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Estimation of soil potassium availability for predicting the response to applied potassium in rice field

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ABSTRACT

The available potassium in the rice soils representing six districts of Meghalaya was determined by five chemical extraction methods in order to find out the most reliable soil testing method for predicting response of rice crop to applied K for in the acid soils. Total K in the soils ranged from 1200-3950 mg kg^{-1} and exchangeable, non-exchangeable and lattice K fractions constituted 5.1, 8.6 and 85% of total K, respectively Distribution of various fractions of K in different soil groups followed in the order: Vertisols > Inceptisols > Ultisols > Alfisols > Entisols. Nitric acid extractable K recorded highest values of available K, ranging from 105 to 748 kg ha^{-1}, whereas the ammonium acetate extractable K varied from 71-403 kg ha^{-1}. Dry matter yield and K uptake widely varied from 13.45-55.77 g pot^{-1} (30x30cm) and 109-1008 mg pot^{-1} (30x30cm) with a yield and uptake response of 20 to 110 and 27-247 %, respectively. Water soluble and exchangeable forms of K contributed 65, 68, 44, 66 and 44 percent variation to the extractable K by ammonium acetate, sulphuric acid, nitric acid, hydrochloric acid and calcium chloride, respectively. Water soluble and exchangeable forms of K showed highly significant relationship with K uptake of rice, indicated that these two forms significantly contributed to K nutrition of rice. Ammonium acetate extractable K was found superior to the other extraction methods as it showed highly significant relationship with plant growth parameters, with a critical limit of 194 kg ha^{-1}, below which the crop showed response to the applied K fertilizers. The H_2SO_4 extractable K was also found equally good as it showed highly significant relationship with plant growth parameters and various forms of K, with a critical limit of 210 kg ha^{-1}.

Key words: *Soil K fractions, K availability indices, rice yield, K uptake, acid soil, critical limit*

Rice occupy 80 % of the gross cropped area in Meghalaya and the total fertilizer consumption in the state ammount to 5.13 thousand tonnes (19.4 kg ha^{-1}) with a wide N:P:K ratio of 12.3:8.1:1.0, according to the estimates of 2006-07 (FAI, 2008). Around 15 mha of area in the north eastern region is found to be acidic (pH 4.0 - 6.3) owing to deficiency of several nutrients, including potassium (Bhatt *et al*., 2004). *Jhuming* (shifting cultivation) and heavy rainfall in the region led to a soil loss of 147-170 t ha^{-1} yr^{-1} (NEC, 1995) causing depletion of natural resources and limiting the crop productivity. Wide variations between crop removal and K additions through various sources besides low consumption of K containing fertilizers resulted in depletion of native K reserves in the soils. Soil potassium exists in solution, exchangeable, and non-exchangeable forms that are in dynamic equilibrium with each other. Solution and exchangeable K are replenished by non-exchangeable K when they are depleted by plant removal or leaching. Some non-exchangeable K held in the inter-layers of expandable 2:1–type clay minerals such as illite and vermiculite can be released relatively easily to provide a substantial portion of the K removed by crops during the growing season (Richards *et al*., 1988; Rahmatulla *et al*., 1994).

Continuous mining of K from the soils is due to application of low rates of K containing fertilizers, leaching of K occurred during flooding which is a pre requisite for rice cultivation (Mehdi *et al*., 2001). Number of extracting solutions are used to assess plant

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available K in different parts of the world (Knudsen *et al*., 1982). Various extractants have been tried for their suitability for fertilizer recommendations of K for rice in other parts of the country (Sekhon, 1995 and Yadvinder Singh and Bijay Singh, 2001) and no data is available on K availability in the soils of north eastern region of due to India its diverse soil and climatic conditions. In this context, the present investigation was undertaken to evaluate various extractants so as to find out the most reliable soil test method for K availability and critical limits for predicting response of rice to applied K in the soils of Meghalaya.

MATERIALS AND METHODS

Fifty three bulk soils (0.30 m depth) were collected during 2003-04 from rice growing areas representing six out of seven districts of Meghalaya *viz*., Ri-Bhoi - 21, Jaintia Hills - 6, East Khasi Hills - 8, West Khasi Hills - 6, West Garo Hills - 7 and South Garo Hills - 5. The soils were shade dried, powdered, sieved with 2.0 mm sieve, and analysed for textural components and other physico-chemical properties (Jackson, 1973). Total N (Jackson, 1973) and vailable N was extracted (Subbiah and Asija, 1956). The available P was estimated (Bray and Kurtz, 1945).

The soils were analyzed for various forms of K, viz., water soluble, exchangeable, non exchangeable, lattice and total K (Page *et al*., 1982). Available K in the soils was estimated by five extractants *viz*., 1) 1.0 N NH_4OAc, pH 7.0 (Muhr *et al*., 1965), 2) 6.0 N H_2SO_4 (Hunter and Pratt, 1957), 3) 1.0 N HNO_3 (Wood and DeTurk, 1941), 4) 0.5 N HCl (Garman, 1957) and 5) 0.01 M $CaCl_2$ (Woodruff and McIntosh, 1960).

Five kg each of the 2.0 mm sieved soil was taken in to the pots (having a size of 30 cm diameter x 30 cm height), soaked, thoroughly mixed with water and kept for submergence for 10 days. An uniform dose of N @ 150 kg ha^{-1} in the form of urea at 3 equal split doses at 0, 15 and 30 days after transplanting (DAT), entire P (39.3 kg ha^{-1}) in the form of single super phosphate before planting were applied. Two levels of K @ 0 and 75 kg ha^{-1} were replicated thrice in a completely randomized block design and it was applied in two equal split doses in the form of muriate of potash at 0 and 30 DAT. A medium duration rice *cv* Shah Sarang-1 seedlings of 30 days old were transplanted at two per hill and three hills per pot at equal spacing. The water level was maintained 2.0 cm above the surface throughout the experiment and the crop was harvested at 60 DAT, washed thoroughly, oven dried and the dry matter yield (DMY) was recorded. Plant samples were ground, digested in diacid mixture (HNO_3 & $HClO_4$, 7:3) and the total K was estimated by using flame photometer (Jackson, 1973) and K uptake was computed.

The data were analysed by (Panse and Sukhatme, 1978) and Linear correlation coefficients were worked out between K availability indices and forms of K and also between forms of K and soil properties. Correlation coefficients were derived between forms and availability indices with plant growth parameters. Stepwise regression analyses were done to assess the relative contribution of various forms of K towards the K availability indices and plant growth parameters. Relative yield, relative K uptake and per cent yield/ uptake response were derived as

Relative yield (%) =
{Control yield ÷ Treatment yield}x 100
Relative uptake (%) =
{Control uptake ÷ Treatment uptake} x 100
Yield response (%) =
{(Treatment yield – Control yield) ÷ Control yield} x 100
Uptake response (%) =
{(K uptake in treatment – uptake in control) ÷ K uptake in control} x 100

RESULTS AND DISCUSSION

The soils were widely varied in texture (Table 1) with a clay content of 11.2 - 41.6 %. The soils were strongly to moderately acidic (pH 4.27 - 5.56) and having 0.61 - 5.28 % org. C, 0.084 - 0.501 % total N, 182 - 603, 5.26 - 27.78 and 70.6 - 403.2 kg ha^{-1} of available N, P and K, respectively. Vertisols recorded highest total N and available N, P, and K followed by Inceptisols, Ultisols, Alfisols and Entisols.

The dry matter yield varied from 13.5 - 45.4 g pot^{-1} in control and 24.8 - 55.8 g pot^{-1} with the addition of K @ 75 kg ha^{-1} (Table 2). Addition of K has shown a yield response of 20 - 110 % across all the soils with a relative yield of 48 - 83 %. Among the various soil groups, Entisols show highest yield response (67%) followed by Alfisols (63%), Ultisols (44%), Vertisols

Table 1. Physico-chemical properties of rice soils of Meghalaya

Type of soil	Textural components (%)				pH	Org C (%)	Total N (%)	Available nutrient (kg ha^{-1})		
	Coarse sand Mean Range	Fine sand Mean Range	Silt Mean Range	Clay Mean Range	Mean Range	Mean Range	Mean Range	N Mean Range	P Mean Range	K Mean Range
Alfisols	19.86±1.35	26.89 ± 1.35	26.2±1.38	26.6±0.75	4.63±0.06	1.56 ± 0.12	0.248±0.018	304±20.1	9.68±0.76	169±19.5
	10.73-29.79	16.92-37.72	16.0-40.0	20.0-32.8	4.27-5.15	0.67-2.24	0.105-0.361	207-502	6.27-19.38	76-343
Entisols	18.89±2.51	41.9±3.41	16.9±1.52	21.9±1.55	5.14±0.10	0.83±0.07	0.140±0.027	229±14.1	7.87±0.98	116±19.5
	9.81-28.20	27.38-53.00	11.2-24.0	16.0-26.0	4.92-5.56	0.61-1.09	0.084-0.266	182-289	5.26-12.32	71-215
Inceptisols	17.52±1.09	24.58±2.48	31.3±1.68	26.1±1.62	4.66±0.09	2.40±0.27	0.337±0.028	440±37.6	13.9±2.03	305±28.9
	12.44-23.46	12.68-37.39	20.0-38.4	19.2-35.4	4.35-5.40	1.23-4.30	0.168-0.501	289-603	7.39-27.78	125-403
Vertisols	16.13±1.05	27.03±1.17	20.4±2.70	36.0±1.45	4.65±0.05	2.73±0.58	0.364±0.03	448±36.0	16.26±2.48	203±16.9
	10.56-19.05	21.74-30.07	12.8-35.2	32.0-41.6	4.45-4.76	1.16-5.28	0.238-0.496	307-583	8.06-26.21	151-279
Ultisols	19.65±2.31	30.26±1.74	26.5±1.70	23.2±1.74	4.57±0.05	1.75±0.25	0.294±0.026	350±37.5	14.25±1.12	214±28.5
	11.54-36.96	21.65-41.57	19.6-33.6	11.2-28.8	4.36-4.82	1.12-3.57	0.140-0.409	194-577	8.74-20.16	115-393

(35%) and Inceptisols (30%). The K uptake ranged from 109 - 748 mg pot^{-1} in control and 263 - 1008 mg pot^{-1} in K treated pots with a wide variation in uptake response (27 - 247%). Entisols recorded highest mean uptake response (158%) followed by Alfisols (132%), Ultisols (92%), Vertisols (66%) and Inceptisols (61%). The relative K uptake ranged from 29 - 79 %, revealed that the added K fertilizers have significant influence on K uptake by rice in these acidic soils. The individual effect of soils, K levels and their interaction on DMY and K uptake were found significant. A wide variation in DMY, concentration and uptake of K by rice was observed which could be attributed to wide variations in physico-chemical regime of the soils and accumulation as well as mineralization of organic matter in the valley areas, where the lowland paddy being extensively cultivated in the north eastern states (Patiram *et al*., 1989).

Total K in the soils varied from 1200 - 3950 mg kg^{-1} with a mean of 2927 mg kg^{-1} (Table 3). Occurrence of various fractions of K in different soil groups followed in the order: Vertisols > Inceptisols > Ultisols > Alfisols > Entisols. Water soluble, exchangeable and non exchangeable forms of K were appreciably low in these soils might be due to continuous cropping without externally added K. These results are in accordance with the findings of Santhy *et al*. (1998). The water soluble and exchangeable forms of K lost through leaching and runoff due to torrential rainfall in this region and low CEC of the soils which could not hold the exchangeable and non exchangeable forms of K consequent to mass action effect (Patiram and Prasad, 1984).

Highest available K was recorded with the extraction of 1.0 N HNO_3 (Table 3), ranged from 105 - 748 kg ha^{-1} (mean 416 kg ha^{-1}) over the other extractants, which may be due to boiling of the soils with HNO_3 which tend to cause more dissolution of fixed K into the soil solution. Extraction of soils with strong acids like 6.0 N H_2SO_4 could also solubilize most of the fixed K and released into the soil solution. The available K extracted by 1.0 N ammonium acetate ranged from 71 - 403 kg ha^{-1} with a mean of 203 kg ha^{-1}. Extraction of available K by various extractants was followed the trend: HNO_3 > H_2SO_4 > NH_4OAc > HCl > $CaCl_2$. Highest NH_4OAc extractable K was observed in Inceptisols (305 kg ha^{-1}) followed by Ultisols

Table 2. Effect of potassium on dry matter yield and K uptake

Soil type	Dry matter yield (g pot^{-1})		Yield response (%)	Relative yield (%)	K uptake (mg pot^{-1})		Uptake response (%)	Relative K uptake (%)
	K_0	K_{75}			K_0	K_{75}		
Alfisols	13.5-40.2 (22.1)	25.8-51.6 (34.5)	21.6-109.6 (63.0)	48-82 (63)	109-543 (256)	263-868 (522)	27.1-247.3 (131.6)	29-79 (47)
Entisols	14.1-28.7 (21.7)	24.8-47.4 (35.8)	47.9-76.3 (66.6)	57-68 (60)	157-413 (220)	432-801 (543)	93.7-193.9 (157.9)	34-52 (39)
Inceptisols	24.7-42.5 (31.8)	32.0-55.8 (41.2)	20.1-64.1 (30.1)	61-83 (77)	201-748 (455)	416-1008 (695)	30.1-118.2 (60.9)	46-77 (64)
Vertisols	21.5-45.4 (33.6)	30.0-54.8 (45.6)	20.8-49.2 (34.7)	67-83 (75)	262-603 (460)	479-925 (749)	32.2-88.5 (65.9)	53-76 (61)
Ultisols	14.4-38.4 (26.4)	28.9-50.7 (36.8)	21.9-101.5 (43.9)	50-82 (71)	142-578 (338)	351-827 (605)	37.2-146.7 (91.7)	41-73 (54)
Mean	26.4	38.0	60.2	62	335	606	80.9	55
CD (P=0.05) Soils		2.46			38.25			
CD (P=0.05) K levels		0.48			7.43			
CD (P=0.05) Interaction		3.48			54.09			

Parentheses indicate the mean values

(214 kg ha^{-1}) and Vertisols (203 kg ha^{-1}), while it was lowest in Entisols (116 kg ha^{-1}) and Alfisols (170 kg ha^{-1}). A total of 25, 52 and 23% soils falls under low (<120 kg ha^{-1}), medium (120-280 kg ha^{-1}) and high (> 280 kg ha^{-1}) categories, respectively. The extraction of available K in various soil groups by H_2SO_4, HNO_3, HCl and $CaCl_2$ was shown similar pattern as with NH_4OAc. However, the extraction with $CaCl_2$ was found lowest among all the reagents, ranged from 40 - 423 kg ha^{-1} (mean 166 kg ha^{-1}), indicating that the $CaCl_2$ has low solubilization effect on the non exchangeable and lattice K forms in these strongly acid soils.

The data in Table 4 revealed that all forms of K (water soluble, available, non exchangeable, reserve and total K) established significantly positive relationship amongst themselves, indicating thereby the existence of some sort of (dynamic) equilibrium between fractions of soil potassium. Similar results were also found by Nath and Purkaystha (1988). The available K extracted by various methods showed significant relationship with total K, which is the main source for various forms of K and a part of the total K was released into the soil solution by hydrolytic action of these reagents. All the K availability indices showed highly significant relationship with water soluble and exchangeable K forms which are considered to be the main source of available potassium. However, these extractants also showed positive and significant relationship with non exchangeable or fixed K which may be ascribed to release of some of the fixed K into soil solution as and when the exchangeable K depleted substantially to attain the equilibrium (Sekhon *et al*., 1992). Amongst the availability indices, NH_4OAc extractable K showed highly significant relationship with water soluble, exchangeable, non exchangeable K, lattice K and total K, emphasizing that NH_4OAc has the potentiality to extract all forms of K and it could be better than the other extraction methods for estimation of available K.

Significantly positive relationship was observed between organic C with water soluble K ($r=0.60^{**}$), exchangeable K ($r=0.71^{**}$), and non exchangeable K ($r=0.62^{**}$), total K ($r=0.59^{**}$) and lattice K ($r=0.51^{**}$), which might be due to the fact that the organic matter was the source for retention and availability of different forms of K. Highly significant relationship between organic C and exchangeable K in comparison to other forms of K is due to functional groups in organic matter facilitates exchange of K^+ ions from the inter layers of K containing minerals. In general, the relationship of all K availability indices with lattice K is inferior to other K fractions. This might be due to the fact that K is mainly included in the solution (water soluble and exchangeable K) and non exchangeable forms and least from lattice K. All the forms of K had non significant relationship with clay and significantly negative

Table 3. Extraction of available potassium and its fractions in rice soils of Meghalaya

Soil type	K fraction (mg kg^{-1})					K availability index (kg ha^{-1})				
	Total K	Water soluble K	Exch. K	Non Exch. K	Lattice K	NH_4OAc-K	H_2SO_4-K	HNO_3-K	HCl-K	$CaCl_2$-K
Alfisols	1450-3750 (2783)	8.8-60.0 (23.5)	57-253 (130)	109-375 (233)	1238-3158 (2396)	76.2-342.7 (169.5)	112.0-416.6 (199.1)	188.2-748.2 (385.5)	62.7-418.9 (179.9)	40.3-423.4 (148.1)
Entisols	1200-2550 (1900)	6.5-15.5 (10.9)	39-103 (71)	87-196 (143)	1028-2264 (1675)	70.6-215.0 (116.3)	58.2-233.0 (139.5)	105.3-445.8 (268.2)	51.5-181.4 (118.4)	40.3-168.0 (101.8)
Inceptisols	2350-3900 (3182)	16.0-66.0 (42.4)	94-312 (192)	208-411 (285)	1887-3315 (2662)	125.4-403.2 (304.8)	136.6-430.1 (310.8)	280.0-705.6 (514.8)	141.1-367.4 (272.3)	76.2-398.7 (229.3)
Vertisols	3100-3950 (3414)	8.5-47.5 (32.8)	88-264 (191)	178-415 (295)	2565-3291 (2896)	151.2-278.9 (202.6)	165.8-371.8 (248.3)	306.9-689.9 (462.4)	165.8-331.5 (220.5)	118.7-266.6 (165.1)
Ultisols	1950-3900 (3285)	14.0-59.0 (28.4)	108-345 (165)	197-413 (302)	1497-3470 (2790)	115.4-393.1 (213.7)	129.9-383.0 (229.8)	275.5-631.7 (433.7)	105.3-304.6 (209.2)	56.0-315.8 (173.7)
Mean	2927	27.9	150	253	2496	203.0	227.0	416.0	202.0	166.0
SEm (±)	98.4	2.4	9.2	11.4	85.6	13.4	12.8	20.2	12.2	13.7

relationship with soil pH. In acid soils, H^+ and hydroxy-aluminium ions compete with K^+ ions for the exchange or adsorption sites and are able to keep more K^+ ions in solution phase and reduce their susceptibility to fixation. As the pH increases, the H^+ and hydroxyl aluminium ions are neutralized, making it easier for the K^+ ions to move closer to soil colloidal surfaces where they become susceptible to fixation (Subba Rao and Brar, 2002). Negative relationship between soil pH and various forms of K was also reported by Panwar *et al*. (2002) and Kozak *et al*. (2005).

In general, the relationship between K availability indices with lattice K is inferior to total K, because the lattice K and fixed K can be grouped together and make up the pool of non-exchangeable inorganic K, whereas total K includes both solution and fixed K among which solution K is readily available for plant uptake (Syers, 1998). Significant correlations exists between the water soluble and exchangeable forms of K which suggests that the removal of water soluble K gets equilibrated directly from the exchangeable form to meet the crop requirement and closely related to K removal by cropping. These results are in corroboration with the findings of Patiram and Prasad (1984). It can be concluded that water soluble or exchangeable K is better extracted by NH_4OAc (1.0 N) and H_2SO_4 (6.0N) reagents.

Step down regression equations worked out between various forms and extractable K by different methods to find out the relative contribution of various forms to the available K as extracted by different methods are listed in Table 5. Water soluble and exchangeable K together accounted for 65.3 % variation to the NH_4OAc extractable K, while the inclusion of other fractions influenced the observed variation to an extent of 5.5 % to the regression. However, the water soluble and exchangeable K together accounted for 67.9, 66.1 and 44.3 % variation to the available K pool as extracted by H_2SO_4, HCl and $CaCl_2$ methods, respectively, whereas water soluble and non-exchangeable K accounted for 44.4 % variation to the HNO_3 extractable K and inclusion of other K fractions did not influence the R^2 value, indicating that the boiling of soils with HNO_3 tend to cause more dissolution of non-exchangeable K and replenishes the exchangeable and solution forms of K. Thus, the results indicated that both water soluble and exchangeable

Table 4. Correlation coefficients (r) between K fractions with K availability indices and soil properties

K availability index/ Soil property	Water soluble K	Exchangeable K	Non exchangeable K	Lattice K	Total K
NH_4OAc-K	0.79^{**}	0.72^{**}	0.48^{**}	0.48^{**}	0.56^{**}
H_2SO_4-K	0.79^{**}	0.77^{**}	0.59^{**}	0.25	0.38^{*}
HNO_3-K	0.64^{**}	0.60^{**}	0.53^{**}	0.34^{*}	0.42^{*}
HCl-K	0.78^{**}	0.71^{**}	0.48^{**}	0.26	0.37^{*}
$CaCl_2$-K	0.65^{**}	0.60^{**}	0.36^{*}	-0.01	0.10
Soil pH	-0.55^{**}	-0.54^{**}	-0.43^{**}	-0.36^{*}	-0.42^{*}
Organic carbon	0.60^{**}	0.71^{**}	0.62^{**}	0.51^{**}	0.59^{**}
Clay	0.08	0.22	0.08	0.01	0.03
Water soluble K	-	0.79^{**}	0.58^{**}	0.38^{*}	0.50^{**}
Exchangeable K	0.79^{**}	-	0.76^{**}	0.43^{**}	0.58^{**}
Non exchangeable K	0.58^{**}	0.76^{**}	-	0.56^{**}	0.69^{**}
Lattice K	0.38^{*}	0.43^{**}	0.56^{**}	-	0.98^{**}
Total K	0.50^{**}	0.58^{**}	0.69^{**}	0.98^{**}	-

** and * Significant at 1.0 and 5.0 percent level, respectively

Table 5. Step down regression equations between forms of K with availability indices

Dependent variable	Regression equation	R^2
NH_4OAc-K	$Y = 15.36 + 3.03^{**} X_1 + 0.58^{*} X_2 – 0.39 X_3 + 0.04 X_4 + 0.004 X_5$	0.708^{**}
	$Y = 52.73^{**} + 3.31^{**} X_1 + 0.39^{*} X_2$	0.653^{**}
H_2SO_4-K	$Y = 102.63^{**} + 2.68^{**} X_1 + 0.52^{*} X_2 + 0.11 X_3 – 0.02 X_5$	0.695^{**}
	$Y = 71.50^{**} + 2.56^{**} X_1 + 0.56^{**} X_2$	0.679^{**}
HNO_3-K	$Y = 184.02^{**} + 3.82^{**} X_1 + 0.22 X_2 + 0.31 X_3 + 0.01 X_5$	0.447^{**}
	$Y = 191.03^{**} + 4.28^{**} X_1 + 0.42^{*} X_3$	0.444^{**}
HCl-K	$Y = 94.85^{**} + 3.33^{**} X_1 + 0.38^{*} X_2 – 0.07 X_3 – 0.01 X_5$	0.669^{**}
	$Y = 68.52^{**} + 3.31^{**} X_1 + 0.27 X_2$	0.661^{**}
$CaCl_2$-K	$Y = 148.07^{**} + 2.86^{**} X_1 + 0.56^{*} X_2 – 0.02 X_3 – 0.06^{**} X_5$	0.549^{**}
	$Y = 37.70^{*} + 2.63^{**} X_1 + 0.37^{*} X_2$	0.443^{**}

** and * Significant at 1.0 and 5.0 percent level, respectively

forms were the major contributors to the available K as extracted by NH_4OAc, H_2SO_4, HCl and $CaCl_2$ methods and non-exchangeable and water soluble forms of K in case of HNO_3 extraction method. It can be suggested that both water soluble and exchangeable K together being suitably extracted by 1.0N NH_4OAc and 6.0N H_2SO_4 reagents as indicated by their higher R^2 values over the other extraction methods.

All the forms of K had positive and significant relationship with relative yield, relative K uptake, dry matter yield and K uptake in control pots Table 6. Exchangeable K showed highly significant relationship with relative yield ($r = 0.68^{**}$) and relative K uptake ($r = 0.70^{**}$) followed by water soluble K. Among the various forms, exchangeable (r=0.65**) and water soluble K (r=0.063**) showed highly significant relationship with K uptake by rice whereas exchangeable 0.47** and non exchangeable 0.45** K forms showed highly significant relationship with dry matter yield.

All the K availability indices showed positive and significant relationship with plant growth parameters (Table 6). Ammonium acetate extractable K showed highly significant relationship with relative yield ($r = 0.80^{**}$), relative K uptake ($r = 0.83^{**}$) and control K uptake ($r = 0.74^{**}$), indicating its superiority in extraction of available K in the rice soils of Meghalaya. The H_2SO_4 extractable K also showed highly significant relationship with control K uptake ($r=0.71^{**}$), relative yield ($r=0.67^{**}$) and relative K uptake ($r=0.70^{**}$) and it could also be considered equally efficient for K estimation in these soils. The available K extracted by

Table 6. Relationship (r) between K fractions and availability indices with plant growth parameters

Forms of K / availability index	Relative yield	Relative K uptake	DMY (Control)	K uptake (Control)
Forms of K				
Water soluble K	0.64**	0.69**	0.34*	0.63**
Exchangeable K	0.68**	0.70**	0.47**	0.65**
Non exchangeable K	0.55**	0.61**	0.45**	0.55**
Lattice K	0.53**	0.54**	0.33*	0.45**
Total K	0.60**	0.62**	0.39**	0.53**
K availability index				
NH_4OAc-K	0.80**	0.83**	0.44**	0.74**
H_2SO_4-K	0.67**	0.70**	0.53**	0.71**
HNO_3-K	0.58**	0.59**	0.47**	0.62**
HCl-K	0.57**	0.60**	0.40*	0.63**
$CaCl_2$-K	0.43*	0.44**	0.33*	0.55**

** and * Significant at 1.0 and 5.0 percent level, respectively

different reagents and various forms of K showed significantly higher relationship with K uptake rather than dry matter yield, because plant growth is not only governed by K availability but also several other nutrients. However, in situations, where other nutrients are not limiting plant growth, K uptake and K content in plants at critical stages of crop growth should be correlated with dry matter yield and available soil potassium.

Step down regression equations between plant growth parameters and available K extracted by various reagents (Table 7) were drawn to find out the suitable K extraction method based on relative contribution of extractable K with biological indices. Exchangeable and water soluble K alone accounted for 42.7 and 39.7% variation, respectively towards the K uptake by rice and inclusion of water soluble and lattice K forms increased the variation by 3.6 and 2.9%, respectively, however, the non exchangeable K did not influence the

Table 7. Step down regression equations between forms and availability indices of K with plant growth parameters

Dependent variable	Regression equation	R^2
K uptake (Control)	$Y = 0.298 + 2.75^{*} X_1 + 0.83 X_2 + 0.05 X_3 + 0.05 X_5$	0.492**
	$Y = 2.26 + 2.73^{*} X_1 + 0.87^{*} X_2 + 0.05^{*} X_5$	0.492**
	$Y = 98.34^{*} + 2.94^{*} X_1 + 1.03^{**} X_2$	0.463**
	$Y = 91.23^{*} + 1.63^{**} X_2$	0.427*
Dry matter yield (Control)	$Y = 13.04^{**} - 0.048 X_1 + 0.046 X_2 + 0.012 X_3 + 0.002 X_5$	0.252
	$Y = 13.29^{**} + 0.036 X_2 + 0.013 X_3 + 0..01 X_5$	0.249
	$Y = 13.63^{**} + 0.045^{**} X_2 + 0.002 X_5$	0.243
	$Y = 17.73^{**} + 0.058^{**} X_2$	0.221
K uptake (Control)	$Y = 8.04 + 0.86^{**}$ NH_4OAc-K + 0.65 H_2SO_4-K + 0.26 HNO_3-K– 0.52 HCl-K+0.03 $CaCl_2$-K	0.607**
	$Y = 6.96 + 0.85^{**}$ NH_4OAc-K + 0.67 H_2SO_4-K + 0.25 HNO_3-K – 0.50 HCl-K	0.607**
	$Y = 20.12 + 0.81^{**}$ NH_4OAc-K + 0.47 H_2SO_4-K + 0.11 HNO_3-K	0.598**
	$Y = 32.57 + 0.81^{**}$ NH_4OAc-K + 0.61^{**} H_2SO_4-K	0.595**
	$Y = 78.88^{*} + 1.26^{**}$ NH_4OAc-K	0.549**
Dry matter yield (Control)	$Y = 12.20^{**}$ –1.36 NH_4OAc-K+0.079^{**} H_2SO_4-K+0.019 HNO_3-K–0.027 HCl-–0.039 $CaCl_2$-K	0.370*
	$Y = 12.20^{**} + 0.079^{**}$ H_2SO_4-K – 0.019 HNO_3-K – 0.027 HCl-K – 0.039 $CaCl_2$-K	0.370*
	$Y = 12.28^{**} + 0.074^{**}$ H_2SO_4-K + 0.013 HNO_3-K – 0.048^{**} $CaCl_2$-K	0.362*
	$Y = 14.03^{**} + 0.085^{**}$ H_2SO_4-K – 0.042* $CaCl_2$-K	0.347*
	$Y = 15.85^{**} + 0.046^{**}$ H_2SO_4-K	0.280

where, X_1= represent water soluble, X_2 = exchangeable, X_3 = non-exchangeable, X_4 = total K, X_5 = lattice K
** and * Significant at 1.0 and 5.0 percent level, respectively; R^2 – Coefficient of multiple determination

regression. Similarly, exchangeable K alone accounted for 22.1 % variation towards the dry matter yield of rice and the inclusion of other forms influenced the observed variation by 3.1 % only, indicating that the exchangeable K is the major contributor towards the K nutrition of rice.

Ammonium acetate and sulphuric acid extractable K together accounted for 59.5% variation the control K uptake and other reagents have not shown any significant effect on R^2 values. The available K extracted by NH_4OAc alone accounted for 54.9 % variation to the K uptake, indicating that ammonium acetate is superior over that of other K extraction methods. However, H_2SO_4 extractable K alone accounted for 50.7 % variation to the K uptake and it can also be considered suitable for extraction of available K. The H_2SO_4 and $CaCl_2$ extractable K together recorded an observed variation of 34.7% towards dry matter yield and H_2SO_4 alone accounted for 28% variation to the regression, emphasized that the crop yield was not only influenced by K nutrition but also several other factors including addition of that particular nutrient.

The critical limits for available K in the soils were found to be 194 and 210 kg ha^{-1} in respect of ammonium acetate and sulphuric acid methods (Fig. 1 and 2), below which the crop shown significant response to the applied K fertilizers. In order to know the adaptability and reliability of suitable K methods in the present study, it was further studied the per cent yield and uptake responses as per the derived critical limits (Table 8). Higher yield responses (64.8 & 63.8 %) were recorded at below CL and lower responses (30.7 & 36.4) were observed at above the CL of 194 and 210 kg ha^{-1}, respectively. However, the uptake response to the applied K is higher than yield response, which was found to be 138 & 141 % at below the CLs and 63 & 72 % at above the CL in respect of NH_4OAc and H_2SO_4 methods.

Among all the K availability indices, neutral normal ammonium acetate extractable K was found better than other methods as it showed significantly higher relationship with the plant growth parameters. It had highly significant relationship with all forms of K especially solution and exchangeable fractions which are the main constituents for K nutrition of the crop. The 6.0N H_2SO_4 was also found equally efficient for

Table 8. Reliability of soil test methods for potassium

K availability index	CL (kg ha^{-1})	Total No. of soils	Percent yield response in soils below CL			Percent yield response in soils above CL			Percent uptake response in soils below CL			Percent uptake response in soils above CL		
			Soils	Mean	Range	Soils	Mean	Range	Soils	Mean	Range	Soils	Mean	Range
NH_4OAc-K	194	53	29	64.8	29.7-109.6	24	30.7	20.1-60.2	29	138.1	51.4-247.3	24	63.3	27.1-134.4
H_2SO_4-K	210	53	25	63.8	28.3-101.5	28	36.4	20.1-109.6	25	140.9	51.4-247.3	28	71.5	27.1-144.2

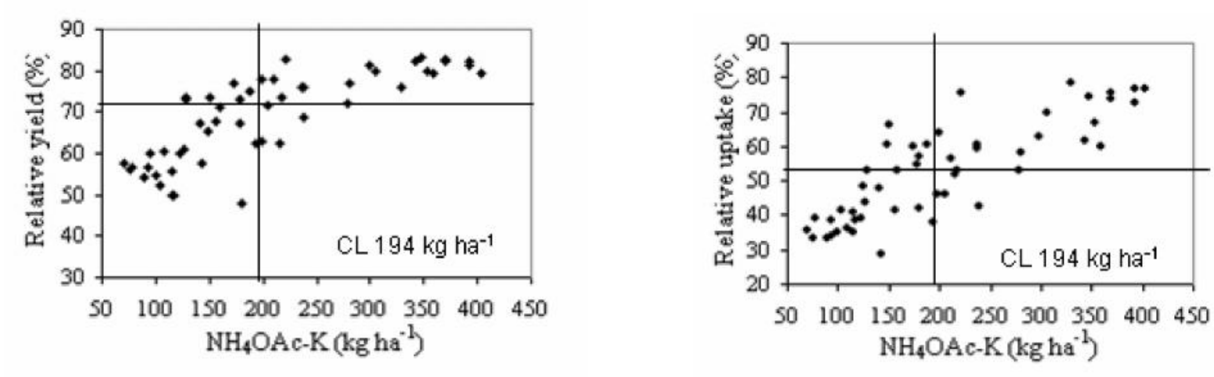

Fig. 1. Critical limit for ammonium acetate extractable K in rice soils

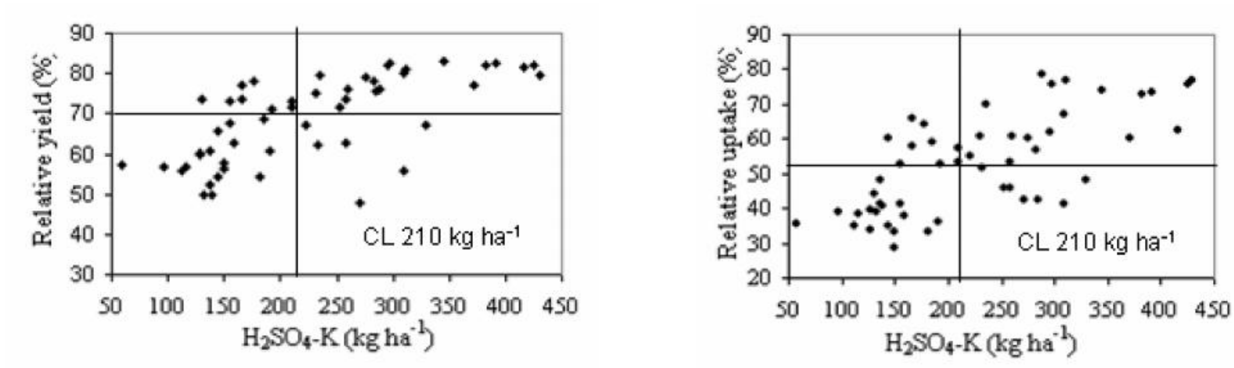

Fig. 2. Critical limit for H_2SO_4 extractable K in rice soils

K extraction as it showed highly significant relationship with the K uptake by rice and various forms, which were the major contributors for K nutrition. In order to obtain highest response to applied K fertilizers and to enhance the K use efficiency in the acid soils of Meghalaya, it is necessary to consider the critical levels of 194 and 210 kg ha^{-1} of available soil potassium in respect of ammonium acetate and sulphuric acid extraction methods, respectively.

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