

## Potassium Supplying Power of Selected Alkaline-Calcareous Soils in the North-west of Iran

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### ABSTRACT

Solution potassium (So-K) and exchangeable K (Ex-K) extracted by  $\text{NH}_4\text{OAc}$  are the major sources of potassium used by plants, but initially non-exchangeable K (NEx-K) can also contribute significantly to plant uptake. Perennial ryegrass (*Lolium Perenne*, cv. Roper) was successively planted in ten surface soil samples with different clay mineralogical composition belonging to five soil types to determine the contribution of Ex-K and NEx-K to K availability in the greenhouse during 260 d (five cuttings). Before planting, soil samples were leached to remove So-K and Ex-K so that the plants would use more K from the NEx-K pool. The leaching was performed using 0.1 M chloride solution containing Ca and Mg in the molar ratio of 4:1. The soil types having initially high NEx-K contents showed a high K uptake. A highly significant positive correlation was observed between total K uptake and illite content for the unleached soils ( $r = 0.81, P < 0.01$ ) and the Ca/Mg leached soils ( $r = 0.75, P < 0.01$ ). Significant declines in the plant K concentration values were observed between the first and the last cutting: from 4.1 to 2.3  $\text{g kg}^{-1}$  (a drop of 45%) for the unleached soils and from 3.4 to 2.1  $\text{g kg}^{-1}$  (a drop of 39%) for the leached soils. By the five cuttings of ryegrass, the concentrations of  $\text{NH}_4\text{OAc-K}$  had significantly ( $P < 0.01$ ) declined in all unleached and leached soils. A pronounced decline in  $\text{NH}_4\text{OAc-K}$  concentrations (a drop of 86% for unleached soil and 89% for leached soil) were detected in the soils belonging to Typic Calcixerepts containing high amount of illite. The NEx-K uptake by ryegrass ranged from 421 to 859  $\text{mg kg}^{-1}$  for the unleached soils and from 410 to 574  $\text{mg kg}^{-1}$  for the leached soils. Among the soils, NEx-K uptake accounted for up to 96% of the total uptake removed by five harvests of ryegrass herbage. For the unleached soils, NEx-K uptake was significantly ( $P < 0.01$ ) related to total K uptake. There were large differences in NEx-K uptake from soils that had similar  $\text{NH}_4\text{OAc-K}$  values. Hence, K buffer power and soil types coupled with available K must be taken into account when planning any application of K.

**Keywords:** Clay minerals,  $\text{NH}_4\text{OAc-K}$ , Non-exchangeable K, Potassium supplying power, Ryegrass, Successive planting.

### INTRODUCTION

Potassium supplying power defined as the ability of a soil to release K from K-containing minerals has been studied by many investigators (Fergus and Martin, 1974; Memon *et al.*, 1988; Surapaneni *et al.*, 2002a). Potassium supplying power is the result of two factors pertaining to (1) the soluble and exchangeable K in soil, and (2) the slowly available K, mainly non-

exchangeable K (NEx-K) and the rate that this form of K becomes available to the plants following consumption of the readily available K form. In addition, K level in the soil depends on other factors such as soil environment, CEC, species of cations adsorbed by the exchange sites and the cultivation practices and history of the soil (Karamanos and Turner, 1977).

Solution and exchangeable K are the major sources of potassium used by plants,

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but NEx-K can also contribute significantly to plant uptake over longer periods. Soils with a potential to release non-exchangeable K plants are those with 2: 1 clay minerals of the mica or illite type, or with K-rich primary minerals such as feldspars in a finely divided state. Thus, it might be expected that the ability to release K, would be at least partly related to soil type, since this depends on parent material and pedo-genetic processes.

Non-exchangeable K may be released from soil minerals such as mica and vermiculite when the soluble and exchangeable K have decreased following plant uptake (Sparks, 1980; Martin and Sparks 1985; Olk *et al.*, 1995). This release appears to be a diffusion process under neutral conditions (Martin and Sparks, 1983), although structural decomposition may be important under acid conditions (Feigenbaum *et al.*, 1981).

Results from a greenhouse study on high K soils ( $\text{NH}_4\text{OAc-K}$  from 280 to 840  $\text{mg kg}^{-1}$ ) revealed that sorghum (*Sorghum bicolor* L.) did not show any significant yield response to applied K after nine successive cuttings (Hipp, 1969). Moreover, the decline in exchangeable K over the nine crops was least for soils with higher K bearing mineral contents. In a study on Colorado soils, a high correlation was observed between the release of non-exchangeable K to five consecutive alfalfa (*Medicago sativa* L.) cuttings and clay content (Reddy, 1976). Data from field and greenhouse studies on alfalfa indicated that medium and fine textured soils were capable of supplying sufficient K to a 12 t/ha annual alfalfa crop for a period of three years while the K supply in coarse textured soils was sufficient for only one year (Reddy, 1976).

Methods used to study the K-supplying power of soil are mostly biological and depend upon depletive experiments either in the field or in glasshouse pot culture trials. They involve growing plants until K is exhausted, and measuring cumulative plant uptake of K to obtain a direct measure of K-supplying power (Kirkman *et al.*, 1994). The

K-supplying power of the soil is a combination of its exchangeable K and the non-exchangeable K.

The contribution of non-exchangeable (NEx-K) to plants is well recognized for a long time (Schmitz and Pratt, 1953). However, the majority of the K release data in the literature have been reported for highly weathered soils (Havlin and Westfall, 1985) while few K release studies have been reported for relatively unweathered, calcareous or alkaline semi-arid region soils, where responses to fertilizer K are seldom observed due to native high exchangeable K levels.

The objective of this study was to assess the K supplying power of alkaline-calcareous semi-arid region soils, using successive cropping of ryegrass as the test crop in the greenhouse. .

## MATERIALS AND METHODS

### Soils

Ten surface soil samples (0-30 cm) with different clay mineralogical composition belonging to five soil types, namely, Typic Calcixerepts, Typic Haploxerepts, Typic Endoaquepts, Vertic Endoaquepts, and Vertic Calcixerepts were used. The parent material of studied soils consisted of alluvial deposits. The soils were taken from the uncultivated (virgin) area adjacent to the major sugar beet growing soils of Western Azarbaijan Province located in north-west of Iran. The virgin areas are under vegetation including shrubs and various native grasses. A semi-arid climate exists in the region with mean annual rainfall of 280 mm and mean minimum and maximum temperatures of  $-4^\circ\text{C}$  in winter and  $37^\circ\text{C}$  in summer. All soil types were classified in Inceptisols order according to USDA Soil Taxonomy (Soil Survey, 1999).

The soil samples were air dried and ground to pass through a 2 mm-sieve before use. pH was determined using 1:5 soil to 0.01 M  $\text{CaCl}_2$  suspension (v/wt) by a glass

electrode (Rayment and Higginson, 1992). Particle size distribution was determined by the sedimentation procedure using the pipette method after dispersing the soil with sodium hexametaphosphate (Gee and Bauder, 1986). The total  $\text{CaCO}_3$  in soil expressed as the calcium carbonate equivalent (CCE) was determined by a rapid titration method (Rayment and Higginson, 1992). Organic matter was determined by wet digestion (Nelson and Summer, 1996). Cation exchange capacities of the soils were determined by the 1 M NaOAc, pH 7 method.

### Mineralogical Analyses

Mineralogical analyses, consisting of x-ray diffraction, were performed on the <2mm clay fraction. Prior to soil mineral fractionation, sub samples were treated with 30%  $\text{H}_2\text{O}_2$  to remove organic matter (Kunze, 1965) and with Na-dithionite-citrate-bicarbonate to remove Fe oxides (Mehra and Jackson, 1960). Sand was separated from silt and clay by wet sieving and clay was separated from silt by centrifugation and decantation. X-ray diffractograms were obtained with a computer-controlled Shimatzo XRD-6000 instrument employing a  $\text{CuK}_\alpha$  radiation source from oriented clay. The mineralogical composition of the clay fraction treated by Mg-saturated, Mg-plus ethyleneglycol-solvated, K-saturated, and K-saturated and-heated was determined by X-ray diffraction analysis. Semi-quantitative estimates of relative clay-mineral percentages were obtained from measurement of diffractogram peak areas, which were multiplied by the weighting factors of Biscaye (1965): four times the illite peak area, two times the kaolinite+chlorite peak area, and one time the smectite peak area, then normalized to 100%. Random powder diffraction patterns were obtained after back-filling the powdered samples into aluminum holders and scanning them from 4 to  $65^\circ 2\theta$ . A step

A step size of  $0.02^\circ 2\theta$  and scan speed of  $1^\circ 2\theta$  were used for all the samples.

### Soil K Forms

Soil solution K (So-K) was determined by shaking air-dried soil (5 g) with distilled water (25 ml) overnight, followed by centrifugation and filtration.  $\text{NH}_4\text{AOc}$ -extractable K (exchangeable plus water soluble potassium) was measured by shaking soil (<2 mm, 10 g) with ammonium acetate (buffered at pH 7, 1 mol  $\text{l}^{-1}$ , 25 ml) for 10 min in an end-over-end shaker; it was then centrifuged and filtered, and K was analyzed using flame photometer (Knudsen *et al.*, 1982). The values for Ex-K were calculated by subtracting the soil solution K values from the  $\text{NH}_4\text{AOc}$ -extractable K. The  $\text{HNO}_3$ -extractable K was determined by boiling soil (<2 mm, 2.5 g) with  $\text{HNO}_3$  (1 mol  $\text{l}^{-1}$ , 25 ml) for 10 min and analyzing the extracted K using flame photometer (Knudsen *et al.*, 1982). Initial Non-exchangeable K (initial NEx-K) was calculated by subtracting exchangeable K from  $\text{HNO}_3$ -soluble K.

### Leaching of Water Soluble K and Exchangeable K

Soil samples were leached to remove So-K and Ex-K so that in the subsequent greenhouse experiments the plants would use more K from the NEx-K pool. The leaching was performed using 0.1 M chloride solution containing Ca and Mg in the molar ratio of 4:1 on a shaker. The choice of this ratio was based on the approximate exchangeable Ca:Mg ratio of these soils. After centrifuging, the leachate was discarded. The soil:solution ratio used for leaching was 1:25. The pH of the leaching solution was adjusted to the mean pH of the soils (7.5) prior to leaching to prevent any major changes to the natural pH of the soils (Surapaneni *et al.*, 2002). The soils were washed free of excess chloride



and air dried.  $\text{NH}_4\text{OAc}$  extractable K ( $\text{NH}_4\text{OAc-K}$ ) in the leached soils was measured on air dry samples to determine if the artificial leaching procedure had removed all the native Ex-K and So-K.

### Greenhouse Experiments

The K-supplying power of the unleached and the artificially leached soils were determined in a greenhouse experiment using the procedure described by Surapaneni *et al.* (2002). In this procedure, a plant is grown in washed sand to form a K-starved root mat then replanting this root mat onto soil. For this, a 250-ml plastic container with the bottom removed was placed in a second intact plastic container and filled with 400 g of water washed silica sand. Perennial ryegrass (*Lolium Perenne*, cv. Roper) was used as the test crop and 40 seeds per pot were sown and later thinned to 20 seedlings per pot. A basal K-free nutrient solution (Middleton and Toxopeus, 1973) was then applied regularly and moisture was maintained daily at field capacity with distilled water. After 45 days, the ryegrass roots had grown through the sand and formed a dense mat at the base of the pots. The plants were cut to 20–30 mm above the sand surface. The K content of this cutting (before replanting onto soil) was negligible. The inner pot (with roots) was transferred into another intact pot containing 35 g of soil that had previously been moistened to field capacity. As a control treatment, the inner container was transferred onto 50 g of water-washed silica sand. The addition of K-free nutrient solution was continued until the completion of the experiment and the pots were watered daily with distilled water to a predetermined weight.

Of the 10 unleached soils used in the study, 4 were selected to receive complete (including K) nutrient solution so that K deficiency symptoms in the pot trial could be compared with a benchmark. The experiment thus involved two treatments, unleached and leached soils, with four

replicates giving a total of 84 pots including the four control pots, plus 16 ( $4 \times 4$ ) pots that received nutrient solution containing K. The pots were randomized and repositioned twice a week in the greenhouse to minimize any effects of uneven environmental factors, such as light, temperature, and air movement. The plants were harvested five times. After each harvest, the plants materials were clipped and dried at  $70^\circ\text{C}$  for dry matter yield, K concentration, and K uptake determinations. The K concentration in the plant extract was determined by atomic emission spectroscopy. After the final harvest, the soil was separated from the sand and roots were carefully separated from the soil. The roots were not analyzed for K because of the problems of quantitative recovery of root material and the difficulties of washing roots and removing soil contamination without, at the same time, leaching out root K. The soils were air dried and analyzed for exchangeable K. The total uptake of shoots from unleached and leached soils was obtained from the sum of the uptake of the five individual harvests and expressed as  $\text{mg kg}^{-1}$  air-dry soil.

Potassium taken up by plant shoots from non exchangeable sources (NEx-K) was calculated as follows (Surapaneni, *et al.*, 2002):

$$\text{NEx-K uptake} = \text{total K uptake} - \Delta\text{NH}_4\text{OAc-K}$$

Where, K uptake ( $\text{mg kg}^{-1}$ ) = Total amount of K removal by ryegrass shoots from a soil over the five harvests,  $\Delta\text{NH}_4\text{OAc-K}$  ( $\text{mg kg}^{-1}$ ) = Change in  $\Delta\text{NH}_4\text{OAc-K}$  in the soil over the experiment, i.e.,  $\text{NH}_4\text{OAc-K}$  before cropping –  $\text{NH}_4\text{OAc-K}$  after cropping

### Statistical Analysis

Variances of plant dry matter yield, K concentration, and K uptake were analyzed by using CoStat statistical package (CoHort Software, 2005) assuming a randomized complete-block design. Correlation/regression analysis of data was

carried out using the StatView program (Abacus Concepts, 1996).

## RESULTS AND DISCUSSION

### Characteristics of Soils

The analytical results of the soils used in the greenhouse study are presented in Table 1. The soils were calcareous with calcium carbonate equivalent (CCE) contents ranging from 50 to 128 g kg<sup>-1</sup> and alkaline with pH ranging from 7.1 to 7.7. Clay contents were relatively high (mean = 340 g kg<sup>-1</sup>, range = 170-570 g kg<sup>-1</sup>). Soil texture varied from sandy loam to clay with organic carbon contents ranging between 5.0 and 14 g kg<sup>-1</sup> soil. The semi-quantitative estimates of relative clay-mineral percentages revealed that the predominant mineral in the clay fraction was illite in Typic Haploxerepts and Typic Calcixerepts and smectite in Vertic Endoaquepts and Vertic Calcixerepts (Table 2). Almost equal amounts of illite, chlorite+kaolinite, and smectite were recorded in Typic Endoaquepts soil type.

The values of the various forms of K for the five major soil types are presented in Table 1. Values of NH<sub>4</sub>OAc-K ranged from 80 to 747 mg kg<sup>-1</sup>. According to the new soil test interpretation classes for K (Mallarino *et al.*, 2003), most soils are grouped under very high category (>201 mg K kg<sup>-1</sup>, Table 1). Typic Haploxerepts, Typic Calcixerepts, and Typic Endoaquepts soil types had the high amounts of initially non-exchangeable K (NEx-K) as compared with the Vertic Endoaquepts and Vertic Calcixerepts soil types (Table 2). This could be attributed to the presence of high amount of K bearing minerals (mainly illite), which, upon weathering, release K and contribute to various forms of soil K as evident from previous semi-quantitative clay mineralogical studies (Hebsur and Satyanarayana, 2002).

**Table 1.** Characteristics of the soils used in the greenhouse study and forms of K.

Soil no.	Soil Subgroups	pH	OC	CCE	Clay	CEC	EC	HNO <sub>3</sub> -K	Initial NEx-K	NH <sub>4</sub> OAc-K	Ex-K
				g kg <sup>-1</sup>		cmol <sub>c</sub> kg <sup>-1</sup>	dS m <sup>-1</sup>		mg kg <sup>-1</sup>		
S1	Typic Calcixerepts	7.6	5.0	92	280	25	0.74	263	213	80	79
S2	Typic Calcixerepts	7.7	11	120	240	22	0.95	1474	727	747	723
S3	Typic Calcixerepts	7.6	17	190	300	29	0.42	1254	974	280	276
S4	Typic Calcixerepts	7.5	15	140	570	37	0.62	849	556	293	292
S5	Typic Calcixerepts	7.7	10	77	170	25	1.32	408	187	221	215
S6	Typic Calcixerepts	7.6	29	128	190	29	0.79	555	227	328	319
S7	Typic Haploxerepts	7.1	8.0	50	310	23	4.00	702	522	181	179
S8	Typic Endoaquepts	7.3	9.0	52	270	30	0.38	345	196	149	147
S9	Vertic Endoaquepts	7.3	16	52	550	33	0.66	489	155	334	330
S10	Vertic Calcixerepts	7.5	11	280	570	35	0.73	618	177	440	437

HNO<sub>3</sub>-K, HNO<sub>3</sub>-extractable-K; NEx-K, non-exchangeable K; Ex-K, exchangeable K; OC, organic carbon; CCE, calcium carbonate equivalent

**Table 2.** Percent distribution of minerals in the clay fractions of the studied soils.

Soil type	Illite	Chlorite + Kaolinite	Smectite
Typic Calcixerepts	70	19	11
Typic Haploxerepts	69	15	16
Typic Endoaquepts	40	35	25
Vertic Calcixerepts	25	31	44
Vertic Endoaquepts	30	29	41

### Total K Uptake and K Concentration from Unleached and Leached Soils

The results of the successive cropping of ryegrass are summarized in Table 3. The data listed refer to the pots that were not fertilized with K. The values of total K uptake varied from 440 to 1062 mg kg<sup>-1</sup> for the unleached soils and from 428 to 945 mg kg<sup>-1</sup> for the leached soils. The soil types having high initially NEx-K contents (Table 1) had the highest K uptake, suggesting that differences in the K-supplying capacities of the soils were associated with availability of initial soil NEx-K to ryegrass (Richard *et al.*, 1988). A highly significant positive correlation was observed between the values of total K uptake and illite content for the unleached soils ( $r = 0.81$ ,  $P < 0.01$ ) and the leached soils ( $r = 0.75$ ,  $P < 0.01$ ), indicating that most of the K taken up by plants was released from illite. Surapaneni *et al.* (2002b) also found a strong relationship ( $r = 0.73$ ,  $P < 0.001$ ) between K uptake and the percentage of mica contents in the soils of New Zealand. Moreover, initial soil NEx-K was unrelated to chlorite plus kaolinite, indicating that most of the K absorbed by the plants came most likely from the interlayers of illite. Thus, soils that supplied more initial soil NEx-K to ryegrass contained more illite (Table 2) in the clay fraction than the soils that supplied less NEx-K. Similar results have been reported for the northeastern Portuguese soils (Portela, 1993) and for the soils of New Zealand (Surapaneni *et al.*, 2002b). There was significant positive relationship between initial soil NEx-K and NEx-K uptake by the

plant (NEx-K uptake = 0.49 initial NEx-K + 346,  $R^2 = 0.80$ ,  $P \leq 0.001$ ). It can be concluded that use of a soil test that includes a measure of non-exchangeable K i.e. acid extractable K, may be a vital part of identifying variations in the plant available K status of the soils.

The results of K concentrations in the first and last cutting of ryegrass are presented in Table 3. Successive cropping of ryegrass resulted in changes in the K concentrations in the ryegrass herbage between the start and the end of the greenhouse experiment. There was a decline in K concentrations in all unleached and leached soils. Significant declines in the K concentration values from 4.1 to 2.3 g kg<sup>-1</sup> (a drop of 45%) were observed for the unleached soils and from 3.4 to 2.1 g kg<sup>-1</sup> (a drop of 39%) for the leached soils. The K concentrations in the first and last cutting of ryegrass were related to the NEx-K extracted by HNO<sub>3</sub>. This form of K best explained the K concentration in the first and last harvests of ryegrass, explaining 55% and 98% of the variations in the K concentration in the leached soils, respectively (Figure 1). As expected, this trend was not observed in the first cutting of the plant in the unleached soils due to the presence of considerable amounts of NH<sub>4</sub>OAc-K in these soils. However, for the last cutting NEx-K uptake explained 71% of the variations in the K concentration in the unleached soils (Figure 1).

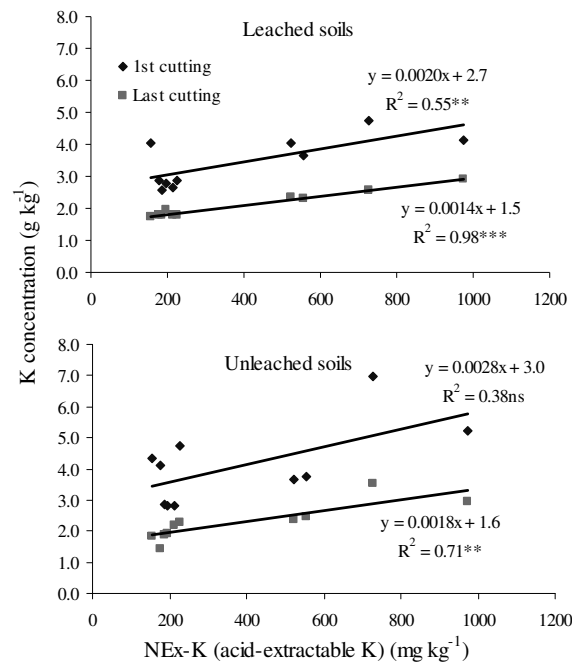
### NH<sub>4</sub>OAc-K after Cropping in the Unleached and Leached Soils

Results of NH<sub>4</sub>OAc-K measurements for the unleached and leached soils are

**Table 3.** Mean  $\pm$  standard deviation of total K uptake ( $\text{mg kg}^{-1}$ ),  $\text{NH}_4\text{OAc-K}$  after cropping ( $\text{mg kg}^{-1}$ ), and plant K content ( $\text{g kg}^{-1}$ ) of the first and the last cuttings of ryegrass from unleached and Ca/Mg leached soils.

Soil no	Unleached soils				Leached soils			
	$\text{NH}_4\text{OAc-K}$ before cropping	$\text{NH}_4\text{OAc-K}^a$ after cropping	K concentration <sup>b</sup>		$\text{NH}_4\text{OAc-K}$ after cropping	K concentration		
			1 <sup>st</sup> cut	Last cut		1 <sup>st</sup> cut	Last cut	
S1	80	71 $\pm$ 3.6	2.8 $\pm$ 0.026	2.2 $\pm$ .061	62 $\pm$ 0.0	2.6 $\pm$ 0.012	1.8 $\pm$ 0.014	
S2	747	104 $\pm$ 7.1	7.0 $\pm$ 0.079	3.5 $\pm$ 0.039	84 $\pm$ 7.1	4.8 $\pm$ 0.124	2.6 $\pm$ 0.043	
S3	280	122 $\pm$ 3.6	5.2 $\pm$ 0.079	3.0 $\pm$ 0.046	99 $\pm$ 0.0	4.1 $\pm$ 0.052	2.9 $\pm$ 0.032	
S4	293	166 $\pm$ 20	3.8 $\pm$ 0.021	2.5 $\pm$ 0.032	147 $\pm$ 3.6	3.7 $\pm$ .057	2.3 $\pm$ 0.061	
S5	221	61 $\pm$ 3.6	2.9 $\pm$ 0.020	1.9 $\pm$ 0.025	61 $\pm$ 3.6	2.6 $\pm$ 0.048	1.8 $\pm$ 0.035	
S6	328	61 $\pm$ 3.6	4.7 $\pm$ 0.044	2.3 $\pm$ 0.044	54 $\pm$ 7.1	2.9 $\pm$ 0.060	1.8 $\pm$ 0.022	
S7	181	71 $\pm$ 18	3.7 $\pm$ 0.026	2.4 $\pm$ 0.038	74 $\pm$ 7.1	4.0 $\pm$ 0.071	2.4 $\pm$ 0.026	
S8	149	109 $\pm$ 14	2.8 $\pm$ 0.062	1.9 $\pm$ 0.033	89 $\pm$ 7.1	2.8 $\pm$ 0.041	1.9 $\pm$ 0.045	
S9	334	118 $\pm$ 8.6	4.3 $\pm$ 0.060	1.8 $\pm$ 0.014	120 $\pm$ 25	4.0 $\pm$ .051	1.7 $\pm$ 0.032	
S10	440	185 $\pm$ 14	4.1 $\pm$ 0.041	1.4 $\pm$ 0.034	167 $\pm$ 3.6	2.9 $\pm$ .065	1.8 $\pm$ .013	
Mean	305	107	4.1	2.3	96	3.4	2.1	
C.V.	0.61	0.40	0.31	0.27	0.39	0.22	0.20	
Mean of differences		198 <sup>c</sup>		1.8 <sup>d</sup>	209 <sup>c</sup>		1.3 <sup>d</sup>	
t-test values		3.5		6.1	3.7		7.8	
P values		$P \leq 0.01$		$P \leq 0.001$	$P \leq 0.01$		$P \leq 0.001$	

<sup>a</sup> Mean of four replicates; <sup>b</sup> A total of 35 g soil and 20 plants per pot using a procedure described by Surapaneni *et al.* (2002). <sup>c</sup> between before cropping and after cropping; <sup>d</sup> between the first and the last cutting.



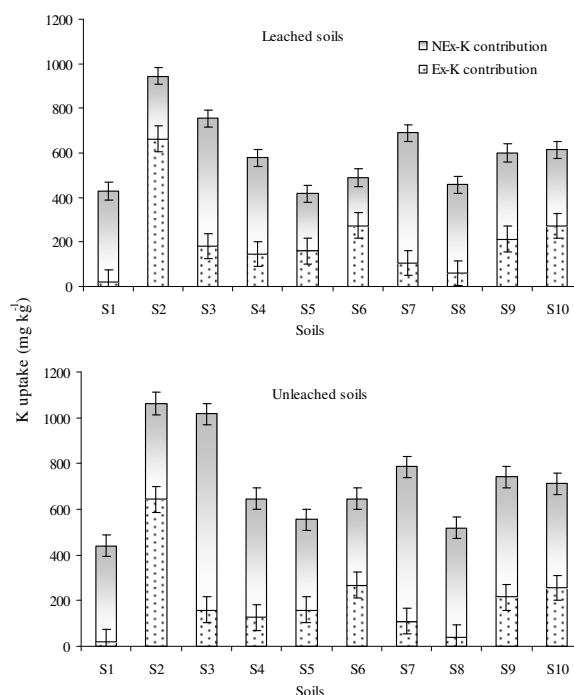
**Figure 1.** Relationships between K concentration and initial non-exchangeable K (acid-extractable K) for the first and the last cuttings of ryegrass from unleached and leached soils. The slopes of linear regressions were not statistically significant,  $P > 0.05$ .

presented in Table 3. The  $\text{NH}_4\text{OAc}$  values for the unleached soils ranged from 61 to 185  $\text{mg kg}^{-1}$ , with mean value of 107  $\text{mg kg}^{-1}$ , and, for the leached soils, the range was from 61 to 167  $\text{mg kg}^{-1}$ , with mean value of 96  $\text{mg kg}^{-1}$ . By the five cuttings of the ryegrass, the concentrations of  $\text{NH}_4\text{OAc-K}$  had significantly ( $P < 0.01$ ) declined in all unleached and leached soils. The largest decline occurred in the high K soils, which had the highest  $\text{NH}_4\text{OAc-K}$  concentrations at seeding. For example, a pronounced decline in  $\text{NH}_4\text{OAc-K}$  contents (a drop of 86% for unleached soil and 89% for the leached soil) was detected in S4 soil belonging to Typic Calcixerepts containing high amount of illite (Table 2). A significant drop in  $\text{NH}_4\text{OAc-K}$  concentrations (93%) as a result of successive cropping of ryegrass was also reported for Pallic soils of North and South Islands, New Zealand (Surapaneni *et al.*, 2002a).

### Contribution of NEx-K to Total K Uptake

The contributions of Ex-K and NEx-K to total K uptake by ryegrass shoots from leached and unleached soils are presented in Figure 2. Of the total K uptake, the amount that was not derived from Ex-K was assumed to have originated from the NEx-K pool. The NEx-K uptake ranged from 421 to 859  $\text{mg kg}^{-1}$  for the unleached soils and from 410 to 574  $\text{mg kg}^{-1}$  for the leached soils. All the unleached and Ca/Mg leached soils released NEx-K during the crop growing period. This indicates that although artificial leaching greatly reduced the Ex-K of all soils, it did not result in much change in NEx-K uptake (Figure 2). Among soils, NEx-K uptake accounted for up to 96% of the total uptake removed by five harvests of ryegrass herbage for the leached and





**Figure 2.** Contribution of  $\text{NH}_4\text{OAc-K}$  and NEx-K uptake to total K uptake from unleached and leached soils. Vertical lines are standard error of means at 95 % probability.

unleached soils. For the unleached soils, uptake of NEx-K was linearly related to total K uptake ( $y = 0.95x + 177$ ,  $R^2 = 0.74^{**}$ ), with an intercept corresponding to a total K uptake of  $177 \text{ mg kg}^{-1}$  when uptake of NEx-K was Zero, that is, when all uptake was from exchangeable sources. This relationship suggested that uptake was initially solely from exchangeable sources, but, once a critical depletion stage had been reached, uptake was mainly from the initially non-exchangeable fraction, with only a small further contribution from exchangeable sources (since the slope was  $<1$ ). A similar relation between uptake of NEx-K and total K uptake was not observed for the leached soils because, before the start of the experiment, the exchangeable K fraction was removed (leached) from the soils. Probably, this fraction could be taken up by plant, which in turn produced more roots to take up more soil initial NEx-K from the unleached soils. Similar findings have been reported for the two Queensland soils with different clay mineralogical compositions (Memon *et al.*, 1988). There

were large differences in NEx-K uptake from soils that had similar  $\text{NH}_4\text{OAc-K}$  values at seeding (before cropping) (Table 3). For examples, ryegrass grown on the S4 unleached soil extracted  $519 \text{ mg NEx-K/kg}$  whereas  $859 \text{ mg NEx-K/kg}$  was taken up from the unleached S3 soil. Similarly, in the unleached S6 and S9 soils, large differences occurred in the amount of NEx-K taken up by ryegrass. Hence, the differences in total K uptake at seeding could be explained in terms of greater uptake of NEx-K. The results are supported by those of Richard *et al.* (1988) and Smith and Matthews (1957) who reported that total uptake by alfalfa was highly correlated with the amount of NEx-K uptake.

It is recognized that data obtained in pot trials can not be used for assessing the field situation because the volume of soil from which K is removed by plants is much smaller in pots (Portela, 1993). Moreover, the test plant, ryegrass, has a great potential for exploiting soil K from the non-exchangeable pool (Steffens, 1986). The high density of the root system is able to



reduce K concentration in the soil solution and promote release of K from the interlayers. It has been reported that one year of intensive cropping with ryegrass was approximately equivalent to 10-15 years of normal cropping in the field (Weber and Grimme, 1986).

### CONCLUSION

It can be concluded that by the five cuttings of ryegrass, the concentrations of  $\text{NH}_4\text{OAc-K}$  had significantly declined in all unleached and leached soils. Among the soils studied, NEx-K uptake accounted for up to 96% of the total uptake removed by five harvests of ryegrass herbage. There were large differences in NEx-K uptake from soils that had similar  $\text{NH}_4\text{OAc-K}$  values. However, the results of the greenhouse experiment can be used as a guide in assessing the field situation. Since available K does not fully describe K supplying power of the soils, in the interest of fertilizer efficiency and economy, soil types and K buffer power must also be taken into account when planning any application of K to the soil. In this regard, beside the exchangeable and the solution K forms, considering the non-exchangeable K ( $\text{HNO}_3$ -extractable K) might improve assessment of the status of plant available K.

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## قدرت فراهمی پتاسیم در برخی از خاکهای قلیایی-آهکی شمالغرب ایران

ع. صمدی

### چکیده

به منظور تعیین سهم نسبی K قابل عصاره گیری با استات آمونیوم (NH<sub>4</sub>OAc-K) و K غیر قابل تبادل (NEX-K) در قابلیت استفاده پتاسیم، ده نمونه خاک سطحی دارای کانی های مختلف رس متعلق به پنج زیر گروه خاک انتخاب شد و در آنها ریگراس چند ساله (*Lolium Perenne*, cv. Roper) کشت شد و به مدت ۲۶۰ روز (پنج برداشت) در گلخانه تحقیقاتی رشد کرد. نتایج نشان داد که مقدار کل جذب پتاسیم توسط گیاه در خاکهایی که NEX-K زیادی داشتند، بیشتر بود. همبستگی مثبت بسیار معنی دار بین مقادیر کل جذب پتاسیم و مقدار ایلیت در خاکهای شستشو نیافته ( $r = 0.81, P < 0.01$ ) و شستشو یافته ( $r = 0.75, P < 0.01$ ) مشاهده گردید. همچنین همبستگی مثبت معنی داری بین جذب NEX-K و مقدار ایلیت و اسمکتایت برای خاکهای آبشویی شده ( $r = 0.73, P < 0.01$ ) و خاکهای آبشویی نشده ( $r = 0.71, P < 0.01$ ) وجود داشت. کاهش معنی دار در غلظت پتاسیم از ۴/۱ تا ۲/۳ گرم بر کیلوگرم (کاهش ۴۵ درصد) در خاکهای شستشو نیافته و از ۳/۴ تا ۲/۱ گرم بر کیلوگرم (کاهش ۳۹ درصد) در خاکهای شستشو یافته مشاهده شد. تا پنج برداشت ریگراس، مقادیر NH<sub>4</sub>OAc-K بطور معنی دار ( $P < 0.01$ ) در همه خاکهای آبشویی نشده و آبشویی شده کاهش یافت. کاهش قابل ملاحظه در مقادیر NH<sub>4</sub>OAc-K (کاهش ۸۶ درصد در خاکهای شستشو نیافته و ۸۹ درصد در خاکهای شستشو یافته) در خاکهای متعلق به Typic Calcixerepts با مقدار زیاد ایلیت مشاهده گردید. مقدار فراهمی NEX-K به گیاه از ۴۲۱ تا ۸۵۹ میلی گرم بر کیلوگرم در خاکهای شستشو نیافته و از ۴۱۰ تا ۵۷۴ میلی گرم بر کیلوگرم در خاکهای شستشو یافته متغیر بود. میان همه خاکها، ۹۶ درصد از کل پتاسیمی که تا پنج برداشت توسط ریگراس جذب شده بود، ناشی از جذب NEX-K توسط گیاه بود. در خاکهای شستشو یافته، رابطه مثبت معنی داری ( $P < 0.01$ ) بین مقدار کل جذب پتاسیم و جذب NEX-K توسط گیاه مشاهده شد. خاکهایی که مقدار NH<sub>4</sub>OAc-K مشابه داشتند، تفاوت زیادی در جذب NEX-K نشان دادند. بنابراین لازم است قدرت بافری و نوع خاک همراه با K قابل استفاده در برنامه های توصیه کودی پتاسیم در نظر گرفته شود.