AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

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1. SUBJECT CLASSIFICATION	A. PRIMARY AGRICULTURE
	B. SECONDARY SOILS AND FERTILIZERS

2. TITLE AND SUBTITLE

NITROGEN FERTILIZATION OF CORN AND SORGHUM GROWN IN OXISOLS AND ULTISOLS IN PUERTO RICO

3. AUTHOR(S)

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4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1974	8 PAGES	ARC RQ-631.84072-F793

7. REFERENCE ORGANIZATION NAME AND ADDRESS

CORNELL UNIVERSITY
DEPARTMENT OF AGRONOMY
ITHACA, NEW YORK 14850

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

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10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-AAA-819	

12. DESCRIPTORS	
High price N, leaching losses N, humid tropics, crop yields, sulfur coated urea, side dress application	13. PROJECT NUMBER 931-11-120-127
	14. CONTRACT NUMBER AID/csd - 2834
	15. TYPE OF DOCUMENT RESEARCH PAPER

AID 590-1 (4-74)

Reprinted from AGRONOMY JOURNAL
Vol. 66, July-August 1974, p. 534-540

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ABSTRACT

The requirement of fertilizer N for high yields, its generally high price, and the ever-present possibility of large leaching losses of inorganic N makes it essential that fertilizer N be managed as efficiently as possible in the humid tropics. Three rates and 2 times of application of fertilizer N were applied to 15 corn (*Zea mays* L.) and 3 sorghum (*Sorghum bicolor* Moench) crops on 2 Ultisols and 3 Oxisols during 5 successive growing seasons in Puerto Rico to determine the most effective means of applying fertilizer N to these crops. Additional objectives were to determine the apparent recovery of fertilizer N by the crops; the interrelationships between crop yield, N fertilization and soil inorganic N content; and the effectiveness of slow-release sulfur-coated urea as a source of fertilizer N for corn and sorghum. All soils had been under cultivation for at least 50 years and received relatively high rates of fertilizer for the last 20 years.

The results indicated that: 1) postplant sidedress applications of fertilizer N resulted on the average in higher yields and plant recovery of fertilizer N than preplant applications; 2) when there were no limiting factors of climate or disease, and there was a response to N, the recovery of postplant applied N was comparable to that observed in temperate areas; 3) maximum corn grain yields were approximately 6.3 metric tons/ha; 4) near-maximum corn grain yields were obtained with 67 kg/ha of postplant-applied N; 5) preplant-applied sulfur-coated urea was no more effective than preplant urea in increasing yields or N recovery; 6) soil inorganic N content was generally not a good index of soil N supplying power in these soils; 7) drought and disease frequently reduced yields; 8) there was very little residual effect of the fertilizer N applied in this experiment; and 9) the clayey Oxisols and Ultisols in Puerto Rico had a relatively high N-supplying power.

Additional index words: Soil inorganic N, Sulfur-coated urea, Fertilizer N recovery.

IT is widely recognized that fertilizer N must be applied to sustain high crop yields on Oxisols and Ultisols in the humid tropics (15,16). The ever-present possibility of large leaching losses of inorganic N, the generally high price of fertilizer N, and the low economic level of the average farmer in these areas make it essential that N fertility be managed as efficiently as possible.

In temperate areas, postplant applications of fertilizer N generally result in larger yield increases in corn and higher recovery of fertilizer N than preplant applications (13; Bouldin, D.R., W. S. Reid, and D. J. Lathwell. 1971. Fertilizer practices which minimize nutrient loss, Agron. Paper No. 925, Agron. Dept., Cornell Univ.) Since information of this nature is scarce for the humid tropics, the present study was conducted to determine the relative effectiveness of these two methods in representative Oxisols and Ultisols in Puerto Rico. Additional objectives were to determine: 1) optimum rates of fertilizer N; 2) the interrelationships between crop yield, N fertilization and soil inorganic N contents; and 3) the effectiveness of slow release sulfur-coated urea as a source of fertilizer N for corn and sorghum.

MATERIALS AND METHODS

Five sites were selected for representative soil series of Ultisols and Oxisols. Three of the soils, Humatas (Typic Tropohumult), Catalina (Tropeptic Haplorthox) and Torres (Orthoxic Tropudult), are in the interior uplands of Puerto Rico at elevations of 220 to 580 m above sea level. The other two soils, Piña (Typic Haplorthox) and Coto (Tropeptic Eutrorthox), are on the northern coastal plain at elevations of 50 to 130 m above sea level. The average summer maximum and minimum temperatures are approximately 29 and 21C at the interior sites and 32 and 22C at the coastal sites. The average winter maximum and minimum temperatures are approximately 3C lower than in the summer at all sites. Solar radiation ranges from an average of 300 langleys/day in the winter to 500 langleys/day in the summer. Average yearly precipitation for all sites is between 1,650 and 2,000 mm/year with only two months (February and March) receiving, on the average, less than 100 mm/month. The evaporation from a class A pan in the summer is approximately 6 mm/day in the coastal plain sites and 5 mm a day in the interior sites. This drops to 4 and 3 mm/day for the coastal and interior sites, respectively, during the winter. The Humatas and Torres sites had been in improved, fertilized pasture for several years. The Catalina site had been under continuous cultivation for at least 30 years with crops such as taniers, yams, plantains, and tobacco. The Piña soil was in a pineapple research field but had lain fallow for 2 years. The Coto was a subsoil which had been exposed by land leveling in 1960, fallow since that date, and remained essentially barren, presumably due to the extreme zinc deficiency that became apparent during the N experiment.

Four of the soils are clays; Piña is a sandy loam. Selected chemical characteristics of the soils are listed in Table 1. It should be pointed out that the Al saturation in both Ultisol subsoils is approximately 60%, enough to limit root growth in Al sensitive crops such as sorghum (5).

The first crop of corn was planted in the summer of 1970 at four of the sites. The cropping sequence for all sites is shown in Table 2.

The soils were initially limed to a pH of 5.5 and, when necessary, additional lime was applied before subsequent plantings to maintain this pH. Blanket applications of 224 kg/ha of P_2O_5, 168 kg/ha of K_2O as K_2SO_4, and 56 kg/ha of Mg as $MgSO_4 \cdot 7H_2O$ were plowed under prior to planting each crop. Four kg/ha of Zn as $ZnSO_4 \cdot 7H_2O$ were included in the blanket fertilizer for the Piña soil beginning with the winter 1970-71 crop and for all soils in the summer of 1972. Soil insecticides were incorporated with the broadcast fertilizer.

There were eight treatments with five replications in a randomized block design. Individual plots were 4.9 × 9.8 m. Pioneer X-306, a hybrid corn developed in Jamaica for tropical conditions, was planted in 76 cm rows at a population of 43,000 to 48,000 seed/ha. RS-671 sorghum was planted in 51-cm rows at a rate of 11.2 kg of seed/ha.

The fertilizer treatments were 34, 67, and 134 kg/ha of N applied as a preplant broadcast or a postplant sidedress when the plants were 30 to 45 cm high (4 to 5 weeks after plant-

[1] Joint contribution from the Department of Agronomy, Cornell University, Ithaca, N.Y., as Agronomy Paper No. 1071, and the Agricultural Experiment Station, University of Puerto Rico, Mayaguez Campus, Rio Piedras, Puerto Rico. This study was part of the work supported by the USAID under research contract csd-2490 entitled: "Soil fertility requirements to attain efficient production of food crops on the extensive, deep, well-drained but relatively infertile soils of the humid tropics." Received Nov. 15, 1973.

[2] Assistant Professor of Soil Science, Research Technician, and Professor of Soil Science, Cornell University, respectively.

Table 1. Selected chemical properties of soils used in N experiments.

Soil	Depth	OM	N	pH	CEC (NH_4OAc)	Σ Cations	Exchangeable cations Ca^{2+}	Mg^{2+}	K^+	Al^{3+}
	cm	%	%		meq/100 g					
Humatas (Typic Tropohumult; clayey, mixed, isohyperthermic)	0–25	3.7	0.17	5.0	17.0	7.9	6.4	0.8	0.7	0.0
	25–50	1.2		4.6	13.6	12.4	3.0	0.8	0.2	8.4
Torres (Orthoxic Tropudult; clayey, mixed, isohyperthermic)	0–25	3.6	0.23	4.7	13.0	7.4	5.6	1.2	0.4	0.2
	25–50	0.9		4.8	9.8	6.8	2.0	0.4	0.4	4.0
Catalina (Tropeptic Haplorthox; clayey, kaolinitic,	0–25	3.9	0.24	5.5	15.0	8.7	7.1	1.0	0.6	0.0
	25–50	1.2		5.3	8.2	4.8	4.0	0.6	0.0	0.2
Piña (Typic Haplorthox; psammentic, oxidic, isohyperthermic)	0–25	1.6	0.07	4.9	3.7	2.5	1.3	0.8	0.1	0.3
	25–50	0.7		4.8	2.9	2.3	1.2	0.7	0.0	0.4
Coto (Tropeptic Eutrorthox; clayey, kaolinitic, isohyperthermic)	0–25	1.0	0.10	6.1	5.6	6.4	4.8	1.5	0.1	0.0
	25–50	0.5		6.4	5.0	6.5	4.5	1.9	0.1	0.0

ing). The N source was urea except for a 67 kg/ha preplant treatment of experimental sulfur-coated urea (SCU) from TVA. The SCU for the first crop had a dissolution rate of 0.6%/day between the 5th and 14th days. The SCU used on the second and third crops had a dissolution rate of 1.1%/day between the 3rd and 7th days, and that used for the 1972 crop on Piña had a dissolution rate of 4.4%/day for the first 7 days. The preplant treatments were plowed under and the postplant treatments were applied in bands 15 cm from the row and 5 cm under the soil surface. The crops grown on the Coto soil received 2 foliar applications of 0.5% $ZnSO_4$, 3 and 5 weeks after planting, which eliminated visual Zn deficiency symptoms. The Piña summer 1970 crop received one foliar application of Zn, 6 weeks after planting.

The crops planted in 1970 and the summer of 1971 received 112 kg/ha of 10-10-10 starter at planting, banded 5 cm to the side and 5 cm below the seed. This practice was stopped when an experiment on the same soils showed that with a postplant sidedress N application of 134 kg/ha, the starter had no effect on yield.

The same treatments were maintained on the same plots throughout the experiment. At the Catalina, Humatas, and Torres sites in the summer of 1972, no N was applied to the plots previously receiving urea in order to determine the residual effects of the previous N treatments. The summer crops were planted between April 27 and May 21 except for the 1971 crop at the Piña site which was planted June 23. The winter crops were planted between September 22 and November 24.

Fall army worms (*Spodoptera frugiperda*) in corn were controlled by weekly applications of DDT for the first crop and of Sevin for subsequent crops. Beginning in the fall of 1971, Parathion was applied over the row 1 week after planting to control lesser corn stalk borers (*Elasmopalpus lignosellus*). Dithane was applied at weekly intervals to inhibit northern leaf blight (*Helminthosporium turcicum*) after symptoms appeared in the winter corn crop. Weeds were controlled in the first two crops by hand weeding, in the third and fourth crop by Simazine and by Dacthal with supplemental hand weeding in the 1972 crops.

The length of time to reach maturity for corn and sorghum ranged from 120 to 135 days.

Grain and stover were harvested from 7.6 and 3.8 m, respectively, if the two center rows of each plot. Subsamples were taken for shelling percentage and moisture and N content. All stover and grain was removed from the field before preparing the field for the next crop.

Soil samples for inorganic N analyses were composites of six cores per plot. The samples were air dried and stored in the freezer until analyzed. Inorganic N content was determined by extracting the soil with 1 *N* KCl and determining NH_4^+ and NO_3^- by the method described by Lathwell et al. (12). Samples taken after the summer and winter crops were designated fall and spring samples, respectively.

RESULTS AND DISCUSSION

Yield

The yield potential of approximately 6.3 metric tons/ha of grain (S.M. Sehgal, Pioneer Hi-Bred Corn Co., Spanish Town, Jamaica, private communication) for the corn hybrid used, Pioneer X-306, was obtained in 4 of the 14 corn crops (Table 2). Baynes (1) conducted variety trials on four Caribbean islands for 3 years and observed that Pioneer X-306 produced an average of 5.2 metric tons/ha and individual crop yields varied from 1.9 to 7.9 metric tons/ha. Chesney (6) working with X-306 in Guyana obtained a maximum grain yield of 4.6 metric tons/ha of husked cobs that were "reasonably dry". In our experiments the grain yield of five crops was reduced by drought, and the three corn crops planted in the fall of 1971 were

Table 2. Effect of rate and time of application of N on grain yield.

Soil	N applied method	Summer 1970 (corn) Grain yield (15% H_2O)	Winter 1970-71 (sorghum) Grain yield (15% H_2O)	Summer 1971 (corn) Grain yield (15% H_2O)	Winter 1971-72 (corn) Grain yield (15% H_2O)	Summer 1972 (corn) Grain yield (15% H_2O)
	kg/ha	metric tons/ha				
Catalina	0	5.9	2.5**	2.5 a†	2.9	3.4 ab
	34 P*	6.3	2.5	2.6 ab	2.9	2.8 a
	34 S	6.1	2.5	3.0 abc	3.5	3.5 ab
	67 P	6.3	2.3	2.9 ab	3.6	3.0 ab
	67 S	5.8	2.8	3.6 c	3.5	3.2 ab
	67 PX	5.8	2.2	2.9 ab	3.5	
	134 P	5.9	2.9	3.2 bc	3.5	3.7 bc
	134 S	6.0	2.8	3.6 c	3.4	3.6 ab
	134 S'					4.4 c
		NS	NS		NS	
Humatas	0	4.5 a	1.7 a	3.1 a	1.7	3.0 a
	34 P	4.2 a	1.9 a	3.8 ab	1.7	2.9 a
	34 S	5.1 ab	3.2 b	3.7 ab	1.7	2.9 a
	67 P	4.7 a	1.7 a	4.4 ab	2.0	3.2 a
	67 S	6.3 c	3.7 b	4.8 b	1.9	2.8 a
	67 PX	5.0 ab	2.1 a	4.5 b	1.9	
	134 P	5.9 bc	2.0 a	4.3 ab	2.6	2.9 a
	134 S	6.6 c	4.3 c	4.4 ab	2.3	2.6 a
	134 S'					6.2 b
					NS	
Piña	0	3.1	1.0 a	.5		2.1 a‡
	34 P	3.0	.8 a	.6		2.9 b
	34 S	2.8	1.6 ab	.6		3.4 bc
	67 P	3.1	1.2 ab	.8		3.4 bc
	67 S	3.1	2.0 bc	.6		4.4 cd
	67 PX	3.2	1.5 ab	.6		3.7 bc
	134 P	3.0	2.4 c	.6		5.1 d
	134 S	3.0	2.3 c	.6		5.1 d
		NS		NS		
Coto	0	1.7 a				
	34 P	2.8 bc				
	34 S	2.6 b				
	67 P	3.5 cd				
	67 S	4.1 d				
	67 PX	3.1 cd				
	134 P	4.8 c				
	123 S	5.1 c				
Torres	0				4.9	5.8
	34 P				4.5	6.2
	34 S				5.3	5.9
	67 P				5.1	6.0
	67 S				4.8	5.9
	134 S				4.6	6.1
	134 P				4.9	5.9
	134 S'§				4.9	5.8
					NS	NS

* P, preplant broadcast; S, postplant sidedress, PX, SCU preplant broadcast, S', postplant sidedress in summer '72. ** Underlined treatments did not receive fertilizer. † Values followed by the same letter within a given crop are not statistically different at the 5% level using Duncan's Multiple Range Test. ‡ Planted in fall, 1972. § Received no Mg in winter 71-72.

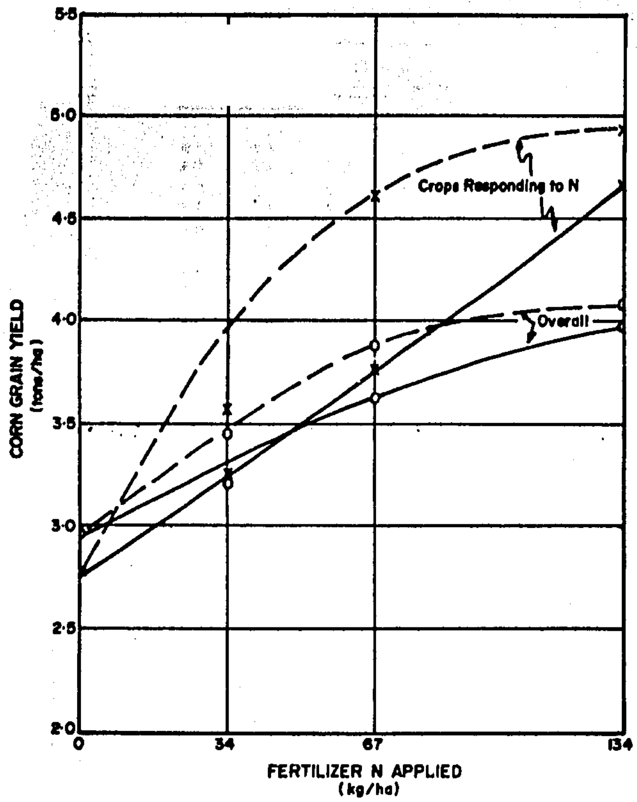

Fig. 1. Average effect of fertilizer N on corn grain yield in metric tons/ha. — Preplant application, ···· postplant sidedress application, □ SCU overall average, Δ SCU, crops responding to N.

adversely affected by a relatively little known disease, tar spot (*Phyllachora maydis*). Corn grain/stover ratios ranged from 0.23 to 1.19. All crops which were not affected by yield-limiting factors had grain stover ratios higher than 0.85.

In all drought-affected crops, the leaves were wilting by 10 A.M. for a total of more than 2 weeks and in some cases for up to 4 weeks. The drought occurred during the silking stage in three of the crops (Catalina, summer 1971; and Piña, summers 1970 and 1971) and resulted in low grain/stover ratios. In the other drought-affected crops (Humatas, summer 1971 and Catalina, 1972) there was insufficient rainfall during the early growth of the plants, resulting in small plants with grain/stover ratios similar to those of the maximum yield crops. At the Catalina site there was less than 60 mm/month of rainfall in June and July of 1971, and in May and June of 1972. The evaporation during all these months was over 150 mm/month. Normal rainfall for this period is 120 to 150 mm/month. A traffic pan that restricted root growth to the upper 20 cm of soil and the low available water content of the Piña soil severely aggravated the rainfall shortage at this site. The traffic pan was destroyed by deep chiseling in the early spring of 1971 but had reformed by the middle of the following crop. It was only after an irrigation system was installed in 1972 that more than 3.5 metric tons/ha of grain were obtained at the Piña site.

The maximum sorghum grain yield for the three sites was 4.3 metric tons/ha. This approximates the maximum previously observed in Puerto Rico (F. Abruña, private communication), but is much lower than those observed in other tropical countries (8).

N Response

Response to N fertilizer ranged from no response for the first crops in the Catalina and Torres soils and in the drought and disease affected crops, to a marked response in several cases (Table 2). The Coto subsoil and the final crop in Piña appeared to be the only cases in which 134 kg/ha were not enough to produce the apparent yield potential of 6.3 metric tons/ha.

The overall average response of corn grain yield to fertilizer N was low, with 134 kg/ha fertilizer N only increasing yield from 3 to 4 metric tons/ha (Fig. 1). However, we believe that this response is not representative of normal, long-term conditions for growing corn in this area because it includes such a large number of crops that did not respond to N due to: 1) the abnormally low summer rainfalls during part of the experimental period; 2) the disease in winter crops that, in the future, would not be planted during this season unless the disease problems had been overcome; and 3) two of the initial crops were grown in soils with either an exceptionally high inorganic N content (Catalina) or a high N- supplying power (Torres). Thus a more useful indication of average N response in these soils can be obtained by averaging the data from only those crops where there was a significant response to fertilizer N. As expected, this average curve showed a more pronounced response to the fertilizer N, with 134 kg/ha increasing yields from an average of 2.8 to 4.9 metric tons/ha (Fig. 1). Both average response curves show that 67 kg/ha of postplant applied N produced near maximum yields. It is also evident that the soils had a relatively high N-supplying power, as the average yield of the plots receiving no fertilizer N was approximately 3 metric tons/ha. This high N-supplying power may be due to the history of high rates of fertilizer use on these soils and is probably not representative of the N supplying power of Oxisols and Ultisols which have been cropped for several years with little or no added fertilizer.

It was observed that in general, as would be expected, the soils with higher organic matter and total N contents had a higher N supplying power than the lower organic matter Piña sandy loam and Coto subsoil (Table 3).

Time of Application

Among the corn crops that responded to N, the postplant sidedress applications of N were markedly superior to the preplant applications in increasing grain yield and apparent recovery of fertilizer N (Fig. 1 and Table 4). This was especially true with the near optimum application rate of 67 kg/ha, where the postplant N application produced 840 kg/ha more grain than, and an apparent fertilizer N recovery of almost twice that of, the same rate of N applied before planting.

The time of application did not generally make such a large difference in yield or N recovery in the overall average because of the previously mentioned lack of N response in a number of crops. It should be

Table 3. Effect of rate and time of application of fertilizer N on plant N content and apparent recovery of fertilizer N.

Soil	N applied, method	Summer 1970 (corn) Plant N	Summer 1970 (corn) Apparent fert. N recovery*	Winter 1970-71 (sorghum) Plant N	Winter 1970-71 (sorghum) Apparent fert. N recovery	Summer 1971 (corn) Plant N	Summer 1971 (corn) Apparent fert. N recovery	Winter 1971-72 (corn) Plant N	Winter 1971-72 (corn) Apparent fert. N recovery	Summer 1972 (corn) Plant N	Summer 1972 (corn) Apparent fert. N recovery	Avg Plant N	Avg Apparent fert. N recovery
		kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
Catalina	0	139	-	47†	-	56	-	83	-	68†	-	77	-
	34 P**	152	38	53	18	81	74	83	0	66	0	87	42
	34 S	142	9	49	6	79	68	104	62	64	0	88	45
	67 P	144	7	48	1	87	46	112	43	63	0	91	30
	67 S	135	0	57	15	102	69	95	18	70	3	92	33
	67 PX	129	0	43	0	78	33	-	-	-	-	83	6
	134 P	145	4	58	8	117	46	105	16	88	15	103	30
	134 S	145	4	58	8	133	57	110	20	95	20	108	37
	134 S'									144	42		
Humatas	0	104	-	36	-	60	-	54	-	58†	-	62	-
	34 P	107	9	40	12	78	53	46	0	57	0	66	12
	34 S	130	76	56	59	78	53	60	18	55	0	76	50
	67 P	111	7	37	1	81	31	68	21	59	1	71	16
	67 S	145	61	60	36	103	64	63	13	53	0	85	42
	67 PX	119	22	49	19	89	43	-	-	-	-	86	28
	134 P	145	31	44	6	112	39	75	16	56	0	86	22
	134 S	180	57	71	26	110	37	89	26	54	0	101	36
	134 S'									140	61		
Piña	0	83	-	21	-			22	-	51‡	-	44	-
	34 P	88	15	17	0			23	3	61	29	47	9
	34 S	86	9	29	24			24	6	65	41	51	20
	67 P	98	22	23	3			29	10	68	25	55	15
	67 S	97	21	37	24			27	7	88	55	62	27
	67 PX	99	24	35	21			25	4	74	34	58	21
	134 P	109	19	51	22			28	4	108	43	74	22
	134 S	97	21	47	19			37	11	114	47	74	22
Coto	0	43	-									43	-
	34 P	60	50									60	50
	34 S	55	35									55	35
	67 P	75	48									75	48
	67 S	77	51									77	51
	67 PX	72	43									72	43
	134 P	111	51									111	51
	134 S	107	48									107	48
Torres	0							128	-	155†	-	142	-
	34 P							141	38	143	0	142	0
	34 S							168	118	155	0	162	59
	67 P							149	31	149	0	149	10
	67 S							174	69	148	0	161	28
	134 P							172	33	156	1	164	16
	134 S							179	38	137	0	158	12
	134 S'§							166	28	176	16	171	22

* Fertilized plant N minus check plant N/fertilizer N applied ** P = prepland broadcast, S = postplant sidedress, PX = SCU preplant broadcast, S' = postplant sidedress in summer '72. † Underlined treatments did not receive fertilizer, apparent N recovery is calculated for fertilizer applied the previous crop. ‡ Planted in Fall '72. § Received no Mg, winter '71-72 crop.

pointed out that there were also a few crops with N response where no statistical difference in yields between pre- and postplant treatments were observed (Table 2). This occurred when no excess rain fell during the first 6 weeks after planting.

The greatest difference in effectiveness of fertilizer N due to time of application occurred in the winter sorghum crop at the Humatas site where there was no response to preplant N and a large response to postplant N (Table 2). The ineffectiveness of preplant applied N in this case was probably a result of the shallow rooting (20 cm) of the Al sensitive sorghum roots caused by the high Al saturation in the subsoil of this Ultisol, coupled with the leaching of fertilizer N from the surface soil by heavy rains (400 mm in 2 weeks) that began immediately after the fertilizer was incorporated.

It is hypothesized that the fertilizer N was leached from the surface soil in the form of urea, as it has been shown in our laboratory that in this soil 75% of added urea is still present as urea 4 hours later. It is difficult to understand why in this case the SCU was not more effective than urea.

Recovery of Fertilizer N

The apparent recovery of fertilizer N varied from almost 0% in several cases to a high of 55 to 65% of the postplant applications of 67 or 134 kg/ha in six of the corn crops (Table 3). Low recovery was generally associated with lack of N response and/or high rainfall soon after preplant applications.

Table 4. Average effect of rate and time of application of fertilizer N on plant N content and apparent N recovery.

All fertilized corn crops N applied, method	All fertilized corn crops Plant N content	All fertilized corn crops Apparent N recovery	Fertilized corn crops responding to N Plant N content	Fertilized corn crops responding to N Apparent N recovery
kg/ha	kg/ha	%	kg/ha	%
0	75	-	63	-
34 P*	84	26	77	43
34 S	90	45	81	55
67 P	93	27	84	32
67 S	99	36	103	60
67 PX	86	24	86	35
134 P	112	28	119	42
134 S	117	31	129	49

* P, preplant plowdown; S, postplant sidedress; PX, SCU preplant broadcast.

Since a relatively large number of crops did not respond to fertilizer N for reasons of drought, disease, and initially high soil inorganic N contents, the overall average fertilizer N recovery was low (Table 4). However, by eliminating the crops where no significant response to N was observed, an average of 60% of the applied N was recovered from the near optimum 67 kg/ha of postplant sidedress applied treatment. This recovery is comparable to the fertilizer N recoveries by corn observed in the continental United States (13, 14) and by Jones (10) in northern Nigeria.

The average recovery by the corn crops where there was a N response shows the marked superiority of the postplant treatments, especially at the near optimum rate of 67 kg/ha, where there was almost twice as much

Table 5. NO^-_3 -N content in the top 75 cm of soil.

Soil	Depth	Spring 1970	Fall 1970		Spring 1971		Fall 1971		Spring 1972		Fall 1972	
		O-N	O-N	134 N excess*	O-N	134 N excess	O-N	134 N excess	O-N	134 N excess	O-N	134 N excess
	cm	kg/ha										
Catalina	0-25	158	26	13	23	2	11	29	10	14	6	2
	25-50	62	20	20	21	0	16	4	7	38	2	3
	50-75	49	35	27	29	7	7	22	11	27	3	3
	Total	269	81	60	73	9	34	55	28	79	11	8
Humatas	0-25	94	33	1	24	0	9	20	13	9	6	0
	25-50	54	32	5	23	0	11	6	8	16	4	1
	50-75	31	31	14	24	0	5	16	8	30	2	5
	Total	179	96	20	71	0	25	42	29	55	12	6
Piña	0-25	97	21	11	12	0					0	0
	25-50	49	19	26	8	2					0	0
	50-75	34	49	0	30	0					0	0
	Total	180	89	37	50	2					0	0
Coto	0-25	43	8	0								
	25-50	39	5	0								
	50-75	30	9	0								
	Total	112	22	0								
Torres	0-25						43		24	36	26	3
	25-50						21		34	8	23	8
	50-75						12		30	0	25	7
	Total						76		88	44	74	18

* NO_3^- -N in 134 kg/ha postplant N plots minus NO_3^- -N in O-N plots.

N recovery from the sidedress treatments as from the preplant application. The overall recovery of N by all crops at all sites also shows the superiority of postplant applications in supplying N to corn and sorghum. Jones (10) did not observe this superiority of postplant treatments in northern Nigeria, but, as he explained, this was due to their particular rainfall pattern that only wets the soil to a maximum depth of 45 cm during the first 4 weeks after the corn is planted. With this situation, the roots grow downward with the advancing water front and preplant applied N is not leached beyond the root zone during the first few weeks of plant growth.

Sulfur-coated Urea

The slow release SCU was in no crop statistically superior to the same application rate of preplant applied urea in increasing yields or in recovery of fertilizer N (Tables 2 and 3). Average N recovery by corn from 67 kg/ha of preplant SCU was slightly lower than the recovery from the same rate of preplant urea (Tabel 4). The N recovery by those corn crops which respond to N also indicated that there was no difference in effectiveness between preplant applied urea and SCU.

Residual Effect of Fertilizer N

The data from the summer 1972 crops receiving no fertilizer N demonstrated that there was very little residual effect from the previous N treatments on crop yield or N uptake (Tables 2 and 3). The only recovery of fertilizer N of any magnitude was the 20 and 27 kg/ha more N in the 134 kg/ha pre- and postplant treatments, respectively, than in the check treatment at the Catalina site. The residual N at this site was probably a result of the relatively low N recoveries from these treatments in the previous winter crop. The lack of residual effects at Humatas, in spite of a total application of 538 kg/ha of N in the two highest rate treatments, was somewhat surprising. Apparently the excess N from previous treatments was leached beyond the root zone or incorporated into non-readily-mineralized organic matter. It is unlikely that significant denitrification occurred as the surface soils are quite well drained, and it has been shown (Dubey, H. D. and R. H. Fox. 1974. Denitrification losses from humid tropical soils of Puerto Rico. Submitted for publication.) that denitrification does not occur in these subsoils.

The residual effect of N applied during this experiment would undoubtedly have been greater had the stover been incorporated into the soil rather than removed from the plots.

Soil Inorganic N Contents

The NO^-_3 contents of the top 75 cm of soil are given in Table 5. Soil NH^+_4 contents are not given since they were low (2 to 6 ppm except for Torres, which had 5 to 10 ppm) and constant with time and depth.

The inorganic N content in the top 75 cm of soil at all sites was quite high at the beginning of the experiment and in all but the Torres soil had dropped to very low values after 2½ years and four or five crops. The 269 kg/ha of soil NO^-_3 —N present before the first crop at Catalina was high enough to produce a yield of 5.8 metric tons/ha of grain in the check plots and no response to fertilizer N. This initially high inorganic N content at all sites may have been due to such factors as: 1) increased mineralization and nitrification resulting from liming of the soils one month prior to sampling (18); 2) the gradual buildup of NO^-_3 —N during the relatively dry period the previous 2 months, as has been observed in Africa and the Caribbean (9, 17, 18); 3) a NO^-_3 flush caused by rains rewetting the soil after a dry season (2, 3, 17), as the soil was relatively dry at all sites for 2 months (30 to 60 mm/month) rainfall and evaporation of 100 to 200 mm/month) before a moderate rain (20 to 60 mm) fell approximately 2 weeks before soil sampling; or 4) residual inorganic N from previously applied fertilizer N.

There was some accumulation of NO^-_3 in the top 75 cm of soil in the 134 kg/ha postplant N treatments, but it was not cumulative and generally occurred after a crop of little, if any, response to N (Tables 3 and 5). The soil NO^-_3 content of the 134 kg/ha preplant

N treatments plots was very similar to that of those receiving 134 kg/ha postplant N. The lack of accumulation is not surprising as at least once every year there was sufficient rainfall to leach NO^{-}_{3} from the top 75 cm of soil.

Evidence of this leaching can be seen in the spring 1972 sampling at the Catalina and Humatas sites where relatively large amounts of excess NO^{-}_{3} were in the lower horizons. The excess NO^{-}_{3} —N in the profile of the 134 kg/ha postplant treatments at Humatas had apparently leached out before the roots reached this depth, since there was no more N taken up by the corn in this treatment than by the plants growing in the check plots in the residual N experiment the following summer. It appears that some of the 79 kg of excess N in the profile of the Catalina soil was utilized by the corn in the residual study since the plants in this treatment contained 20 kg/ha more N than the plants in the check plots (Table 3).

As would be expected under these climatic conditions, soil inorganic N content is not a very good index of the N-supplying power of the soil. There was no significant correlation between the NO^{-}_{3} —N content of the upper 75 cm of soil before planting (Table 5) and the N content of the corn in the check plots (Table 3) in the experiments where climate or disease were not yield limiting (i.e., maximum yield over 5.0 metric tons/ha). This lack of correlation is due to a number of factors: 1) soil inorganic N content is a function of the rainfall pattern before sampling (2, 3, 7, 9); 2) high rainfall may leach the inorganic N present at sampling below the root zone before the plants can absorb it; and 3) in soils with a high N mineralization capacity, such as Torres, a large amount of organic N can be mineralized in a short time. For example, in the samples taken in the fall of 1971 at the Torres site, 3 weeks prior to planting, there was a total of 116 kg/ha of NH_4^+ plus NO^{-}_{3} —N in the top 75 cm of soil, but 8 weeks later, the inorganic N content in the check plots had almost doubled to 228 kg/ha. NH^{+}_{4} —N was included here since higher than normal NH^{+}_{4} was observed in the latter sampling, apparently due to more rapid mineralization than nitrification during this period. As noted earlier, there was no response to N in this crop.

Analysis of soil samples taken in the fall of 1972 indicated that there had been essentially no change in organic matter or total N content in the surface soils since 1970. There was also no difference in organic matter or total N content between those soils which had received 134 N kg/ha per crop for four crops and those which had received no N fertilization.

CONCLUSIONS

The results of these experiments confirm the general observation that preplant applications of N are much less efficient in increasing crop yields than are postplant applications of N. In our opinion, there seems to be no reason to consider preplant applications of N as a feasible alternative in the humid tropics, except in the case of soils very deficient in N, where a relatively small amount of fertilizer N is needed at planting to maintain early season growth at near maximum rates. The bulk of the fertilizer N should always be applied just before the period of maximum growth, which with corn begins approximately 5 weeks after germination.

The results also demonstrate that in spite of the humid tropical climate and history of intensive cropping in Puerto Rico, the clayey Oxisols and Ultisols studied have a relatively high N supplying power. The high N status of these soils is probably due to a history of high application rates of N fertilizer, and to the fact that two of the sites were in fertilized pasture when the experiment was initiated. Furthermore, with the absence of a long dry season, weeds very quickly cover fallow fields and absorb inorganic N, thus reducing leaching losses. In support of this latter hypothesis, it is documented that the organic matter and total N contents of soils in the tropics are positively correlated with total yearly rainfall (4, 10).

There does not appear to be any basic difference between the fate of fertilizer N in Oxisols and Ultisols except that with the high Al satuartion in the Ultisol subsoils, any N leached below the plow layer is unavailable to Al sensitive crops such as sorghum.

In summary, it was found in these experiments that in Oxisols and Ultisols in Puerto Rico: 1) postplant sidedress applications of fertilizer N resulted on the average in higher yields and higher plant recovery of fertilizer N than did preplant applications; 2) when there were no limiting factors of climate or disease, and there was a response to N, the recovery of postplant applied N was comparable to that observed in temperate areas; 3) near-maximum corn grain yields were obtained with 67 kg/ha of postplant applied N; 4) preplant-applied sulfur-coated urea was no more effective than preplant-applied urea in increasing yields or N recovery; 5) soil inorganic N content was generally not a good index of soil N supplying power in these soils; 6) drought and disease frequently reduced yield; 7) maximum corn grain yields were 6.3 metric tons/ha; and 8) there was very little residual effect of applied fertilizer N.

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