha/year P_2O_5 doses, respectively. These P amounts were spread and ploughed down. In 1969 in autumn the experiment was set up on the same NK bases, and new P quantities (0 kg/ha, 40 kg/ha, 80 kg/ha, 120 kg/ha P_2O_5) were applied to each plot treated previously. The addition of new doses was repeated in 1970 and in 1971 in autumn.

The three-year results, obtained by the new experiment, showed that the mean efficiency of both of the P residues and the new P doses was significant. The negative interaction between the effects of P residues and new P doses was also significant in every year. The more P residues were present in the soil, the less was the marginal efficiency of the new P doses. On the average of 3 years, the efficiency of 100 kg previous P was equal to that of 50 kg P_2O_5; according to the P balance, the efficiency of P residues was equal to that of about 70 kg new P.

The changes in the AL- and $NaHCO_3$-soluble P contents indicated the changes in the P balance and the decrease in the efficiency of new P doses. In the analized range 100 kg P added to the soil increased the AL- and $NaHCO_3$-soluble P contents of the soil roughly by 1 and 0.5 mg %. The curves of grain yields levelled more and more out for soils having 10 – 12 mg % AL-soluble P_2O_5 and 13 – 16 ppm $NaHCO_3$-soluble P contents.

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