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Distribution of inorganic N fractions and N availability indices in the rice soils of Meghalaya

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ABSTRACT

The potentially mineralizable N was evaluated by different chemical oxidation methods in 53 rice soils representing from six districts of Meghalaya. A wide variation in dry matter yield and N uptake was observed in the sampled, ranging from 13.7 - 55.8 g pot^{-1} and 155 - 1527 mg pot^{-1} with a yield and uptake response of 13 - 91 and 28 - 171 per cent, respectively. The ammoniacal N in the soils ranged from 28 - 207 kg ha^{-1} with a mean of 88 kg ha^{-1}, while the nitrate N ranged from 3 - 44 kg ha^{-1} (mean 22 kg ha^{-1}). Highest available N was recorded with dichromate oxidation that ranged from 1004 - 4390 kg ha^{-1}, whereas the alkaline permanganate and acid permanganate extractable N recorded 182 - 603 and 157 - 470 kg ha^{-1}, respectively. Alkaline $KMnO_4$ and acid $KMnO_4$ extractable N showed significantly higher relationship with all the plant growth parameters over the other extraction methods and the critical limits were found to be 320 and 286 kg ha^{-1}, respectively. The fertilizer recommendations for rice have to be modified so as to enhance the N use efficiency in the soils of Meghalaya.

Key words: *rice, soil, inorganic N fractions, N availability, biological indices, Meghalaya*

Rice is the major food crop in Meghalaya and occupies 80 % of the gross cropped area (Anonymous, 2003). Meghalaya ranks third in total fertilizer consumption (3.86 thousand tones) and nutrient consumption per unit gross cropped area (15 kg ha^{-1}) among the North Eastern states with higher consumption of N fertilizers (FAI, 2001). The fertilizer ratings for various crops are being advocated based on organic matter status of the soils by the soil testing laboratories (STLs) even in the hilly areas (Verma *et al*., 1980), which does not represent the mineralizable N status of the soils. The potentially mineralizable N in the soil rich in organic matter is low and needs efficient and judicious management of N fertilizers in order to enhance the efficiency of added fertilizers as well as to minimize the expenditure on fertilizer inputs. In this context, the present investigation was carried out to evaluate different N availability indices in order to find out the most reliable and rapid soil test method for determining the available N status and to establish the critical limits to predict the crop response to applied N in the soils of Meghalaya.

MATERIALS AND METHODS

Bulk soil samples (0 - 30 cm depth) were collected during 2003-05 from 53 locations representing rice growing areas from 6 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 processed and analysed for textural components by Robinson Pipette method (Piper, 1966) and other chemical properties as per the standard methods outlined by Jackson (1973).

Inorganic N fractions (NH_4^+-N and NO_3^--N) in the soils were extracted with 2.0M KCl solution and NH_4^+-N was determined by steam distillation using MgO and NO_3^--N content after NH_4^+-N distillation in the same extract by adding Devarda's alloy (Bremner, 1965). The sum of NH_4^+-N and NO_3^--N was taken as mineral N. Organic carbon was estimated by the method of Walkley and Black (1934). Total N was determined by Kjeldahl method as described by Jackson (1973). Nitrogen availability in the soils was estimated by four chemical oxidation methods (Alkaline $KMnO_4$, acid

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$KMnO_4$, $K_2Cr_2O_7$ and H_2O_2). Alkaline $KMnO_4$-N was extracted by distillation of soil with $KMnO_4$ and NaOH (Subbiah and Asija, 1956). Acid $KMnO_4$-N was extracted by shaking the soil with 0.1N $KMnO_4$ in 1.0N H_2SO_4 followed by steam distillation (Stanford and Smith, 1978). In chromic acid method, oxidation of organic matter with $K_2Cr_2O_7$ and dilution with H_2SO_4 followed by steam distillation was undertaken (Sharma and Sud, 1980). In H_2O_2 method, the soil was oxidized with 30 % H_2O_2 followed by extraction with 2.0M KCl and distillation with NaOH (Sahrawat, 1982).

Five kg each of the processed soil was potted, soaked, thoroughly mixed with water and kept for submergence for 10 days. Two levels of N @ 0 and 150 kg ha^{-1} in the form of urea were applied in three replications in a completely randomized block design. A uniform dose of P @ 40 kg ha^{-1} in the form of single super phosphate at basal and K @ 75 kg ha^{-1} in the form of muriate of potash in two equal splits at basal and 30 days after transplanting (DAT) were applied. The N was applied in three equal split doses *i.e.* at 0, 15 and 30 DAT. Rice (*cv* Shah Sarang-1) seedlings of 30 days old were transplanted at 2 seedlings $hill^{-1}$ with hills in a pot. The water level was maintained throughout the experiment and the plants were taken at 60 DAT, washed thoroughly, oven dried and the dry matter yield (DMY) was recorded. The plant samples were ground, digested in conc. H_2SO_4 and analysed for N content by steam distillation (Humphries, 1956) and the N uptake was computed. Bray's per cent yield (% Y) and per cent uptake (% U), per cent yield/ uptake response were calculated as

Bray's % Y / % U = {(Control yield/ uptake)/ (Treatment yield/ uptake)} x 100

Per cent yield / uptake response = {(Treatment yield/ uptake – Control yield/ uptake) / (Control yield/ uptake)} x 100

Simple linear correlations were worked out between N availability indices and plant growth parameters. Step down regression equations were worked out between N availability indices with inorganic N fractions and soil properties. Critical limits for available N for the suitable methods were derived by plotting scatter diagram between Bray's per cent yield/uptake versus soil test values (Cate and Nelson, 1965).

RESULTS AND DISCUSSION

The soils varied widely in texture with a clay content of 11.2 - 41.6 % with highest mean clay content (30.1 %) in the soils of West Khasi Hills, while it was the lowest in the soils of West Garo Hills (25.2 %) and the soils belong to clay loams-18, sandy clay loams-14, loams-14 and sandy loams-7 and representing Ultisols, Inceptisols, Entisols and Alfisols (Table 1). The soils were strongly to moderately acidic (pH 4.27 - 5.56)

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

Location/ District	No. of soil samples	Textural component (%)				pH	Available nutrient (kg ha^{-1})		
		Coarse sand	Fine sand	Silt	Clay		N	P	K
Ri-Bhoi	21	12.0-29.8 (20.9)	16.9-36.3 (27.1)	16.0-34.0 (24.2)	18.8-40.0 (27.5)	4.27-5.02 (4.68)	188-521 (303)	5.94-20.16 (11.55)	104-286 (174)
Jaintia hills	6	12.4-23.5 (17.5)	24.8-34.4 (30.0)	20.8-36.8 (26.2)	19.2-33.6 (25.9)	4.39-4.77 (4.50)	414-603 (493)	7.39-24.75 (13.55)	279-392 (343)
East khasi hills	8	10.6-37.0 (18.6)	20.8-37.4 (28.2)	12.8-35.2 (27.2)	11.2-41.6 (25.5)	4.36-4.81 (4.58)	301-583 (466)	12.8-27.8 (18.34)	125-403 (262)
West khasi hills	6	12.1-27.3 (18.7)	14.2-37.7 (23.9)	19.2-38.4 (26.7)	24.0-32.6 (30.1)	4.35-4.85 (4.57)	289-564 (406)	7.22-13.22 (9.94)	115-370 (256)
West garo hills	7	9.8-22.8 (17.3)	12.7-53.0 (32.7)	16.0-40.0 (24.3)	16.0-35.4 (25.2)	4.73-5.42 (5.14)	220-295 (254)	5.26-12.54 (8.65)	76-211 (110)
South garo hills	5	10.7-24.6 (15.2)	31.6-51.3 (39.3)	11.2-22.4 (17.8)	22.4-32.8 (27.1)	4.34-5.56 (4.74)	182-383 (253)	5.82-14.78 (9.54)	71-198 (134)
Mean	-	18.9	29.1	24.5	27.0	4.70	349.9	11.79	202.5
SEm (±)	-	0.78	1.17	0.93	0.83	0.04	16.65	0.73	13.42

Values in parentheses indicate the mean values and having 0.61 - 5.28 % of org. C, 0.084 - 0.501 % total N, 182 - 603, 5.26 - 27.78 and 71 - 403 kg ha^{-1} of available N, P and K, respectively.

Application of N @ 150 kg ha^{-1} recorded a dry matter yield of 13.65 - 55.77 g pot^{-1} with a yield response of 13-91 percent across all the soils (Table 2). Higher yield response to the applied N was observed in the soils of West Garo Hills, Ri-Bhoi and South Garo Hills. The N uptake in the soils ranged from 155 - 1171 mg pot^{-1} in control pots and 378 - 1567 mg pot^{-1} with the application of 150 kg N ha^{-1}. The response in terms of N uptake ranged from 28 - 171 percent due to application of N over the control. The effect of soils, N levels and the interaction between soils and nitrogen on DMY and N uptake was found to be significant. It was found that the relative yield (% Y) ranged from 52 - 88 % and the relative uptake (% U) varied from 37 - 78 %. Though some of the soils contained higher amount of available N, rice plants gave significantly higher yield and uptake response to the applied N fertilizers, which may be due to lower mineralization of N as influenced by soil and climatic conditions of the region. Lower response to externally added N may be due to wide variation in native soil fertility and accumulation of more organic matter in the valley areas, where the lowland paddy being extensively cultivated in the North Eastern states.

The ammoniacal N in the soils ranged from 28 - 207 kg ha^{-1} with a mean of 88 kg ha^{-1}. The soils of East Khasi Hills recorded higher amount of NH_4-N (82 - 207 kg ha^{-1}) followed by West Khasi Hills (57 - 188 kg ha^{-1}) and Jaintia Hills (69 - 132 kg ha^{-1}). Highest amount of NO_3-N (13.5 - 43.9 kg ha^{-1}) was recorded in the soils of East Khasi Hills followed by Jaintia Hills (15.7 - 37.6 kg ha^{-1}). The mineral N was found to be highest (119 - 213 kg ha^{-1}) in the soils of East Khasi Hills over the other districts. Ammoniacal N was the dominant fraction of mineral N and it constituted 80% of the mineral N in the rice soils of Meghalaya. Higher levels of ammoniacal and mineral N was observed in the soils of East Khasi Hills and Jaintia Hills, which may be due to application of higher doses of N fertilizers in rabi season for vegetable crops and subsequently its utilization by kharif paddy. Presence of higher organic matter (4.1 - 5.4 %) in these areas also favoured the retention of various inorganic and organic forms of N and mineralization of organic N into inorganic N fractions, led to higher amount of mineral N (Majumdar *et al*., 2002).

Table 2. Effect of nitrogen on dry matter yield and N uptake by rice

Location/ District	No. of soils	Dry matter yield (g pot^{-1})		Yield response (%)	Bray's % Y	N uptake (mg pot^{-1})		Uptake response (%)	Bray's % U
		N_0	N_{150}			N_0	N_{150}		
Ri-Bhoi	21	15.6-45.0 (27.4)	25.8-55.8 (39.0)	19.4-89.5 (47.8)	53-84 (69)	220-936 (446)	453-1503 (801)	37.8-170.1 (90.8)	37-73 (54)
Jaintia hills	6	22.9-28.9 (26.4)	30.0-35.6 (33.2)	13.8-44.0 (26.7)	69-88 (79)	505-683 (576)	790-938 (857)	37.2-58.0 (49.8)	63-73 (67)
East khasi hills	8	23.8-48.4 (32.7)	32.3-54.8 (39.9)	13.3-35.6 (23.4)	74-88 (81)	340-1171 (686)	516-1527 (955)	28.3-54.2 (41.3)	65-78 (71)
West khasi hills	6	19.1-43.9 (30.4)	31.7-51.7 (40.7)	17.7-67.7 (39.7)	60-85 (73)	400-1069 (677)	772-1465 (1093)	37.1-113.3 (69.0)	47-73 (60)
West garo hills	7	16.9-35.9 (23.0)	28.4-50.1 (39.1)	39.4-91.2 (70.5)	52-72 (59)	201-737 (321)	418-1262 (670)	71.2-170.8 (122.0)	37-58 (46)
South garo hills	5	13.7-26.7 (19.2)	24.8-37.3 (31.4)	27.1-90.4 (68.6)	53-79 (61)	155-470 (270)	378-809 (587)	72.1-150.9 (126.9)	40-58 (45)
CD (P=0.05) Soils	2.83			91.98					
CD (P=0.05) N levels	0.55			17.87					
CD (P=0.05) Interaction (SxN)	4.01			130.08					

Values in parentheses indicate the mean values

A wide variation in organic C content in the soils was observed which ranged from 0.61 - 5.28 % with a mean of 1.83 %. Out of 53 soils studied, 5 were medium in org. C (> 0.50 - 0.75 %) and the rest were high in org. C (> 0.75%) as per the ratings of Ghosh and Hasan (1980). Total N in the soils varied from 0.084 - 0.501 % with a mean of 0.276 % (Table 3). The available N as extracted by alkaline $KMnO_4$ showed medium in 30 soils (280 - 560 kg ha^{-1}), low in 18 soils (< 280 kg ha^{-1}) and high in 5 soils (> 560 kg ha^{-1}) and it constituted 5.65 % of the total N content of the soils which might be ascribed to lower mineralization of organic matter due to low temperature and other edaphic factors (Singh and Datta, 1988). The chromic acid oxidizable N recorded higher values of available N ranged from 1004 - 4390 kg ha^{-1} with a mean of 2663 kg ha^{-1}, which constituted 42.6 % of total N. The highest extractability of available N with dichromate might be due to oxidation of soil with 1.0 N $K_2Cr_2O_7$ followed by heat of dilution with conc. H_2SO_4, distillation with strong alkali (1.0 N NaOH) and boiling tend to cause more hydrolysis and dissolution of soil organic matter. These results are in agreement with the findings of Sharma and Sud (1980) and Laxminarayana and Rajagopal (2000). High amount of dichromate oxidizable N was observed in the soils of West Khasi Hills followed by Ri-Bhoi and East Khasi Hills. The available N as extracted by acid $KMnO_4$ ranged from 157 - 470 kg ha^{-1} (mean 313 kg ha^{-1}), whereas the H_2O_2 oxidation method recorded lowest values in comparison to other oxidation methods, ranged from 113 - 427 kg ha^{-1} with a mean of 265 kg ha^{-1}. Lower values of extractable N with this method might be due to instability of H_2O_2, which loses its activity on standing (Sahrawat, 1982).

Organic carbon had significantly higher relationship with all the N availability indices in the order of total N > alkaline $KMnO_4$-N > acid $KMnO_4$-N > NH_4-N > H_2O_2-N > $K_2Cr_2O_7$-N (Table 4). Since organic matter is the main source for total N and other N fractions and the extractants draw N from the organic pools, all the N availability indices showed positive and significant relationship with organic. C (Verma *et al*., 1980). Total N is the main pool for all N fractions and hence all the N extraction methods showed significant correlations with total N indicating that a part of the total N has been released by oxidative and hydrolytic action of these reagents. The available N extracted by all the oxidation methods were significantly correlated with organic. C, total N and NH_4-N, indicating that the available N extracted by these reagents included all mineral N and a part of organic N (Sahrawat, 1982). Among the various oxidation methods, alkaline $KMnO_4$ extractable N had highly significant relationship with H_2O_2-N ($r = 0.91^{**}$) > acid $KMnO_4$-N ($r = 0.89^{**}$) > ammoniacal N ($r = 0.79^{**}$) > $K_2Cr_2O_7$-N ($r = 0.91^{**}$).

Table 3. Inorganic N fractions and N availability indices in rice soils of Meghalaya

Location/ District (No.of soils samples)	Org. C (%)	Total N (%)	NH_4-N	NO_3-N	Mineral N	Alkaline $KMnO_4$-N	Acid $KMnO_4$-N	$K_2Cr_2O_7$-N	H_2O_2-N
						kg ha^{-1}			
Ri-Bhoi (21)	0.95-2.77 (1.45)	0.216-0.370 (0.272)	28.2-194.4 (69.9)	6.3-37.6 (20.6)	34.5-210.1 (90.5)	194-521 (303)	207-408 (282)	1568-4390 (3048)	151-414 (235)
Jaintia hills (6)	1.72-4.30 (2.37)	0.344-0.501 (0.406)	69.0-131.7 (97.2)	15.7-37.6 (26.1)	103.5-150.5 (123.4)	414-603 (494)	345-439 (393)	2258-4077 (3021)	301-408 (352)
East khasi hills (8)	1.55-5.28 (3.10)	0.339-0.496 (0.386)	81.6-207.0 (141.1)	12.5-43.9 (32.1)	119.2-213.2 (173.3)	301-583 (466)	326-452 (394)	2321-4140 (3065)	201-427 (318)
West khasi hills (6)	1.65-3.15 (2.47)	0.210-0.378 (0.303)	56.5-188.3 (98.8)	18.8-34.5 (25.1)	84.7-222.8 (123.9)	289-565 (406)	326-470 (392)	1066-4077 (2457)	263-408 (329)
West garo hills (7)	0.67-1.80 (1.24)	0.084-0.238 (0.148)	43.9-156.8 (72.6)	3.1-31.4 (15.2)	47.1-188.2 (87.8)	220-295 (254)	213-301 (252)	1066-2321 (1855)	100-263 (213)
South garo hills (5)	0.61-1.17 (0.76)	0.091-0.140 (0.109)	28.2-125.4 (79.7)	6.3-18.8 (11.9)	34.5-141.1 (91.6)	182-383 (253)	157-326 (212)	1004-2070 (1355)	113-307 (198)
Mean	1.83	0.276	88.3	21.95	110.2	350	313	2663	265
SEm (±)	0.14	0.014	6.56	1.39	7.04	16.7	11.2	119.4	11.5

Parentheses indicate the mean values

Table 4. Linear correlation coefficients (r) between inorganic N fractions and availability indices with soil properties

N availability index/ soil property	Org. C	Total N	NH_4-N	NO_3-N	Mineral N	Alkaline $KMnO_4$-N	Acid $KMnO_4$-N	H_2O_2-N	$K_2Cr_2O_7$- N
Org. C	-	0.79^{**}	0.59^{**}	0.32^{*}	0.62^{**}	0.74^{**}	0.71^{**}	0.59^{**}	0.52^{**}
Total N	0.79^{**}	-	0.47^{**}	0.49^{**}	0.54^{**}	0.77^{**}	0.78^{**}	0.63^{**}	0.71^{**}
NH_4-N	0.59^{**}	0.48^{**}	-	0.25	0.98^{**}	0.79^{**}	0.67^{**}	0.73^{**}	0.43^{*}
NO_3-N	0.32^{*}	0.49^{**}	0.25	-	0.43^{*}	0.41^{*}	0.44^{**}	0.43^{*}	0.32^{*}
Mineral N	0.61^{**}	0.54^{**}	0.98^{**}	0.43^{*}	-	0.81^{**}	0.71^{**}	0.77^{**}	0.46^{**}
Alkaline $KMnO_4$-N	0.74^{**}	0.77^{**}	0.79^{**}	0.41^{*}	0.81^{**}	-	0.89^{**}	0.91^{**}	0.57^{**}
Acid $KMnO_4$-N	0.71^{**}	0.78^{**}	0.67^{**}	0.44^{**}	0.71^{**}	0.89^{**}	-	0.83^{**}	0.54^{**}
H_2O_2-N	0.59^{**}	0.63^{**}	0.73^{**}	0.43^{*}	0.77^{**}	0.91^{**}	0.83^{**}	-	0.42^{*}
$K_2Cr_2O_7$-N	0.52^{**}	0.71^{**}	0.43^{**}	0.32^{*}	0.46^{**}	0.57^{**}	0.54^{**}	0.42^{*}	-
Clay	0.18	0.10	0.18	0.02	0.17	0.17	0.21	0.21	0.15
pH	-0.28	-0.44^{**}	-0.31^{*}	-0.29	-0.35^{*}	-0.44^{**}	-0.38^{*}	-0.39^{*}	-0.36^{*}

** and * Significant at 1 and 5 percent level, respectively

The NH_4-N, NO_3-N and other soil parameters (org. C, total N, pH and clay) contributed 83 % variation towards the alkaline $KMnO_4$ extractable N, while it was 82 % with the NH_4-N and total N and NH_4-N alone accounted for 62 % of the observed variation to the alkaline $KMnO_4$-N. However, NH_4-N and total N together accounted for 72, 51 and 64 % of the variation to the available N as extracted by acid $KMnO_4$, acid dichromate and hydrogen peroxide, respectively (Table 5). It was found that organic C alone contributed 59 % variation to the ammoniacal N, indicating that organic matter is the main pool for N and its availability depends on the mineralization as influenced by various soil parameters. The relative contribution of different inorganic N fractions and soil parameters towards the N uptake by rice indicated that 66 % of variation was accounted by NH_4-N, NO_3-N, total N, org. C, pH and clay content of the soil with a greater contribution from NH_4-N fraction (48 %). The results indicated that ammoniacal N is the major contributing fraction to the N nutrition of the crop and available N extracted by all the methods.

All the N availability indices were positively and significantly correlated with plant growth parameters (Table 6). The available N extracted by alkaline $KMnO_4$ showed highly significant relationship with Bray's per cent yield ($r = 0.78^{**}$) and per cent uptake ($r = 0.76^{**}$), indicating its superiority in N extraction over the other methods in the rice soils of Meghalaya, similar to the findings of Gupta *et al.* (1989). Acid $KMnO_4$ extraction method was also found to be equally good in these soils as it showed highly significant relationship with control yield ($r = 0.40^{*}$) and control N uptake ($r = 0.77^{**}$). Ammoniacal N showed highly significant relation with Bray's % Y, % U, control yield and control N uptake ($r = 0.62^{**}, 0.59^{**}, 0.41^{*}$ and 0.69^{**}, respectively), emphasizing its contribution in the N nutrition of rice crop. Significantly negative relationship was observed between N availability indices and percent yield/uptake response, indicating that the soils rich in available N gave lower yield and uptake response to the externally added N, whereas the soils low in available N have shown higher response in terms of yield and N uptake, which indicates that the soils low in available N responded more to applied N fertilizers than the soils with high status of available N.

The critical limit for organic C delineating high and low status in rice soils of the present study was found to be 1.70 % (Fig. 1). However, the critical limits for other chemical oxidation methods were derived as 320 kg ha^{-1} for alkaline $KMnO_4$-N (Fig. 2), 286 kg ha^{-1} for acid $KMnO_4$-N (Fig. 3), 2525 kg ha^{-1} for $K_2Cr_2O_7$ -N (Fig. 4) and 258 kg ha^{-1} for H_2O_2-N (Fig. 5).

Among all the N availability indices, alkaline $KMnO_4$ and acid $KMnO_4$ methods were found to be the best as they are strongly correlated with all the biological indices and can be adopted for routine analysis in the soil testing laboratories of this region. It is necessary that the existing fertility ratings needs to be modified as per the critical limits while recommending the N fertilizers for rice in Meghalaya

Table 5. Step down regression equations showing the relationship between inorganic N fractions and soil properties with N availability indices

Dependent variable	Regression equation	R^2
Alkaline $KMnO_4$-N	180.63 +1.29** NH_4-N + 0.38 NO_3-N + 9.20 Org. C + 502.44 Total N + 0.34 Clay – 24.98 pH	0.828**
	177.24 + 1.35** NH_4-N + 579.03** Total N – 22.72 pH	0.826**
	62.31** + 1.37** NH_4-N + 602.85** Total N	0.823**
	173.84** + 1.99** NH_4-N	0.617**
Acid $KMnO_4$-N	80.84 + 0.60** NH_4-N + 0.61 NO_3-N + 2.93 Org. C + 428.35** Total N + 1.20 Clay + 2.12 pH	0.736**
	95.76** + 0.62** NH_4-N + 472.50** Total N + 1.20 Clay	0.732**
	125.60** + 0.65** NH_4-N + 473.35** Total N	0.724**
	213.18** + 1.14** NH_4-N	0.442**
$K_2Cr_2O_7$-N	996.66 + 2.93 NH_4-N – 4.84 NO_3-N – 196.14 Org. C + 6861.32** Total N + 11.10 Clay – 68.52 pH	0.536**
	604.61 + 2.93 NH_4-N – 191.29 Org. C + 6679.06** Total N + 11.32 Clay	0.533**
	890.91** + 3.10 NH_4-N – 177.05 Org. C + 6599.62** Total N	0.527**
	958.39** + 2.07 NH_4-N + 5511.20** Total N	0.514**
H_2O_2-N	128.97 + 0.98** NH_4-N + 1.13 NO_3-N – 6.99 Org. C + 271.07* Total N + 1.26 Clay – 15.09 pH	0.669**
	85.90** + 0.98** NH_4-N + 1.20 NO_3-N + 241.48** Total N	0.657**
	96.27** + 0.98** NH_4-N + 297.12** Total N	0.641**
	151.24** + 1.29** NH_4-N	0.537**
NH_4-N	153.66 + 0.30 NO_3-N + 28.74** Org. C – 45.48 Total N + 0.58 Clay – 24.16 pH	0.619**
	134.38 + 0.20 NO_3-N + 25.51** Org. C + 0.61 Clay – 24.16 pH	0.617**
	160.51** + 26.69** Org. C – 25.77 pH	0.611**
	35.52** + 28.87** Org. C	0.592**
N uptake	-386.78 + 2.28** NH_4-N + 2.86 NO_3-N + 19.03 Org. C + 635.90* Total N + 10.20** Clay + 27.12 pH	0.659**
	-259.53** + 2.36** NH_4-N + 2.62 NO_3-N + 735.33** Total N + 10.39** Clay	0.656**
	-233.33** + 2.38** NH_4-N + 856.75** Total N + 10.25** Clay	0.646**
	21.00 + 2.61** NH_4-N + 864.06** Total N	0.583**
	180.86** + 3.50** NH_4-N	0.476**

** and * Significant at 1 and 5 per cent level, respectively

Table 6. Correlation coefficients (r) between inorganic N fractions and N availability indices with plant growth parameters

N availability index	Bray's % Y	Bray's % U	DMY (control)	N uptake (control)	Percent yield response	Percent uptake response
Org. C	0.61**	0.61**	0.29	0.63**	-0.59**	-0.56**
Total N	0.75**	0.74**	0.29	0.62**	-0.74**	-0.70**
NH_4-N	0.62**	0.59**	0.41*	0.69**	-0.61**	-0.55**
NO_3-N	0.51**	0.60**	0.15	0.39*	-0.53**	-0.57**
Mineral N	0.68**	0.66**	0.41*	0.72**	-0.68**	-0.62**
Alkaline $KMnO_4$-N	0.78**	0.76**	0.35*	0.75**	-0.77**	-0.72**
Acid $KMnO_4$-N	0.76**	0.74**	0.40*	0.77**	-0.75**	-0.72**
H_2O_2-N	0.68**	0.63**	0.37*	0.71**	-0.69**	-0.60**
$K_2Cr_2O_7$-N	0.49**	0.46**	0.26	0.47**	-0.50**	-0.45**

** and * Significant at 1 and 5 percent level, respectively

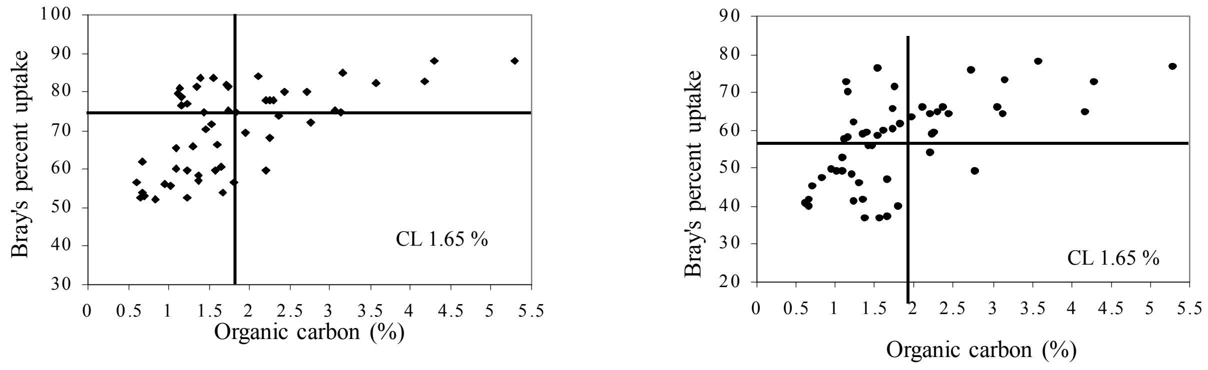

Fig. 1. Critical limit for organic carbon in rice soils

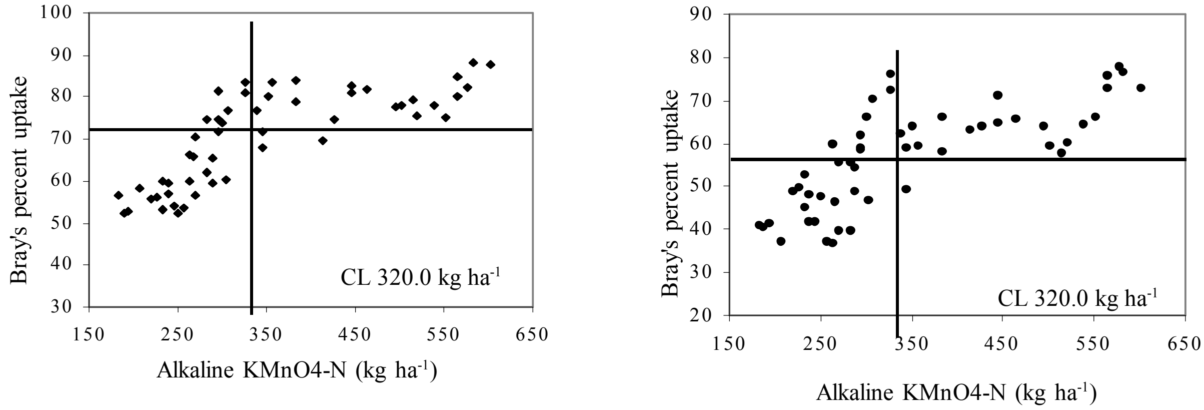

Fig. 2. Critical limit for alkaline KMnO4-N in rice soils

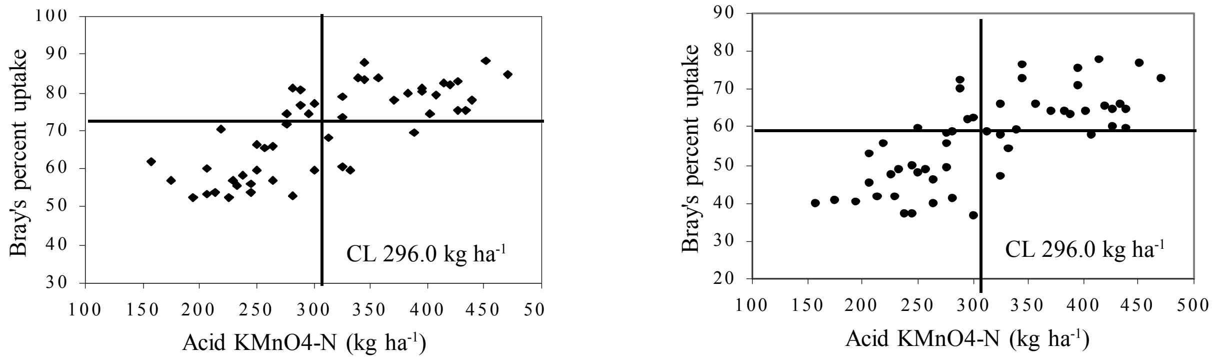

Fig. 3. Critical limit for acid KMnO4-N in rice soils

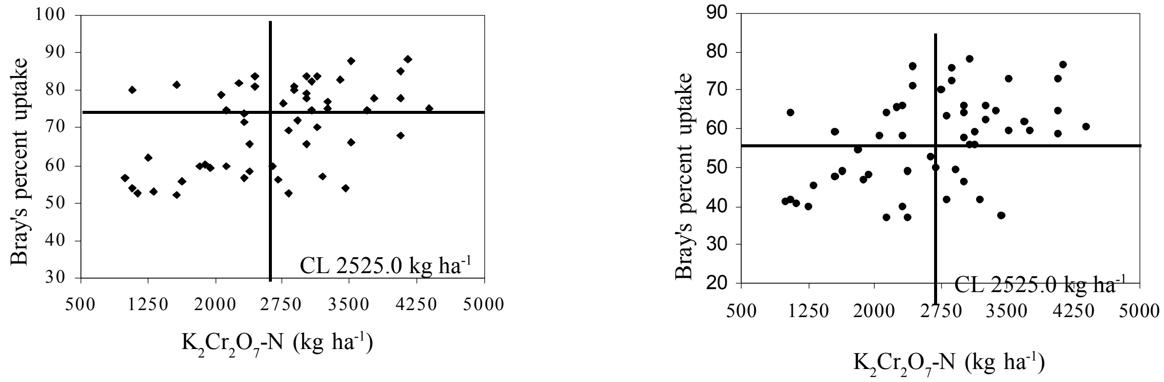

Fig. 4. Critical limit for dichromate oxidizable N in rice soils

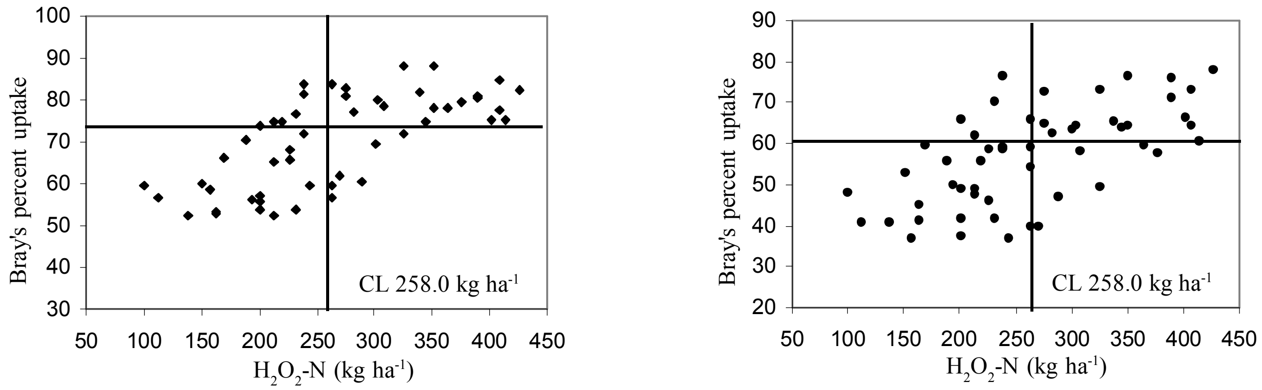

Fig. 5. Critical limit of H2O2-N in rice soils

in order to enhance the N use efficiency and to minimize the expenditure on fertilizer cost.

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