J. Agric. Sci. Technol. (2006) Vol. 8: 77-89

Contribution of Inorganic Phosphorus Fractions to Plant Nutrition in Alkaline-Calcareous Soils

A. Samadi[1]

ABSTRACT

To evaluate the relationships between soil inorganic phosphorus P (P_i) fractions, the soil P test and plant parameters such as plant P uptake, dry matter yield, tissue P concentration and relative yield, glasshouse experiments and chemical analyses were conducted on 13 calcareous soils from six agricultural and seven adjacent bushland (virgin soil) sites. Four rates of P (0, 15, 30, 60 mg/kg soil) were applied as reagent-grade KH_2PO_4 to the soils in a randomised complete block design with three replications. Perennial ryegrass (*Lolium perenne* cv. Roper) was grown and forage was harvested five times over a period of 210 days. Successive harvesting resulted in the depletion of plant available P as measured by $NaHCO_3$-extractable P, which coincided with the decrease in the plant dry matter yield and P uptake. After five harvests, the order of reduction in P_i fractions induced by cropping without added P was Ca_{10}-P>Al-P>Ca_2-P>Ca_8-P>occluded-P>Fe-P for the virgin soils and Ca_2-P>Al-P>Ca_{10}-P>Ca_8-P>Fe-P>occluded-P for the agricultural soils. The order of abundance of P_i fractions for P treated-soils was non-occluded Al and Fe phosphate (Al-P+Fe-P)>secondary Ca-bound P (Ca_2-P+Ca_8-P)>acid-extractable P (Ca_{10}-P)>occluded-P for both virgin and agricultural soils. Although a marked proportion of added P was transformed into less soluble Al and Fe phosphates, successive harvesting had depleted considerable percentages of these fractions. Highly significant (p<0.001) relationships were found for P uptake vs. Olsen-P, P uptake vs. P_i fractions (Ca_2-P, Ca_{10}-P, Al-P, Ca_8-P, Fe-P) and Olsen-P vs. P_i fractions. $NaHCO_3$-extractable P seems to be adequate for evaluating plant available P in calcareous soils. However, the closer relationship for the Fe-P fraction vs plant P uptake than for Olsen-P versus plant P uptake indicates that $NaHCO_3$ may not provide the best estimate of plant available P for calcareous soils. Using stepwise regression analysis, it was found that the Ca_2-P fraction was most predictive of P uptake (60%), total dry matter (68%), relative yield (74%) and Olsen-P (69%), followed by the Fe-P fraction.

Keywords: Availability, Calcareous soils, Inorganic P fractions, $NaHCO_3$-extractable P, Plant P uptake.

INTRODUCTION

A knowledge of the relationships between the different forms of P in a wide range of soils and of available P as measured by plant growth and soil chemical testing is useful for a better understanding of the capacity of P forms to sustain an adequate supply of P to plants. The correlation technique has been widely used to study the availability of inorganic P forms to plants. For calcareous soils, several researchers (Taylor and Wood, 1981; Awad and Ashoor, 1986) agree that the Olsen-$NaHCO_3$ (Olsen *et al.*, 1954) soil test method correlates best with the Ca-P fraction. In contrast, for the calcareous soils of Nebraska and Uttar Pradesh, it was found that Olsen-P was most closely related to Fe-Al-P fractions (Hooker *et al.*, 1980) and Al-P fraction (Tripathi *et al.*, 1970), respectively.

The relationships between plant P uptake and inorganic forms of P in calcareous soils

[1] Department of Soil Science, Urmia University, P. O. Box: 165, Urmia, 57134, Islamic Republic of Iran.
e-mail: asamadi@myway.com

[Downloaded from jast.modares.ac.ir on 2024-10-12]

[DOR: 20.1001.1.16807073.2006.8.1.2.0]

are not clearly defined. Plant P uptake is commonly related to Ca-P (Kamprath and Watson, 1980), resin extractable P (Yang *et al*., 1990), and citrate-bicarbonate P (CB-P) (Solis and Torrent, 1989). For acid soils, however, P uptake by plants is commonly related to Al-P and Fe-P (Tripathi *et al*., 1970 Patiram and Prasad, 1990). The greater availability of Al- and Fe-P than Ca-P was due to the higher specific surface activity of Al-P and Fe-P compared to other forms of inorganic P (Chang and Chu, 1961). Al-Abbas and Barber (1964) found that the Fe-P fraction accounted for most of the available P and they subsequently developed a chemical method for the selective dissolution of Fe-P as a technique to evaluate available P in soil. Once information is available on which forms of soil P are related to plant growth and P uptake for a given soil, it is possible to select soil tests which best reflect the amounts of these forms of P in the soil. The $NaHCO_3$ procedure of Olsen generally gives the best prediction of P uptake for calcareous soils (Ryan and Ayubi, 1981; Yang *et al*., 1990; Rahmatallah *et al*., 1994). However, there are exceptions to this generalization. For example, there was a poor relationship between plant response and $NaHCO_3$-extractable P for a wide range of calcareous Syrian soils (Matar, 1992). The author attributed this to the presence of significant amount of Fe oxides, which would have retained much P.

Previous studies on calcareous soils from Western Australia (Samadi and Gilkes, 1998) showed that Ca_2-P, Ca_8-P, Al-P and Fe-P fractions made significant contributions to available P as estimated by 0.5 M $NaHCO_3$ extractable P (Olsen *et al*., 1954). However, the question remains as to what relationships exist between the previously mentioned P_i fractions and P uptake by plants. This study was carried out to investigate relationships between plant growth parameters (P concentration, P uptake, dry matter yield, and relative yield), inorganic forms of soil P and soil P test. The aim was to identify which inorganic P fractions are major sources of plant available P as indicated by plant P-uptake.

MATERIALS AND METHODS

Soils

13 surface soil samples (0-10 cm), representative of six agricultural soils and seven of their virgin counterparts, were used for the laboratory and the greenhouse studies. The profile characteristics and physico-chemical properties of the soil samples are described elsewhere (Samadi and Gilkes, 1998).

Glasshouse Experiment

A successive cropping experiment ("exhaustion trial") was conducted on pots containing one kilogram of these soils. Four levels of P (0, 15, 30, 60 mg/kg) were applied as KH_2PO_4. Basal nutrients (K_2SO_4, 84 mg/kg; $MgSO_4.7H_2O$, 23 mg/kg; $MnSO_4.4H_2O$, 15 mg/kg; $ZnSO_4.7H_2O$, 9 mg/kg; $CuSO_4.5H_2O$, 4 mg/kg; H_3BO_3, 0.8 mg/kg; $CoSO_4.7H_2O$, 0.4 mg/kg; $NaMoO_4.2H_2O$, 0.7 mg/kg) were applied in solution. Ammonium nitrate (165 mg/kg) was applied in solution at fortnightly intervals. The nutrients were thoroughly mixed with the soil by shaking in a plastic bottle for one minute. One kg of each treated soil was placed on 200 g of washed sand in 15-cm plastic pots. The experiment was replicated three times in a randomized complete-block design. Thirty seeds of perennial ryegrass (*Lolium Perenne*, cv. Roper) were sown and thinned to 20 per pot after emergence. The control pots contained no plants but were otherwise managed identically. The plants were grown in a temperature controlled (20 $^oC \pm 2$) greenhouse. Soils were watered daily with distilled water and pots were weighed twice weekly to adjust moisture content to 80% field capacity. Plants were harvested consecutively (five cuts in total) about 1 cm above the soil level. The first harvest was seven weeks after emergence. The remain-

[Downloaded from jast.modares.ac.ir on 2024-10-12]

[DOR: 20.1001.1.16807073.2006.8.1.2.0]

ing four harvests were conducted at approximately six week intervals, with the total growth period being 210 days. After each harvest, soils were fertilized with the basal nutrients to ensure nutrient sufficiency. The plant material was dried immediately at 70 ^{o}C, weighed, ground, and stored until analysis. Plant samples were digested in 3:1 concentrated nitric and percholoric acid. Phosphorus concentration in the digest was determined by the molybdovanado phosphoric acid method. The absorbance was read on a spectrometer at 460 nm (Murphy and Riley, 1962).

Relative yields represent the ratio of total dry matter mass (sum of five harvests) for P-untreated soil over the maximum yield for P-treated soil expressed as a percentage. As the difference between P_{60} and P_{30} was negligible, the total dry matter yield at the P application rate of 30 mg P/kg was considered for the calculation of relative yield.

Severe soil P exhaustion due to repeated harvesting was indicated by visual P-deficiency symptoms (purpling, stunted growth and mortality), and by the inadequate levels of $NaHCO_3$-extractable P in the soils.

After each harvest, 50g of soil was collected, dried at 40° C, ground, and stored for chemical analysis. Soil samples from the cropped (P-treated and P-untreated) and non-cropped soils were extracted with 0.5 M $NaHCO_3$ at pH 8.5 and sequentially fractionated for P_i fractions by the method of Jiang and Gu (1989).

To understand better the importance of sparingly soluble P in the nutrition of plants, total plant uptake of P is represented as a percentage of the total change in P_i for the non-cropped and cropped unfertilized soils as follows:

$$P.U._{T\Delta Pi} = \text{Total P uptake} \times 100/T\Delta P_i \quad (1$$

$$T\Delta P_i = \Sigma\Delta P_i = \Sigma(C_{i0} - C_{i5}) \quad (2$$

where $PU_{T\Delta Pi}$ is the plant P uptake (mg/pot) as a percentage of the total change in P_i fractions ($T\Delta P_i$) (mg/kg), ΔP_i is the change in each P_i fraction, C_{i0} is the concentration of each fraction (mg/kg) in the P-untreated non-cropped soil, C_{i5} is the concentration of the same fraction in the P-untreated cropped soil after the fifth cutting (mg/kg).

The relative depletion of available P (Olsen-P) for the non-cropped and unfertilized cropped soils was calculated as follows:

$$R.D. = (C_{0av}-C_{5av}) \times 100/C_{0av} \quad (3$$

where R.D. is the relative depletion of available P, C_{0av} is the concentration of available P (mg/kg) in the P-untreated non-cropped soils, C_{5av} is the concentration of available P in the P-untreated cropped soil. All soils being sampled after the fifth cutting.

The percentage reduction in each P_i fraction in P treated soils as result of successive cropping was calculated as follows:

$$\Delta P_{iT} = (C_{p1}-C_{p5}) \times 100/C_{p1} \quad (4$$

where ΔP_{iT} is the percentage reduction in each P_i fraction for P treated soils, C_{p1} is the concentration of each fraction (mg/kg) in the P-treated cropped soil after the first cutting, and C_{p5} is the concentration of each fraction in the P-treated cropped soil after the fifth cutting. Note that this form of analysis dose not demonstrate that changes in P forms during the experiment were due to plant P uptake as changes in P forms may have occurred through chemical reactions that were not associated with root activity.

The Mitscherlich equation, $y = a - b \exp(-cx)$, the rescaled Mitscherlich equation, $y = a - b \exp(-(cx)^n)$, the generalized hyperbola equation, $y = a - \left(\frac{b}{1+1/m(cx)^m}\right)$, (Campbell and Keay, 1970), and the rescaled generalized hyperbola equation, $y = a - \left(\frac{b}{1+1/m((cx)^n)^m}\right)$, were fitted to the dry matter yield where y is the dry matter yield (mg/pot), x is P level (mg/kg) and a is maximum yield, b is yield response, c, n and m are coefficients.

Statistical Analysis

Analyses of variance in dry matter yield and P content was conducted using the GenStat program (Lane *et al*., 1987) employing

[Downloaded from jast.modares.ac.ir on 2024-10-12]

[DOR: 20.1001.1.16807073.2006.8.1.2.0]

a randomized complete block design. Correlation and regression analysis of data was carried out by the StatView program (Abacus Concepts, 1996).

RESULTS AND DISCUSSION

Plant Growth Parameters

The result of this study demonstrated that dry matter and P uptake by ryegrass responded to P application to the virgin and agricultural soils over five successive growth periods. Cumulative dry matter yield data (five harvests) for cropped unfertilized soils ranged from 18 to as low as 1.4 g/pot and the cumulative plant P uptake ranged from 19 to as low as 1.8 mg/pot. Among response equations, the rescaled Mitscherlich equation fitted well to the dry matter yield. All response curves showed that added P produced substantial responses in dry matter. The response of plants to P application was consistently higher for the virgin soils than for the agricultural soils for all five harvests.

Soil P Forms

The values of inorganic P fractions and available P (Olsen-P) as well as the relative depletion (RD) of available P as induced by successive cropping for P-untreated (non-cropped control) and (cropped) soils after the fifth cutting are presented in Table1. In most cases, the depletion of available P was higher for agricultural soils than for virgin soils. This was expected since the agricultural soils supplied much more P for plant growth than that inferred from plant analysis. Thus, successive cropping resulted in the decrease in plant available P (Figure 1), which coincided with the decrease in plant dry matter yield and P uptake for all soils including the P-treated and P-untreated soils (Figure 2). The relatively low dry matter and P uptake for the first cut are due to the establishment of the plants during this initial phase. Soil P exhaustion by successive harvests was indicated by visual P deficiency symptoms and by inadequate levels of available P (Olsen-P <10 mg P/kg soil (Bowman and Watanable., 1978; Kamprath and Watson, 1980; Fixten and Ludwick, 1982) in particular, for the virgin soils.

The change in different soil P_i fractions (ΔP_i) as a result of chemical reactions or crop removal during the pot experiment and plant P uptake as a percentage of the total change (decreased) in P_i fractons ($P.U._{T\Delta Pi}$) for the non-cropped and cropped soils without added P are presented in Table 2. The changes in P_i fractions varied widely among the soils. Generally, the order of change in P_i

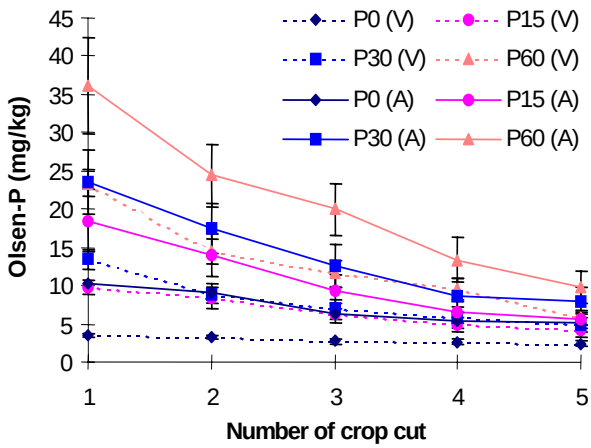

Figure 1. Effect of successive crops of ryegrass on plant available P (average values for all soils) at different levels of P for the virgin (V) and agricultural (A) soils.

[Downloaded from jast.modares.ac.ir on 2024-10-12]

[DOR: 20.1001.1.16807073.2006.8.1.2.0]

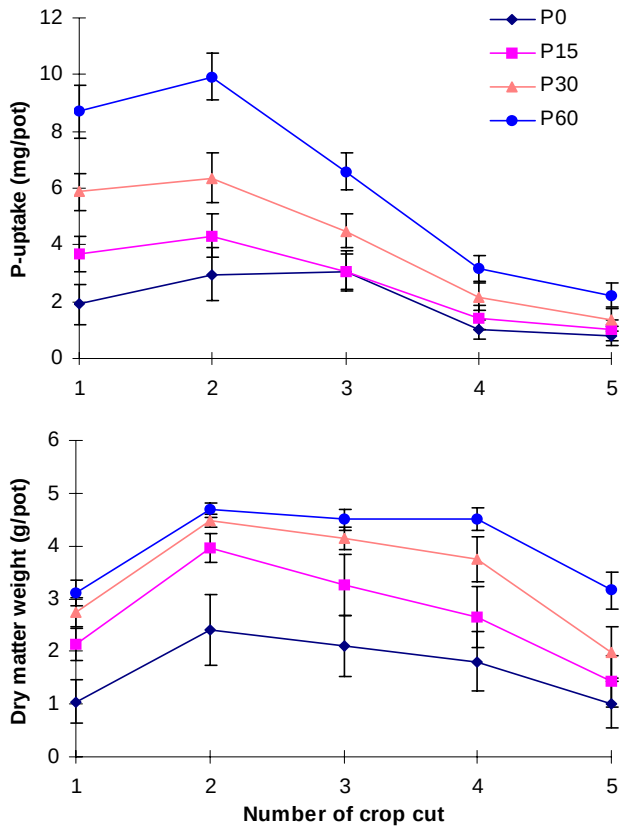

Figure 2. Total P uptake (average values for all soils) and dry matter weight (average values for all soils) of ryegrass at different P levels for successive crop cuts.

fractions was Ca_{10}-P>Al-P>Ca_2-P>Ca_8-P>occluded-P>Fe-P for the virgin soils and Ca_2- P>Al-P>Ca_{10}-P>Ca_8-P>Fe-P>occluded -P for the agricultural soils. As expected, the Ca_2-P fraction which is P extracted by 0.25 M $NaHCO_3$ at pH 7 was the form of P which was most easily transformed into less soluble P forms and/or removed by ryegrass from the P-untreated agricultural soils. In virgin soils, however, Ca_{10}-P was the dominant fraction which had been converted into other fractions and/or removed by ryegrass. The ability of plants to utilize acid-soluble P (Ca_{10}-P) fractions has been attributed to acidification of the rhizosphere (Grinsted *et al.*, 1982). The utilization of sparingly soluble P pools such as $NaHCO_3$-, NaOH- and HCl-soluble pools has been reported for pasture grasses (Armstrong and Helyar, 1992). It has been suggested that the ability of plants to absorb less soluble P compounds from soil is dependent upon both the quantity of these compounds in the soil and the ability of the plant to reduce the P concentration in the soil solution to values below those corresponding to the solubility product of these compounds (Bieleski, 1976). Measurements of the sorption isotherm of these calcareous soils (Samadi, 1999) showed that they are relatively low to medium buffered. Thus the depletion of the labile fractions by plant roots would permit the maintenance of low soil solution P concentrations during plant growth and thus enhance desorption/dissolution of Ca_{10}-P.

The reduction of total soil P fractions ($T\Delta P_i$) due to chemical reactions and/or plant uptake after the fifth cutting varied

[Downloaded from jast.modares.ac.ir on 2024-10-12]

[DOR: 20.1001.1.16807073.2006.8.1.2.0]

Table 1. The concentrations of inorganic P fractions and available P (mg/kg) for cropped and non-cropped virgin (V) and agricultural (A) soils without added P after the fifth cutting of ryegrass, P uptake, mean relative yield and relative depletion of available P (RD).

Soil	Mean relative yield (%)	P uptake (mg/pot)	Ca_2-P		Ca_8-P		Al-P	
			Non-cropped	Cropped	Non-cropped	Cropped	Non-cropped	Cropped
2 kell 9 *(V)*	19	1.9	4.8	4.5	12.0	8.1	26.5	17.8
3 Kell 9 *(A)*	83	16.1	34.0	10.2	67.5	52.7	77.0	71.4
10 Bea *(V)*	37	2.5	3.5	2.5	5.0	3.2	5.0	4.7
11 Bea1 *(A)*	27	19.1	25.0	7.4	60.0	43.0	68.0	45.7
12 Bea1 *(V)*	92	3.5	4.8	3.2	2.5	2.3	12.0	6.4
13 Bea1 *(A)*	29	8.1	20.5	5.2	10.5	9.6	34.5	15.5
15 Kon 5 *(V)*	63	1.9	3.7	3.0	5.0	4.2	7.0	6.9
16 Kon 5 *(A.)*	15	17.3	18.0	4.9	11.0	4.2	20.0	9.5
17 Kon 1 *(V)*	83	4.3	11.0	4.9	3.0	2.5	13.5	10.0
18 Kon 1 *(A)*	33	19.4	17.5	8.2	7.5	6.0	40.5	26.7
26 SG 2 *(V)*	85	1.5	5.0	3.5	5.0	3.5	7.0	6.4
27 SG 2 *(A)*	11	8.8	8.5	7.0	16.0	8.5	20.0	14.3
Mean *(V)*	62	2.6	5.5	3.6	5.4	4.0	11.8	8.7
Mean *(A)*	56	14.8	20.6	7.1	28.8	20.7	43.3	30.5

Soil	Fe-P		O-P		Ca_{10}-P		Olsen-P		RD (%)
	Non-cropped	Cropped	Non-cropped	Cropped	Non-cropped	Cropped	Non-cropped	Cropped	
2 kell 9 *(A)*	19.0	17.4	16	14	7.6	5.2	3.2	1.5	53
3 Kell 9 *(A)*	32.0	27.0	30	30	37.5	20.1	15.6	8.1	48
10 Bea *(V)*	11.5	8.3	25	22	11.0	4.5	4.2	2.1	47
11 Bea1 *(A)*	35.0	23.9	30	29	40.5	15.8	17.6	7.5	57
12 Bea1 *(V)*	8.0	9.3	37	23	7.5	4.4	4.1	2.0	50
13 Bea1 *(A)*	17.5	12.8	26	27	16.5	9.5	5.6	3.6	36
15 Kon 5 *(V)*	6.0	5.5	33	37	14.0	6.0	4.5	3.1	31
16 Kon 5 *(A.)*	30.0	17.6	49	51	29.0	19.6	8.2	3.1	61
17 Kon 1 *(V)*	13.0	11.9	20	24	9.0	7.4	4.1	3.2	20
18 Kon 1 *(A)*	25.5	22.1	30	38	16.5	15.0	8.3	5.2	35
26 SG 2 *(V)*	3.0	2.6	10	13	7.0	2.4	3.2	2.7	10
27 SG 2 *(A)*	7.0	6.5	9	11	12.5	5.9	6.8	3.5	48
Mean *(V)*	10.1	9.2	23.5	22.2	9.4	5.0	3.8	2.4	35
Mean *(A)*	24.5	18.3	29.0	31.1	25.4	14.3	10.3	5.2	48

between 5 and 94 mg/kg soil with an average of 13 mg/kg soil for virgin soils and 50 mg/kg soil for agricultural soils (Table 2). It is noteworthy that this decrease was much larger than the total amount of P removed by cutting, indicating that chemical reactions in the soil had also decreased these forms of P that contribute to $T\Delta P_i$. The percentage of the total change in P_i fractions ($P.U._{T\Delta Pi}$) recovered as total P uptake ranged from 10 to 90%, with an average of 20% and 30% for virgin and agricultural soils, respectively (Table 2). These results suggest that most changes in P_i fractions were due to chemical reactions rather than to plant uptake. The discrepancy between the net decrease in measured P_i fractions ($T\Delta P_i$) and plant P uptake indicates that P was converted to

[Downloaded from jast.modares.ac.ir on 2024-10-12]

[DOR: 20.1001.1.16807073.2006.8.1.2.0]

Table 2. Reductions in the concentrations of soil inorganic fractions (ΔP_i) between non-cropped and cropped unfertilized soils after the fifth cutting of ryegrass, $P.U._{T\Delta Pi}$ which is total plant P uptake as a percentage $T\Delta P_i$.

Soil	Reduction (Δ) in P_i fractions (mg/kg)						$T\Delta P_i$ (mg/kg)	$P.U._{T\Delta Pi}$ (%)
	ΔCa_2-P	ΔCa_8-P	ΔAl-P	ΔFe-P	ΔO-P	ΔCa_{10}-P		
2 kell 9 *(V)*	0.3	3.9	8.7	1.6	2.0	2.4	19	10
3 Kell 9 *(A)*	23.8	14.8	5.6	5.0	-0.1[a]	17.4	67	24
10 Bea *(V)*	1.0	1.8	0.3	3.2	3.0	6.5	16	16
11 Bea1 *(A)*	17.6	17.0	22.3	11.1	1.0	24.7	94	20
12 Bea1 *(V)*	1.6	0.2	5.6	-1.3	14.4	3.1	24	15
13 Bea1 *(A)*	15.3	0.9	19.0	4.7	-1.0	7.0	46	18
15 Kon 5 *(V)*	0.7	0.8	0.1	0.5	-4.1	8.0	6	31
16 Kon 5 *(A.)*	13.1	6.8	10.5	12.4	-2.0	9.4	50	34
17 Kon 1 *(V)*	6.1	0.5	3.5	1.1	-4.0	1.6	9	48
18 Kon 1 *(A)*	9.3	1.5	13.8	3.4	-8.0	1.5	21	90
26 SG 2 *(V)*	1.5	1.5	0.6	0.4	-3.3	4.6	5	28
27 SG 2 *(A)*	1.5	7.5	5.7	0.5	-2.3	6.6	20	45
Mean *(V)*	1.9	1.4	3.1	0.9	1.3	4.4	13	20
Mean *(A)*	13.4	8.1	12.8	6.2	-2.1	11.1	50	30

(V) = virgin soil, *(A)* = agricultural soil,
[a] a negative sign indicates an increased amount.

forms not identified by the analytical procedure used in this research. Indeed the discrepancy may be larger than the 80 or 70% of $T\Delta P_i$ indicated as some P uptake may have originated in organic P forms that were not measured in this study.

Addition of P to the soils increased the contents of all P_i fractions in most instances for the virgin and agricultural soils (Table 3). Much of the added P was recovered as P_i forms from the soils after the first harvest but recovery decreased substantially for the fifth harvest (Table 3). When all P_i fractions are summed (sum-P_i), the agricultural soils had higher values of sum-P_i than the virgin soils. After the first cutting, non-occluded Al and Fe phosphates were the dominant fractions followed by secondary Ca-bound P (Ca_2-P and Ca_8-P). This indicates that much applied P was converted within a short time to Al-P and Fe-P. The increase in Al-P due to the addition of P was greater than the increase in Fe-P at all P rates. As the rate of P application increased the proportion of Al-P continued to rise. The greater increase in Al-P than Fe-P and the greater proportional increase in Al-P with increasing P addition presumably may be ascribed to the greater reactivity of P with aluminium than iron compounds. Thus, significant proportions of applied P were transformed into less soluble Al and Fe phosphates and considerable percentages of these forms were removed by successive cropping, in particular for Fe-P in the agricultural soils (Table 3).

Relationships between Plant Parameters, Inorganic P Fractions and Method of Assessing of Soil P Status

Simple correlation data identifying relationships between parameters and soil P test values with P_i forms are presented for non-cropped and cropped unfertilized soils in Table 4. Total dry matter yield, P uptake and relative yield were significantly related to all P_i fractions with the exception of occluded-P in non-cropped and cropped soils. There were no significant relationships between tissue P concentration and any P_i fraction, showing that this growth parameter

[Downloaded from jast.modares.ac.ir on 2024-10-12]

[DOR: 20.1001.1.16807073.2006.8.1.2.0]

Table 3. The mean values of the concentrations of inorganic P fractions (P_i) and their percentage reductions (ΔP_i%) between the first and fifth cuttings of ryegrass for all virgin and agricultural soils as influenced by P application.

Soil	P level	Ca_2-P			Ca_8-P			Al-P		
		1st cut	5th cut	$\Delta(Ca_2\text{-}P)$	1st cut	5th cut	$\Delta(Ca_8\text{-}P)$	1st cut	5th cut	Δ(Al-P)
		(mg/kg)		(%)	(mg/kg)		(%)	(mg/kg)		(%)
Virgin	P_0	3.9	3.6	9	4.1	4.0	2	8.6	8.7	-2
	P_{15}	8.6	6.2	28	6.1	6.3	-4	12.2	10.7	13
	P_{30}	12.0	6.4	47	6.9	6.3	9	14.5	11.6	20
	P_{60}	20.4	8.6	58	10.0	7.5	25	21.2	14.9	30
Agricultural	P_0	11.6	7.1	38	21.1	20.7	2	33.8	30.5	10
	P_{15}	14.5	7.3	50	22.1	24.7	-12	35.5	32.1	10
	P_{30}	18.9	8.5	55	24.7	25.6	-4	37.8	35.4	6
	P_{60}	30.2	12.3	59	31.2	33.1	-6	44.3	37.3	16

Soil	P level	Fe-P			O-P			Ca_{10}-P			Sum-P_i		
		1st cut	5th cut	Δ(Fe-P)	1st cut	5th cut	Δ(O-P)	1st cut	5th cut	$\Delta(Ca_{10}\text{-}P)$	1st cut	5th cut	$\Delta(\text{Sum-}P_I)$
		(mg/kg)		(%)	(mg/kg)		(%)	(mg/kg)		(%)	(mg/kg)		(%)
Virgin	P_0	8.6	9.2	-7	22.8	22.2	3	6.7	5.0	26.2	55	52	-3
	P_{15}	12.1	10.6	12	19.3	21.7	-12	8.9	6.4	28	67(12) [a]	62(10)	-5
	P_{30}	11.7	11.8	-1	20.5	25.8	-26	7.7	6.6	14	73(18)	68(16)	-5
	P_{60}	15.0	12.8	14	19.2	22.6	-18	8.0	5.4	32	94(39	72(20)	-22
Agricultural	P_0	22.0	18.3	17	29.3	31.1	-6	19.1	14.3	25	137	122	-15
	P_{15}	27.0	21.9	19	28.0	31.2	-11	17.5	21.8	-25	145(8)	139(17)	-6
	P_{30}	27.7	23.8	14	26.3	32.2	-22	18.5	17.1	7	154(17)	142(20)	-12
	P_{60}	34.0	24.4	28	30.5	34.6	-13	20.0	17.0	15	190(53)	159(37)	-31

[a] Values in parenthesis are the increases in sum-P_i due to fertilization for first cut and indicate that much of the added P (ie 15, 30, 60 mg/kg) was recovered in the inorganic fractions

[Downloaded from jast.modares.ac.ir on 2024-10-12]

[DOR: 20.1001.1.16807073.2006.8.1.2.0]

Table 4. Correlation coefficients (r) between plant parameters (total dry matter yield, P uptake, relative yield, and tissue P concentration) and inorganic P fractions and plant available P (Olsen- P) for non-cropped and cropped unfertilized soils.
r = 0.84 for $P<.0001$, 0.78 for $P<0.001$, and 0.55 for $P<0.05$

	Non-cropped soils						
	Ca_2-P	Ca_8-P	Al-P	Fe-P	Occluded-P	Ca_{10}-P	Olsen-P
Total dry matter	0.839	0.604	0.747	0.917	0.171	0.831	0.795
Total P uptake	0.804	0.628	0.736	0.901	0.109	0.830	0.810
Relative yield	0.873	0.648	0.792	0.925	0.162	0.849	0.820
Tissue P conc.	0.173	0.068	0.176	0.190	-0.258	0.098	0.365
Olsen-P	0.862	0.937	0.887	0.851	0.062	0.934	

	Cropped soils (Fifth cut)						
	Ca_2-P	Ca_8-P	Al-P	Fe-P	Occluded-P	Ca_{10}-P	Olsen-P
Total dry matter	0.717	0.535	0.603	0.811	0.665	0.931	0.734
Total P uptake	0.745	0.544	0.613	0.798	0.630	0.927	0.744
Relative yield	0.738	0.586	0.692	0.824	0.615	0.920	0.764
Tissue P conc.	0.413	-0.029	0.129	0.182	0.230	0.313	0.310
Olsen-P	0.790	0.910	0.879	0.797	0.351	0.806	

could not be used to evaluate soil P status in the present study. The relationships between the soil P test and P_i fractions followed the same trend as for the plant parameters. A comparison of correlation coefficients for relationships of P uptake with P_i fractions and Olsen-P suggests that Olsen-P is an adequate test for evaluating plant available P in calcareous soils. However, the closer relationship of the Fe-P fraction with P uptake, dry matter yield, and relative yield than for the Olsen-P may indicate that $NaHCO_3$-extractable P does not provide the best possible estimate of plant available P for the calcareous soils of Western Australia. Earlier work showed that this soil test predicted only 47% of the variation in standard P requirement (P adsorbed at 0.2 mg/L) of the soils, and by inclusion of the ratio of CDB-extractable Fe(Fe_d) to active calcium carbonate (ACCE) in the regression equation, the coefficient of determination (R^2) increased to 82% (Samadi, 1999).

Relative Contributions of P_i Forms to Plant p Uptake and Soil P Test Values

In order to indicate the contribution of the various P forms to plant P uptake and available P estimated by Olsen P, the changes in P_i fractions during plant growth as influenced by the crop and chemical reactions (i.e. those listed in Table 2) were introduced as independent variables into a stepwise regression analysis to predict plant data (Table 5). The R^2 values reported in Table 5 indicate that changes in the Ca_2-P fraction was the major predictor of variation in the total plant P uptake (60% of variation explained), total dry matter yield (68%), relative yield (74%) and Olsen-P (69%). These results support the interpretation that the Ca_2-P fraction is the most important plant available P_i fraction (Samadi and Gilkes, 1998). The ΔP_i fraction that greatly increased the R^2 values of the multivariate relationships for P uptake, total dry matter and relative yield was the ΔFe-P fraction (being P extracted by 0.1 *M* NaOH-Na_2CO_3 solution). These results suggest that iron phosphate can be a signifi-

[Downloaded from jast.modares.ac.ir on 2024-10-12]

[DOR: 20.1001.1.16807073.2006.8.1.2.0]

Table 5. Stepwise multiple regression equations relating total dry matter yield for fifth cutting, P uptake, relative yield and Olsen-P to the changes in P_i forms after the fifth cutting for virgin and agricultural soils without added P.

Total P uptake	R^2
$y = 9.3 + 2.3\ \Delta Ca_2\text{-}P$	0.595^{**}
$y = 8.0 + 1.4\ \Delta Ca_2\text{-}P + 2.4\ \Delta Fe\text{-}P$	0.701^{**}
$y = 7.9 + 1.2\ \Delta Ca_2\text{-}P + 2.2\ \Delta Fe\text{-}P + 0.51\ \Delta Ca_8\text{-}P$	0.709^{**}
Total dry matter	
$y = 10.0 + 1.9\ \Delta Ca_2\text{-}P$	0.679^{**}
$y = 9.0 + 1.2\ \Delta Ca_2\text{-}P + 1.8\ \Delta Fe\text{-}P$	0.770^{***}
$y = 10.4 + 1.4\ \Delta Ca_2\text{-}P + 2.2\ \Delta Fe\text{-}P + 0.57\ \Delta Ca_8\text{-}P$	0.797^{**}
Relative yield	
$y = 20.4 + 3.3\ \Delta Ca_2\text{-}P$	0.738^{***}
$y = 19.0 + 2.3\ \Delta Ca_2\text{-}P + 2.8\ \Delta Fe\text{-}P$	0.783^{***}
$y = 15.2 + 1.9\ \Delta Ca_2\text{-}P + 2.1\ \Delta Fe\text{-}P + 1.1\ \Delta Ca_8\text{-}P$	0.797^{***}
Olsen-P	
$y = 2.6 + 0.52\ \Delta Ca_2\text{-}P$	0.702^{***}
$y = 2.3 + 0.25\ \Delta Ca_2\text{-}P + 0.55\ \Delta Ca_8\text{-}P$	0.927^{***}
$y = 2.2 + 0.23\ \Delta Ca_2\text{-}P + 0.55\ \Delta Ca_8\text{-}P + 0.051\ \Delta Al\text{-}P$	0.947^{***}

Significant at $p < 0.01$, and $p < 0.001$

cant source of P for plants in calcareous soils (Samadi and Gilkes, 1999). The second P_i fraction that significantly increased the R^2 values for Olsen-P alone was the ΔCa_8-P fraction.

CONCLUSION

Results from pot and laboratory experiments indicated that the Ca_2-P fraction is the form of P most easily removed by plants and that it is highly related ($r = 0.91$, $p<0.0001$) to soil P test (Olsen P). In addition to this fraction, Al-P, Fe-P, Ca_{10}-P were to some extent depleted by ryegrass. The significant positive relationships between the Ca_2-P, Al-P, Fe-P and Ca_{10}-P fractions and plant P uptake may indicate the partial availability of P in these fractions to plants. The second most important P_i fraction contributing to plant P uptake was the Fe-P fraction (P-extracted by 0.1 *M* NaOH-Na_2CO_3 solution). It is unwise to use statistical inference as a basis for identifying mechanisms occurring in the complex soil system and it is commonly observed that soil P tests are merely indicative of plant available P. The fitted equations do not specifically determine forms of plant available P but can be useful in developing optimum soil test procedures.

The utilization of sparingly soluble phosphate by plants might be explained by root exudation of organic acids including acetic, lactic and oxalic acids (Grierson, 1992). Hoffland (1992) concluded that organic acid exudation was highly effective in increasing P uptake from rock phosphate. The exudation of citrate by white lupin could increase P availability by mobilizing P from sparingly soluble Fe and Al phosphates (Gardner *et al.*, 1982). Thus, knowledge of the mechanism of P uptake by roots of different species will assist the interpretation of soil chemical tests and aid in developing more predictive tests for a wide range of soil characteristics.

ACKNOWLEDGMENT

The author gratefully acknowledges the fi-

[Downloaded from jast.modares.ac.ir on 2024-10-12]

[DOR: 20.1001.1.16807073.2006.8.1.2.0]

nancial support of Urmia University, Iran, during the study.

REFERENCES

1. Abacus C`oncepts 1996. StatView reference (Abacus Concepts, Inc. Berkerly, CA).
2. Al-Abbas, A. H., and Barber, S. A. 1964. A Soil Test for Phosphorus Based upon Fractionation of Soil Phosphorus: II. Development of the soil test. *Soil Sci. Soc. Amer. Proc*., **28**: 221-224.
3. Armstrong, R. D., and Helyar, K. R. 1992. Changes in Soil Phosphate Fractions in the Rhizosphere of Semi-arid Pasture Grasses. *Aust. J. Soil Res*., **30**: 131-143.
4. Awad, K. M., and Ashoor, N. I. 1986. Phosphorus in Calcareous Soils: 1-Inorganic Phosphorus Fractions and their Relation to some Chemical Indices of Phosphorus Availability. *Iraqi J. Agric. Sci. Zanso*., **4**: 47-64.
5. Bowman, R. A., and Watanable, F. S. 1978. Greenhouse Evaluation of Residual Phosphate by Four Phosphorus Methods in Neutral and Calcareous Soils. *Soil Sci. Soc. Am. J.*, **42**: 451-454.
6. Campbell, N. A., and Keay, J. 1970. Flexible Techniques in Describing Mathematically a Range of Response Curves of Pasture Species. In: "*Proc. XI Internat Grassland Cong*", Surfers Paradise, Australia.
7. Chang, S. C., and Chu, W. K. 1961. The Fate of Soluble Phosphate Applied to Soils. *J. Soil Sci.*, **12**: 286-294.
8. Colwell, J. D. 1963. The Estimation of the Phosphorus Fertilizer Requirements of Wheat in Southern New South Wales by Soil Analysis. *Aust. J. Exp. Agric. Anim. Husb*., **3**: 100- 7.
9. Fixen, P. E., and Ludwick, A. E. 1982. Residual Available Phosphorus in Near Neutral and Alkaline Soils. II. Persistence and Quantitative Estimation. *Soil Sci. Soc. Am. J.*, **46**: 335-338.
10. Grierson, P. F. 1992. Organic Acids in the Rhizosphere of *Banksia integrifolia* L. F. *Plant Soil*, **44**: 259-265.
11. Hoffland, E. 1992. Quantitative Evaluation of the Role of Organic Exudation in the Mobilization of Rock Phosphate by Rape. *Plant Soil*, **140**: 279-289.
12. Hooker, M. L., Peterson, G. A., Sander, D. H., and Bagger, L. A. 1980. Phosphate Fractions in Calcareous Soils as Altered by Time and Amount of Added Phosphate. *Soil Sci. Soc. Am. J.*, **44**: 269-277.
13. Jiang, B., and Gu, Y. 1989. A Suggested Fractionation Scheme of Inorganic Phosphorus in Calcareous Soils. *Fertilizer Res*., **20**: 159-165.
14. Kamprath, E. J., and Watson, M. E. 1980. Conventional Soil and Tissue Tests for assessing the Phosphorus Status of Soils. In: "*The Role of Phosphorus in Agriculture*". (Ed.): Khasawneh F. E., American Society of Agronomy, Madison, WI, PP. 433-469
15. Lane, P., Galwey, N., and Alvey, N. 1987. "*Genstat 5: An introduction*" Oxford University Press, Oxford, New York.
16. Matar, A., Torrent, J., and Ryan, J. 1992. Soil and Fertilizer Phosphorus and Crop Responses in the Dry Land Mediterranean zone. *Adv. Soil Sci*., **18**: 79-146.
17. Murphy, J. and Riley, J. P. 1962. A Modified Single Solution Method for the Determination of Phosphate in Natural Waters. *Anal. Chim. Acta*, **27**: 31-143.
18. Olsen, S. R., Cole, C. V., Watanabe, F. S., and Dean, L. A. 1954. Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. Circ. 939, USDA, U. S. Government Printing Office, Washington, DC.
19. Patiram, R. N. R., and Prasad, R. N. 1990. Forms of Soil Phosphorus and Suitable Extractants for Available Phosphorus in Acid Soils of Sikkim. *J. Indian Soc. Soil Sci.*, **38**: 237-247.
20. Rahmatullah, Gill, M. A., Shaikh, B. Z., and Salim, M. 1994. Bioavailability and Distribution of Phosphorus among Inorganic Fractions in Calcareous Soils. *Arid Soil Res. and Rehab*, **8**: 227-234.
21. Ryan, J., and Ayubi, A. G. 1981. Phosphorus Availability Indices in Calcareous Lebanese Soils. *Plant Soil*, **62**: 141-145.
22. Samadi, A., and Gilkes, R. J. 1998. Forms of Phosphorus in Virgin and Fertilized Calcareous of Western Australia. *Aust. J. Soil Res.*, **36**: 585-601.
23. Samadi, A. 1999. Forms of Soil Phosphorus in Calcareous Soils of South-Western Australia. Ph.D. Thesis. The University of Western Australia. Perth, Australia.
24. Samadi, A., and Gilkes, R. J. 1999. Phosphorus Transformations and their Relationships with Calcareous Soil Properties of South

[Downloaded from jast.modares.ac.ir on 2024-10-12]

[DOR: 20.1001.1.16807073.2006.8.1.2.0]

Western Australia. *Soil Sci. Soc. Am. J.*, **63**: 809-815.
25. Solis, P., and Torrent, T. 1989. Phosphate Fraction by Calcareous Vertisols and Inceptisols of Spain. *Soil Sci. Soc. Am. J.*, **53**: 456-459.
26. Taylor, R. M., and Ellis, B. G. 1978. A Mechanism of Phosphate Adsorption by Soil and Anion Exchange Resin Surfaces. *Soil Sci. Soc. Am. J.*, **42**: 432-436.
27. Tripathi, B. R., Tandon, H. L. S., and Tyner, E. H. 1970. Native Inorganic Phosphorus forms and their Relation to some Chemical Indicies of Phosphate Availability for Soils of Agra District. *India Soil Sci.*, **109**: 93-101.
28. Yang, J. E., and Jaccobsen, J. S. 1990. Soil Inorganic Phosphorus Fractions and their Uptake Relationships in Calcareous Soils. *Soil Sci. Soc. Am. J.*, **54**: 1666-1669.

سهم شکل های فسفر معدنی در تغذیه گیاه در خاکهای آهکی- قلیایی

ع. صمدی

چکیده

به منظور ارزیابی روابط بین اجزا فسفر معدنی (P_i) با آزمونهای فسفر خاک و پارامترهای گیاه از قبیل جذب فسفر توسط گیاه، مقدار ماده خشک و عملکرد نسبی گیاه، آزمایشهای گلخانه‌ای و تجزیه های شیمیایی خاک و گیاه در 13 خاک آهکی (شش نمونه از خاکهای زراعی و هفت نمونه از خاکهای بکر مجاور) به اجرا درآمد. چهار سطح فسفر: صفر، 15، 30 و 60 میلی گرم در کیلوگرم از منبع KH_2PO_4 در قالب طرح بلوکهای کاملاً تصادفی با سه تکرار به خاکها اضافه و تلخه چند ساله (*Lolium Perenne cv.*, Roper ryegrass) درآنها کاشته شد. قسمت هوایی گیاه پنج بار بطور متوالی طی یک دوره 210 روزه برداشت شد. برداشت متوالی گیاه به تخلیه فسفر قابل استفاده گیاه (قابل عصاره‌گیری با $NaHCO_3$) منجرگردید که با کاهش عملکرد ماده خشک وجذب فسفرتوسط گیاه همراه بود. بعد ازپنج برداشت، تقلیل اشکال P_i درخاکهای بکربدون مصرف P به‌ترتیب: Ca_{10}-P>Al-P>Ca_2-P>Ca_8-P>occluded-P>Fe-P ودرخاکهای زراعی به‌ترتیب Ca_2-P>Al-P>Ca_{10}-P>Ca_8-P>Fe-P>occluded-P که با مصرف P ، فراوانی این اجزا به ترتیب زیر بودند:

[(Al-P)+(Fe-P)]>[(Ca_2-P)+(Ca_8-P)]>Ca_{10}-P>occluded-P (فسفاتهای محبوس شده دراکسیدهای Fe و Al)

هر چند بخش قابل ملاحظه‌ای از فسفر مصرف شده به اشکال کم محلول فسفات‌های آهن و آلومینیوم تغییر شکل یافت، با برداشت متوالی گیاه درصد قابل توجهی از این شکلها از خاک تخلیه گردید. روابط معنی دار بالایی ($P < 0/001$) بین جذب فسفر با اولسن-P ، جذب فسفر با اجزا P_i (Ca_2-P, Ca_8-P, Al-P, Ca_{10}-P) و اولسن-P وجود داشت. همچنین بین اجزا P_i با اولسن-P رابطه معنی‌دار برقرار بود. به نظر می رسید روش عصاره گیری با $NaHCO_3$ برای ارزیابی فسفر قابل استفاده گیاه در خاکهای آهکی مناسب

[Downloaded from jast.modares.ac.ir on 2024-10-12]

[DOR: 20.1001.1.16807073.2006.8.1.2.0]

است، لیکن روابط نزدیکتر بین Fe-P با جذب P گیاه در مقایسه به اولسن-P با جذب P گیاه نشان داد که $NaHCO_3$ امکان دارد نتواند فسفر قابل استفاده گیاه را در خاکهای آهکی بخوبی پیش‌بینی نماید. با استفاده از تجزیه رگرسیونی چند مرحله ای مشخص گردید که Ca_2-P بعد از آن Fe-P می تواند در پیش بینی جذب فسفر گیاه (60٪)، ماده خشک (68٪) ، عملکرد نسبی (74٪)، اولسن-P (69٪) مورد استفاده قرار گیرد.

[Downloaded from jast.modares.ac.ir on 2024-10-12]

[DOR: 20.1001.1.16807073.2006.8.1.2.0]