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A COMPARATIVE STUDY OF DIFFERENT METHODS FOR OBTAINING AN INDEX OF NITROGEN AVAILABILITY IN UPLAND SOILS

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A study on 50 soils with wide range of properties was conducted to find out a simple, rapid and reliable method of obtaining an index of soil N availability. Three chemical methods; mineral plus mineralizable N determination by modified alkaline permanganate method, mineral N as (NH_4 + NO_3) and NO_3-N estimation by 2 N KCl were found promising as the soil N values obtained by these methods showed high correlation with mineral N of incubation test (r = 0.92, 0.88 and 0.85, respectively) and N uptake by wheat plants (r = 0.90, 0.87 and 0.85, respectively). The relationship between yield response of wheat plants to applied N in pots and soil available N determined by the three methods was also studied.

Key words: Alkaline $KMnO_4$ extraction, Incubation, N uptake, Soil N availability.

Introduction

Despite more global serverity of plant available N deficiency problem than any other nutrient element, a well accepted method for its estimation is yet to be found. This is partially because nearly all soil N (97 to 99%) is present in very complex organic form which slowly becomes available to plants after conversion to inroganic forms through microbial decomposition of organic matter [1]. Making N fertilizer recommendations without knowing the N supplying capability of a soil can lead to inefficient use of N, less economical crop production and N pollution. To improve assessment of N fertilizer requirements there is need to find a method that will provide a satisfactory index of soil N availability and will permit reasonably accurate prediction of the amount of fertilizer N required to produce a desired crop yield. Therefore, several efforts in this regard have been made in the past and consequently many methods for assessing soil N availability have been proposed which have been reviewed by various authors [1-3]. Of these, the biological methods involving soil incubation have generally been considered relatively satisfactory [3]. However, major limitation of these methods is that they are time consuming. Therefore, scientists have long been searching for a rapid chemical method. To evaluate some of the important chemical methods and their modifications for assessing soil N availability, considerable work has been carried out in this laboratory [4-7].The results obtained so far showed the modifed alkaline-permanganate extraction to be a relatively rapid and raliable method for estimating available N in upland soils. A detailed study was carried out to further test this method alongwith other chemical and biological methods. Evaluation of the methods was made by comparing their performance in relation to yield and N uptake by wheat plants.

Proper calibration of a soil test value againts crop responses from the applications of nutrient in question is also required for its meaningful interpretation. A simplified approach involves plotting of relative or percentage yeild and the soil test value [8], and a suitable test makes it possible to separate soils in two groups, deficient and nondeficient [9]. Therefore, an attempt was made in this study to correlate the promising available soil N tests with yield response of wheat to N application in pots.

Materials and Methods

Soils. The study employed 50 soils (0-20 cm) with greatly varying properties which were collected from agricultural fields of 20 districts of Punjab, Pakistan (Table 1). The sampling area represented a broad range of climatic conditions; irrigated plains, rainfed lands and wet mountains.

Irrigated plains cover areas between Sutlej and Jhelum rivers; different flood plains and bar uplands; climate semiarid to arid, subtropical continental; mean daily maximum and minimum temperatures 39.5 and 6.2°, respectively in the east and 41-42 and 6°, respectively in the southwest; mean annual rainfall 300-500 mm in the east and 200-300 mm in the southwest; canal irrigated agriculture. Rainfed lands cover Salt Range, Pothowar Plateau and the Himalyan Piedmonts plains; nearly humid, mean daily maximum and minimum tempeatures 38.5 and 3-6°, respectively; mean monthly rainfall 200 mm in summer and 36-50 mm in winter; rainfed agriculture. Wet mountains cover high mountains and plateaus, humid with mild summers and cold winters; mean daily maximum and minimum temperatures 35 and 0-4°, respectively; mountain tops snow clad in winter and spring; mean

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monthly rainfall 236 mm in summer and 116 mm in winter; 25% of the area under rainfed agriculture, the rest under forest [10].

The soil samples were air dried soon after collection from the field, crushed and passed through a 2 mm screen. The soils were analysed for various properties (Table 1).

TABLE 1. THE LOCATION, AGRO-ECOLOGICAL ZONE AND PROPERTIES OF THE SOILS.

Soil No.	Location	Agro-eco-logical	Previous cropping zone	pH	EC[a]	$CaCO_3$ equiv. (%)	OM[b] (%)	Nitrogen NH_4 (mg/kg)	NO_3 (mg/kg)	Total (%)	P[c] (mg/kg)	Clay (%)	Texture[d]
	FAISALABAD												
1.	Jhopal	IP[e]	Fallow	7.7	1.90	6.55	0.57	0.0	40.7	0.042	4.4	22.5	SCL
2.	Chak 263/RB, Dajkot	IP	Maize	7.7	0.60	4.55	1.15	3.5	8.5	0.077	2.3	23.4	CL
3.	AARI Fruit Plant Nursery	IP	Mango orchard (standing crop)	7.6	0.80	4.70	3.35	2.8	16.2	0.171	139.9	19.4	SCL
4.	Ghausia Nursery, Mall Road	IP	Flowering plants	7.4	1.00	4.60	2.44	1.4	42.1	0.140	47.4	21.8	CL
	TOBA												
5.	Chak 18	IP	Wheat-fallow	7.4	2.54	7.45	0.77	1.1	25.0	0.056	4.6	26.7	LC
6.	Chak 335/GB	IP	Wheat-fallow	7.5	2.60	7.70	1.36	0.0	33.0	0.074	23.4	26.8	LC
	SAHIWAL												
7.	Chak 187	IP	Cotton-fallow	7.6	1.59	6.00	0.96	0.7	35.1	0.069	4.8	16.2	SCL
8.	Chak 217/EB	IP	Maize	7.8	1.18	9.65	1.40	1.1	8.2	0.061	4.9	13.8	SL
	VEHARI												
9.	Chak 5/WB	IP	Wheat-fallow	7.8	8.90	9.50	1.17	2.1	64.5	0.078	7.1	24.4	CL
10.	Chak 155/WB	IP	Sorghum	7.8	4.50	12.30	1.50	4.2	21.8	0.085	6.4	29.8	LC
	MULTAN												
11.	17 Kassi	IP	Sorghum	7.8	0.80	5.95	1.36	4.9	13.4	0.090	2.9	26.6	LC
12.	Goyal Pur	IP	Sorghum	7.8	1.19	6.75	1.89	3.5	15.5	0.113	5.4	29.8	LC
13.	Moza Habib Mun	IP	Sorghum	7.7	0.90	9.00	1.33	2.1	8.5	0.079	2.9	21.2	CL
14.	Moza Ghulam Nar	IP	Sorghum	7.8	0.60	6.60	0.93	1.4	5.7	0.055	3.1	22.2	SCL
	RAHIM YAR KHAN												
15.	Moza Trinda	IP	Sorghum	7.8	2.00	10.00	1.70	1.4	2.6	0.112	3.8	43.0	LC
	MIR KHAN												
16.	Mahmood Kot	IP	Sugarcane–sorghum	7.6	2.21	9.45	1.03	1.8	19.0	0.070	2.5	22.6	CL
	MUZAFFAR GHAR												
17.	Basti Imam Wala	IP	Sorghum	7.7	0.50	11.65	1.65	3.9	5.7	0.098	6.1	36.5	LC
18.	Moza Chak Godar	IP	Sorghum	7.9	1.21	8.25	0.68	1.1	3.6	0.037	1.7	13.0	SL
	RAJANPUR												
19.	Wasti Rindan	IP	Maize-fallow	7.9	1.22	8.20	1.46	3.5	9.9	0.065	4.4	17.0	SCL
20.	Kot Tahir	IP	Sorghum	7.8	1.40	12.35	1.20	3.5	5.0	0.065	3.1	23.0	CL
	JHANG												
21.	Moza Dhoriwala	IP	Sorghum	7.6	0.60	11.15	1.44	4.2	15.9	0.096	1.9	32.2	LC
22.	Moza Venokah	IP	Sorghum	7.8	0.78	8.25	1.52	1.8	13.4	0.094	4.6	26.2	LC
	SARGODHA												
23.	Chak 107 Jannobi	IP	Maize	7.4	3.95	5.40	1.46	1.1	71.2	0.097	6.4	24.4	CL
24.	Chak 18 Shumali	IP	Sugarcane	7.8	0.71	6.20	0.82	2.1	11.0	0.049	3.4	17.4	SCL
	GUJRAT												
25.	Gojra Town, Phalia	IP	Wheat-fallow	7.6	0.40	2.60	1.22	3.5	8.9	0.084	7.6	46.4	C

(Continue...)

(Table 1, continued)

26. Basti Dhol Rajian Da,	IP	Sorghum	7.4	0.60	2.35	1.58	3.5	19.4	0.107	10.4	45.4	C
PHALIA												
27. Charan Wala, Phalia	IP	Wheat-fallow	7.5	0.60	2.20	1.12	4.9	11.3	0.072	3.5	21.4	SCL
SIALKOT												
28. Malkan Da Daira	IP	Rice	8.0	0.55	5.05	0.94	4.2	6.4	0.055	5.3	14.2	L
29. Kotli Haji Pur	IP	Rice	7.7	0.72	3.00	0.73	6.3	14.8	0.128	5.8	42.2	LC
30. Kotli Kurlan Di	IP	Rice	7.7	1.21	3.15	1.76	3.5	16.9	0.118	8.8	36.6	LC
31. Area of Ghlotian	IP	Rice	7.8	0.80	3.70	1.23	7.0	15.5	0.076	6.2	29.0	LC
GUJRANWALA												
32. Pind Roop	IP	Rice	7.6	0.83	2.15	1.14	6.0	13.7	0.071	5.6	19.0	SCL
33. Kot Mian	IP	Rice	7.8	1.50	4.05	1.24	4.6	11.0	0.066	6.7	17.4	SCL
SHEIKHUPURA												
34. Chuharkana	IP	Maiz	8.1	0.50	3.75	0.85	2.5	12.4	0.052	3.5	17.4	SCL
35. Pind Nabi Pur	IP	Rice	7.4	0.41	1.85	1.27	3.5	7.5	0.081	4.8	21.4	SCL
LAHORE												
36. Basti Araian Wala	IP	Sorghum	7.6	0.80	5.50	1.33	4.6	8.9	0.081	5.8	24.2	SCL
37. Baddo Ke		Sorghum	7.6	0.43	2.45	0.88	3.9	6.1	0.058	1.7	20.2	SCL
QASOOR												
38. Tulvandi, Chunian	IP	Rice	7.7	1.81	8.40	1.25	0.7	13.4	0.084	23.5	36.6	LC
39. Meer Kot	IP	Rice	7.7	1.00	6.70	1.08	2.8	11.7	0.060	17.1	15.6	SCL
OKARA												
40. Basti Hansan	IP	Sorghum	7.7	0.57	6.55	1.22	0.7	1.9	0.086	3.3	36.0	LC
41. Chak 40 D, Dipalpur	IP	Sorghum	8.2	1.60	10.35	1.08	0.4	13.4	0.071	2.8	23.6	CL
D. G. KHAN												
42. Basti Mulana	IP	Sorghum	7.9	1.40	11.25	0.91	2.5	2.9	0.056	4.1	26.6	SC
43. Basti Moza Yare Wali	IP	Sorghum	8.1	5.40	12.35	1.02	3.5	3.6	0.064	4.6	39.6	LC
RAWALPINDI												
44. Dhok Chiari Dalal	RFL[f]	Sorghum	7.5	0.35	12.30	0.91	3.2	4.3	0.064	2.3	24.8	CL
45. Barani College	RFL	Sorghum	7.5	0.40	2.20	1.23	1.8	3.6	0.090	1.5	21.4	CL
JHELUM												
46. Dhok Mohal	RFL	Millet	7.7	0.35	2.25	0.61	3.5	3.3	0.041	4.4	12.4	SL
47. Purana Sohawa	RFL	Millet	7.8	0.25	8.05	0.54	3.2	2.9	0.032	1.8	8.8	SL
MURREE												
48. Sugarcane Res. Station, Charral Pani	WM[g]	Sugarcane	7.4	0.42	4.95	2.40	6.7	15.5	0.112	26.3	31.4	LC
49. Sanitorium	WM	Maize	7.5	0.60	12.45	3.00	4.6	14.5	0.156	9.2	27.4	LC
50. Ghora Gali	WM	Maize	7.5	0.52	12.45	2.69	5.6	11.7	0.131	16.9	16.4	SCL

a. Electrical conductivity of saturation extract, b. Organic matter, c. $NaHCO_3$-extractable phosphorus, d. SCL, CL, LC, SL, C, L, SC refer to sandy clay loam, clay loam, loamy clay, sandy loam, clay, loam and sandy clay, respectively, e. Irrigated plains, f. Rainfed lands, g. Wet monutains.

Chemical methods of measuring soil available N. Organic matter contents of the soils were determined by dichromate oxidation [11] and total N by salicylic acid-thiosulphate modification of Kjeldahl method [12]. Mineral N (NH_4 and/or NO_3) of the soils was estimated by steam distillation method using MgO and Devarda alloy [13].

Modified alkaline-permanganate method that ensured the inclusion of soil nitrate [14] was used to estimate mineral plus mineralizable N in soils. The method involved two-stage distillation as follows: 4 g soil sample was placed in 500 ml flat bottom flask and 20 ml of 0.32% $KMnO_4$ solution and 2.5% NaOH solution were added. It was connected to the distillation apparatus and 50 ml of the distillate was collected in 5 ml of boric acid-indicator mixture. The flask was then disconnected and contents were cooled. 1/2 g Devarda alloy was then added to the flask and further distillation was done until another 50 ml distillate was collected. Ammonium-N in the distillate was determined by titrating it against 0.005 N H_2SO_4.

Biological method of measuring soil available N. The method involved aerobic incubation of soils. Triplicate soil samples (50 g) were placed in plastic vessels with lids having a central hole to provide gaseous exchange. Soils were brought to 75% field capacity with deionized water and incubated at 30± 1° for 4 weeks. Soil moisture was maintained at 75% field capacity throughout. At the end of the incubation period, the soils in vessels were thoroughly mixed and subsamples were analysed for mineral N [13].

Pot culture. Wheat (*Triticum aestivum* L.) was used as a test crop for correlation and calibration of N availability tests. Triplicate 1.5 kg samples of each soil were weighed into plastic pots lined with polythene bags. Nitrogen was applied as $(NH_4)_2SO_4$ at the rate of 40 kg ha^{-1} to each soil except control. All the pots received a basal dressing of P at the rate of 17.5 kg ha^{-1} as KH_2PO_4. Soils were brought to field capacity with deionized water. Nine seeds of wheat (cv. Blue silver) were sown in each pot and the stand thinned to 5 seedlings thereafter. Soil moisture was maintained daily, at field capacity, throughout the plant growth period. Plants were cut at the soil surface 40 days after germination, oven dried (70° for 48 hrs) and weighed. Total N in the ground plant material was determined by a semi-micro Kjeldahl procedure [15].

Results and Discussion

Relationship of dry matter yield and N uptake by wheat with soil available N measured by different methods. Mineral N of soils after 4 weeks of incubation ranged from 11.5 to 94.8 mg kg^{-1} soil, organic matter content, 0.54 to 3.35%; NO_3-N, 1.9 to 71.2; $(NH_4 + NO_3)$-N, 2.6 to 72.3 and mineral plus mineralizable N (by modified alkaline permanganate method), 60.1 to 149.4 mg kg^{-1} soil. All the methods indicated a wide range in N availability across the experimental soil samples. Comparison of different biological and chemical methods to obtain soil N availability index in relation to dry matter yeild and N uptake by wheat plants has been made in Table 2. Mineral N of incubation test showed high correlation with wheat dry matter yield (r = 0.88) and N uptake (r = 0.96, Fig. 1). The results confirmed aerobic soil incubation to be a fairly reliable method for assessing available soil N. This method has a reasonable basis because of similarity in factors responsible for release of mineral N and conversion of organic N to available N during plant growth. However, this method has a big demerit in that it consumes more time. A previous study carried out in this laboratory on 35 soils revealed that at least 4 weeks soil incubation is required to obtain meaningful results [16].

TABLE 2. CORRELATION COEFFICIENTS FOR INDEXES OF N AVAILABILITY VS. DRY MATTER YIELD AND N UPTAKE BY WHEAT (N= 50).

Measure of available N	Correlation coefficient (r)	
	Dry matter	N uptake
BIOLOGICAL		
1. Mineral N of aerobic incubation	0.88**	0.96**
CHEMICAL		
1. Mineral plus mineralizable N by modified alkaline permanganate method	0.83**	0.90**
2. Mineral N as (NH_4+NO_3) by 2 N KCl	0.68**	0.87**
3. Mineral N as NO_3 by 2 N KCl	0.65**	0.85**
4. Total N	0.62**	0.51**
5. Organic matter	0.59**	0.46**

** Significant at P<0.01.

Of the chemical methods tried, mineral plus mineralizable N by modified alkaline-permanganate method most closely correlated with wheat dry matter yield (r = 0.83) and N uptake (r = 0.90, Fig. 2). Soil N values obtained by this method also showed high correlation with the mineral N of incubation test (r = 0.92). The results confirmed our previous findings [7]. The modified alkaline-permanganate method has been shown to provide better estimate of the available N in upland soils becuase it involves two measurements (i) readily mineralizable N and (ii) instantly available N [14]. The method is rapid and easy to run and has been widely used for assessing available N pool in soils, especially in India [14].

Mineral N as NH_4 plus NO_3 extracted by 2 N KCl appeared as second best chemical index of available N as its

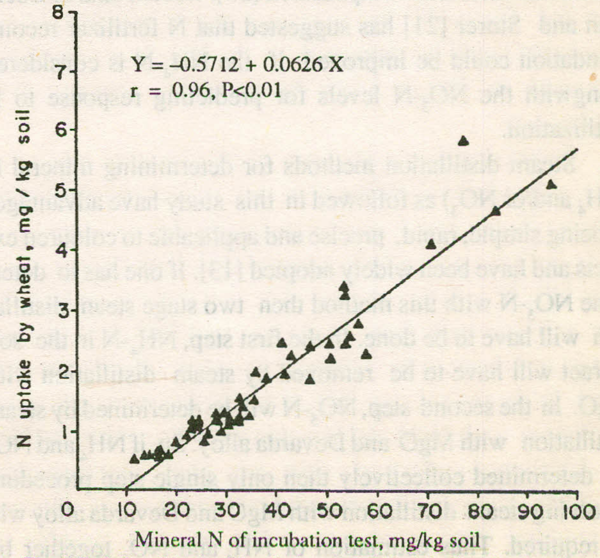

Fig. 1. Relationship, for 50 soils, between N uptake by wheat and mineral N produced on aerobic incubation of soils at 30±1° for 4 weeks.

correlation with the N uptake by wheat plants was also high (r = 0.87, Fig. 3). Correlation between this index and incubation test was also good (r = 0.88). The results indicated the worth of this method for available soil N estimation. McCracken *et al.* [17] working on soil N availability indexes (biological and chemical) found KCl-extractable (NH_4 + NO_3)-N as the best index for predicting soil N availability to corn. Similar results have been reported by other investigators for crops like wheat, potatoes and sugar beet [18].

Mineral N as NO_3 extracted by 2 N KCl also showed good correlation with N uptake by plants (r = 0.85, Fig. 4) and the value obtained was close to that obtained with (NH_4 + NO_3)-N. The index also correlated well with the incubation test (r = 0.85). In the recent years, NO_3-N test has been reported by many investigators as a good predictor of soil N availability to crops like corn [17,19,20]. Keeney and Nelson [13] reported that 13 States in USA are currently measuring NO_3-N content in their soil testing laboratories and utilizing these values in making N fertilizer recommendations.

Soil nitrate test is being used more widely for making nitrogen fertilizer recommendations [21]. The literature seldom refer to the NH_4-N content of soil. Although the amount of residual mineral N as NH_4 found in most soils is low [22] and inclusion of KCl-extractable NH_4-N results in negligible improvement in correlation over KCl-extractable NO_3-N alone [17] but still researchers have pointed out that NH_4-N could also be considered alongwith NO_3-N to predict soil N availability [22]. Kansas State University uses N test which includes NO_3-N plus NH_4-N [1]. In case of cool spring soils particularly where nitrification is likely more inhibited than is mineralization, inclusion of NH_4-N with NO_3-N in routine soil analysis, to make fertilizer N recommendation for winter wheat, has been much emphasized [23]. Recent data of Lockman and Storer [21] has suggested that N fertilizer recommendation could be improved if the NH_4-N is considered alongwith the NO_3-N levels for predicting response to N fertilization.

Steam distillation methods for determining mineral N (NH_4 and/or NO_3) as followed in this study have advantages of being simple, rapid, precise and applicable to coloured extracts and have been widely adopted [13]. If one has to determine NO_3-N with this method then two stage steam distillation will have to be done. In the first step, NH_4-N in the soil extract will have to be removed by steam distillation with MgO. In the second step, NO_3-N will be determined by steam distillation with MgO and Devarda alloy. So, if NH_4 and NO_3 are determined collectively then only single step procedure involving steam distillation with MgO and Devarda alloy will be required. Thus estimation of NH_4 and NO_3 together by steam distillation procedure is rather more easy and rapid than

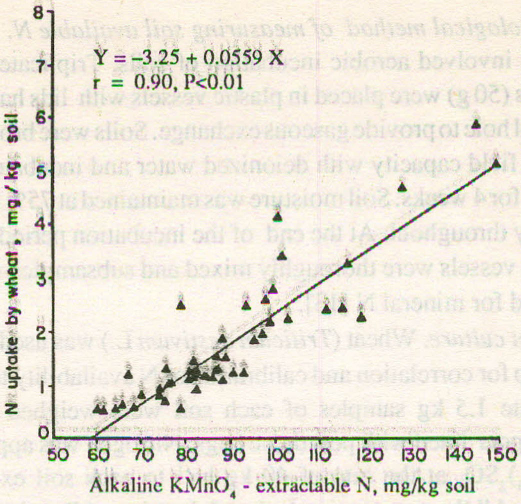

Fig. 2. Relationship, for 50 soils, between N uptake by wheat and available soil N estimated by modified alkaline-permanganate method.

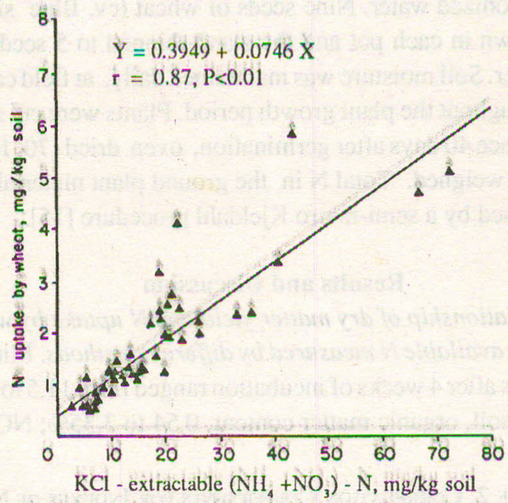

Fig.3. Relationship, for 50 soils, between N uptake by wheat and available soil N estimated as (NH_4 +NO_3)-N by 2 N KCl.

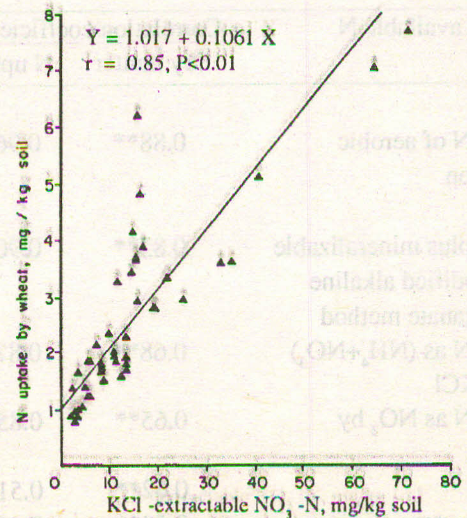

Fig. 4. Relationship, for 50 soils, between N uptake by wheat and available soil N estimated as NO_3-N by 2 N KCl.

that of NO_3 alone. Ease in determination of $(NH_4 + NO_3)$ -N favours this method for obtaining an index of soil N availability.

Correlation of soil total N and organic matter vs dry matter yield and N uptake was significant but lower as compared to other chemical measures of soil available N. Chemical methods involving determination of total N and organic matter have been found to be of little value [24,.25]. Under conditions where soil organic matter is low (<1%, like that of Pakistan), soil organic matter is not a good measure of available N [26].

Relationship between yield response of wheat to applied N and soil available N measured by different methods. Using Cate-Nelson graphical technique, when soil N values obtained by the three promising methods were plotted against percentage dry matter yield (yield of -N/yield of +N x 100),

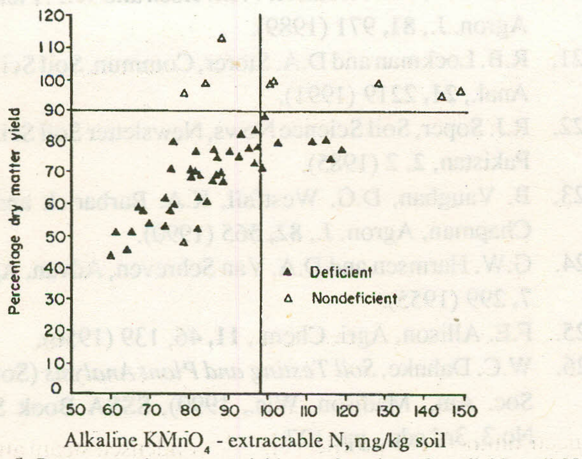

Fig. 5. Percentage dry matter yield as a function of available soil N estimated by modified alkaline permanganate method.

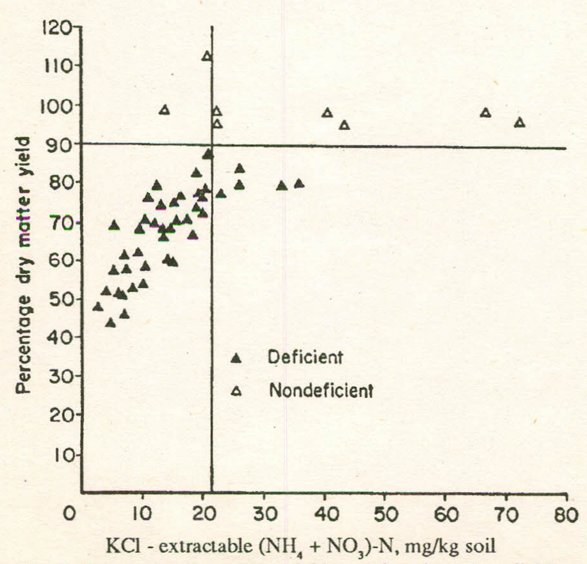

Fig. 6. Percentage dry matter yield as a function of available soil N estimated as $(NH_4 + NO_3)$-N.

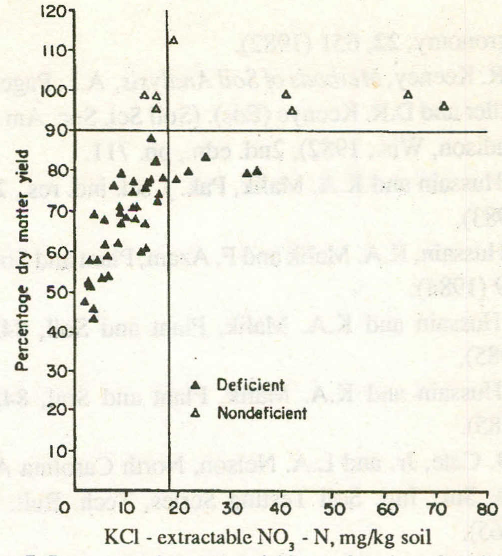

Fig. 7. Percentage dry matter yield as a function of available soil N estimated as NO_3 - N.

$(NH_4 + NO_3)$- and NO_3-N estimation methods separated deficient from nondeficient soils more clearly than the method involving determination of mineral plus mineralizable N (Figs. 5-7). Percentage yield of 90 was used as the horizontal critical level as this best partitioned soils into the upper right and lower left quadrant i.e., nondeficient and deficient soils, respectively, which is the objective of the Cate-Nelson procedure. About 98, 21 and 18 mg N/kg soil appeared to be the critical levels of alkaline $KMnO_4$-extractable-N, KCl-extractable (NH_4+NO_3)-N and KCl-extractable NO_3-N, respectively.

Overall results of the present study revealed that, of the chemical methods tried, the three methods; mineral plus mineralizable N determination by modified alkaline-permanganate method, $(NH_4 + NO_3)$- and NO_3-N estimation by 2 N KCl hold considerable promise for providing good indexes of available N in upland soils. It also appears that these methods could work on most alkaline calcareous soils because soils under different crops and with greatly varying properties were used in the studies. The critical levels as determined in the pot study, though may not be directly applicable to field conditions yet they could provide a good basis for further research and interpretations. Field studies on these promising N availability tests using different upland crop species are now warranted to establish critical levels of available N in the field.

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