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METHODS OF MEASURING AVAILABLE NUTRIENTS IN WEST INDIAN SOILS

1. NITROGEN

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SUMMARY

Methods of measuring available N have been compared using response and uptake data from maize grown on 155 West Indian soils in greenhouse experiments. Total soil N and Cornfield's alkaline hydrolysable N gave best estimates of available N when all soils were considered together. Correlations between test data and N uptake were best for acid soils, for soils with large cation exchange capacities and for soils with between 80 and 99 per cent base saturation. Differences between correlations for soils from different islands could usually be related to these soil properties.

INTRODUCTION

Methods of measuring available soil nutrients have been compared to find those most suitable for routine use with West Indian soils. In the first stage of the programme methods have been screened by comparison of test data with yield response to fertilizers and with nutrients absorbed by maize in greenhouse experiments. This paper is concerned with methods of estimating available soil nitrogen, Parts 2 and 3 will deal with phosphorus and potassium.

In addition to measuring total soil nitrogen, potentially available nitrogen can be estimated by measuring that mineralized in standard aerobic or anaerobic laboratory incubations, by measuring the fraction of organic nitrogen easily hydrolysed or oxidised by mild extractants or by measuring some other fraction of soil organic matter which either defines its state of decomposition or the activity

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of soil micro-organisms. Examples of all these methods have been tested.

There have been few reported comparisons of available nitrogen tests using tropical soils. Nitrogen mineralized in aerobic incubations has been related to nitrogen uptake by sugar-cane in Hawaii [14], tobacco quality in New Zealand [12], greenhouse tomatoes and field maize in Kenya [11] and to maize and tobacco in Southern Rhodesia [13]. Tamhave and Subbiah (1962) suggested that an alkaline permanganate extract gave the best estimate of nitrogen available to rice and wheat in Indian soils.

MATERIALS AND METHODS

Soils

Bulk samples (0–26 cm) of 155 of the main agricultural soils were taken from 12 Commonwealth Carribbean Islands. Where possible samples were from areas which had not recently received fertilizers. Soil types were chosen to provide a wide range of properties; these are summarised in Table 1. The soils used included those formed on coral limestone, volcanic materials, igneous rocks and various mixed alluvia.

Samples were air-dried passed through a 1.25-cm sieve for the pot test; 2 mm sub-samples were stored in waxed containers for analysis.

Greenhouse experiments

The standard greenhouse experiment for soils from each island or island group was divided into two parts. In one part, consisting of NPK, NP, NK and PK treatments, responses to either N, P or K were measured in the presence of the other two nutrients; in the second part, yields from soils given N, P, K, lime (to pH 6.5), Mg and trace elements were compared with

TABLE 1

Ranges and mean values of some properties of soils used in greenhouse experiments

Island	No. of soils	pH		C.E.C. (me/100 g)		% Base saturation		C : N	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
Trinidad	30	5.4	4.0–6.8	20.4	3.9–68.9	62.5	15–100	10.8	8.0–21.6
Tobago	20	6.9	6.1–8.9	23.2	2.9–43.7	98.4	69–100	10.6	7.7–19.5
Jamaica	40	6.9	5.1–7.7	23.3	3.4–69.2	94.2	27–100	10.4	7.0–12.8
Barbados	20	7.4	5.5–7.9	27.9	9.8–52.0	98.8	78–100	10.6	8.3–13.2
Windward Islands	31	5.7	4.7–6.6	22.8	4.4–54.9	64.5	5–100	11.2	8.8–13.5
Leeward Islands	14	6.4	5.1–7.7	22.8	6.1–52.9	86.4	42–100	12.3	10.0–15.3
All soils	155	6.4	4.0–8.9	22.7	2.9–69.2	81.8	5–100	11.1	7.0–21.6

TABLE 2

Concentrations of fertilizers used in greenhouse experiment

Nutrient	Concentration of element in soil (ppm)		Salt used
	Jamaican soils	All other experiments	
N	100	200	NH_4SO_4
P	100	100	NaH_2PO_4
K	100	200	K_2SO_4
Mg	50	50	$MgSO_4.7H_2O$
Trace elements			
Fe	22	10	$FeC_6H_5O_7.5H_2O$
Mn	1.35	1	$MnSO_4.4H_2O$
Cu	0.15	1	$CuSO_4.5H_2O$
Zn	0.16	1	$ZnSO_4.7H_2O$
B	0.80	1	H_3BO_3
Mo	0.01	0.01	$(NH_4)_6Mo_7O_{24}.4H_2O$

yields from treatments in which either lime, Mg or trace elements were omitted to check whether these nutrients were limiting growth. A control treatment was included in which no fertilizers were used and all treatments were replicated three times in a randomised block design. The concentrations of added nutrients are given in Table 2.

Maize (variety PT66) * was used as a test crop. Four plants were grown from seed for 35 days in one kg samples of soil contained in 12.7 cm plastic pots. Plants were watered by standing the pots of soil in saucers of deionised water. After harvesting, dry weight yields and the concentrations of N, P and K were determined in the plant tops.

Because of quarantine regulations all the greenhouse experiments could not be done in one island. Experiments were done in Trinidad, Jamaica, Barbados, St. Vincent and St. Lucia; soils from Grenada were tested in St. Vincent and those from Dominica, Tobago and the Leeward Islands in Trinidad.

Methods of measuring available nitrogen

All analyses were done on air-dry samples.

1. Total nitrogen was determined by a semi-micro Kjeldahl method using a selenium catalyst. Samples were ground to pass a 100 mesh sieve before analysis.

2. Nitrogen mineralized in aerobic incubations was measured by Bremner's method [1]; NH_4–N and NO_2–N were determined in 2 N KCl extracts before and after incubation and the increase in NH_4–N plus NO_3–N during the 14 days incubation designated Δ min. –N. Mineralizable N was also measured by Gasser's method [5] for 40 soils from Jamaica. This method differs

* Kindly supplied by the Ministry of Agriculture and Lands, Jamaica.

from Bremner's in that soils are incubated at 50 per cent of water holding capacity for 21 days in Gasser's method whereas they are mixed with sand and incubated at a standard moisture content for 14 days in Bremner's method.

3. Nitrogen mineralized during 7, 14 and 21 day anaerobic incubations was measured by Waring and Bremner's method [21]. Increases in NH_4–N are designated Δ NH_4–N (7), (14) or (21) respectively.

4. Organic nitrogen oxidised to NH_4–N by alkaline permanganate was measured by Zaccariah's [22] method for Jamaican soils and by Truog's method [10] for all soils.

5. Easily hydrolysable nitrogen was measured by Cornfield's [2] alkaline hydrolysis method and by an acid hydrolysis technique in which 50 ml 0.1 N, 1.0 N or 5.0 N HCl were added to 10 g (< 2mm) soil, allowed to stand for 24 hours, shaken on a reciprocating shaker for two hours and NH_4–N in filtered extracts distilled with excess 0.1; 1.0 or 5.0 N NaOH. NH_4–N released in this way is designated 0.1 N HCl–N, 1.0 N HCl–N and 5.0 N HCl–N respectively.

6. Jenkinson [9] has proposed a method for estimating potentially available N based on extractable glucose. This method (Jenkinson, private communication, 1966) was tested by estimating glucose extracted by 0.1 N Ba $(OH)_2$ or 0.01 N $NaHCO_3$ with anthrone reagent.

7. Hoyt [6 7 8] has shown that chlorophyll is rapidly decomposed in soil and has suggested that that which remains may indicate the amount of fresh plant residues in the soil and hence the reserve of readily mineralizable nitrogen. Chlorophyll was determined in all soils by Hoyt's method [6].

RESULTS

Full details of maize yields, and soil and plant analyses are given by Cornforth *et al.*[4] and Walmsley *et al.*[16–19].

Response of maize to fertilizers

Table 3 shows the numbers of soils from each region which responded to added fertilizers. At the 1.0 per cent level of probability 79 per cent responded to nitrogen, 67 per cent to phosphorus and 35 per cent to potassium.

Correlations between soil analysis and pot experiment data

Table 4 shows correlation coefficients between soil test data and either the percentage yield of maize or the amount of nitrogen absorbed by maize in the PK treatment. Percentage yield is the yield from the PK treatment calculated as a percentage of that from the NPK treatment.

One calcareous sand from Tobago was discarded be cause of diffi-

TABLE 3

The numbers of soils in which maize responded to N, P, K, Mg, lime and trace elements in the greenhouse experiments
(Total numbers of soils in each group are in parenthesis)

Islands	Fertilizer											
	N		P		K		Mg		Lime		Trace elements	
	$P =$ .05	$P =$ .01	$P =$ .05	$P =$ .01	$P =$ .05	$P =$ .01	$P =$ .05	$P =$ .01	$P =$ .05	$P =$ .05	$P =$ .05	$P =$ .01
Trinidad (30)	19	18	18	16	16	15	*	*	*	*	*	*
Tobago (20)	14	14	14	13	13	6	*	*	*	*	*	*
Jamaica (40)	38	36	31	27	14	19	5	2	0	0	1	1
Barbados (20)	20	20	14	12	5	3	0	0	*	*	1	1
Windward Islands (31)	25	22	29	28	13	12	2	2	2	2	3	2
Leeward Islands (14)	13	13	9	8	0	0	2	2	*	*	3	2
All soils (155)	129	123	115	104	61	55	9**	6**	2+	2+	8**	6**

* Treatments not tested. ** 105 soils. + 71 soils.

culties in obtaining consistent analytical results, thus 154 soils were used for correlations.

Correlations of estimates of available N are usually better with nutrient uptake than with per cent yield. This is because in some of the soils there are factors other than nutrient supply which limit yield and response to added nutrients but which have a smaller effect on nutrient uptake. Because of this test methods will be assessed by their relationship with N uptake. Only test methods which can account for more than 50 per cent of the variations in N uptake ($r^2 > 0.50$) are considered to give satisfactory estimates of available soil N.

Correlation coefficients have been calculated for all soils, for soils from separate islands or island groups and for groups of soils divided on the basis of pH, cation exchange capacity and per cent base saturation.

All soils. All correlation coefficients between test methods and N uptake are significant at the 0.1 level of probability. Only for total N and Cornfield's-N does r^2 exceed 0.50, indicating that at least 50 per cent of the variation in N uptake be accounted for by

TABLE 4

Correlations coefficients between test values and per cent yield or N uptake by maize from PK treatments. Per cent yield is the yield from PK treatments as a percentage of that from the NPK treatments

Islands Number of soils	Trinidad 30	Tobago 19	Jamaica 40	Barbados 20	Windwards 31	Leewards 14	Total (154)
Correlation between test values and per cent yield							
Total N	.23	.56**	.55***	.32	.66***	.64*	.41***
Δ min. N							
Gasser [5]	—	—	.48**	—	—	—	—
Bremner [1]	.13	.68***	.37*	.48**	.43*	.74**	.38**
Δ NH_4–N [21]							
7 days	.10	.74***	.45**	.52*	.42*	.80***	.37***
14 days	.08	.70***	.50***	.39	.42*	.84***	.44***
21 days	.11	.63**	.52***	.32	.48**	.76**	.44***
Acid hydrolysis							
0.1 *N* HCl–N	.41*	.14	.38*	.52*	.68***	.73**	.37***
1.0 *N* HCl–N	.24	.37	.40**	.31	.77***	.70**	.42***
5.0 *N* HCl–N	.24	.34	.37*	.60**	.65***	.75**	.40***
Alkaline hydrolysis[2]	.10	.58**	.53***	.53*	.77***	.77**	.46***
Permanganate oxidation							
Truog [10]	.02	.31	.37*	.42	.68***	.76**	.37***
Zacchariah [22]	—	—	.28	—	—	—	—
Extractable glucose							
in 0.01 *N* $Ba(OH)_2$	—	—	.55***	—	—	—	—
in 0.01 *N* $NaHCO_3$	.26	.33	.65***	.19	.32	.83***	.35***
Chlorophyll [6]	.13	.18	.36*	.12	.54**	.56*	.24*
Correlation between test values and N uptake							
Total N	.91***	.52*	.72***	.21	.51**	.74**	.71***
Δ min. N							
Gasser [5]	—	—	.86***	—	—	—	—
Bremner [1]	.72***	.88***	.84***	.65**	.67***	.95***	.69***
Δ NH_4–N [21]							
7 days	.62***	.88***	.69***	.51*	.60**	.97***	.62***
14 days	.57**	.85***	.81***	.46*	.54**	.98***	.60***
21 days	.58**	.81***	.82***	.27	.61**	.97***	.62***
Acid hydrolysis							
0.1 *N* HCl–N	.69***	.21	.45**	.41	.90***	.90***	.54***
1.0 *N* HCl–N	.97***	.36	.63***	.22	.94***	.87***	.67***
5.0 *N* HCl–N	.95***	.37	.63***	.59**	.66***	.86***	.69***
Alkaline hydrolysis [2]	.89***	.64**	.77***	.58**	.79***	.88***	.78***
Permanganate oxidation							
Truog [10]	.59***	.57**	.70***	.43	.80***	.83***	.58***
Zacchariah [22]	—	—	.54***	—	—	—	—
Extractable glucose							
in 0.1 *N* $Ba(OH)_2$	—	—	.87***	—	—	—	—
in 0.01 *N* $NaHCO_3$	.69***	.60**	.74***	.27	.24	.95***	.56***
Chlorophyll [6]	.37*	.38	.32*	.38	.65***	.46	.34***

these methods. Nitrogen hydrolysed by 5.0*N*HCl and Δ min. N almost obtained this value ($r^2 = .48$).

Islands and Island Groups. Cornfield's method and Δ min. N gave $r^2 > .50$ for soils from four of the six geographical regions. Neither method gave a good correlation with N uptake from Barbados soils; Δ min. N was also poor for Windward Island soils and Cornfield's method with those from Tobago. Total N, Δ NH_4–N (21), 1.0 *N* HCl–N and Truog's–N gave $r^2 > .50$ for soils from three out of the six groups.

All methods except chlorophyll gave good correlations with N absorbed from Leeward Islands soils and none did for soils from Barbados. Only chemical estimates of available N were satisfactory for the Windward Islands and only incubation tests were good for soils from Tobago.

pH. In general correlations between test values and N uptake were better for acid soils (Table 5). For soils of pH less than 5.5, $r^2 > 0.50$ for total N, Δ min. N, 5.0 *N* HCl–N and Truog–N. Although many of the correlations between test values and N uptake from soils in the pH 5.5–7.0 and pH > 7.0 groups were significant at the 0.1 per cent level of probability, r^2 was always less than 0.50 Incubation methods gave best estimates of available N in the pH 5.5–7.0 group while total N, Δ NH_4–N (14) and 1.0 *N* HCl–N were best for soils above pH 7.0.

Cation exchange capacity. Table 5 shows that it is easier to predict available N in soils with large rather than in those with small cation exchange capacities.

Cornfield–N, 5.0 *N* HCl–N and Δ min. N were all well correlated with N absorbed from soils with a cation exchange capacity greater than 30 me per 100 g. No methods gave correlations significant at the 1 per cent level of probability for soils with a cation exchange capacity less than 10 me per 100 g and while correlations for soils with cation exchange capacities between 10 and 30 me per 100 g were significant at the 1.0 or 0.1 per cent levels, r^2 never exceeded 0.50.

Per cent base saturation. Soil tests were able to estimate available nitrogen best in soils with between 80 and 99 per cent base saturation; r^2 exceeded 0.50 for all the incubation tests, Cornfield–N and extractable 'glucose' for soils in this group (Table 5). None of the tests were good for soils with less than 80 per cent base satura-

TABLE 5

Correlation coefficients between test values and N uptake by maize from PK treatments, soils grouped on the basis of pH, cation-exchange capacity and per cent base saturation

	pH			Cation-exchange capacity			Per cent base saturation			
	pH <5.5	5.5–7.0	>7.0	<10	10–30	>30	<60	60–80	80–99	100
Number of soils	39	71	44	32	88	34	34	14	22	84
Total N	.79***	.40***	.63***	.07	.38***	.69***	.13	.26	.68***	.45***
Δ min. N (Bremner)	.73***	.65***	.51***	−.10	.35**	.74***	.20	.27	.82***	.49***
Δ NH_4–N (7)[21]	.68***	.63***	.44**	.09	.37***	.64***	.18	.11	.78***	.46***
Δ NH_4–N (14)	.60***	.68***	.60***	.06	.48***	.69***	.20	.18	.82***	.55***
Δ NH_4–N (21)	.63***	.61***	.52***	.14	.48***	.66***	.25	−.03	.83***	.48***
Acid hydrolysis										
0.1 *N* HCl–N	.53***	.34**	.59***	.37*	.37***	.50***	.35*	.19	.53*	.41***
1.0 *N* HCl–N	.67***	.50***	.62***	.13	.41***	.64***	.34	.13	.60**	.48***
5.0 *N* HCl–N	.73***	.43***	.57***	.07	.37***	.75***	.22	.11	.67***	.46***
Alkaline hydrolysis [2]	.83***	.56***	.60***	−.10	.46***	.78***	.18	.30	.78***	.59***
Permanganate oxidation (Truog)[10]	.57***	.45***	.55***	−.15	.30**	.64***	.11	.08	.67***	.51***
Extractable glucose (.01 *N* $NaHCO_3$)	.55***	.51***	.43**	.24	.28***	.58***	.20	.21	.74***	.37***
Chlorophyll [6]	.30	.25*	.55***	.39*	.29**	.34	.08	−.02	.65***	.47***

tion. Cornfield's N ($r^2 = .38$) and Δ NH_4–N (14) ($r^2 = .30$) were best for the fully saturated soils, most of which contained free calcium carbonate.

DISCUSSION

When all the soils studied are considered together, total N and Cornfield's alkaline hydrolysable N give best estimates of N absorbed by maize in pot-tests .Nitrogen hydrolysed by 1.0 or 5.0 *N* HCl and that mineralized in aerobic incubations are almost as good. When the soils are considered on a geographical basis, correlations between test data and nitrogen uptake are usually better and more tests give satisfactory estimates of available N, although the same few methods are usually in the best group. Differences in correlations for any method between soils from different regions may be due to differences in sampling dates, greenhouse conditions or inherent soil differences between the islands or island groups.

Although Saunder *et al.*[13] found that no restriction on time of sampling was necessary when estimating available N by incubation methods in East Africa, it has recently been shown in Trinidad that mineralizable N fluctuates widely throughout the year, apparently depending on rainfall and soil moisture [3]. Although this is of obvious importance when sampling soils from field experiments, it is less important in the present study as soil pretreatment insures that samples analysed are similar to those used in the pot tests where moisture conditions are uniform.

Greenhouse conditions varied slightly from region to region but plant populations and cultivation were standardised.

Inherent soil differences appear to cause the correlation coefficients to differ between geographical regions. All tests were poor for Barbados soils, these had an average pH of 7.4 and 90 per cent of them were completely base saturated, containing from 0.7 to more than 30 per cent free calcium carbonate. Table 5 shows that when soils were grouped on their chemical characteristics, soil tests were least effective on soils above pH 7.0 or 100 per cent base saturated. In addition, Barbados soils contain little total N (average $0.168 \pm .010$ per cent) compared with other West Indian soils (average for all soils $0.253 \pm .015$ per cent) and maize on all Barbados soils responded to fertilizer nitrogen, thus the range of values for soil tests and yield response or N uptake are small and correlation coefficients correspondingly poor.

Only the incubation methods gave good correlations ($r^2 > 0.50$) with N uptake from Tobago soils; 95 per cent of these were completely base saturated and 30 per cent had a pH > 7.0 (average 6.9).

The poor correlations between mineralizable N and yield or N uptake for Windward Island soils are because some of the soils from St. Lucia and Dominica were stored in a slightly moist state before being used. Before laboratory incubation these soils contained 59 and 81 ppm mineral N respectively compared with 27 and 20 ppm in the soils from Grenada and St. Vincent. Thus nitrogen may have been mineralized during storage. This, however did not increase the proportion of total N extracted in the chemical methods.

The failure of soil tests to estimate available N in soils with a small or unsaturated base exchange capacity is not serious in practise; field trials have shown that such soils supply little nitrogen to crops and satisfactory yields depend entirely on fertilizer nitrogen [20].

Although most of the islands from which soils were taken for this study are politically independent of each other, all are served by the Regional Research Centre of the University of the West Indies. It is thus of advantage if a single method of estimating available soil nitrogen can be selected for routine use for soils from all regions. Of the methods so far tested total–N, Δ min.–N and Cornfield's–N have proved best; before any of these can be used in a fertilizer advisory scheme they must be calibrated with the results of field experiments. Such calibrations are being prepared for bananas and maize and will be reported in subsequent publications.

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