Assessment of Soil N, P, and K Status of Selected Paddy Growing Areas of Tanzania

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Abstract

Suitable diagnostic criteria to assess the N, P and K status of rice growing areas particularly in developing countries like Tanzania are required. The objective of this study was to develop such criteria in selected rice growing areas of Tanzania and relate nutrient levels to rice response to fertilizer application. Soil samples from 10 paddy growing areas of Tanzania were tested for N, P and K using selected indices. Nitrogen supply was assessed by organic carbon (OC), total N and alkaline-$KMnO_4$-N while P was assessed by Olsen, Bray-1 and the iron oxide coated-filter paper strip (Pi) methods. Potassium was extracted by neutral 1N NH_4OAc. Extractable nutrients were correlated with DM yields and nutrient uptake from a glasshouse experiment which was also used to assess response of rice to these nutrients. Of the three N indices evaluated, only OC correlated significantly ($r = 0.73$, $P < 0.05$) with rice DM yield thus serving as a good index of N supply. As for P indices, Olsen P gave a highly significant correlation with rice DM yield ($r = 0.85$, $P < 0.01$) while the relationships with the other two methods gave lower correlation coefficients. All the soils tested were deficient in N and thus no critical level for N could be established while six soils out of 10 were deficient in P. The critical soil P level for Olsen method was estimated to be 20 mg/kg. The extracted K values were all found to be higher than critical values established elsewhere. Therefore, N and P are important constraints to rice production in Tanzania and appropriate recommendations should be drawn and demonstrated to farmers.

Key words: Suitable diagnostic, criteria, indices, correlation

Introduction

The nutrient deficiency problems frequently encountered in rice cropping systems are those due to N and P (De Datta, 1981) and to a lesser extent K particularly after long periods of cultivation (Kemmler, 1980). Of the three nutrients, nitrogen is considered to be the most important in rice production and its deficiency limits rice yields Worldwide (Buresh and De Datta, 1991). Phosphorus, on the other hand, is the most limiting nutrient in rice production only in some soil types (Patnaik, 1978; Jones *et al.*1982). Jones *et al.* (1982) considered P deficiency to be the most important factor limiting rice yields in Ultisols, Oxisols, Sulfaquepts and some Vertisols.

Despite the realisation that N and P deficiencies are important constraints to rice production in most soils, there are still no suitable indices for testing the availability of these nutrients in different soil types where rice is grown (Sanchez, 1976; IRRI, 1992). Properly calibrated soil test methods are required so as to develop appropriate fertilizer recommendations which will lead to efficient use of fertilizers and reduce risks of polluting underground water (Beringer, 1985; Cabrera and Kissel, 1988). Earlier work has, in some cases, given contradictory results regarding N and P indices. For instance, Singh *et al.* (1976) and Bajaj *et al.* (1967) found alkaline-$KMnO_4$ N to be a suitable index for assessing N availability in some soils of Tanzania and India, respectively. Other works e.g. Singh and Tripathi (1970) and Sahrawat (1983), found OC and total N to be suitable indices for assessing N availability in soils of India and Philippines, respectively.

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Semoka *et al.* (1996), on the other hand, obtained poor correlation between OC and rice DM yield suggesting that it was not a good index of N availability for the soils tested. With regard to P, Semoka *et al.* (1996) suggested the use of Pi method in assessing P availability in rice soils of Morogoro and Kilosa districts of Tanzania.

Since soil test data varies with environmental conditions (Beringer, 1985), it is apparent that method(s) specific to certain conditions are needed to effectively evaluate the available quantity of a particular nutrient in the soil and relate this quantity to the fertilizer requirement of the crop. The objectives of the present study were:

- to assess the suitability of selected indices of N, P and K for use in testing soils from selected rice growing areas of Tanzania;
- to identify nutrient deficiencies in these soils and;
- to assess the response of rice to application of these nutrients.

Materials and Methods

Bulk composite soil samples from the top 0 to 20 cm were collected from ten important rice growing areas of Mbeya, Morogoro and Coast regions of Tanzania. The composite samples were air dried and ground to pass through an 8 mm sieve for glasshouse experiment. A subsample of one kg from each location was ground to pass through a 2 mm sieve and used for laboratory analyses.

Soil analysis

The soils were analysed for soil pH (Peech, 1965), cation exchange capacity (CEC), and exchangeable Potassium (K), Calcium (Ca), Magnesium (Mg) and Sodium (Na) (Chapman, 1965). Particle size distribution was determined by hydrometer method as described by Day (1965) and the textural class by USDA textural class triangle (USDA, 1975). The soil N status was assessed by organic carbon (Allison, 1965), total N (Bremner, 1965) and alkaline $KMnO_4$ (Subbiah and Asija, 1956). The first two indices are standard methods recommended for routine soil analysis in Tanzania, while alkaline $KMnO_4$ method has been found to work well in a number of soils (Singh and Tripathi, 1970). The extractable P was assessed by the Olsen (Olsen *et al.*, 1954), Bray-1 (Bray and Kurtz, 1945) and filter paper strip (Pi) (Menon *et al.*, 1989a) methods. The physico-chemical properties of the selected sites are given in Table 1.

Table 1: Some physico - chemical properties of the soils used in pot experiment

Location	pH	Exc. basesh (cmol(+) kg^{-1})				CEC (cmol(+) kg^{-1})	TC[1]	Soil Classification
	(H_2O)	Ca^{2+}	Mg^{2+}	Na^+	K^+			
Kilangali[a]	4.9	6.76	3.90	0.39	0.47	19.4	C	Vertic Cambisols*
Mlali[a]	5.9	8.67	6.12	0.56	0.37	19.4	CL	Eutric Fluvisols*
Mkindo[a]	5.8	3.39	0.67	0.24	0.21	7.7	SCL	Gleyic Cambisols*
Mgomba[a]	5.6	9.05	5.93	0.73	1.19	24.1	C	Vertic Fluvisols*
Kigongoni[b]	5.5	12.25	9.55	2.70	0.60	40.6	C	-
Ruvu A[b]	5.6	9.08	7.16	0.70	0.69	31.9	C	-
Ruvu B[b]	5.9	8.75	5.64	0.75	0.26	24.4	C	-
Majengo[c]	5.7	6.55	1.96	0.44	1.07	15.9	CL	-
Malenga[c]	5.5	1.55	0.69	0.43	0.35	8.2	C	Vertic Cambisols
Kapunga[c]	6.7	5.37	0.53	2.03	1.05	9.5	C	-

1 = Textural Class, C = clay; CL = clay loam ; SCL = sand clay loam; a = soils From Morogoro region, b = from Coast region, c = from Mbeya region; * = JICA (1996) interim report on irrigation projects of central Wami river basin,

Glasshouse experiment

Rice (*Oryza sativa* L) cultivar Super India, that is commonly grown in the sampled areas, was used as a test crop in all soils. Four kilogramme portions of each soil were weighed into clean five litres plastic pots. The plastic pots had drainage holes at the bottom which were plugged with cotton wool to prevent soil loss. Appropriate quantities of P were thoroughly mixed with the soil samples before sowing. Four treatments namely: an absolute control, a control for P where 200 mgN /kg was applied, a treatment with both N and P and finally one with N, P and K. Phosphorus and K were each applied at a rate of 50 mg/kg. The four treatments were designated as N_0P_0 , $N_{200}P_0$, $N_{200}P_{50}$, and $N_{200}P_{50}K_{50}$,respectively. The subscript numbers on the nutrients indicate the rates of the different nutrients in mg/kg soil added to the soil. The treatments were replicated three times and arranged in a randomized complete block design in the glasshouse. The fertilizers used were: monocalcium phosphate ($Ca(H_2PO_4)_2.H_2O$) as a source of P , sulphate of ammonia ($(NH_4)_2SO_4$) as a source of N and K_2SO_4 to supply K.

The soils were moistened to field capacity and allowed to equilibrate for two days. Then 10 pre-germinated seeds were transplanted to each pot and the seedlings were thinned to 5 plants/pot fourteen days after planting (DAP). Water content was maintained at field capacity for the first 21 DAP after which the pots were flooded soon after the first N dose of 400 mg N/pot was applied. The second equivalent N dose was applied at 36 DAP. Shoots were harvested at 51 DAP, which is comparable with a number of other glasshouse studies (Eemoka et al. 1996), by cutting at 1 cm above the soil surface. The shoots were washed in 0.5N HCl and rinsed twice in distilled water, dried in an oven at 65°C to constant weight and weighed to obtain DM yield. The samples were then chopped into small pieces and ground using a cyclone sample mill with stainless steel blades to a fineness < 1 mm for plant analysis.

Plant analysis

Plant samples were digested using the wet digestion procedure described by Okabelo *et al.* (1993) with the following modification: nine ml (instead of 4.4) of the digestion mixture were added to 0.3 g of the ground plant samples and digested at 360°C for 1.5 h. One drop of hydrogen peroxide was added to samples that had not become colourless and heated for a few minutes to clarify. After cooling, 25 ml of distilled water were added to dissolve sediments. The volume was made up to 100 ml ready for the analysis of N and P. Nitrogen in the digests was determined by steam distillation and titration (Okalebo et al., 1993) while P content was determined colorimetrically (Murphy and Riley, 1962).

Data analysis and interpretation

The DM yield response to N and P application and the uptake of N and P by rice plants were analysed statistically using the Statigraphics programme and means were compared using Duncan's multiple range test. Percentage yield was calculated to estimate the response to N and P using the following formula defined by Sanchez (1976).

$$\%yield = \frac{DM\ \ yield\ of\ the\ control \times 100}{DM\ \ yield\ of\ treatments\ for\ the\ nutrient(s)}$$

It should be noted that whenever the response to a certain nutrient was evaluated, all other nutrients suspected to be deficient were applied at optimum levels.

The selection of a suitable method for assessing the availability of N and P was based on simple correlation relationships between yields of the control treatments and the extractable nutrients by different methods. The graphical method of Cate and Nelson (Cate and Nelson, 1965) was used to estimate the critical level of a particular nutrient using a particular method.

Results and Discussion

N supply and rice response to N application

The N contents of the soils using the three indices tested are given on Table 2. The total N values fell in the very low to low levels on the basis of ratings recommended by Landon

Table 2: Soil nitrogen contents (N) determined by three indices together with rice drymatter yield and percent yield data

Location	Total N (%)	Organic C (%)	Alkaline $KMnO_4$-N (mg/kg)	Drymatter yield Absolute control	DM yield for N treatment	Percent yield of absolute control
Kilangali	0.13	1.59	257.6	5.5	23.6	23
Mlali	0.19	2.49	257.6	5.9	18.5	32
Mkindo	0.08	1.49	128.8	3.9	19.6	20
Mgomba	0.18	2.04	257.6	4.1	25.7	16
Kigongoni	0.12	1.31	386.4	2.2	13.5	16
Ruvu A	0.11	1.12	193.2	2.7	8.4	32
Ruvu B	0.08	1.18	257.6	1.5	3.3	46
Majengo	0.08	0.93	193.2	2.8	23.8	12
Malenga	0.10	0.99	193.2	1.9	5.3	37
Kapunga	0.20	1.89	322.0	2.5	8.0	32
Mean	0.13	1.50	244.7			

(1984). On the basis of OC, Singh *et al.* (1976) established a critical value of 1.75% for maize in soils of Morogoro region, implying that seven of these soils would be rated as deficient in N and three as being sufficient in N. The alkaline $KMnO_4$ N ranged from 129 - 386 mg/kg and are within the range of 123.4 - 469.3 mg/kg reported by Singh and Tripathi (1970) for soils of India.

All the soils responded to N application and the relative yield of the control ranged from 12 - 46% i.e. the response to N was 54 – 88%, indicating that all the soils needed N for high drymatter yields. Four soils viz: Kilangali, Mkindo, Mgomba and Majengo gave higher DM yields after N application than the other soils. The higher response to N application in these soils were expected because of their relatively lower organic matter contents. Similar responses to N application have been reported in Tanzania by Temu (1985), Semoka and Shenkalwa (1985), and Semoka et al. (1996). In India, Singh and Kumar (1996) found a high grain yield response under field conditions when N rates were increased from 0 to 200 kg/ha. They found the mean grain yield for the control to be 3.7 t/ha and 8.0 t/ha when 200 kg N /ha was applied. However the DM yields on four of the experimental soils were still very low (< 9 g/pot) even after correcting N deficiency suggesting that some other nutrient was limiting yield.

Phosphorus supply and response to P application

The extractable P using three P indices, the DM yields of rice shoots and the percent yields are indicated in Table 3. Nine of the 10 soils tested had Bray 1 extractable P values below a critical level of 20 mg/kg suggested by Semoka *et al.* (1996) in some soils of Morogoro district. Olsen extractable P was relatively high and all the soils tested had extractable P values greater than the critical value of 4.25 mg/kg reported by Jones *et al.* (1982) for soils of Punjab, India. The trend of results with the Pi method indicated that only Mkindo soil had an extractable P value greater than the critical value of 35.0 mg/kg suggested by Semoka *et al.* (1996) for some soils of Morogoro district.

Six soils out of ten responded to P application indicating that P was also a limiting nutrient in these soils in addition to N. Phosphorus application in the six soils increased DM yields by two times or more. In the soil from Ruvu B, P was more limiting than N because the percent response due to N application (Table 2) was lower than that due to P application. In

Table 3: Extractable phosphorus determined by three P indices, DM yield of rice shoots for three of the treatments tested and percent yield for the P control treatments

Location	Bray 1	Olsen	Pi	Drymatter yield (mg/pot)			Percent yield of P control
				$N_1P_0K_0$	$N_1P_1K_0$	$N_1P_1K_1$	
Kilangali	6.4	66.1	15.4	23.6a	25.0a	27.0a	95
Mlalil	3.4	38.2	24.7	18.5b	22.9a	21.7ab	81
Mkindo	24.5	80.2	64.5	19.6a	19.4a	21.5a	101
Mgomba	10.6	48.2	24.3	25.7a	31.2a	28.2a	83
Kigongoni	5.2	15.9	8.2	13.5c	21.0b	24.0a	64
Ruvu A	4.7	13.0	7.4	8.4b	19.6a	16.3a	43
Ruvu B	1.6	6.8	3.9	3.3b	16.2a	16.5a	20
Majengo	15.0	50.5	28.4	23.8a	23.8a	25.0a	100
Malenga	1.2	6.3	4.1	5.3b	14.4a	14.2a	37
Kapunga	7.2	9.5	5.6	8.0b	20.9a	20.4a	38

Means for drymatter yield in the same row followed by the same letter are not significantly different at 5% By Duncan's multiple range test

Malenga, Kapunga and Ruvu A soils, the increase in rice drymatter yields due to P was comparable to that due to N. All the soils which responded to P application had relatively low extractable P by all the methods tested. No significant response to P was obtained in Kilangali, Mkindo, Mgomba and Majengo soils. Lack of response to P application in these soils was attributed to their relatively high contents of extractable P (Table 3).

Potassium supply and response to K application

The effect of K application on drymatter yield is given on Table 3. A significant response to K application was only observed in Kigongoni soil. This soil had the highest CEC (40 cmol (+)/kg) and a potassium saturation of 1.5%. Usually K saturation values of < 2.0% are rated as low and suggest possibility of K deficiency (Kemmler, 1981). Two other soils had low K saturation; Mkindo (2.7%) and Ruvu B

Table 4: Effects of N and P application on N concentration in rice shoots and N uptake

Location	N Concentration (%)			N uptake (mg/pot)		
	N_0P_0	N_1P_0	N_1P_1	N_0P_0	N_1P_0	N_1P_1
Kilangali	1.03b	2.55a	2.45a	56.7y	599.3z	604.2z
Mlali	1.44c	3.16a	2.97ab	75.1x	583.5y	679.4yz
Mkindo	1.13b	3.24a	3.11a	43.6y	636.8z	609.3z
Mgomba	0.95b	2.27a	2.13a	38.8y	586.1z	662.4z
Kigongoni	1.02c	2.70a	2.48ab	22.5x	361.6y	518.6z
Ruvu A	0.97b	2.64a	2.49a	25.9x	222.5xy	498.9z
Ruvu B	1.13b	2.83a	2.64a	16.5x	93.4y	428.0z
Majengo	0.97c	2.35ab	2.65a	27.1x	555.5y	628.6yz
Malenga	0.86b	3.00a	3.19a	16.6x	159.7y	458.9z
Kapunga	1.05b	2.88a	2.84a	26.5x	229.7y	592.4z
Mean	1.05b	2.74a	2.69a	34.9x	402.8y	568.1z

Values in the same row and for the same parameter followed by the same letter are not significantly different at 5% using Duncan's multiple range test

(1.0%) but did not give significant responses to K application.

Concentration of N and P in rice shoots and uptake

Nitrogen concentration in the control treatment ranged from 0.86% in Malenga to 1.44% in Mlali with mean value of 1.05% (Table 4). These values are below the optimum N concentration range of 1.8 to 2.5% reported by Wallihan *et al.* (1974) confirming that none of the soils tested in the study supplied sufficient N to rice plants. Nitrogen application increased N concentration in rice shoots to the range of 2.27 - 3.24% with a mean value of 2.74%. This range is within the optimum range reported by Wallihan *et al.* (1974) and comparable to a critical level of 2.37% reported by Temu (1985) in soils of Mbarali rice farm, in Tanzania. Thus, the application of N at 200 mg/kg corrected N deficiency in all soils.

Data on N uptake (Table 4) indicated that N application significantly increased N uptake in all soils over the control. Mean N uptake in the control treatments was 34.9 mg/pot which is significantly lower than the uptake from treatments which received N and P. In soils where P was severely limiting, namely Kigongoni, Ruvu A, Ruvu B, Malenga and Kapunga, N uptake was significantly higher when N and P were applied together than when only N was applied. This means that P application enhanced N uptake. This observation agrees with the results of Semoka and Shenkalwa (1985) who obtained a positive interaction of N and P on N uptake in soils of Morogoro district, Tanzania.

Phosphorus concentration in the P control treatments ranged from 0.11 to 0.35% (Table 5). Plants grown on soils from Malenga, Kigongoni, Ruvu NAFCO and Kapunga had the lowest P concentration. The P concentration values in these soils are higher than the critical deficiency level of 0.1% established by Tanaka and Yoshida (1970) but six of the values were lower than the level of 0.2% generally considered adequate for most plants. Phosphorus application had no significant influence in shoot P concentration except in Mlali but the practice increased P concentrations to sufficiency levels except in soils from Kapunga, Malenga, Ruvu A, and Kigongoni. Semoka and Shenkalwa (1985) also obtained low P values ranging from 0.09 to 0.19% using three levels of P, i.e. 0, 30 and 60 kg/ha in soils of Morogoro district. Temu (1985), on the other hand, obtained slightly higher values ranging from 0.20 to 0.25% at flowering stage under field conditions. Phosphorus uptake varied considerably between soils. In P control treatments (treatment with N application), P uptake ranged from 5.8 mg/pot in Malenga soil to 67.8 mg/pot in Mkindo soil. The results also show that, P application increased P uptake significantly in

Table 5: Effects of N and P application on P concentration in rice shoots and P uptake

Location	P concentration (%)			P uptake (mg/pot)		
	N_0P_0	N_1P_0	N_1P_1	N_0P_0	N_1P_0	N_1P_1
Kilangali	0.29a	0.24a	0.26a	16.1y	56.8z	66.9z
Mlali	0.30ab	0.23c	0.26b	17.9x	42.2y	60.4z
Mkindo	0.30b	0.35ab	0.34ab	11.5x	67.8yz	44.6y
Mgomba	0.23ab	0.16b	0.18ab	9.5x	41.9y	57.0yz
Kigongoni	0.18a	0.13a	0.15a	4.0x	16.8xy	30.5yz
Ruvu A	0.31a	0.14b	0.18b	8.4y	11.2y	35.1z
Ruvu B	0.24a	0.18ab	0.21a	3.5y	5.9y	33.0z
Majengo	0.28a	0.26a	0.23a	7.9y	63.2z	54.7z
Malenga	0.20a	0.11a	0.13a	3.8y	5.8y	18.6z
Kapunga	0.18a	0.14ab	0.08b	4.6y	11.0y	17.4yz
Mean	0.25a	0.19a	0.20a	8.7x	32.3y	41.8yz

Values in the same row and for the same parameter followed by the same letter are not significantly different at 5% using Duncan's multiple range test

Mlali, Ruvu A, Ruvu B and Malenga soils. In Ruvu B and Malenga soils, P application increased P uptake more than threefold. This was attributed to the low extractable P contents of these soils as well as low DM yields in treatments without P (Table 3).

Nitrogen, phosphorus and potassium availability indices

Of the three N indices tested, OC gave significant correlation coefficients with rice drymatter yield ($r = 0.73$, $P < 0.05$) and N uptake ($r = 0.77$, $P < 0.05$) of the absolute control treatments while the relationships between total N and alkaline $KMnO_4$-N with these plant parameters were not significant (Table 6). These results are partly different from those of Singh and Tripathi (1970) who found OC and alkaline $KMnO_4$-N to be significantly correlated with percent yield response with the alkaline $KMnO_4$-N having the highest correlation coefficient. Sahrawat (1983) and Bajaj *et al.* (1967), on the other hand, obtained significant correlations for total N and alkaline $KMnO_4$-N and recommended their use in assessing N availability in soils of Philippines and India, respectively. We therefore recommend that OC be tentatively adopted for assessing N supply in lowland rice soils in Tanzania. Nevertheless since plants in all the soils used in this study responded to N application (response > 50%), a critical N level could not be established.

Among the extractants tested for assessing available P, Olsen method gave the highest correlation with either DM yield of the control treatments ($r = 0.92$, $P < 0.01$) or P uptake by plants in the control treatments ($r = 0.97$, $P < 0.01$). The Bray-1 and Pi methods also gave significant correlation coefficients with these parameters but the coefficients were lower than that for the Olsen method. Wamsley and Cornforth (1973) also found Olsen-P to be better correlated with percentage yield of maize ($r = 0.37$) in a pot experiment and recommended it for use in West Indian soils on the ground that this index was less sensitive to changes in soil properties. A previous study by Semoka *et al.* (1996) in other soils of Tanzania, found the Pi method to be better than the Olsen and Bray 1 in predicting P availability in lowland rice soils. In view of these findings, we recommend that the Olsen method be tentatively adopted for assessing P availability in these soils but that the Bray 1 and Pi methods be used as alternatives where appropriate. The critical P values established from this study under glasshouse conditions were 20.0, 10.0 and 26.0 mg/kg for the Olsen, Bray-1 and Pi methods, respectively.

For the assessment of K supply in soils only the neutral normal ammonium acetate method was evaluated. The ammonium acetate K was significantly correlated with K uptake but the correlation with drymatter yield was not significant. Therefore this method is tentatively rec-

Table 6: Correlation coefficients (r) for the relationships between N, P and K availability indices versus drymatter yield of the control and N, P and K uptake.

Nutrient	Method	"r" values for drymatter	Critical value (mg/kg)	"r" values for uptake
N	Total N	0.46ns	-	0.469ns
	OC	0.73*	#	0.77*
	Alkaline $KMnO_4$-N	-0.11ns	-	-0.08ns
P	Bray -1	0.61ns	10.0	0.83*
	Olsen	0.85**	20.0	0.97**
	Pi	0.61ns	26.0	0.82*
K	NH_4Oac	0.33ns	-	0.79*

*= Significant at 5%, ** = significant at 1%, ns = Nonsignificant, #=critical value could not be established as all values were in the deficiency range

ommended for assessing K supply in paddy soils in Tanzania, but further evaluation of the method aimed at establishing a critical K level for rice is required.

Conclusions and Recommendations

From the findings of the study, it was concluded that; nitrogen and phosphorus were among the major soil fertility constraints in the soils studied while the supply of K was found to be marginal in a few soils. Nitrogen was deficient in all soils while 60% of the soils were deficient in P and three soils had marginal levels of K. It was also concluded that, soil testing should be used to assess the fertility status of the rice growing areas and that, OC and Olsen P proved suitable for use in assessing N and P availability in the soils, respectively. The results obtained in this study should however be confirmed by field experiments and thus generate site specific fertilizer recommendations. In the meantime, farmers should be encouraged to adopt available fertilizer recommendations with respect to N and P.

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