Agropedology, 1998, **8**, 94-100

Prediction of plant available potassium in kaolinitic soils of India

*S.K. Pal**

Potash Research Institute of India, Sector-19, Gurgaon-122 001, Haryana.

Abstract

The effectiveness of five extractants, NH_4OAc, HNO_3, NaCl, AB-DTPA and Mehlich-3 was evaluated on 25 Indian soils dominated by kaolinitic clay minerals for prediction of plant available K to sorghum (*Sorghum vulgare* Pers.) grown in Neubauer technique. Total K uptake by five crops of 20 days old was used to measure plant available soil K. The average amount of K extracted were in the following order : AB-DTPA = HNO_3 < NaCl ≤ NH_4OAc ≤ Mehlich-3. The amount of K extracted by five extractants were significantly correlated with each other. The highest simple correlation with K uptake by sorghum was obtained with HNO_3-K ($r^2 = 0.945^{**}$) and the lowest with Mehlich-3-K ($r^2 = 0.636^{**}$). The K uptake was taken as the dependent variable and soil K extracted by the extractants, exchangeable Ca and Mg, organic carbon, cation exchange capacity (CEC), content of silt and clay as independent variables to develop stepwise regression model. Inclusion of soil properties improved the effectiveness of prediction except by HNO_3. In HNO_3-K model no soil properties could contribute significantly towards the improvement of prediction. However, based on the final R^2, HNO_3 is the best as a predictor of availability of K in kaolinite dominated soils.

Additional keywords: Potassium extractants, plant available K, sorghum, kaolinitic soil).

Introduction

Almost all the soil testing laboratories in India and also in abroad use 1*N* NH_4OAc solution of pH 7 as extractant to evaluate the available potassium status for making fertilizer recommendation. While evaluating the available potassium status the mineral make up vis-a-vis the ionic environment of the soils has grossly been undermined (Goswami *et al.* 1976). Various factors which can affect the availability of soil K are mineralogical characteristics, texture, CEC, organic matter, quantity/Intensity relations, interactions with other cations (Ca^{++}, Na^+, NH_4^+, Al^{+++}), moisture regime and environmental stresses (Chatterjee and Maji 1984).

Richards and Bates (1988) suggested that in addition to NH_4OAc-K, inclusion of step K (Haylock 1956) as a plant available K might improve the prediction of plant available K in Ontario soils. However, extraction of step K is time consuming exercise and not practical in routine analysis. It appears that a simple method is needed. Richards and Bates (1989) also found that 0.1*N* HNO_3 and 2*M* NaCl extractable K could explain more variation in total K uptake than did NH_4OAc. However, with inclusion of soil properties such as plant available non-exchangeable K and soil organic matter, NH_4OAc may be one of best predictors of availability of K in Ontario soils (Liu and Bates 1990).

Ammonium bicarbonate - DTPA (AB-DTPA) (Soltanpour and Schwab 1977; Soltanpour and Workman 1979) and Mehlich-3 (Mehlich 1984) used for the simultaneous extractions of number of macro and micro-nutrients in soils. Little is known about the efficiency of these multi-element extractants on Indian soils dominated by kaolinitic clay mineral.

The objective of this study was, therefore, to evaluate the effectiveness of several extractants mentioned above for prediction of the plant available K in kaolinitic soils of India.

* Present address: Dept. of Ag. Chem. & Soil Sci., N.B. Campus, B.C.K.V., Cooch Behar, West Bengal.

Materials and methods

Twenty five surface samples were screened out for this study from six important soil series [Kodad from Nalgonda, A.P.; Vijayapura and Tyamagondalu from Bangalore, Karnataka; Doddabhavi from Coimbatore, T.N.; Kumbhave-5 from Ratnagiri, Maharashtra and Nedumangad from Trivandrum, Kerala] already collected, processed and analysed for evaluation of their K supplying capacities using conventional method. All the soil series were characterised by kaolinite dominated clay mineral (Sekhon *et al.* 1992). Samples were selected from the bulk to provide a wide range of soil physical and chemical properties (Table 1).

Table 1. Selected physical and chemical properties of the soils

Soil properties	Range	Mean	CV(%)
Sand (g kg^{-1})	100-900	699	24.0
Silt (g kg^{-1})	20-780	118	128.9
Clay (g kg^{-1})	80-340	184	44.1
pH	5.0-7.3	5.9	10.6
Organic carbon (g kg^{-1})	1.9-10.5	4.9	44.6
Exch. Ca (cmol (p+) kg^{-1})	1.7-8.1	3.8	57.7
Exch. Mg (cmol (p+) kg^{-1})	0.6-3.5	1.5	61.9
CEC (cmol(p+) kg^{-1})	3.2-12.6	7.2	37.0

Table 2. Extractants used to determine soil K

Extractant	Composition	Soil : extractant ratio	Extraction period	References
NH_4OAc	1*M* NH_4OAc pH 7.0	1:5	5 min	Hanway and Heidel (1952)
HNO_3	0.1*M* HNO_3	1:10	16 h	MacLean (1961)
NaCl	1*M* NaCl pH 7.0	1:10	15 min	McKeague (1978)
AB-DTPA	1*M* NH_4HCO_3 0.005*M* DTPA pH 7.6	1:2	15 min	Soltanpour and Schwab (1977); Soltanpour and Workman (1979)
Mehlich-3	0.2*M* HOAc 0.025*M* NH_4NO_3 0.015*M* NH_4F 0.013*M* HNO_3 0.001*M* DTPA pH 2.5	1:10	5 min	Mehlich (1984)

Determination of soil properties

Soil pH was measured in 1:2.5 soil-water suspension by glass electrode method. Exchangeable Ca and Mg and CEC were determined by extracting soil with 1*N* NH_4OAc of pH 7 (Jackson 1968). Soil organic carbon was estimated by Walkley-Black's rapid titration procedure. Particle size fractionation was carried out by international pipette method. The mineralogical composition of the clay fraction of the soil series was determined by X-ray diffraction technique (Whittig and Allardice 1986) of the oriented slide on a 1729-1710 Philips X-ray diffractometer.

Determination of K availability

Soil K was extracted with NH_4OAc, NaCl, HNO_3, AB-DTPA and Mehlich-3 as described in table 2. Potassium content in the extract was estimated on an EEL Corning Flame Photometer.

Green house experiment

Plastic containers were filled with 50g quartz and 100g of soil. To each container 100 seeds of sorghum (*Sorghum vulgare* Pers.) and N and P both @20 kg ha^{-1} in the form of $(NH_4)_2SO_4$ and $(NH_4)_2HPO_4$ were added in each cropping. Five crops each with 20 days duration were raised. The containers were watered by weight to field moisture capacity already determined as required.

Plant analyses

Plant materials were oven dried at 70°C, weighed, ground to pass a 1 mm sieve and wet digested with trinary acid mixture (HNO_3 : $HClO_4$: H_2SO_4 : 10 : 4 : 1 v/v). Potassium content in the acid extract was measured in a flame photometer.

Statistical analysis

Two procedures were used for statistical analyses. The first was the calculation of simple correlation between the amounts of K removed by the extractants. The second was a stepwise regression by which a series of equations were developed. In multiple regression equations total K uptake by five sorghum crops was used as dependent variable. Potential independent variables were K extracted by one of the extractants and soil parameters.

Results and discussion

Characteristics of the soil

There is a wide variation in physical and chemical properties of the soils selected for this study (Table 1). The table shows that soil pH values vary between 5.0 and 7.3, clay contents between 80 and 340 g kg^{-1}, organic carbon contents between 1.9 and 10.5 g kg^{-1} and CEC between 3.2 and 12.6 cmol(p+) kg^{-1}.

Amounts of K extracted

The range and average amounts of K extracted from the air dried samples of 25 soils with the five extractants are presented in table 3. The mean quantities of K extracted by the extractants were in the ascending order : AB-DTPA = HNO_3 < NaCl $\leq$ NH_4OAc $\leq$ Mehlich-3.

Although the extractants removed different quantities of K from the soils, the amounts were highly correlated among themselves (Table 4). Among the five extractants the higher correlations were noted between AB-DTPA-K, NH_4OAc-K, HNO_3-K and NaCl-K.

Prediction of K availability to sorghum

The amount of K taken up by sorghum was used as a measure of availability of soil K. Potassium uptake was significantly correlated with the amounts of K extracted by the five extractants (See step 1 in Tables 5-9). The significant lowest correlation was observed with Mehlich-3, while the highest was noted with HNO_3. Similar relationship was also observed with dry matter production of sorghum (data not presented).

Table 3. Amounts of K (mg kg^{-1}) removed by the five extractants

Extractants	Range	Mean	CV(%)
NH_4OAc	22.5-340	121	62.8
HNO_3	21.0-244	103	54.2
NaCl	50.0-272	120	45.5
AB-DTPA	30.0-290	103	62.9
Mehlich-3	30.0-470	124	71.1

Table 4. Correlation coefficient (r) for K removed by the extractants

Extractant	Extractants			
	HNO_3	NaCl	AB-DTPA	Mehlich-3
NH_4OAc	0.978	0.977	0.995	0.896
HNO_3		0.980	0.988	0.876
NaCl			0.982	0.880
AB-DTPA				0.902

L.S.C. for 23 d.f. at 1% level is 0.505.

In stepwise regression, attempt was made to improve the predictability of K availability with each extractant by inclusion of other soil parameters. No restriction was imposed, allowing independent variables to enter the model competitively. The sequence of entry into the model depends solely upon the degree of contribution of each variable to the model. The models developed with the extractants are presented stepwise in tables 5-9. All the variables in the models were significant at 5% probability level.

Mehlich-3: Among the potential variables, Mehlich-3 was considered first and gave an R^2 of 0.636 (Table 5). The second variable entered was Ca, which improved the R^2 to 0.747. With the introduction of third variable, silt, into the model, the R^2 further raised to 0.805. In other words, these three independent variables altogether can explain 80.5% variability in K uptake values. The negative regression coefficient of silt suggests that less K was available to sorghum on higher silt containing soils. This is probably due to negative effect of silt content on clay which is the actual site for immediately available K.

NaCl: The first two variables entered into the equations were K and Ca as in Mehlich-3-K model. Inclusion of Ca as independent variable improved R^2 from 0.899 to 0.936 (Table 6).

Table 5. Stepwise regression equation for predicting total K uptake (Y) by sorghum using Mehlich-3*

Step	Variable entered	Equation	R^2
1.	K	$Y = 37.95 \pm 15.56^{**} + 0.04 \pm 0.23K$	0.636
2.	Ca	$Y = 25.56 \pm 12.71 + 0.03 \pm 0.02K + 1.24 \pm 4.38\ Ca$	0.747
3.	Silt	$Y = 30.59 \pm 11.17 + 0.03 \pm 0.21K + 1.11 \pm 3.86Ca - 0.15 \pm 0.41\ Silt$	0.805

* Silt content in g $100g^{-1}$, ** S.E. of Estimate

AB-DTPA: The first two variables entered into the model in the same order as in the previous two extractants, and produced a similar model R^2 to that in the NaCl-K equation in step 2 (Table 7). When the third variable, CEC entered into the equation the value of R^2 further raised to 0.944 with a negative regression coefficient suggesting that high CEC has a negative effect on K uptake. Similar relation was also observed by Liu and Bates (1990) working with southern Ontario soils.

Table 6. Stepwise regression equation for predicting total K uptake (Y) by sorghum using NaCl

Step	Variable entered	Equation	R^2
1.	K	$Y = 13.68 \pm 8.20 + 0.03 \pm 0.45K$	0.899
2.	Ca	$Y = 9.27 \pm 6.41 + 0.03 \pm 0.41K + 0.66 \pm 2.60\ Ca$	0.936

Table 7. Stepwise regression equation for predicting total K uptake (Y) by sorghum using AB-DTPA

Step	Variable entered	Equation	R^2
1.	K	$Y = 27.53 \pm 6.81 + 0.02 \pm 0.39K$	0.636
2.	Ca	$Y = 24.50 \pm 6.28 + 0.02 \pm 0.36K + 0.68 \pm 1.52\ Ca$	0.938
3.	CEC	$Y = 30.93 \pm 5.98 + 0.02 \pm 0.37K + 1.54 \pm 4.04Ca - 1.32 \pm 2.38\ CEC$	0.944

NH_4OAc: The first three variables entered in the same order as in AB-DTPA-K model but resulted in slightly lower three term model R^2 (0.940) (Table 8) which suggested that contribution of Ca and CEC in NH_4OAc-K model were slightly lesser than that of AB-DTPA-K model.

HNO_3: HNO_3 extractable K alone can explain 94.5% variation in the K uptake of sorghum and no other soil parameter can improve the model (Table 9).

Table 8. Stepwise regression equation for predicting total K uptake (Y) by sorghum using NH_4OAc

Step	Variable entered	Equation	R^2
1.	K	$Y = 27.43 \pm 6.77 + 0.02 \pm 0.33K$	0.931
2.	Ca	$Y = 25.04 \pm 6.49 + 0.02 \pm 0.31K + 0.71 \pm 1.25 Ca$	0.934
3.	CEC	$Y = 31.75 \pm 6.17 + 0.02 \pm 0.32K + 1.58 \pm 3.86Ca - 1.36 \pm 2.48 CEC$	0.940

Table 9. Stepwise regression equation for predicting total K uptake (Y) by sorghum using HNO_3

Step	Variable entered	Equation	R^2
1.	K	$Y = 20.97 \pm 6.07 + 0.02 \pm 0.46K$	0.945

The predictive ability of the four extractants, Mehlich-3, AB-DTPA, NH_4OAc and NaCl was improved when some soil properties were incorporated into the equations. In all cases the first two variables entered into the respective model were K and Ca. When these two variables entered into the equations, almost similar variation in K uptake was explained, NH_4OAc-K ($R^2 = 0.934$), NaCl-K ($R^2 = 0.936$) and AB-DTPA-K ($R^2 = 0.938$), while less variation was explained by Mehlich-=3 ($R^2 = 0.747$) than the others. Similar conclusion was also drawn by Liu and Bates (1990). Again, with the introduction of third variable namely, CEC, AB-DTPA-K ($R^2 = 0.944$) explained same variation as the equation developed with NH_4OAc-K ($R^2 = 0.940$) and ultimately it was proved that Mehlich-3 ($R^2 = 0.805$) was the least efficient among the five extractants used for this purpose. However, among the five extractants considered in this study HNO_3-K explained the highest variation in K uptake by sorghum and its predictability not at all improved with the inclusion of any soil parameter. If the final equations (R^2) were considered, AB-DTPA-K and NH_4OAc-K model were equally efficient in predicting plant available K in kaolinitic soils and could explain the same variation as with HNO_3-K model. The final equations developed above with the four extractants contained parameters including, Ca, CEC and silt that are not routinely measured in soil testing laboratories. So, HNO_3-K would be the best to use to predict K availability in kaolinitic soils as this extractant explained the highest variability even without considering the other soil parameters.

Acknowledgement

The author is grateful to Mr. S.N. Basak for providing stepwise regression computer program and for advice on the statistical analysis.

References

Chatterjee, R.K., and Maji, B. (1984). Physico-chemical factors affecting the availability of potassium in soils. *PR II Research Review Series No. 1*: 62-75.

Goswami, N.N., Bapat, S.R., Leelavathi, C.R. and Singh, R.N. (1976). Potassium deficiency in rice and wheat in relation to soil type and fertility status., *Bulletin Indian Society of Soil Science* **10**, 194-196.

Hanway, J.J. and Heidel, H. (1952). Soil analysis methods as used in Iowa State College, Soil Testing Laboratory. *Iowa State College Bulletin* **57**, 1-131.

Haylock, O.P. (1956). A method for estimating the availability of non-exchangeable potassium. *Proceedings 6th International Soil Science Congress (Paris), Part B*, 403-408.

Jackson, M.L. (1968). 'Soil Chemical Analysis' (Prentice-Hall of India : New Delhi, India)

Liu, L. and Bates, T.E. (1990). Evaluation of soil extractants for the prediction of plant-available potassium in Ontario soils. *Canadian Journal of Soil Science* **70**, 607-615.

MacLean, A.J. (1961). Potassium-supplying power of some Canadian soils. *Canadian Journal of Soil Science* **41**, 196-206.

McKeague, J.E. (ed.) (1978). 'Manual on Soil Sampling and Methods of Analysis'. (Canadian Soc.Soil Science : Ottawa, Ont.)

Mehlich, A. (1984). Mehlich-3 soil test extractant : A modification of Mehlich-2 extractant. *Communication Soil Science and Plant Analysis* **15**, 1409-1416.

Richards, J.E. and Bates, T.E. (1989). Studies on the potassium supplying capacities of southern Ontario soils.II Nitric acid extraction of non-exchangeable K and its availability to crops. *Canadian Journal of Soil Science* **68**, 199-208.

Richards, J.E. and Bates, T.E. (1989). Studies on the potassium supplying capacities of southern Ontario soils. III. Measurement of available K. *Canadian Journal of Soil Science* **69**, 597-610.

Sekhon, G.S., Brar, M.S. and Subba Rao, A. (1992) Potassium in some benchmark soils of India. *PRII Special Publication*, **3**, pp.20.

Soltanpour, P.N. and Schwab, A.P. (1977). A new soil test for simultaneous extraction of macro and micronutrients in alkaline soils. *Communication in Soil Science and Plant Analysis* **8**, 195-207.

Soltanpour, P.N. and Workman, S. (1979) Modification of the NH_4HCO_3-DTPA test to omit carbon black. *Communication in Soil Science and Plant Analysis* **10**, 1411-1420.

Whittig, L.D. and Allardice, W.R. (1986). X-ray diffraction techniques. In 'Methods of Soil Analysis'. (Ed. A. Klute) pp. 331-362 (ASA-SSSA : Madison, WI).