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NITROGEN-SUPPLYING POWER OF SOME TROPICAL SOILS OF PUERTO RICO AND METHODS FOR ITS EVALUATION

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This study is an evaluation of the N-supplying power of 10 representative Oxisols and Ultisols of Puerto Rico which was made by continuous cropping in the greenhouse. Four chemical extraction methods as well as aerobic incubation procedures were used to obtain an index of N availability in these soils. Nitrogen produced during incubation was highly correlated with N released to the crops. Nitrogen extracted by all the chemical methods used, especially total N extracted by 0.01 M $CACl_2$ solution and potassium sulfate, was highly correlated with N uptake by plants. These results showed that substantial quantities of N can be removed from these soils upon cropping. It was also shown that laboratory chemical methods as well as incubation procedures provide a reliable means for evaluating the N-supplying power of these soils.

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Nitrogen-supplying Power of Some Tropical Soils of Puerto Rico and Methods for its Evaluation[1]

D. J. Lathwell, H. D. Dubey, and R. H. Fox[2]

ABSTRACT

An evaluation of the N-supplying power of 10 representative Oxisols and Ultisols of Puerto Rico was made by continuous cropping in the greenhouse. Four chemical extraction methods as well as aerobic incubation procedures were used to obtain an index of N availability in these soils. Nitrogen produced during incubation was highly correlated with N released to the crops. Nitrogen extracted by all of the chemical methods used, especially total N extracted by 0.01 *M* $CaCl_2$ solution and potassium sulfate, was highly correlated with N uptake by plants. These results showed that substantial quantities of N can be removed from these soils upon cropping. It was also shown that laboratory chemical methods as well as incubation procedures provide a reliable means for evaluating the N-supplying power of these soils.

Additional index words: Chemical extraction procedures, Incubation, Continuous cropping, Ultisol, Oxisol.

IN recent years the need for reliable indices of N availability has been recognized and considerable effort has been expended to evaluate the N-supplying power of temperate region soils (3). Incubation procedures as well as a number of chemical-extraction procedures have been devised to measure mineralizable soil N in these soils (6, 8, 10, 11, 13, 14). Useful soil N availability indices have resulted from these studies. Little is known, however, about the N-supplying power of tropical soils or the applicability of chemical extraction procedures to obtain a measure of the mineralizable N in these soils.

The studies reported here were made to evaluate the N-supplying power of representative Oxisols and Ultisols of Puerto Rico as measured by continuous cropping in the greenhouse. Various chemical-extraction procedures were employed. The relation between the amounts of N extracted by these reagents, mineralizable N by incubation, and N removed by continuous cropping was measured. In addition, the effect of drying these soils upon subsequent N availability was tested in the greenhouse.

MATERIAL AND METHODS

Soils

Of the 10 soils collected for this study (Table 1), during September and November 1970, 9 were surface samples (0 to 20 cm) and 1 was a subsoil (10 to 30 cm). The soils were passed through a 10-mm screen, thoroughly mixed, and air-dried immediately. One subsample was used for the greenhouse study without further treatment and another was passed through a 2-mm screen and stored in polyethylene bags at room temperature for analysis by chemical and incubation methods.

In the analyses reported in Table 1 organic C was determined by the Allison procedure (2), total N by the Kjeldahl method, total organic matter by the Modified Walkley-Black method (5), and pH by the glass electrode at a soil:water ratio of 1:2. Inorganic N in the original soils was extracted by shaking 20 g of soil with 40 ml of 1.0 *N* KCl for 1 hour followed by leaching through a Buchner funnel. Leaching was completed by an additional 60 ml of 1.0 *N* KCl. Ammonium N was determined by distilling a 20-ml aliquot of the extract with MgO into 2% boric acid using a semimicro-Kjeldahl apparatus and titrating the distillate with standard HCl. A second distillation with Devarda's Alloy of the aliquot used earlier for the NH_4^+ determination gave the value for NO_3^--N.

Greenhouse Procedure

To determine the ability of these soils to supply N four consecutive crops were grown on each soil in the greenhouse. On all soils, except the Cialitos [3] and Cialitos [4], the cropping sequence was corn (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench], corn, corn.

On soils Cialitos [3] and Cialitos [4], four consecutive crops of corn were grown. Some 1,600 g of soil (except for Nipe and Piñas soils, where 2,000 g of soil were used per pot) were placed in polyethylene bags in 15-cm-diameter plastic pots. To five replications of each soil, a fertilizer treatment supplying P, K, Mg, and micronutrients, but omitting N, was added. All soils were limed where necessary to bring the pH to 5.5 to 6.0. In addition, a small application of lime was made to the Nipe soil to supply Ca. Seeds of corn or sorghum were planted directly into the pots and were later thinned to four plants per pot for corn and six plants per pot for sorghum. Pots were watered whenever necessary (at least daily), bringing the water content to approximately the field capacity by weighing.

In all soils, except Cialitos [3] and Cialitos [4], the first crop was planted on Oct. 13, 1970 and was grown for 4 weeks. Subsequent crops were also grown for 4 weeks and the fourth crop was harvested March 16, 1971. Soils Cialitos [3] and Cialitos [4] were included in the experiment on Dec. 3, 1970 and the fourth crop on these soils was harvested April 13, 1971. Between each crop, the soil was removed from the pot and mixed and refertilized except before the fourth crop, when no additional treatment was made.

Following harvest of the fourth crop, the soils were removed from the pots and were thoroughly mixed and air-dried in the greenhouse. The soils were then stored in the air-dry condition in the greenhouse from March 17 until April 27, 1971, except for soils Cialitos [3] and Cialitos [4], which were stored from April 13 until April 27, when all soils were repotted (with four replications) and planted to corn to measure N availability in these soils after prolonged drying. Corn was harvested on May 20, 1971.

Plants from each harvest were dried at 60 C, weighed, and ground in a laboratory Wiley Mill. Total N in the ground sample was determined in the Technicon Auto-Analyzer using alkaline phenol and chlorox reagents after digestion of the sample. Each replicate of each harvest was analyzed separately.

Chemical Methods

Method 1. (Estimation of N extracted by 1.0 *N* KCl). In addition to the distillation of inorganic N from the 1.0 *N* KCl extract as described previously, a 20-ml aliquot was heated with 2 ml of concentrated H_2SO_4 in a 100-ml Kjeldahl digestion flask until the water evaporated and the digest cleared. Digestion was then continued for 1 hour. The NH_4^+-N in the digest was determined by distillation with MgO. After diluting the digest with 40 ml of H_2O, sufficient MgO was added to ensure complete neutraliza-

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tion of the acid and to make the solution alkaline. Distillation was continued for 30 to 40 min. which permitted complete distillation of the NH_4^+ present in the sample. No attempt was made to recover NO_3^--N in these extracts. The N measured in all instances then was whatever organic N that was extracted by the four methods used plus the NH_4^+-N present in the soil.

Method 2. (Estimation of N extracted by 1.0 *N* K_2SO_4). In this method, both the extraction procedure and the determination of N in the extract was identical to Method 1, except that 1.0 *N* K_2SO_4 was substituted for 1.0 *N* KCl.

Method 3. (Estimation of N extracted by boiling 0.01 *M* $CaCl_2$ and K_2SO_4 solution). This is essentially the procedure of Keeney and Bremner (8), except that 0.01 *M* $CaCl_2$, as suggested by Stanford (13), was used instead of water and 0.5 *N* K_2SO_4 solution was used instead of a 10% K_2SO_4 solution. Five grams of soil were placed in a 125-ml Erlenmeyer flask and treated with 30 ml of 0.01 *M* $CaCl_2$ solution. The mixture was boiled under reflux for 1 hour. After the mixture had cooled 20 ml of 0.5 *N* K_2SO_4 solution were added, the flask was swirled vigorously to mix the contents, and the mixture was filtered on a Buchner funnel. On one 20-ml aliquot of the filtrate, NH_4^+-N was determined directly by distillation as described previously. A second 20-ml aliquot was treated with 2 ml of concentrated H_2SO_4 and digested as before. Ammonium N was determined by distillation as described previously.

Method 4. (Estimation of N extracted by 0.05 *N* sodium pyrophosphate and 0.5 *N* K_2SO_4). In this procedure, modified from those described by Stanford (12, 13), 10 g of soil were placed in a 125-ml Erlenmeyer flask and 25 ml of 0.05 *N* sodium pyrophosphate of pH 9 to 10 were added. The mixture was shaken for 30 min on a wrist-action shaker. After shaking vigorously to mix the contents, the mixture was filtered on a Buchner funnel. Distillable NH_4^+-N and total NH_4^+-N in the extract were determined by the same procedures described previously.

Incubation Methods

To 50-g samples of soil-sufficient $CaCO_3$ was added to bring the pH to near neutral, after which the soils were placed in 250-ml Erlenmeyer flasks. Sufficient water was added to bring the soils to field capacity and the flasks were capped with "Parafilm." The treatments replicated three times were incubated in the laboratory at 24 C for up to 16 weeks. At 2, 4, 8, and 16 weeks, the three samples for each treatment were taken for the determination of NH_4^+-N and NO_3^--N. The 50-g cultures were shaken with 100 ml of 1.0 *N* KCl for 1 hour followed by leaching through a Buchner funnel. Leaching was completed by an additional 150 ml of 1.0 *N* KCl solution. Ammonium N and NO_3^--N in the extracts were determined separately by the distillation procedures described previously.

RESULTS AND DISCUSSION

All of the soil samples used in these experiments were collected from areas that were under cultivation, although Cialitos samples and the sample of Humatas and Los Guineos were in pasture when they were collected. The area where the Nipe sample was collected apparently had not been cultivated to any extent in recent years. All of the samples are clays, except for the Piñas, which is a loamy sand.

As shown in Table 1, a wide range in soil pH existed, which undoubtedly was a reflection of past treatment since all of these soils, except for possibly the Nipe, are moderately to strongly acid in the natural state. The soils differed widely in organic matter content and total N content, although the subsoil sample from the Cialitos [2S] was the only Ultisol low in organic matter and total N. This sample was taken to provide a wider range in organic matter and total N in these soils.

The Nipe sample came from an area that probably had some of the surface soil removed previously and thus had a lower organic C and total N content than normally might be expected. The C/N ratio was not unusual in these soils and is typical of soils found in other areas. The average values for C and N content are very similar to the Iowa soils used by Keeney and Bremner (6).

Table 1. Some chemical properties of soils.

Soil series	Order	pH	Organic matter, %	Organic C, %	Total N, %	Inorganic N, ppm
Nipe	Oxisol*	5.7	2.4	1.45	0.100	20
Piñas	Oxisol†	4.9	1.4	0.71	0.072	26
Catalina	Oxisol‡	5.4	4.7	2.92	0.280	90
Cialitos [2S]	Ultisol§	6.2	1.8	1.01	0.127	23
Cialitos [4]	Ultisol§	5.0	3.1	1.67	0.196	27
Cialitos [3]	Ultisol§	5.9	4.0	2.24	0.238	35
Humatas	Ultisol*	4.9	4.7	2.50	0.220	52
Cialitos [2]	Ultisol§	6.4	5.9	3.26	0.335	31
Cialitos [1]	Ultisol§	5.8	5.3	3.26	0.320	35
Los Guineos	Ultisol*	4.9	5.7	3.66	0.328	74
Average			3.9	2.27	0.222	41

* Typic Acrorthox. † Psammentic Haplorthox. ‡ Typic Haplorthox. § Orthoxic Tropohumult. ‖ Typic Tropohumult.

Table 2. Nitrogen uptake from soils upon cropping.

Soil	N uptake, mg/Kg soil						
	Crop 1	Crop 2	Crop 3	Crop 4	Total, 4 crops	Crop 5	Total, 5 crops
Nipe	22	5	8	7	42	14	56
Piñas	23	13	10	9	55	9	64
Catalina	90	24	16	12	142	26	168
Cialitos [2S]	16	8	11	6	41	16	57
Cialitos [4]	22	17	10	10	59	16	75
Cialitos [3]	18	15	10	10	53	28	81
Humatas	55	8	9	9	81	23	104
Cialitos [2]	60	19	22	14	117	51	168
Cialitos [1]	90	20	17	16	143	41	184
Los Guineos	145	48	22	14	229	34	263

These soils contained substantial quantities of inorganic N as extracted by 1.0 *N* KCl. The Catalina and Los Guineos samples contained particularly large quantities of inorganic N. These soils in general contained somewhat more inorganic N than those used by Keeney and Bremner (6), with the average being substantially higher. In addition, about half of the inorganic N found in these soils was present as exchangeable NH_4^+ with little variation among soils being found.

The amount of N extracted by four crops (Table 2) varied widely among soils. The first four crops were grown consecutively without drying the soils between crops. The differences in supply of N decreased with cropping, until at the fourth crop much smaller soil differences were found. Undoubtedly some of the difference in uptake by the first crop was due to the initial differences in the initial inorganic N content of the soils. All of the soils declined in their ability to supply N on cropping when no drying step between crops was introduced. Although these soils did decline in ability to supply N with time, even the quantities of N released to the fourth crop were substantial. Since several of these soils released large quantities of N to the first two crops, under field conditions these soils would likely release sufficient N to meet the N requirements of all but the most demanding crops.

The effect of seasonal changes in mineralizable N, especially the influence of drying, has been noted earlier (4). In the field a flush of inorganic N release often results upon wetting these soils following a dry season. The results obtained in pots with the soils used in these experiments also produced a flush of available N subsequent to a drying period. In all soils, except the Piñas, the quantity of N removed by Crop 5 (Table 2) was nearly double or more the quantity removed by Crop 4, and in most instances was greater than the amount removed by Crop 3. Likewise, the drying step introduced between collecting the soils

Table 3. Distillable NH_4^+-N in soil extracts using different extracting solutions and the correlation with N uptake.

Soil	Distillable NH_4^+-N, ppm			
	1*N* KCl	1*N* K_2SO_4	0.01*M* $CaCl_2$	0.05*N* Na-P
Nipe	9	21	16	20
Piñas	8	23	16	19
Catalina	47	55	68	52
Cialitos [2S]	11	23	30	18
Cialitos [4]	15	20	33	20
Cialitos [3]	22	31	36	26
Humatas	23	29	38	29
Cialitos [2]	18	42	36	38
Cialitos [1]	21	30	32	22
Los Guineos	36	45	66	40

	Regression estimates N uptake, 4 crops		Correlation coefficients N uptake, 4 crops
	Intercept	Slope	
1*N* KCl	18.8	3.69	0.74
1*N* K_2SO_4	-30.7	3.97	0.77
0.01*N* $CaCl_2$	- 5.24	2.74	0.79
0.05*N* Na-P	- 9.33	3.74	0.69

from the field and the initiation of cropping in the greenhouse could have contributed to the large quantities of N released to the first crop. It appears that changes in mineralizable N in these soils as a consequence of drying can be measured in greenhouse experiments. Therefore, it may be possible to devise laboratory techniques to evaluate mineralization under varying environmental conditions, thereby obviating the concerns of Cornforth (4).

The quantities of distillable NH_4^+-N extracted by the solutions used (Table 3) varied depending on the method employed. Presumably with both KCl and K_2SO_4, only exchangeable NH_4^+ was extracted. Substantially more NH_4^+-N was extracted by K_2SO_4, however. Thus, the extraction with 1 *N* K_2SO_4 as well as with 0.01 *M* $CaCl_2$, or 0.05 *N* sodium pyrophosphate removed some N fraction that appeared as NH_4^+-N in the extract, since the quantity of NH_4^+-N found in these extracts was considerably higher than that extracted by 1 *N* KCl (12, 13).

The correlation of distillable N with N uptake by four crops was only fair (Table 3), whereas Stanford (13) and Smith and Stanford (11) found the relationship between distillable N and N availability quite satisfactory. While Keeney and Bremner (6) found a close relationship between inorganic N and N uptake by their first crop, we found an r of 0.76 between inorganic N and N uptake by the first crop, which was identical to the correlations with total N uptake by 4 crops.

The total NH_4^+-N removed by the several extracting solutions (Table 4) varied widely depending on the solution used. All solutions obviously removed substantial quantities of organic N. Again, the quantity removed by 1 *N* K_2SO_4 was substantially greater than that removed by 1 *N* KCl. In most soils the largest quantity of N was removed by the boiling 0.01 *M* $CaCl_2$ plus K_2SO_4.

The correlation between total extractable N regardless of methods used and N uptake by either the first four crops or the total of five crops was remarkably high (Table 4) and was higher than the correlation between total soil N and N uptake by four crops (r = 0.79) or by five crops (r = 0.87). Although the initial level of inorganic N varied from soil to soil, the correlation between total extractable N and N uptake by the individual crops was about the same as that for total N uptake by four crops. Therefore, only the correlation coefficients shown in Table 4 are presented.

Table 4. Total NH_4^+-N (digest N) in soil extracts using different extracting solutions and the correlation with N uptake by plants.

Soil	Total NH_4^+-N, ppm			
	1*N* KCl	1*N* K_2SO_4	0.01*M* $CaCl_2$	0.05*N* Na-P
Nipe	21	38	59	44
Piñas	28	48	61	66
Catalina	81	132	137	122
Cialitos [2S]	35	55	53	44
Cialitos [4]	52	79	75	63
Cialitos [3]	40	63	80	70
Humatas	43	71	107	70
Cialitos [2]	63	96	150	107
Cialitos [1]	53	84	113	93
Los Guineos	95	147	177	117

	Regression estimates, N uptake		Correlation coefficient
	Intercept	Slope	N uptake
1*N* KCl total 4 crops	-24.8	2.38	0.90
crop 5	9.1	0.33	0.58
total 5 crops	-16.0	2.73	0.90
1*N* K_2SO_4 total 4 crops	-31.7	1.58	0.91
crop 5	9.2	0.21	0.55
total 5 crops	-22.6	1.80	0.89
0.01*M* $CaCl_2$ total 4 crops	-37.6	1.32	0.92
crop 5	1.9	0.24	0.77
total 5 crops	-37.8	1.59	0.96
0.05*N* Na-P total 4 crops	-53.2	1.58	0.87
crop 5	0.1	0.32	0.70
total 5 crops	-55.1	2.24	0.90

Table 5. Mineralizable N in soils estimated at varying times of incubation and the correlation with N uptake by plants.

Soil	N mineralized, ppm			
	2 weeks	4 weeks	8 weeks	16 weeks
Nipe	9	16	21	46
Piñas	8	15	16	36
Catalina	64	84	95	136
Cialitos [2S]	-5	7	11	29
Cialitos [4]	26	42	53	79
Cialitos [3]	19	22	32	48
Humatas	31	58	69	118
Cialitos [2]	92	121	149	179
Cialitos [1]	88	99	118	172
Los Guineos	129	189	193	260

	Regression estimates, N uptake		Correlation coefficient
	Intercept	Slope	N uptake
2 weeks: total 4 crops	36.5	1.30	0.95
crop 5	14.9	0.24	0.80
total 5 crops	51.3	1.56	0.98
4 weeks: total 4 crops	30.6	1.00	0.96
crop 5	14.9	0.17	0.74
total 5 crops	45.4	1.19	0.98
8 weeks: total 4 crops	26.6	0.92	0.94
crop 5	12.9	0.17	0.80
total 5 crops	39.0	1.11	0.97
16 weeks: total 4 crops	12.3	0.76	0.95
crop 5	11.5	0.13	0.76
total 5 crops	23.4	0.90	0.98

The correlations obtained between total extractable N and N uptake by Crop 5 (after drying) were not as close. The correlation coefficient (r) between N uptake by Crop 5 and total soil N, however, was 0.91, indicating a closer relationship than with the N extracted by the chemical procedures. Considering the correlations obtained between total extractable N and total N uptake by the five crops, however, it should be possible to use these chemical methods to predict N availability even though the total mineralizable N may vary depending on the conditions to which the sample was subjected or on season of the year.

As shown in Table 5, the quantity of N mineralized in all soils increased with the length of the incubation period. The values given are for the sum of NH_4^+-N and NO_3^--N found in the extract. At the end of the 2-week incubation period substantial portions (50%) of the N extracted from most soils was found as NH_4^+-N, while at the end of 16 weeks in all soils almost all of the N was found as NO_3^--N. The correlation between N mineralized and N uptake by the first four crops or by all five crops was extremely high. Furthermore, the length of the incubation period had little

Table 6. Correlation between N mineralized at varying times of incubation and chemical indices of N availability.

Chemical methods	Correlation coefficient (r)			
	N mineralized			
	2 weeks	4 weeks	8 weeks	16 weeks
Total extractable N:				
(a) 1 *N* KCl	0.86	0.89	0.87	0.86
(b) 1 *N* K_2SO_4	0.85	0.87	0.86	0.86
(c) 0.01 *M* $CaCl_2$	0.95	0.96	0.96	0.96
(d) 0.05 *N* Na-P	0.88	0.85	0.86	0.85
Distillable N:				
(a) 1*N* KCl	0.62	0.63	0.61	0.63
(b) 1*N* K_2SO_4	0.73	0.72	0.73	0.71
(c) 0.01 *M* $CaCl_2$	0.68	0.72	0.70	0.70
(d) 0.05 *N* Na-P	0.65	0.66	0.66	0.64

effect on the correlation obtained. Thus, this incubation procedure appears to be highly useful in predicting the ability of these tropical soils to supply N.

As expected, there was a strong correlation between N mineralized in the incubation tests and the total extractable N by any of the chemical procedures used (Table 6). The total N extracted by boiling 0.01 *M* $CaCl_2$ was somewhat more closely related to N mineralization, however, than that extracted by other procedures. The distillable NH_4^+-N found in the extracts was less closely correlated with N mineralized than was the total extractable N. Smith and Stanford (11) compared N mineralized with distillable N and found an excellent relationship. Undoubtedly, a higher portion of the readily hydrolyzable organic N was included in their distillable fraction. In fact, it is possible that their distillable fraction more nearly corresponds to the total extractable N removed by the procedure used in these experiments. It is evident, however, that the mineralizable N by incubation does provide a reliable measure of the N that becomes available to plants and that these chemical methods, especially the 0.01 *M* $CaCl_2$ extract, obtained either by the procedure described here or that of Smith and Stanford (11), gives an accurate measure of a wide variety of soils to supply N.

The procedures developed here were purposely kept simple so they could be used under a wide variety of conditions and with a minimum of necessary equipment. Since these methods were adopted from other methods already described, it is probable that further adaptations to meet a particular situation could be made without jeopardizing the results.

No effort was made to determine the organic fraction or the organic N pool that was contributing to the N supply of these soils as has been done for other soils (7, 9, 12), although Abruña and Vincente (1) have shown that some substantial portion of the organic matter in similar soils of Puerto Rico was highly resistant to oxidation. It is evident, however, that the mineralizable N pool does vary rather widely in these soils even where the organic matter contents are quite similar. Drying of the soils used in these experiments induced a release of soil N on subsequent rewetting and cropping that was measured under greenhouse conditions. The reasons for the increased N release are not obvious, but it is possible that drying and subsequent rewetting brought about physical changes in the clay-organic matter complex that enhanced its attack by microorganisms. These points are worthy of further investigation.

The results of our experiments demonstrate that these tropical soils can supply substantial quantities of N upon cropping. While the absolute quantities that may become available under field conditions cannot be deduced from these results, significant portions of total N requirements of all but the most demanding crops may be met by release from the soil supply. Furthermore, the data presented demonstrate that laboratory-chemical methods as well as incubation procedures provide reliable means for evaluating the ability of these Oxisols and Ultisols of Puerto Rico to supply N.

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