

ΕΔΑΦΟΛΟΓΙΑ.— **Phosphorus soil tests and their suitability for the assessment of available phosphorus of soils**, by *A. D. Simonis**,
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INTRODUCTION

The assessment of available soil P and the development of a reliable index of its availability - despite the vast amount of the work which has been done as yet [3, 4, 6, 10, 17, 19, 20, 24, 26, 27, 28]— it still remains a continuing objective of considerable merit. The complex nature of soil phosphates - multitude of different forms, reactions, compounds, complexes and bonding energies of P in the soil makes the interpretation of the chemical behaviour of soil P and the obtaining of a more definitive measure of soil P supply, very difficult.

A wide variety of methods for assessing soil phosphorus status, differing to their general principles and technical details, have been employed over the years. They include: widely different types of extracting solutions - pure or carbonated water, dilute organic and inorganic acids, neutral, alkaline and buffered salt extractants - anion exchange resin and isotopic exchange methods, as well as, electro-ultrafiltration (EUF) methods. The most reliable methods account for about 60 per cent of the variance in the P responses in the field experiments and about 80 per cent in greenhouse experiments, when the plants are grown under optimum fertilization conditions with all nutrients, except P [5].

The need for a less empirical foundation of soil analysis has led the research workers to specify the fundamental soil parameters of intensity,

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quantity and kinetic, which define phosphorus availability in soils [2, 12, 24]. The amounts of P determined by various empirical methods, usually, constitute composite indices of the quantity and intensity parameters only. Further research is needed to find ways of integrating quantity and intensity parameters with kinetic parameters to give a more unequivocal measure of available soil P and its availability [24].

The main object of the present work was to study the suitability of various methods —that are commonly practised worldwide— for the assessment of available phosphorus in 21 soils, taken from various locations in Northern Greece, as defined by K uptake and dry matter yield of ryegrass, grown in pots.

MATERIALS AND METHODS

1. Soils used and their characteristics.

Twenty one surface soil samples, representative of the main soil types of Northern Greece, were used for the laboratory and the greenhouse studies. The samples were taken at 0-25 cm depth. The basic characteristics of soils used, are given in Table 1. The determination of these characteristics was carried out according to standard procedures [13].

2. Laboratory methods of P analysis used.

The main characteristics of the methods of P analysis used for the assessment of available soil P, are given in Table 2. Determinations of P concentration in the various extracts were made, in duplicate, by molybdenum blue method in a sulfuric acid system with a mixture of SnCl_2 —ascorbic acid— HCl, used as reducing agent [25].

3. Experiments with plants

For correlations between soil analysis data and P uptake by plants and dry matter yield, the following pot-culture technique was employed: One kg quantities of soil thoroughly mixed with 400 g of properly washed

TABLE 1
Parent material, Great Soil Group and general characteristics of the soils used.

No soil	Parent material*	Great Soil Group	clay %/o	silt %/o	organic matter %/o	pH	CaCO ₃ %/o	CEC me/100g soil
1	sch. micaceous	Lithic Dystrochrept	17.2	40.8	1.01	4.18	-	35.10
2	granite	Typic Dystrochrept	9.2	29.6	1.44	5.45	-	25.17
3	dep. mic. sch.	Ultic Haploxeralf	17.2	24.8	1.79	5.45	-	15.33
4	dep. mic. sch.	Ultic Haploxeralf	8.8	17.6	3.38	4.45	-	12.08
5	alluvium	Mollic Xerofluvent	24.8	35.6	6.87	4.95	-	35.20
6	alluvium	Typic Xerofluvent	17.2	45.2	2.61	6.60	neg	36.37
7	alluvium	Typic Xerofluvent	7.2	43.6	1.65	7.12	1.2	35.91
8	dep. cal. mat.	Typic Haploxeralf	35.5	26.9	4.41	6.34	0.6	35.33
9	dep. cal. mat.	Typic Haploxeralf	32.8	28.8	4.23	7.15	0.6	31.33
10	dep. cal. mat.	Vertic Haploxeralf	34.3	27.5	4.84	6.02	0.6	35.23
11	dep. mic. sch.	Vertic Palexeralf	10.8	27.6	4.81	5.05	-	13.05
12	dep. mic. sch.	Typic Haploxeralf	17.2	17.2	6.13	4.85	-	35.10
13	dep. mic. sch.	Ultic Haploxeralf	29.2	17.2	0.50	5.95	-	19.83
14	dep. cal. mat.	Typic Haploxeralf	33.2	27.2	4.04	6.95	1.8	42.50
15	marl	Typic Haploxeralf	36.8	27.6	1.52	7.03	3.0	34.98
16	marl	Vertic Haploxeroll	32.8	33.2	3.42	7.05	13.7	34.58
17	limestone	Lithic Eutrochrept	20.8	51.6	0.97	6.95	1.2	19.33
18	gneiss	Lithic Dystrochrept	6.8	23.6	1.07	4.18	-	12.70
19	gneiss	Lithic Dystrochrept	5.2	15.2	2.24	4.35	-	12.21
20	limestone	Typic Eutrochrept	48.8	43.2	1.47	6.65	1.4	50.00
21	dep. cal. mat.	Calcic Chromoxerert	31.2	18.8	0.72	6.05	neg	19.91

*sch. micaceous=schists micaceous, dep. mic. sch.=deposits from mica schists,
dep. cal. mat.=deposits from calcareous materials.

sand and 50 cc of nutrient solution, containing 10 mmol N as NH_4NO_3 , 5 mmol K as KNO_3 and enough water to achieve a satisfactory potting consistency, were placed in plastic pots. The soils were sown, in triplicate, with 1.5 g of perennial ryegrass seed (*Lolium perenne*-S23 variety) and the pots were placed on a glasshouse bench. Each pot stood in a polyethylene saucer which was used for watering.

The ryegrass was cut consecutively (six cuts in total) every 30 days at soil level. The foliage was dried immediately on aluminium trays at 80° C. After weighing, the foliage was prepared for P analysis. Total plant P was estimated by dry ashing at 550° C and colour development according to the molybdate-vanadate method [13]. The absorbance was read on a spectrophotometer at 420 nm.

RESULTS

The range and mean P-values of soils determined by the different methods used, for the 21 soils, are given in Table 3.

The mean amounts (cumulative) of P obtained by the ryegrass plants from the soils during the period of experiment (184 days), were estimated from the individual amounts of P obtained by successive croppings - cuttings of the plants, and are represented, grafically, in Fig. 1.

The coefficients of correlation between P availability indices of soils and cumulative P uptake by ryegrass and cumulative dry matter yield of ryegrass plants - of the first cutting, as well as, cumulative of successive cuttings - are given, respectively, in Tables 4 and 5.

Furthermore coefficients of correlation for P-values of soils with total P uptake of six cuttings were calculated data from groups of soils, classified on the basis of pH (<5.5, 5.5-7.0 and >7.0), texture (C, SCL and L, SL, LS), cation exchange capacity (CEC) (<20, 20-35 and >30 me/100 g) and per cent base saturation (<60 and >60 per cent). The results are given in Table 6.

DISCUSSION - CONCLUSIONS

Various amounts of P, differing, considerably among themselves, were extracted from the soils by the extractants-methods used (Table 3). Relatively, small amounts of P were extracted with the weak extractants (water, 0.01 M CaCl_2 , 0.2 N ammonium oxalate - intensity methods), but much larger

TABLE 2
Methods of soil analysis used and their characteristics

No	Method	Reagent/extractant	weight of soil (g)	Volume of solution (ml)	time of shaking	Reference
1	Total P	HClO ₄	2.0	30	40'	Jackson (1958)
2	Olsen	0.5 M NaHCO ₃ pH 8.5	5.0	100	30'	Olsen et al (1954)
3	Dirks	carbonated water	40.0	100	60'	Dirks and Scheffer (1933)
4	Water	Dist. water	2.5	50	18 h	Bingham (1949)
5	CaCl ₂	0.01 M CaCl ₂	2.5	50	18 h	Aslyng (1964)
6	Bray I	0.025 N HCl + 0.03 N NH ₄ F	5.0	35	1'	Bray and Kurtz (1945)
7	Bray II	0.1 N HCl + 0.03 N NH ₄ F	5.0	35	1'	Bray and Kurtz (1945)
8	NH ₄ HCO ₃	0.5MN H ₄ HCO ₃ pH 8.5	5.0	100	30'	—
9	H ₂ SO ₄	0.002 N H ₂ SO ₄ pH 3.0	1.0	200	30'	Truog (1930)
10	H ₂ SO ₄	0.2 N H ₂ SO ₄	10.0	250	2 h	Bondorff (1952)
11	Amm. oxalate	0.2 N C ₂ O ₄ (NH ₄) ₂	4.0	100	30'	Joret and Hérbet (1955)
12	Amm. lactate	0.1 N amm. lactate + 0.4 N AcOH	5.0	100	2 h	Egner et al (1960)
13	Resin	Anion resin and disr water	3.0	100	24 h	Cooke and Hislop (1963)
14	Morgan	0.5N OHAc + 0.75 N NaOAc pH 4.8	5.0	25	15'	Morgan (1937)
15	Organic P	30% H ₂ O ₂ + 0.5 NHCl + 0.05 N NH ₄ F	1.0	50	90'	Jackson (1958)
16	N. Carolina	0.05 N HCl + 0.025 N H ₂ SO ₄	5.0	20	5'	Sabbe and Breland (1974)
17	Rate of phosphate release	Anion resin and dist. Water	1.0	25	3 h	Cooke (1966)
18	Phosphate potential	Solutions of 0.01 M CaCl ₂ of varying phosphate concentrations	2.5	50	24 h	Larsen and Curt (1960)
19	P-requirement to give 0.02 ppm in solution	Solutions of 0.01 M CaCl ₂ containing various amount of Ca(H ₂ PO ₄) ₂	3.0	30	6 h	Fox and Kamprath (1970)
20	P-buff. capacity (P-absorbed between 0.25 to 0.35 ppm	Solutions of 0.01 M CaCl ₂ containing various amounts of Ca(H ₂ PO ₄) ₂	3.0	30	6 h	Ozanne and Shaw (1968)
21	EUF	aqueous soil suspension	3.0	30	30'-35'	Németh (1979)

TABLE 3

Ranges and mean values of phosphorus of the soils determined by different methods

No	Extractant/Method	Ranges of values	Mean values
1	Total P ppm	258.2 — 1063.8	523.9
2	0,5 M NaHCO ₃ ppm	3.4 — 31.4	12.7
3	Carbonated water ppm	0.04 — 0.49	0.12
4	Dist. water ppm	0.8 — 3.6	1.8
5	0,01 M CaCl ₂ ppm	0.15 — 1.1	0.69
6	Bray I ppm	8.0 — 213.5	40.0
7	Bray II ppm	11.2 — 341.9	84.3
8	0,5 M NH ₄ HCO ₃ ppm	3.1 — 30.2	11.3
9	0,002 N H ₂ SO ₄ ppm	12.0 — 118.0	35.4
10	0,2 N H ₂ SO ₄ ppm	17.5 — 308.0	145.6
11	0,2 N amm. oxalate ppm	1.2 — 12.5	2.6
12	0,1 N amm. lactate ppm	10.0 — 85.0	37.2
13	Resin ppm	1.5 — 106.5	13.8
14	Morgan ppm	1.5 — 22.8	7.4
15	Organic P ppm	8.2 — 384.7	113.5
16	0,05 N HCl + 0,025 N H ₂ SO ₄ ppm	12.8 — 289.6	110.8
17	Rate phosphate release mgP /kg soil /min 1/2	0.06 — 4.4	0.54
18	Phosphate potential	5.6 — 7.2	6.8
19	P-requirement to give 0,2 ppm in solut. ppm	61.5 — 330.6	199.2
20	P-buffering capacity ppm	25.2 — 71.3	45.5
21	EUf ppm	1.0 — 15.7	5.5

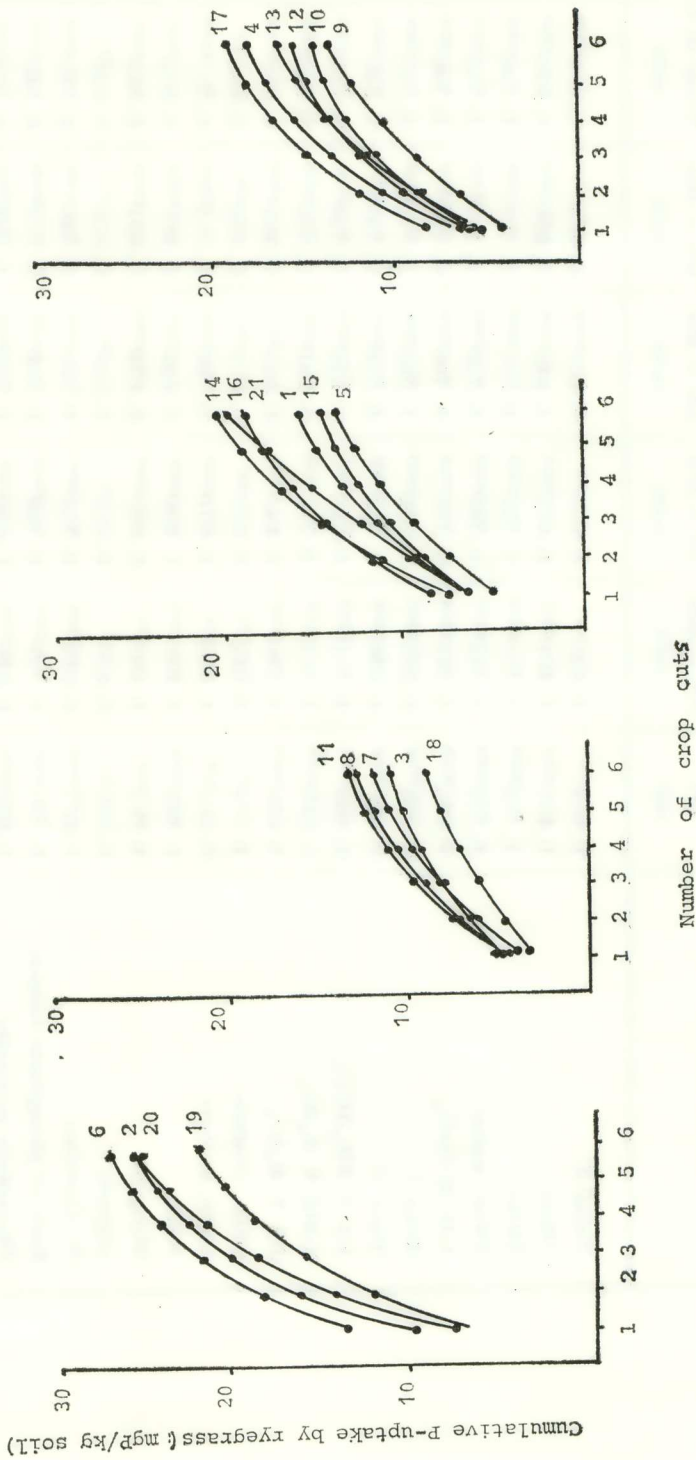


Fig. 1. Cumulative P-uptake by ryegrass by successive cropping from the analysed soils (No 1-31).

TABLE 4
Coefficients of correlation between soil P availability indices and cumulative P uptake
by ryegrass

P-availability index	Correlation coefficient (r)					
	1st cut	1st + 2nd cuts	1st + 3rd cuts	1st + 4th cuts	1st + 5th cuts	Total of 6 cuts
Total P	0.602**	0.620**	0.635**	0.655***	0.675***	0.696***
Olsen	0.835***	0.870***	0.882***	0.892***	0.895***	0.895***
Dirks	0.716***	0.713***	0.723***	0.731***	0.745***	0.758***
Dirst. water	0.772***	0.762***	0.760***	0.758***	0.750***	0.742***
0.01 M CaCl ₂	0.692***	0.704***	0.703***	0.704***	0.707***	0.708***
Bray I	0.698***	0.682***	0.694***	0.703***	0.710***	0.715***
Bray II	0.690***	0.698***	0.712***	0.718***	0.720***	0.723***
0.5 N NH ₄ HCO ₃	0.688***	0.712***	0.720***	0.722***	0.728***	0.734***
0.002 N H ₂ SO ₄	0.697***	0.712***	0.735***	0.740***	0.755***	0.760***
0.2 N H ₂ SO ₄	0.694***	0.790***	0.840***	0.845***	0.880***	0.890***
amm. oxalate	0.512*	0.582**	0.603**	0.612**	0.622**	0.633**
amm. lactate	0.612**	0.640**	0.670***	0.798***	0.712***	0.717***
resin	0.880***	0.890***	0.890***	0.898***	0.907***	0.912***
Morgan	0.612**	0.640**	0.665***	0.678***	0.680***	0.683***
organic P	0.391 ^{ns}	0.428*	0.512*	0.530*	0.531*	0.533*
N. Carolina	0.677***	0.690***	0.702***	0.765***	0.780***	0.795***
Rate of phosphate release	0.791***	0.799***	0.782***	0.759***	0.777***	0.782***
Phosphate potential	0.682***	0.690***	0.699***	0.702***	0.709***	0.712***
P-requirements for 0.2 ppm	0.670***	0.675***	0.690***	0.720***	0.740***	0.755***
P-buffering capacity	0.655***	0.683***	0.674***	0.688***	0.697***	0.705***
EUf	0.692***	0.717***	0.724***	0.775***	0.790***	0.841***

*p < 0.05, **p < 0.01, ***p < 0.001

TABLE 5

Coefficients of correlation between soil P availability indices and cumulative yield of ryegrass plants

P availability index	Correlation coefficient (r)					
	1st cut	1st 2nd cuts	1st 3rd cuts	1st 4th cuts	1st 5th cuts	Total of six cuts
Total P	0.492*	0.510*	0.545**	0.562**	0.593**	0.605**
Olsen	0.692***	0.698***	0.712***	0.726***	0.739***	0.765***
Dirks	0.632**	0.657***	0.669***	0.671***	0.683***	0.690***
Dist. water	0.695***	0.682***	0.677***	0.674***	0.669***	0.665***
0.01 M CaCl ₂	0.504*	0.519*	0.531*	0.557**	0.574**	0.599**
Bray I	0.499*	0.517*	0.542**	0.567**	0.582**	0.603**
Bray II	0.562**	0.571**	0.586**	0.592**	0.601**	0.615**
0.5 M NH ₄ HCO ₃	0.555**	0.567**	0.572**	0.589**	0.606**	0.619**
0.002 H ₂ SO ₄	0.571**	0.586**	0.597**	0.604**	0.621**	0.632**
0.2 N H ₂ SO ₄	0.702***	0.713***	0.743***	0.759***	0.777***	0.792***
Amm. oxalate	0.475*	0.481*	0.487*	0.490*	0.494*	0.504*
Amm. lactate	0.455*	0.469*	0.477*	0.484*	0.503*	0.511*
Resin	0.752***	0.766***	0.789***	0.801***	0.824***	0.837***
Morgan.	0.739*	0.456*	0.471**	0.494*	0.500*	0.511*
Organic P	0.399ns	0.403ns	0.417ns	0.431*	0.437*	0.449*
N. Carolina	0.564**	0.573**	0.599**	0.615**	0.624**	0.660***
Rate of phosphate release	0.602**	0.611**	0.624**	0.639**	0.642**	0.652***
Phosphate potential	0.613**	0.627**	0.651**	0.672***	0.679***	0.681***
P-requirements or 0.2 ppm P	0.607**	0.615**	0.647**	0.663***	0.684***	0.692***
P-buffering capacity	0.542**	0.559**	0.577**	0.584**	0.595**	0.607**
EUf	0.711***	0.725***	0.739***	0.752***	0.766***	0.779***

*P<0.05, **P<0.01, ***P<0.001 ns=non significant

TABLE 6

Coefficients of correlation between soil P-values and cumulative P uptake by ryegrass. Soils were grouped on the basis of pH, texture, CEC and percent base saturation.

P-values	total uptake P											
	pH			texture			CEC (me/100g soil)				percent base saturation	
	<5,5 n=6	5,5-7,0 n=6	7,0< n=9	C, SCL n=10	L, SL, LS n=11	<20 n=8	20-35 n=5	35< n=8	<60 n=10	60< n=11		
Total P	0,960**	0,958***	0,902***	0,910***	0,970***	0,912***	0,976**	0,878**	0,913***	0,877***		
0.5 M NaHCO ₃	0,981**	0,975***	0,960***	0,989***	0,945***	0,945***	0,998***	0,925***	0,947***	0,890***		
carbonated water	0,907*	0,906*	0,911***	0,911***	0,772**	0,913**	0,981**	0,912**	0,904***	0,876***		
dist. water	0,969**	0,952**	0,912***	0,975***	0,870***	0,927***	0,982**	0,899**	0,903***	0,790**		
0.01 M CaCl ₂	0,973**	0,970**	0,890**	0,875***	0,793**	0,937***	0,978**	0,879**	0,898***	0,802**		
Bray I	0,974***	0,962**	0,877**	0,850**	0,720**	0,924**	0,977**	0,876**	0,937***	0,814**		
Bray II	0,976***	0,973**	0,897**	0,852**	0,790**	0,902**	0,981**	0,902**	0,932***	0,803**		
0.5 M NH ₄ HCO ₃	0,974***	0,959**	0,893**	0,899	0,781**	0,913**	0,979**	0,911**	0,926***	0,898***		
0.002 N H ₂ SO ₄	0,958**	0,958**	0,877**	0,913***	0,773**	0,901**	0,979**	0,904**	0,914***	0,812**		
0.2 N H ₂ SO ₄	0,962**	0,967**	0,897**	0,922***	0,972**	0,898**	0,987**	0,897**	0,913***	0,866***		
amm. oxalate	0,960**	0,977***	0,912***	0,931***	0,790**	0,904**	0,986**	0,896**	0,914***	0,877***		
amm. lactate	0,959**	0,961**	0,892**	0,927***	0,719**	0,899**	0,982**	0,903**	0,917***	0,883***		
resin	0,962**	0,963**	0,920***	0,818**	0,852**	0,920**	0,982**	0,903**	0,923***	0,790**		
Morgan	0,888*	0,855*	0,896**	0,841**	0,791**	0,980***	0,970**	0,877**	0,897***	0,813**		
organic P	0,855*	0,855*	0,695*	0,670*	0,652*	0,851**	0,881*	0,672*	0,660*	0,681*		
N. Carolina	0,966**	0,971**	0,876**	0,870**	0,774**	0,914**	0,986**	0,911**	0,922***	0,790**		
Rate of phosphate release	0,962**	0,967**	0,897**	0,872**	0,719**	0,851**	0,987**	0,878**	0,923***	0,788**		
Phosph. potential	0,967**	0,962**	0,875**	0,843**	0,796**	0,908**	0,982**	0,896**	0,931***	0,796**		
P-requirement for 0.2 ppm	0,971**	0,970**	0,902***	0,927***	0,797**	0,917**	0,978**	0,904**	0,909***	0,814**		
P-buffering capacity	0,962**	0,961**	0,890**	0,839**	0,784**	0,902**	0,979**	0,896**	0,914***	0,802**		
EUf	0,952**	0,965***	0,912***	0,875***	0,852**	0,927***	0,979**	0,912***	0,937***	0,898***		

*P<0.05, **P<0.01, ***P<0.001

TABLE 7

Coefficients of correlation between soil P values determined with different methods.

	Total P	0.5 M NaHCO ₃	Carbonated water	Dist. water	0.01 M CaCl ₂	Bray I	Bray II	0.5 M NH ₄ HCO ₃	0.002 N H ₂ SO ₄	0.2 N H ₂ SO ₄	Amm. oxalate
Total P	-	.545	.580	.475	.585	.515	.520	.692	.677	.649	.702
0.5 M NaHCO ₃	-	-	.745	.715	.845	.670	.675	.755	.792	.677	.733
Carbonated water			-	.705	.780	.742	.702	.732	.768	.822	.749
Dist. water				-	.815	.735	.704	.645	.732	.818	.649
0.01 M CaCl ₂					-	.820	.820	.749	.737	.772	.713
Bray I						-	.659	.770	.612	.663	.704
Bray II							-	.698	.645	.768	.722
0.5 M NH ₄ HCO ₃								-	.672	.777	.733
0.002 N H ₂ SO ₄									-	.668	.742
0.2 N H ₂ SO ₄										-	.735
Amm. oxalate											-
Amm. lactate											
Resin											
Morgan											
Organic P											
0.05N HCl +0.025 N H ₂ SO ₄											
Rate of phosphate release											
Phosphate potential											
P-required to give 0.2 ppm P in solution											
P-buffering capacity											
EUF											

Coefficients of correlation >0.652 are statistically significant at P<0.001. Those between 0.537 and 0.652 are significant at P<0.01 and those between 0.423 and 0.637 significant at P<0.05.

amounts with the strong extractants (0.2 N H_2SO_4 , Bray II). However, as far as practical fertilizer advice is concerned, it is not the quantity of P extracted that is of primary importance, but rather if it is a good measure of the soil P status of the ability of soil to release P to plants. For this reason, correlations between plants growth parameters, such as P uptake and dry matter yield and of P extracted by the different methods, were determined.

The correlations between the P obtained by ryegrass and P determined by the different methods, were statistically significant (Table 4). This means that all methods employed, were good indicators of P availability of the soils under investigation. The best correlations, however, with the total P uptake of the 6 cuts of ryegrass plants were obtained by: resin-P ($r=0.912^{***}$), $NaHCO_3$ -P (Olsen-P) ($r=0.895^{***}$), 0.2 N H_2SO_4 -P ($r=0.890^{***}$) and EUF-P ($r=0.841^{***}$). These correlations were, appreciably, superior to other correlations (Table 4), whereas the poorest correlation was obtained with the organic P ($r=0.533^*$). Generally, better correlations were obtained by the quantity methods (like the former ones), in accordance with the assumption that intensive growing of plants, under the experiential conditions in pots, is mainly depended on the quantity parameters [32].

The quantities of soil P determined by 21 tested methods correlated less closely with yield (Table 5). Again, the resin, Olsen, 0.2 N H_2SO_4 and EUF methods proved to be most superior to other methods. The less close correlations indicate, that there are factors other than P supply, such as the chemical, physical and biological soil properties, which affect yield and must have played a role in yield production, but which had a smaller effect on P uptake. Also, since the plants were grown for only a short period (only 184 days) rather than to maturity, the yield recorded may not have been a true reflection on the plant's potential growth. Under these conditions, therefore, P methods should be evaluated by comparing their soil P-values to P-uptake by plants.

The correlations between total P uptake by ryegrass plants and soil P analysis values were, generally, better on the fine texture soils (C, SCL), than on the coarse textured soils (LS, SL, L), as well as, on the soils with base saturation levels $<60\%$, than on soils with base saturation levels $>60\%$ (table 6).

The mean quantities of P extracted with 0.5 M $NaHCO_3$ were, nearly as high, as the resin-P values (Table 3) and were highly correlated between

themselves ($r=0.895^{***}$) (Table 7). Resin, also, was highly correlated with the methods of Bray II ($r=0.870^{***}$), ammonium oxalate ($r=0.870^{***}$), ammonium lactate ($r=0.892^{***}$) and EUF ($r=0.875^{***}$). Very close relationships could be found, also, between Olsen-P values and 0.01 M CaCl_2 ($r=0.845^{***}$) and EUF-P values ($r=0.915^{***}$) (Table 7).

Of all the methods tested, the extraction with 0,5 M NaHCO_3 (Olsen method) proved least sensitive to change in pH, texture, CEC and percent base saturation (Table 6). Therefore, this method proves to be equally effective to the calcareous soils, for which was, initially, proposed, as well as, to the acid soils. The chemistry of the method is such that it should be of value on acid, as well as, on calcareous soils, as there is extraction from the surface of iron and aluminium phosphates, as well as, from the surface of calcium phosphate [13].

It is impossible, in laboratory, to simulate the action of the root system of the plants, and the nearest approximation we can develop, is with the anion exchange resin. This is, generally, regarded as the best method for the determination of the soil available P [28, 29], because conceptually the resin method is sounder than the other methods, but it would be adapted, in routine analysis, with difficulty. On the contrary, the electro-ultrafiltration (EUF) method automates to a high degree the whole process of soil analysis and provides, in addition, information relative to the availability of many other nutrients in the same soil samples [15, 18, 30].

As far as crop response is concerned, the resin and Olsen methods are about equal (Table 4), although one might argue that the resin method is more sound chemically. The Olsen method, however, is more capable of simple automation.

On the basis of the present work results and taking the results of other studies [28, 29, 30] into account, the Olsen and EUF methods are recommended to be used, after their calibration with adequate experiments.

Π Ε Ρ Ι Λ Η Ψ Η

Μέθοδοι ανάλυσης του έδαφους για φωσφόρο και ή καταλληλότητά τους για την έκτίμηση του διαθεσίμου φωσφόρου τών έδαφών

Είκοσι μία μέθοδοι έκτίμησης του διαθεσίμου P τών έδαφών συγκρίθηκαν με τὰ δεδομένα απόδοσης σε ξηρά ούσια και πρόσληψης P με φυτά ryegrass, που πάρθηκαν από 21 αντιπροσωπευτικά έδαφη, σε πειράματα στο θερμοκήπιο. Σημαντικές συσχετίσεις βρέθηκαν να υπάρχουν μεταξύ τών ποσοτήτων του P που προσλήφθηκε από τὰ φυτά ryegrass και τών ποσοτήτων που προσδιορίστηκαν με τις διάφορες μεθόδους. Η πρόσληψη P από τὰ φυτά ryegrass έδωσε τις καλύτερες συσχετίσεις με τή ρητίνη -P ($r=0.912^{***}$), Olsen -P ($r=0.895^{***}$), 0,2 H₂SO₄ -P ($r=0,890^{***}$) και EUF -P ($r=0.841^{***}$), ενώ ή μικρότερη συσχέτιση παρατηρήθηκε με τὸ ὀργανικό κλάσμα του P ($r=0,533^*$). Οι τιμές -P τής ρητίνης, Olsen και EUF συσχετίζονταν στενά μεταξύ τους. Ἀπ' ὅλες τις μεθόδους που χρησιμοποιήθηκαν, ή μέθοδος Olsen βρέθηκε να έπηρεάζεται ελάχιστα από τις ιδιότητες του έδαφους (pH, μηχανική σύσταση, ὀλική έναλλακτική ικανότητα σε κατιόντα και βαθμὸ κορεσμοῦ με βάσεις).

L I T E R A T U R E

1. H. C. Aslyng, Phosphate potential and phosphate status of soils. Acta. Qgric. Scand. **14**: 261-285. 1964
2. S. A. Barber, A diffusion and mass flow concept of soil nutrient availability. Soil Sci. **93**: 39-49. 1962
3. F. T. Bingham, Soil test for phosphate. Cal. Agr. **3** (8), 11, 14. 1949
4. K. A. Bondorf, Studies on the phosphoric acid content of soil. VI. Solubility of soil phosphoric acid in dilute sulfuric acid. Tidsskr. Planteavl. **55**: 185-210. 1952
5. D. A. Boyd, The relationship between crop response and the determination of soil phosphorus by chemical methods. II Tech. Bull. Ministry Agric. Fish. **13**: 13-14. 1970
6. R. H. Bray, and L. T. Kurtz. Determination of total organic and available forms of phosphorus in soils. Soil Sci. **59**: 39-45. 1945
7. I. J. Cooke, and J. Hislop. Use of anion-exchange resin for the assessment of available soil phosphate. Soil Sci. **96**:308-312. 1963

8. I. J. Cooke, A kinetic approach to the description of soil phosphate status. *J. Soil Sci.* **17**:56-64. 1966
9. Dirks-Scheffer, *Zicher für Pflanzener und Bodenk.* B 12-498. 1933
10. H., Egner, H. Riehm und W. R. Domingo. Untersuchungen über die chemische Bodenanalyse als Grundlage für die Beurteilung des Nährstoffzustandes der Böden. II Chemische Extraktionsmethoden zur Phosphor-und Kaliumbestimmung. *K. Lantbr. Högsk. Ann.* **26**: 199-215. 1960
11. R. L. Fox and E. J. Lamprath, Phosphate sorption isotherms for evaluating the phosphate requirements of soils. *Soil Sci. Soc. Amer. Proc.* **34**: 902-907. 1970
12. D. Gunary and C. D. Sutton, Soil factors affecting plant uptake of phosphate. *J. Soil Sci.* **18**: 167-173. 1967
13. M. L. Jackson, *Soil Chemical Analysis*. Costable and Co LTd, London. 1958
14. G. Joret and Hébert, Contribution à la détermination du besoin des sols en acide phosphorique. *Ann. Agron.* **6**: 233-300. 1955
15. G. K. Judel, W. G. Gebauer und K. Mengel, Einfluss der Löslichkeit verschiedener psphatdüngemittel auf die phosphataufnahme und den Ertra von Sommerweizen. *Z. Pflanzenernaehr. Bodenk.* **145**: 296-303. 1982.
16. S. Larsen and M. N. Court, The chemical potentials of phosphate ions in soil solution. *Trans 7th Int. Congr. Soil Sci.* **2**: 413-421. 1960
17. M. F. Morgan, The universal soil testing system. *Conn. Agr. Exp. Stat. Bull.* **392**. 1937
18. K. Németh, The availability of nutrients in the soil as determined by electro-ultrafiltration (EUF). *Advances in Agronomy.* **31**: 155-188. 1979
19. K. Németh, Electro-ultrafiltration of aqueous soil suspension with simultaneously varying temperature and voltage. *Plant and soil.* **64**:7-23. 1982.
20. S. R. Olsen, C. V. Cole, F. S. Watanabe and L. A. Dean, Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *U.S. Dep. Agr. Circ.* 939. 1954
21. S. R. Olsen, F. E. Khasawneh, Use and limitations of physical chemical criteria for assessing the status of phosphorus in soils. In «The Role of Phosphorus in Agriculture». ASA, CSSA, SSA. Madison Wisc. USA p. 361-410. 1980
22. P. G. Ozanne and T. C. Shaw, Advantages of the recently developed phosphate sorption test over the older extractant methods of soil phosphates. *Inter. Soil. Cong. Trans. 9th (Adeleide)* **2**: 273-380. 1968
23. W. E. Sabbe and H. L. Breland. Procedures used by state soil testing laboratories in the southern region of the United States *South Coop. Ser. Bull.* 190.1974
24. R. K. Schofield, Can a precise meaning begiven to available soil phospharus. *Soil and Fertil.* **18**: 373-375. 1955
25. A. D. Simonis, Application of an ascorbic acid-stannous chloride composite reducing agent for developing stable milybdenum blue colour in the determination of phosphorus. Department of Soil Science, University of Aberdeen. 1970
26. A. D. Simonis, Effect of temperature and solvent/soil ratio on the extraction

- of phosphorus and potassium. Ph. D. Thesis University of Aberdeen. 1973
27. A. D. Simonis and S. C. Schinas, Chemical Fertility of soil. III. Modern aspects of plant phosphate availability in soils. *Geoponika, T, 20*, No **221**:273-294. 1974
28. A. D. Simonis, The determination of fundamental characteristics of soils as related to their phosphate supplying power to plants in some representative soils. *Proc. Athens Acad. Vol. 51*, 337-358. 1976
29. A. D. Simonis, Assessment of soil P and K by the exchange resin method. (In press).
30. A. D. Simonis, Determination of nutrient availability in the soil by electro-nitration (EUF). (In press).
31. E. Truog, The determination of the readily available phosphorus of soils. *J. Am. Soc. Agr. 22*: 879-882. 1930
32. E. G. Williams, Chemical soil tests as a Aid to increased productivity. *Trans. Joint Meeting Comm. IV. and V. Inter. Soc. Soil Science. New Zealand. 820-831. 1962.*