

## Correlations Among Different P-Test Methods Studied in a Network of Hungarian P Fertilization Long-term Field Trials

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### Introduction

Phosphorus is an essential nutrient for plant growth and the role of P in the agroecosystem is an important field of agrochemical studies in relation to modern crop production. Long-term field experiments provide unique opportunities for investigating the fate of fertilizer phosphorus (P) in soil. This is of primary importance both from agronomic (recommended fertilizer P doses for optimum crop yields) and environmental point of view (i.e. accumulation of P in soil may represent a considerable potential for P load of surface and sub-surface waters via erosion and P leaching).

The plant available amount of P in soils can be estimated by different extraction methods. The success of estimating available P by an extractant depends on the suitability of the chemical used relative to soil properties (SHARPLEY, 2000). In soils with higher buffering capacity, the dissolved P amount can be less, due to exhaustion of the extraction by the higher exchange capacity of soil, or resorption of extracted P. By increasing the solution-to-soil ratio more P can be extracted from the soils (KAMPRATH & WATSON, 1980). Acid solvents, however, can behave differently in acidic and calcareous soils. By dissolving Ca-phosphates non-available for plants, these methods often overestimate soil P supply in calcareous soils (EGNER et al., 1960; LAKANEN & ERVIÖ, 1971).

The ideal soil P test would take into account intensity (concentration of P in the soil solution) and quantity (the amount of labile P adsorbed on the solid phase), buffering power (the ability of soil to maintain solution concentration when solution is depleted by plant uptake or leaching), and diffusion characteristic of the soil. Weak extractants such as water and CaCl<sub>2</sub> assess the intensity factor, while strong extractants such as acids, complexing ions, and alkaline buffered solutions measure the quantity factor (KAMPRATH & WATSON, 1980).

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Today's challenge in elaborating a soil test method is to select an extractant that accommodates several factors: 1. Multielement; 2. suitable for a range of soil characteristics; 3. having an established relative relationship between elemental level versus crop response (BENTON JONES, 1997).

Nowadays some new methods, among others the anion exchange resin membrane (AERM) and Fe-oxide impregnated paper strip (Pi) tests have attracted interest to assess the "available" phosphorus in soils (VAN RAIJ, 1997). These alternative methods determine the quantity of soil P available to plants with weak chemical extraction, and their advantage is their adaptability to all types of soils irrespective of fertilization history. The amounts of soil P desorbed by the AERM- and Pi methods have been found to be closely correlated to each other and with plant P uptake (DALAL, 1985; INDIATI et al., 1998; LIN et al., 1991). These methods simulate conditions similar to those occurring in the soil solution from which plants adsorb P (MENON et al., 1988). The Fe-oxide impregnated paper strip removes primarily physically bound P from both calcareous and non-calcareous soils. The Pi method describes soil P availability across a wide range of soil properties more accurately than other methods (SHARPLEY, 1991).

In Hungary the AL method (using 0.1 M ammonium lactate and 0.4 M acetic acid as extractant) has been the official soil P-test method since the 1960's (EGNER et al., 1960). The measured AL-P values, however, are strongly influenced by soil properties (such as: soil reaction status and carbonate content). Using Neubauer test trials on large numbers of Hungarian soils with a wide range of soil properties SARKADI et al. (1984) corrected the AL-P values to standard soil characteristics (soil texture, pH and CaCO<sub>3</sub> content). On a wide range of soils, the corrected AL-P values show much better connection with the plant P uptake than the AL-P values.

Seeking relationships among various extractants used in soil analysis is the objective of several studies looking for conversion equations among the different methods and studying the effect of soil properties on relative extractability of nutrients in soil (SHERRELL, 1970.; KLEINMAN et al., 2001). The determination of such equations is especially important when studying a new soil test method, as it allows the use of relations between soil nutrient contents and crop response evaluated by the method which is used.

### Material and Methods

The National Long-term Field Trials (NLFT) were set up in 1967 at 26 different sites, representing the main agro-ecological regions of the country. Due to the lack of adequate financial support, the experiments are carried on nowadays only at 9 sites.

Fertilizer treatments were uniformized for all sites, including increasing nitrogen, phosphorus and potassium rates and combinations of these mineral fertilizers. From the original 20 treatments with 4 replications, 4 treatments were selected for this study from each site:  $N_2P_0K_1$ ;  $N_2P_1K_1$ ;  $N_2P_2K_1$  and  $N_4P_3K_2$ .  $N_2$  refers to annual 150,  $N_4$  to 250 kg N ha<sup>-1</sup>, while  $K_1$  to 200,  $K_2$  to 250 kg K<sub>2</sub>O ha<sup>-1</sup>. The amounts of P given were 0, 60, 120 and 180 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> annually, according to the different P levels ( $P_0$ – $P_3$ ). Both the  $N_2$  and  $N_4$ , as well as the  $K_1$  and  $K_2$  levels refer to good NK supply.

The aim of this study was to compare some soil P-tests, including two innovative methods, on 9 soils of the NLFT. The studied soils – sampled in 1994, in the 27<sup>th</sup> year of the experiment – represented six FAO soil units (Calcaric Phaeosem, Luvic Phaeosem, Haplic Phaeosem, Ochric Luvisol, Eutric Cambisol, Calcaric Fluvisol) (SÁRDI & NÉMETH, 1993), or seven USDA units (Calcic Hapludoll, Aquic Hapludoll, Typic Endoaquoll, Typic Argiudoll, Typic Hapludalf, Typic Udifluent, Orthic Eutrochrept) (SÁRDI & CSATHÓ, 2002), belonging to four different soil texture classes (clay, clay loam, loam, sandy loam). Other properties were: pH (KCl): 3.9–7.4;  $y_1$  (meq/100 g): 0–24; CaCO<sub>3</sub> %: 0–21; clay %: 12–41. The effect of uniform fertilization on soil P-test values can be examined under a wide range of soil properties (DEBRECZENI & DEBRECZENI, 1994).

The AL-, Olsen-, H<sub>2</sub>O-, Pi- and AERM methods were used for estimating available soil phosphorus (Table 1). There were calculated corrected AL-P values on the principle of converting AL-P values obtained on various soils to standard soil properties (loam soil texture, 6.8 pH(KCl), 0.1% CaCO<sub>3</sub>), determined by using Neubauer test trials on large numbers of Hungarian soils with a wide range of soil properties (SARKADI et al., 1984). Linear equations were calculated for determining the correlation between soil P-test methods.

Table 1  
Extraction methods for soil available phosphorus

Method	Solution	Soil to solution ratio (w/v)	Extraction time
AL-P <sup>1</sup>	0.1M NH <sub>4</sub> -lactate + 0.4 M CH <sub>3</sub> COOH	1:20	120 min.
Pi-P <sup>2</sup>	0.01M CaCl <sub>2</sub> + Fe-oxide coated strip	1:40	16 hours
AERM-P <sup>3</sup>	H <sub>2</sub> O + anion exchange resin membrane*	1:30	16 hours
H <sub>2</sub> O-P <sup>4</sup>	Bidistilled water	1:50	2 hours
Olsen-P <sup>5</sup>	0.5 M NaHCO <sub>3</sub>	1:20	30 min.

<sup>1</sup> EGNER et al., 1960; <sup>2</sup> MENON et al., 1988; <sup>3</sup> SAGGAR et al., 1990; <sup>4</sup> SCHACHTSCHABEL, 1973, modified by SARKADI, 1982; <sup>5</sup> OLSEN et al., 1954; \* HCO<sub>3</sub><sup>-</sup> form

Table 2  
The effect of 27 years P fertilization on the P-test values  
(Network of National Long-term Field Trials, 1994)

P	Experimental sites*										
	NH	IR	BI	KO	KA	PU	KE	HB	MO	LSD	Mean
<i>H<sub>2</sub>O-P, mg kg soil<sup>-1</sup></i>											
P <sub>0</sub>	3.6	3.8	6.8	10.3	5.4	5.7	6.6	6.8	7.7	5.0	6.3
P <sub>1</sub>	6.3	7.7	9.5	12.6	8.4	11.0	10.2	9.6	10.1		9.5
P <sub>2</sub>	12.2	11.6	10.9	13.4	17.4	12.8	17.8	11.2	13.1		13.4
P <sub>3</sub>	22.7	16.1	15.2	20.2	19.8	24.1	23.5	18.0	14.0		19.3
LSD	4.9										1.6
M	11.2	9.8	10.6	14.1	12.8	13.4	14.5	11.4	11.2	2.5	12.1
<i>Olsen-P, mg kg soil<sup>-1</sup></i>											
P <sub>0</sub>	3.7	6.4	5.2	7.9	4.8	7.8	7.1	7.7	6.6	8.6	6.4
P <sub>1</sub>	9.4	19.8	11.3	14.1	8.6	16.3	15.6	8.6	20.6		13.5
P <sub>2</sub>	28.1	31.7	14.7	25.2	21.4	20.5	28.8	16.8	29.2		24.0
P <sub>3</sub>	46.5	47.7	21.7	43.0	25.5	25.1	38.1	28.2	34.0		34.4
LSD	7.9										0.9
M	21.9	26.4	13.2	22.6	15.1	17.4	22.4	15.3	22.6	4.3	19.6
<i>Pi-P, mg kg soil<sup>-1</sup></i>											
P <sub>0</sub>	3.2	5.4	6.4	17.0	6.2	9.3	5.9	6.4	11.4	8.1	7.9
P <sub>1</sub>	7.8	14.5	12.5	15.5	10.2	13.8	11.6	12.1	14.6		12.5
P <sub>2</sub>	22.1	26.0	15.5	37.0	31.0	22.8	27.7	18.5	24.8		25.0
P <sub>3</sub>	36.9	37.7	24.1	56.8	35.0	39.3	36.5	33.5	28.7		36.5
LSD	7.7										2.4
M	17.5	20.9	14.6	31.6	20.6	21.3	20.4	17.6	19.9	4.0	20.5
<i>AERM-P, mg kg soil<sup>-1</sup></i>											
P <sub>0</sub>	4.5	7.5	11.5	39.0	11.4	17.9	10.7	12.5	15.5	14.6	14.5
P <sub>1</sub>	11.9	22.3	24.1	38.2	19.9	36.6	20.4	19.5	21.9		23.9
P <sub>2</sub>	37.2	38.6	30.8	67.0	40.0	39.3	41.3	30.1	33.4		39.7
P <sub>3</sub>	55.5	52.0	41.5	104.6	54.6	68.0	53.6	53.6	41.4		58.3
LSD	14.1										4.4
M	27.3	30.1	26.9	62.2	31.5	40.4	31.5	28.9	28.0	7.3	34.1
<i>AL-P, mg kg soil<sup>-1</sup></i>											
P <sub>0</sub>	26.2	53.2	16.3	21.1	12.8	20.9	37.4	27.3	70.0	31.9	31.7
P <sub>1</sub>	49.7	88.9	33.4	46.2	21.6	44.4	91.1	32.1	106.5		57.2
P <sub>2</sub>	109.6	122.3	41.8	84.0	48.8	52.9	119.2	51.5	144.8		86.2
P <sub>3</sub>	174.7	168.1	41.4	136.8	59.4	92.1	163.2	88.4	182.2		123.2
LSD	31.1										11.1
M	90.2	108.2	33.4	72.2	35.6	52.6	103.0	49.7	125.8	15.9	74.6

\* Experimental sites: NH: Nagyhörceök; IR: Iregszemcse; BI: Bicsérd; KO: Kompolt; KA: Karcag; PU: Putnok; KE: Keszthely; HB: Hajdúböszörmény; MO: Mosonmagyaróvár  
LSD = LSD<sub>5%</sub>; M = Mean

## Results

The effect of P application on the soil P-test values was significant on the different P levels and sites (Table 2). There were great differences, however, in the amounts of P dissolved by the different methods. The average effect of the sites varied between 1.5–3.7-fold (H<sub>2</sub>O method–AL method). The acidic AL method was most dependent on the soil reaction and lime status. The highest AL-P values were extracted on the calcareous sandy loam–loam soils with low clay content, meanwhile the lowest AL-P values were obtained on acidic clay loam soils.

P fertilization resulted in a 3–5-fold increase in soluble P contents regarding the different P-test methods, and the absolute values of dissolved P varied greatly (H<sub>2</sub>O-P: 3.6–23.5; Olsen-P: 3.7–48; Pi-P 3.2–56.8, AERM-P: 4.5–104.6; and AL-P: 12.8–182.2 mg P kg<sup>-1</sup>).

The amounts of extracted P increased in the order of: H<sub>2</sub>O-P < Olsen-P < Pi-P < AERM-P < AL-P < corrected AL-P. Taking the AL-method – which is the official soil P-test method in Hungary – as the reference method (100%), this sequence can be expressed by calculating the % ratios between mean values of the P extracted by various methods: 16 < 26 < 28 < 46 < 100 < 115.

When studying the relationship between the P values extracted by the different methods, different soil groups (acidic, calcareous and all soils) were taken into consideration as a basis.

*Acidic soils (Table 3):* The strongest correlation was found between the AL- and the Corr. AL-P methods ( $r = 0.98^{**}$ ). As it was mentioned above, among soil properties, soil CaCO<sub>3</sub> content is the one that mainly determines the AL-P values. Within the acidic soil group, pH has a much less expressed effect on these values. This may be the reason why the AL-P and corrected AL-P values showed the strongest correlation within this group.

*Table 3*  
Correlation coefficient (r) matrix for different methods of extracting soil phosphorus – acidic soils (n=16)

	AL-P	Corr.AL-P	Pi-P	AERM-P	H <sub>2</sub> O-P	Olsen-P
AL-P	1					
Corr.AL-P	0,9804**	1				
Pi-P	0,9449*	0,9105*	1			
AERM-P	0,9680**	0,9489*	0,9663**	1		
H <sub>2</sub> O-P	0,8032	0,7637	0,8802*	0,8233	1	
Olsen-P	0,9515*	0,9014	0,9618**	0,9463*	0,8450	1

\*significant at 0.05; \*\* significant at 0.01; \*\*\*significant at 0.001 probability level

Within the acidic soils group, other close correlations were found between the AL- and AERM-P ( $r = 0.97^{**}$ ), and between the Pi- and AERM-P methods ( $r = 0.97^{**}$ ).

*Calcareous soils (Table 4):* The best correlation was found between the two innovative methods: the Pi- and AERM-P ( $r = 0.99^{***}$ ). The AL-P method showed the best relationship with the Olsen-P method ( $r = 0.93^{**}$ ).

*Table 4*  
Correlation coefficient (r) matrix for different methods of extracting soil phosphorus  
– calcareous soils (n = 20)

	AL-P	Corr.AL-P	Pi-P	AERM-P	H <sub>2</sub> O-P	Olsen-P
AL-P	1					
Corr.AL-P	0,6473	1				
Pi-P	0,8684*	0,7894	1			
AERM-P	0,8298*	0,8092	0,9918***	1		
H <sub>2</sub> O-P	0,7881	0,8910*	0,9359**	0,9459**	1	
Olsen-P	0,9307**	0,6905	0,9579**	0,9411**	0,8711*	1

\*significant at 0.05; \*\* significant at 0.01; \*\*\*significant at 0.001 probability level

*All soils (Table 5):* The best correlation was found between the Pi- and AERM-P ( $r = 0.96^{***}$ ) and the Pi- and H<sub>2</sub>O-P methods ( $r = 0.90$ ). Other close correlations were obtained between the Pi- and Olsen-P ( $r = 0.88^{***}$ ), and between the AL- and Olsen-P methods ( $r = 0.89^{***}$ ), presumably indicating that these methods extracted P from the similar soil-P fraction. The lactic and alkaline extractants dissolve both adsorbed phosphates and Fe-, Al-phosphates and easily dissolvable Ca-phosphates. Otherwise the lactic acid extractants dissolve a considerable amount of the less soluble Ca-phosphates, however this fraction of P is unavailable for plants (FÜLEKY, 1976a,b).

*Table 5*  
Correlation coefficient (r) matrix for different methods of extracting soil phosphorus  
– all soils (n = 36)

	AL-P	Corr.AL-P	Pi-P	AERM-P	H <sub>2</sub> O-P	Olsen-P
AL-P	1					
Corr.AL-P	0,5327	1				
Pi-P	0,6928*	0,8557**	1			
AERM-P	0,5651	0,8994***	0,9618***	1		
H <sub>2</sub> O-P	0,6343*	0,7894**	0,9027***	0,8542**	1	
Olsen-P	0,8977***	0,6710*	0,8847***	0,7912**	0,8159**	1

\*significant at 0.05; \*\* significant at 0.01; \*\*\*significant at 0.001 probability level

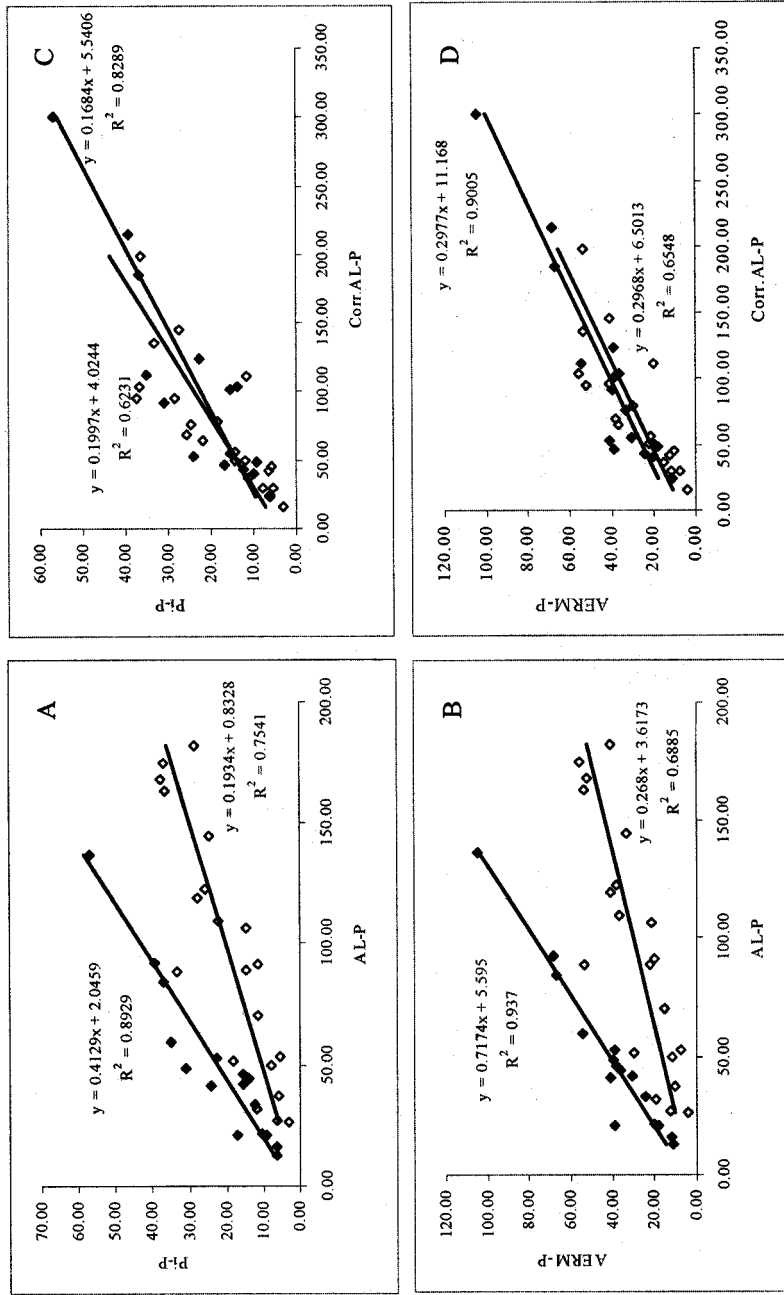


Figure 1 Relationship between the AL-, corrected AL-, Pi- and AERM-P values (◆ non-calcareous soils, ◇ calcareous soils)

Weak correlations were detected between the AL- and the innovative P-test methods (AL–Pi:  $r = 0.70^*$ ; AL–AERM:  $r = 0.56$ ). The reason of this is that the AL-P values depend considerably on the  $\text{CaCO}_3$  status of soils, while the two innovative methods are much less dependent on soil properties. There are two ways to increase the strength of correlation between the four methods:

- to determine new relations dividing soils into calcareous and non-calcareous groups (Figure 1. A, B), or
- to convert the AL-P values to standard soil properties, and afterwards determine relations between the corrected AL-P and Pi-P, or corrected AL-P and AERM-P values (corrected AL-Pi:  $r = 0.86^{**}$ ; corrected AL-AERM:  $r = 0.90^{***}$ ) (Figure 1. C, D).

The corrected AL-method is expected to improve the correlation between crop P uptake and soil P-test values, because this method could abolish differences developed in calcareous and non-calcareous soil groups by using the AL-method.

### Summary

Five soil P-test methods were compared on the soils of the network of unified Hungarian P fertilization long-term field trials. The effect of P application on the soil P-test values was significant on the different P levels and sites. The average effect of the sites varied between 1.5-fold ( $\text{H}_2\text{O}$  method) and 3.7-fold (AL-method).

The amounts of extracted P increased in the order of  $\text{H}_2\text{O-P} < \text{Olsen-P} < \text{Pi-P} < \text{AERM-P} < \text{AL-P} < \text{Corrected AL-P}$ . For studying the relationships between the P values extracted by the different methods, acidic, calcareous and all soils groups were taken into account as a basis. A good correlation was found between the Pi- and AERM-methods in each soil group. Within the acidic soil group, pH has a much less expressed effect on AL-P values, presumably this was the reason why the strongest correlation in this soil group was found between the AL- and the Corr. AL-P methods

The next step in our research will be to calibrate these soil-P tests with plant P uptake and yield responses.

**Key words:** Hungarian field trials, AL-P, AERM-P, Pi-P, corrected AL

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