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NITROGEN FERTILIZATION IN THE HUMID TROPICS

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Ithaca, New York

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16. Abstracts

In the humid tropics, as in temperate areas, sustained high production of non-leguminous crops can be accomplished only by the addition of N to the soil. Two years ago, field experiments were started in Puerto Rico to determine the most efficient means of supplying N fertilizer to non-leguminous crops.

The author discusses the following topics in this excellent research study: the need for and use of N fertilizers; sources of fertilizer N; placement and time of application of fertilizer N; fertilizer N recovery; N-losses; NO_3^- retention; soil test methods; fertility maintenance; nitrogen fertilization experiments in Puerto Rico and conclusions.

The most salient findings of the N fertilization experiments with corn and sorghum have been: (1) postplant applications of N were much more effective than preplant applications in increasing grain yield and N fertilizer uptake, (2) sulfur coated urea was less effective than urea as a preplant application, (3) near maximum maize yields were generally obtained with only 67 kg/ha of N applied, and (4) a maximum maize yield (grain) of 6.5 T/ha was obtained.

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NITROGEN FERTILIZATION IN THE HUMID TROPICS[1/]

Richard H. Fox[2/]

In the humid tropics, as in temperate areas, sustained high production of non-leguminous crops can be accomplished only by the addition of N to the soil. While it is true that mineralization of soil organic matter will provide a certain amount of inorganic N for plant use, whether or not it is sufficient for maximum crop production depends, among other things, on the crop yield potential and N requriements, soil moisture content, quantity of soil organic N and rate of mineralization. This rate of mineralization is in turn dependent upon soil moisture, aeration, temperature, pH, mineralogy and chemical composition, the nature of the organic matter and the previous history of moisture content or temperature of the soil. Often the N supplying power of soil from recently cleared land in the tropics is sufficient for crop production for several years (Cummings 1971; Nye and Greenland 1960). This is especially true with low yielding or low-N-requiring crops. With continued cultivation, however, the soil N content is decreased by crop removal and leaching, and the time eventually arrives when N must be added to sustain high yields. Kass and Drosdoff (1970) estimate that soil N gains from rainfall and non-symbiotic N fixation in grasslands and sugar cane fields in the tropics may vary from 4 to 88 kg/ha-yr. They conclude, however,

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that the N gains from these sources would probably be inadequate for crop production, and this conclusion is borne out by the fact that crops generally respond to N additions in the humid tropics. Richardson (1968) states that N is almost universally deficient in the soils of tropical Africa, and the International Soil Testing Project (1968) found N to be low in most soils of Latin America.

The Need For and Use of N Fertilizers

Most commonly, N is added in the form of plowed-under legumes, manure, or inorganic fertilizer. Almost no green manure crops are currently grown in Africa and Latin America as a source of N for crop production, and the availability of barnyard manure is also limited. Therefore, until economical and practical management systems employing legumes as a N source come into general use, or a more effective means of non-symbiotic fixation of N is discovered, fertilizer N must be applied to the soil in order to sustain high production.

The problem then becomes one of how to manage this fertilizer N in in the most effective manner. This is even more critical in the humid tropics, since not only is fertilizer generally more expensive than in temperate regions, but may be subjected to greater leaching due to the high rainfall.

A great deal of research has gone into the use of fertilizer N on a large number of crops in the humid tropics. Maize was chosen as a representative crop in order to give examples of results which have been reported, and because of its relatively high demand for N, widespread use in Africa and Latin America and potentially high yields under optimum management conditions.

Richardson (1968) reports that positive N responses in maize are almost universal in both east and west Africa. Increased maize yields due to N fertilization are also reported in Central and South America and the Caribbean (Malcolm 1963; Laird 1964; Vázquez 1960; Chesney 1969; Verdade 1969; Orihuela and Espinoza 1968; International Soil Testing 1968).

The optimum amount of fertilizer N depends, of course, upon the yield potential of the variety, supply of essential nutrients, presence of chemical or physical growth-limiting factors in the soil and climate of the area. In early work in Africa it was found that 22 to 45 kg/ha of fertilizer N were generally adequate for the maximum yields of 1000 to 3000 kg/ha obtained (Stephens 1960; Nye 1954; Djokoto and Stephens 1961; Goldsworthy 1967). However, higher yields are being obtained with improved maize varieties or hybrids and higher plant populations which require heavier N applications for maximum yields. There are reports of corn grain yields in the humid tropics ranging from 3000 to 7000 kg/ha with optimum fertilizer N applications of from 67 to 132 kg/ha (Vázquez 1960; Chesney 1969; Brown 1966; Orihuela and Espinoza 1968; Salazar 1965; Pawson 1957; Zambia 1967; International Soil Testing 1968).

Sources of Fertilizer N

The principal source of N fertilizer in both Latin America and Africa seems to be ammonium sulfate. As in temperate regions (Stevenson and Baldwin 1969), it has been generally demonstrated that there is very little difference between sources of inorganic N in their effectiveness in increasing crop yield (Orihuela and Espinoza 1968; Brown 1966; Cummings 1971; Enji 1965; Vicente-Chandler 1964) and that when ammonium sulfate is superior, the increased effectiveness is probably due to its

sulfur content (Vogt 1966). The two chief disadvantages of ammonium sulfate are its low N content, with consequent higher transportation costs per unit of N, and its high residual acidity (Pearson et al. 1962; Abruña et al. 1958; Vicente et al. 1964). This residual acidity not only leads to problems with Al and Mn toxicity in many acid, poorly buffered humid tropical soils, but also leads to increased leaching of cations from the soil profile (Pearson et al. 1962; Bolton 1968). This is not a serious problem where a convenient and inexpensive source of limestone is available, as in Puerto Rico, but where no such material is at hand, this acidifying effect of ammonium sulfate and other residually acid N sources could become a critical factor in deciding whether to use these fertilizers in certain areas of the tropics.

Urea has a much higher N content than ammonium sulfate with resulting lower shipping costs, but it is also much more hygroscopic and thus difficult to handle in the humid tropics. Gaseous ammonia losses may also occur when urea is surface-applied to soils or pastures (Allison 1966) but this is probably a minor concern when compared to its cost and handling characteristics.

Placement and Time of Application of Fertilizer N

Although few experiments have been conducted in the humid tropics on the effect of placement of fertilizer N, it seems reasonable to assume that if surface runoff and possible ammonia volatilization from urea are avoided, placement is not critical to plant yield. For example, Brown (1966) found that placement was not a factor in the effectiveness of N applied to maize in Malawi.

Time of application of N is, however, quite important. It has been shown in temperate regions that maximum yields and minimum N losses generally result when fertilizer N is applied immediately before the phase of rapid plant growth which in maize occurs about four weeks after planting (Bouldin et al.; Lathwell et al.). It appears that the most common method of applying N to maize in Africa and Latin America has been a split application, with the second and larger quantity being applied approximately four weeks after plant emergence (Verdade 1969; Grant 1967 (a); Bromfield 1969; Orihuela and Espinoza 1968). In Malawi, Brown (1966) did not find an effect of time of application of N, but Pawson (1957) in Northern Rhodesia found that applying N six weeks after planting was significantly superior to applying N before planting. The effectiveness of split applications of N is, of course, greatly dependent upon the amount of rainfall, and results may vary from year to year thus explaining the opposing results observed in Africa.

Fertilizer-N Recovery

No published reports of fertilizer N recovery experiments with maize in the humid tropics were encountered. The recovery of fertilizer N applied to maize in the United States is usually on the order of 40 to 60 percent when the N is applied either at the time of planting or as a postplant sidedress (Allison 1966; Pearson, et al. 1960). Vicente, et al. (1964; 1972) found that 48 to 60 percent of fertilizer N applied to pastures in Puerto Rico was recovered in the forage.

N-Losses

It is probably safe to assume that in the humid tropics, as in temperate areas, leaching is the principle pathway of inorganic N loss

from the soil. Losses due to denitrification undoubtedly occur but the magnitude of these losses remains to be determined (Allison 1966).

Dubey (1972) has found that a maximum of 30 percent of added NO_3^- -N was reduced to N_2 or N_2O after two weeks of water-logged conditions in a Puerto Rican Oxisol, Catalina clay. After the same two week period, a maximum of 20 percent of added NO_3^- was lost as gas from Carreras clay, an Ultisol; and from Piñas sandy loam, an Oxisol, 8 percent was lost. Gaseous loss of nitrate added to subsoils was observed only in the Catalina clay and then in only a very small quantity.

It is well known that in most soils, NO_3^- moves with the mass flow of water and will thus be carried out of the soil profile with water lost to drainage or will accumulate in the surface layer when water movement is upward due to evaporation (Wetselaar 1961; 62; Terry and McCants 1970; Thomas 1970; Allison 1966). Nitrate movement in the soil depends on the rate of water movement, soil texture, number of large pores and the anion exchange capacity of the soil (Terry and McCants 1970; Kinjo and Pratt 1971; Harmsen and Kolenbrander 1965).

The rate of NO_3^- movement observed ranged from 4.5 cm per cm of water applied to sandy soils (Terry and McCants 1970; Harmsen and Kolenbrander 1965) to 1 to 2 cm per cm of water applied in heavier soils (Harmsen and Kolenbrander 1965; Wetselaar 1962).

It has been noted that cations also move with NO_3^- and that increased NO_3^- leaching also results in increased loss of bases. Raney (1960) analyzed data from several lysimeter experiments and found that the sum of Ca + Mg + K in the lysimeter leachates was very closely correlated with the content of NO_3^- in the leachate.

The highest rates of NO_3^- loss occur when the soil is denuded of plants (Thomas 1970). Suárez and Rodríguez (1958) found that with monolithic lysimeters in a high rainfall area of Colombia, an average of 360 kg/ha-yr of inorganic N was lost in the leachate from a bare soil, while only 62 kg/ha-yr were lost when the legume Indigofera endecaphylla was planted. This was a silty loam soil with 12 to 16 percent organic matter and a rainfall of 2,400 to 3,150 mm/yr. Bolton (1968) also found large amounts of N leached out of sandy soils in a lysimeter in Malaya under bare soil and he emphasizes that the soil should be left bare for as short a period as possible to avoid N leaching losses.

Another approach to limiting N losses by leaching or denitrification is to keep N in the NH_4^+ form by using nitrification retarders or by releasing the fertilizer N at a slow enough rate that the nitrogen will be absorbed by the plant before it is lost. Prasad et al. (1971) have recently reviewed the literature and found that these two methods have had mixed results in temperate and tropical areas for most crops but that they show real promise for rice grown under alternate drying and flooding conditions. Results presented later in this paper of work with corn in Puerto Rico indicate that sulfur coated urea was a no more efficient source of N than urea and in some cases was less.

NO_3^- Retention

It has also been reported that in some humid tropical soils there is considerable NO_3^- retention (Singh and Kanehiso 1969; Kinjo and Pratt 1971). This adsorption is attributed to the anion exchange complex of the soils studied and was found to increase with increasing acidity of the soil. This anion retention of nitrates is probably most important in volcanic ash

soils that contain high amounts of amorphous material but these authors also reported NO_3^- adsorption in Oxisols.

Soil Test Methods

No general agreement has been reached on a soil test method to predict the N supplying power of the soil. Methods which have been used by soil test laboratories as a basis for fertilizer recommendations include determinations of total soil N, organic matter, inorganic N, and mineralizable N. None of these have proved completely satisfactory. Recently, several chemical extraction procedures have been proposed for estimating the N supplying ability of temperate soils (Keeney and Bremner 1966; Smith and Stanford 1971; Stanford and Legg 1968). Lathwell et al. (1972) found that N uptake by crops grown in pots of Ultisols and Oxisols from Puerto Rico was very well correlated with several of these chemical N extraction procedures, as well as with the aerobic mineralization of N in 2, 4, 8, or 16 weeks. These procedures are being correlated with field experiments this year in Puerto Rico.

Fertility Maintenance

Experience in Puerto Rico has shown that with adequate fertilization and management, a humid tropical soil will maintain its fertility indefinitely. One Oxisol being studied has been under continuous cultivation for 30 to 50 years with crops such as tobacco, corn, yams and taniers; and fertilizer has probably been applied during the last 20 to 30 years. This soil currently has 4.7 percent organic matter and 0.28 percent total N and had a high enough N supplying ability to grow 5884 kg/ha of maize grain with no addition of fertilizer N the first year this site was used. It

was also found in Puerto Rico that after 5 years of applying 800 lbs/A of N to a pasture, there was 0.4 percent more organic matter and 0.04 percent more N in the top 6" of soil than in the unfertilized check (Vicente et al. 1964). Grant (1967 (b)) also demonstrated in Malawi that the nutrient content and fertility of a soil containing 92 percent sand were not lowered in 5 years of continuous cropping with maize, providing the soils were well fertilized.

RECENT NITROGEN FERTILIZATION EXPERIMENTS IN PUERTO RICO

Introduction

Two years ago, field experiments were started in Puerto Rico to determine the most efficient means of supplying N fertilizer to non-leguminous row crops. The soils have been characterized and the climate monitored in the hope that results obtained in Puerto Rico can be extrapolated to other areas of the humid tropics with similar climate and soils.

Puerto Rico is the easternmost island of the Greater Antilles, bounded on the north by the Atlantic Ocean and on the south by the Caribbean Sea, lying at approximately 18°N latitude. The experimental sites are located from 80 to 550 meters above sea level and the average rainfall varies from 1,650 to 2,000 mm/yr. There is usually a short, drier spell in February and March when the average rainfall is less than 100 mm/month but the average monthly precipitation during the rest of the year is between 120 and 200 mm. Crops were not grown during the drier months. The evaporation varies from 140 to 180 mm/month in the summer and from 80 to 120 mm/month in the winter. The average yearly evaporation ranges from 1350 to 1850 mm/yr. The average daily temperature varies throughout the year from 23°C to 27°C at the lower elevation sites, and from 18° to 23°C

at the higher elevation sites. The radiation varies from an average of 311 langleys/day in the winter to an average of 500 langleys/day in the summer.

Methods and Materials

The chemical properties of the soils used in these experiments are given in Table 1. In both the Ultisol subsoils more than 50 percent of the cation exchange capacity is occupied by Al, which could lead to restricted root growth in Al sensitive plants. The soils are clays except the Piñas which is a sandy loam. All sites are moderately to well drained, although slight subsoil mottling occurs in the Carreras and Torres soils. The Piñas sandy loam has a root-restricting traffic pan which re-forms after being broken up by deep chiseling. The Coto clay is a subsoil which was exposed 10 years ago during land-leveling operations and had not been cultivated since that time.

The experimental treatments were 34, 67 and 134 kg/ha of N as urea plowed in before planting and 34, 67 and 134 kg/ha of N as urea applied in a band 15 cm to the side and 5 cm under the soil surface when the plants were 30 to 45 cm high, 4 to 5 weeks after planting. A treatment of 67 kg/ha of N as sulfur coated urea plowed in before planting was also included. The soil was limed to a pH of 5.2 to 5.7 where necessary, and 224 kg/ha of P_2O_5, 168 kg/ha of K_2O as K_2SO_4 and 56 kg/ha of Mg as $MgSO_4$ were applied to all soils. Seventeen kg/ha of $ZnSO_4 \cdot 7H_2O$ were applied to the Piñas site after Zn deficiency symptoms were observed in the first crop. Weeds were controlled by hand and chemically. In efforts to control diseases and insects, plants were treated with insecticides and fungicides and the soil was treated with insecticides.

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

Soil	Depth	OM	N	pH	CEC (NH_4OAc)	Cations	Exchangeable Cations Ca^{++}	Mg^{++}	K^{+}	Al^{+++}
	cm	%	%		meq/100 g					
Carreras (Humatas)	0-15	4.7	0.22	5.0	17.0	13.0	10.8	1.0	1.2	0.0
(Aquic Tropohumult)	30-60	1.2		4.6	13.6	13.4	3.0	0.8	0.2	8.4
Torres	0-15	5.1	0.22	4.7	13.0	6.9	2.2	0.7	0.8	3.2
(Orthoxic Palehumult)	30-60	0.9		4.8	9.8	6.8	2.0	0.4	0.4	4.0
Catalina	0-15	4.7	0.28	5.5	15.0	9.2	7.6	0.8	0.8	0.0
(Tropeptic Haplorthox)	30-60	1.2		5.3	8.2	4.8	4.0	0.6	0.0	0.2
Piña	0-15	1.6	0.07	4.9	3.7	2.5	1.3	0.8	0.1	0.3
(Typic Haplorthox)	30-60	0.7		4.8	2.9	2.3	1.2	0.7	0.0	0.4
Coto	0-15	1.0	0.10	6.1	5.6	6.4	4.8	1.5	0.1	0.0
(Tropeptic Eutrorthox)	30-60	0.5		6.4	5.0	6.5	4.5	1.9	0.1	0.0

Pioneer X-306 hybrid corn was planted at a density of 43,000 to 48,000 plants/ha (17,500 to 19,500 plants/acre). All grain and stover were removed from the fields at harvest.

Results and Discussion

Figure 1 shows the average maize grain yield response to N for the first two years at the Carreras and Catalina sites, and for the one crop grown at the Coto site. The yields were severely reduced both years at the Piñas sandy loam site due to drought and are not included. It can be seen that overall, the postplant application of N resulted in higher grain yields than the preplant application, and that the sulfur coated urea was much less effective than urea. It should also be noted that a relatively high average yield of 3.5 T/ha was obtained for the check and that near-maximum yields were obtained with 67 kg/ha of applied N.

The individual response curves are shown in Figures 2 to 4. The highest grain yield obtained was 6.5 T/ha in Carreras clay in 1970 (Fig. 2). This experimental site was in fertilized non-legume pasture prior to this experiment. The yields in 1971 were reduced due to a drought at this site. The Catalina clay site was in a farmer's field which had been under continuous cultivation for 30 to 50 years. The first corn crop in 1970 yielded an average of 6 T/ha grain with no effect of nitrogen treatment. The 1971 drought during the latter three months of the growing season at this site lowered the maximum grain yield to 3,890 kg/ha (Fig. 3). The maximum stover yields were higher in 1971 than in 1970 but the grain/stover ratio in 1971 was only 0.42, versus 0.82 in 1970 when drought did not affect the grain yield. At the Coto clay site there was a quite low supply of native soil N as this was on exposed subsoil and the response to

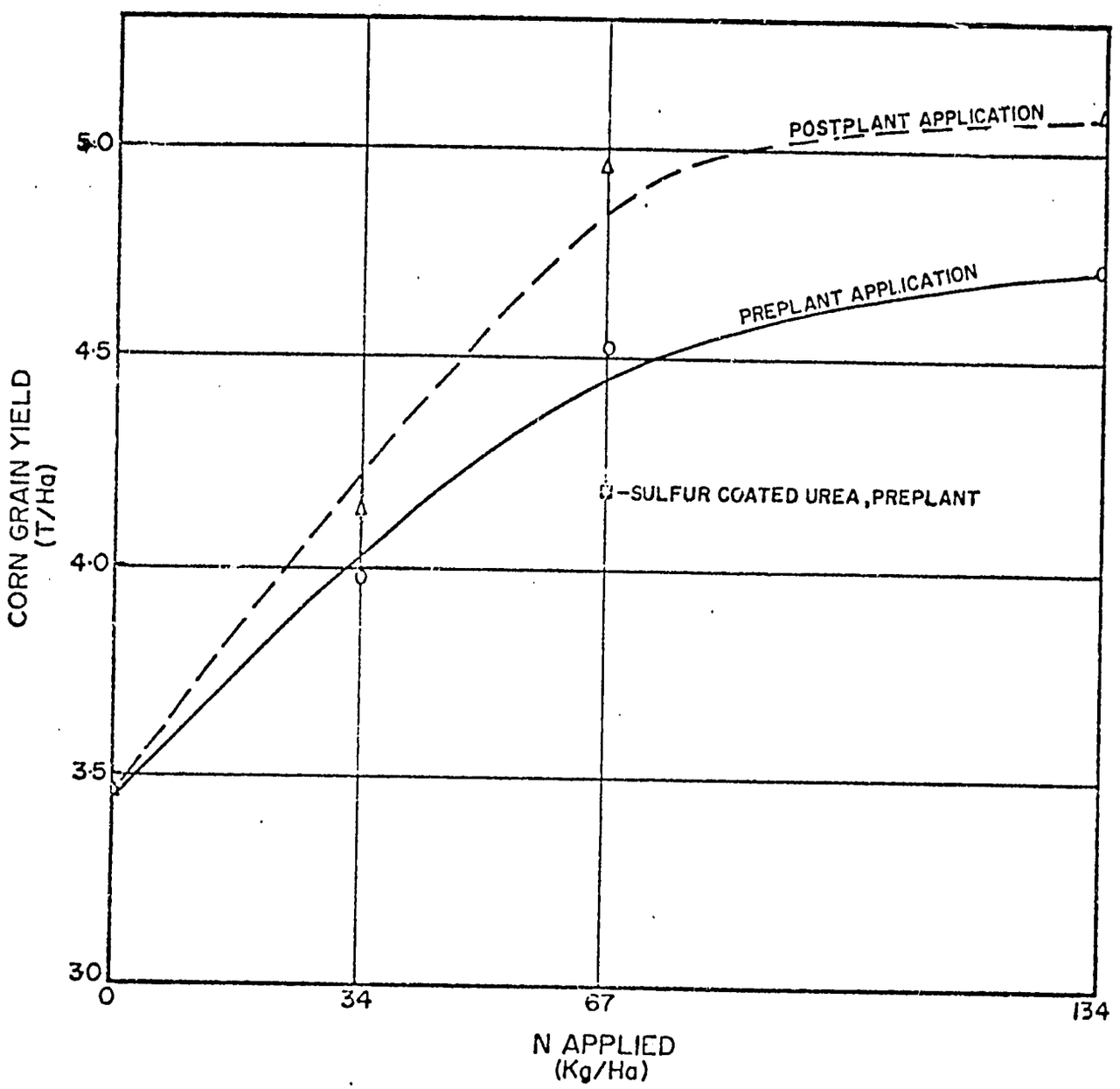

Fig. 1.- Average effect of rate and time of application of fertilizer N on corn grain yield, Carreras and Catalina sites 1970-71, Coto site, 1970.

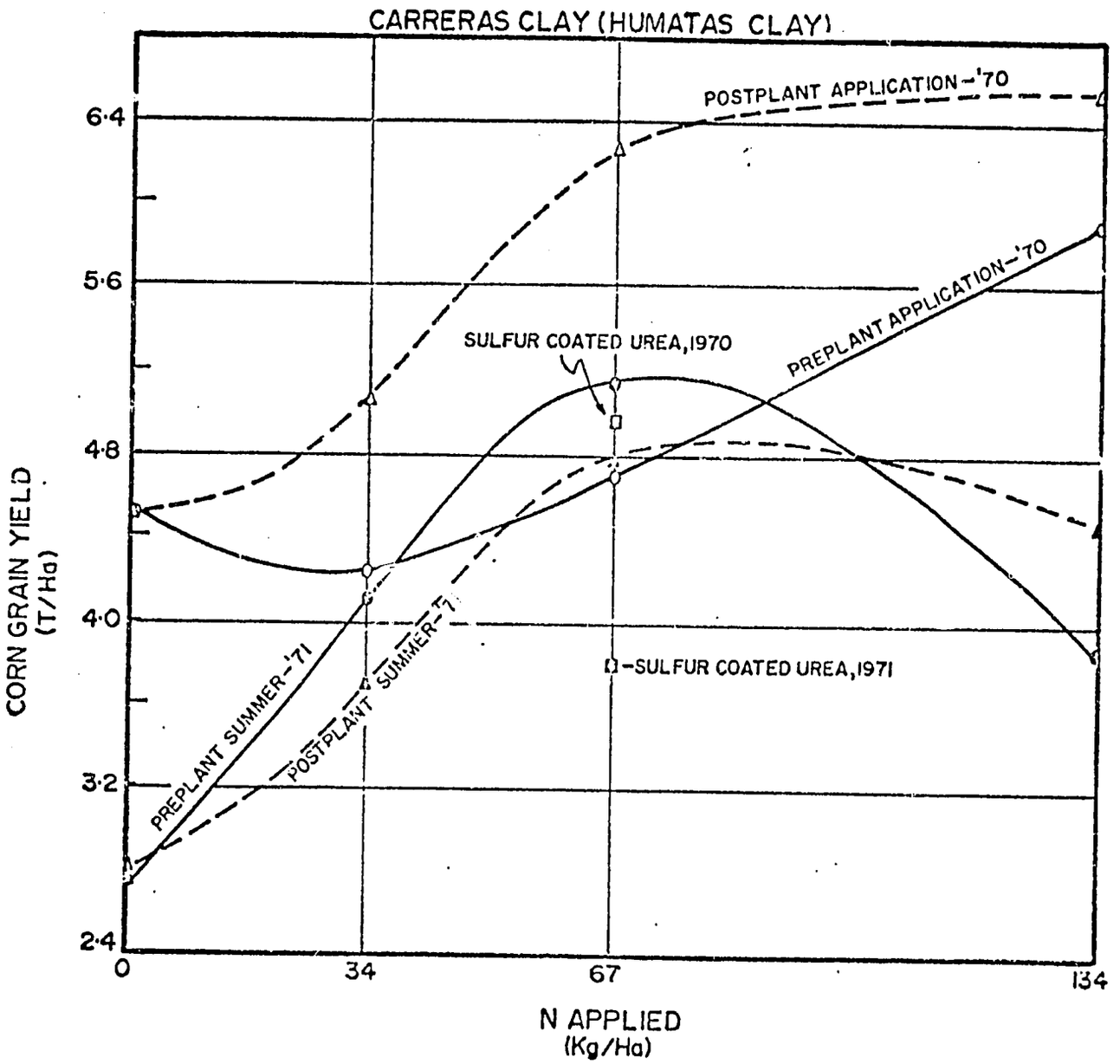

Fig. 2.- Effect of rate and time of application of fertilizer N on corn grain yield, Carreras site.

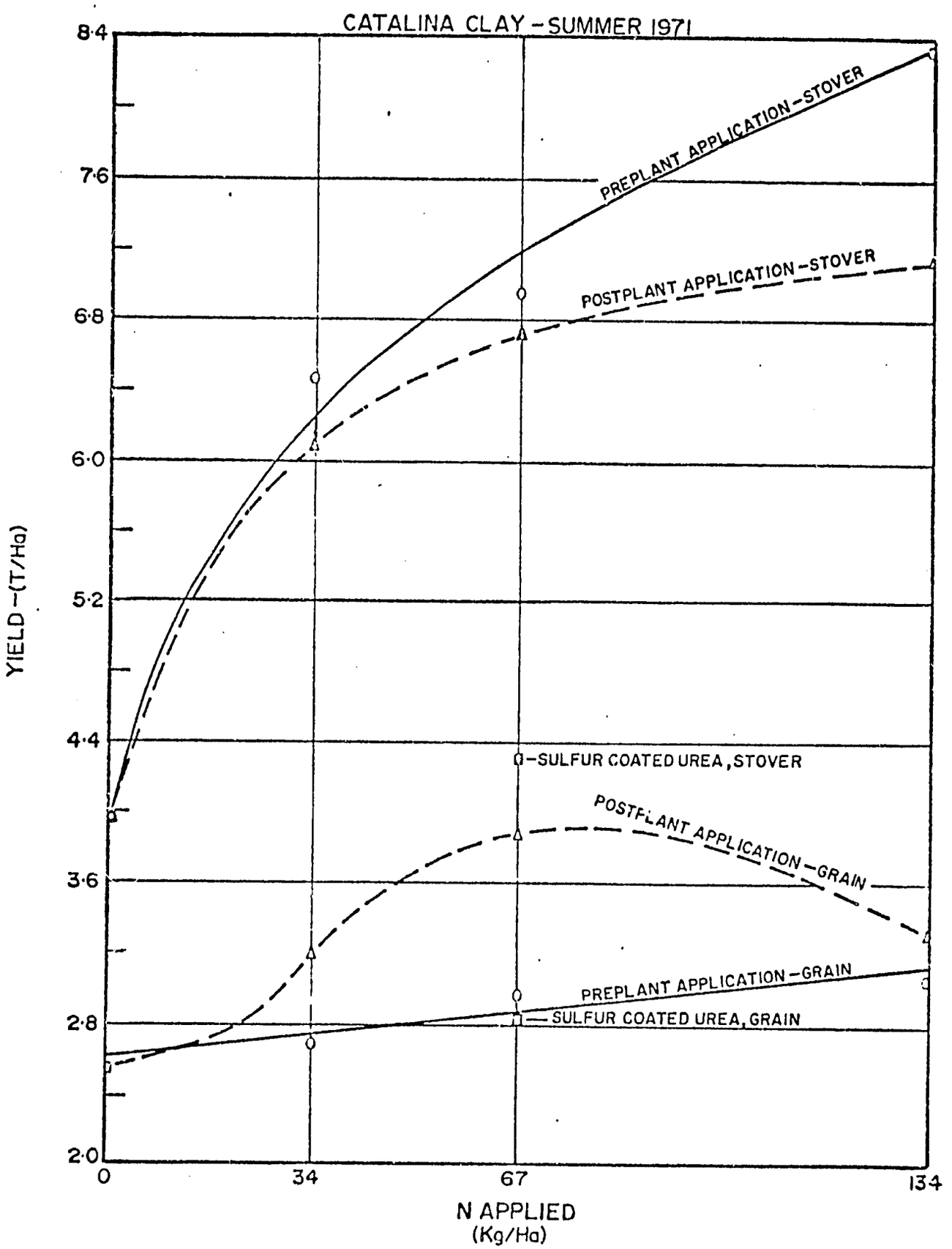

Fig. 3.- Effect of rate and time of application of fertilizer N on corn grain yield, Catalina site.

applied N was almost linear (Fig. 4).

Sorghum was planted at the Catalina, Carreras and Piñas sites during the fall-winter season of 1970-71 and the same treatments were applied as to corn except that no N was added to the Catalina site. There was no difference between yields at the Catalina site. At the other two sites the postplant application proved to be much more effective than the preplant (Figs. 5 and 6). At the Carreras site it began to rain immediately after the preplant fertilizer was incorporated and it rained 40 cm in the following two weeks before the field could be planted. This, combined with the fact that the Al sensitive roots of sorghum were confined to the top 20 cm of soil, rendered the preplant fertilizer ineffective. It was hypothesized that the N fertilizer was leached from the top soil while still in the form of urea, as it has been shown in the laboratory that 75 percent of added urea is still present as urea four hours after being added to this soil.

Table 2 shows the percentage of total applied fertilizer N taken up by the plants in the first two years at the Coto, Carreras and Catalina sites. A much higher percentage of N was recovered from the postplant application than the preplant application. The 40 to 52 percent recovered in the postplant treatments is approximately the same as that observed in temperate regions and indicates that excessive losses do not occur under these particular soil and climate conditions. Postplant application of N will thus result, on the average, in higher yields, higher N and protein content of plants and less N lost from the soil as a potential pollutant of water supplies. The N recovery from preplant sulfur coated urea was similar to that from the same rate of preplant urea.

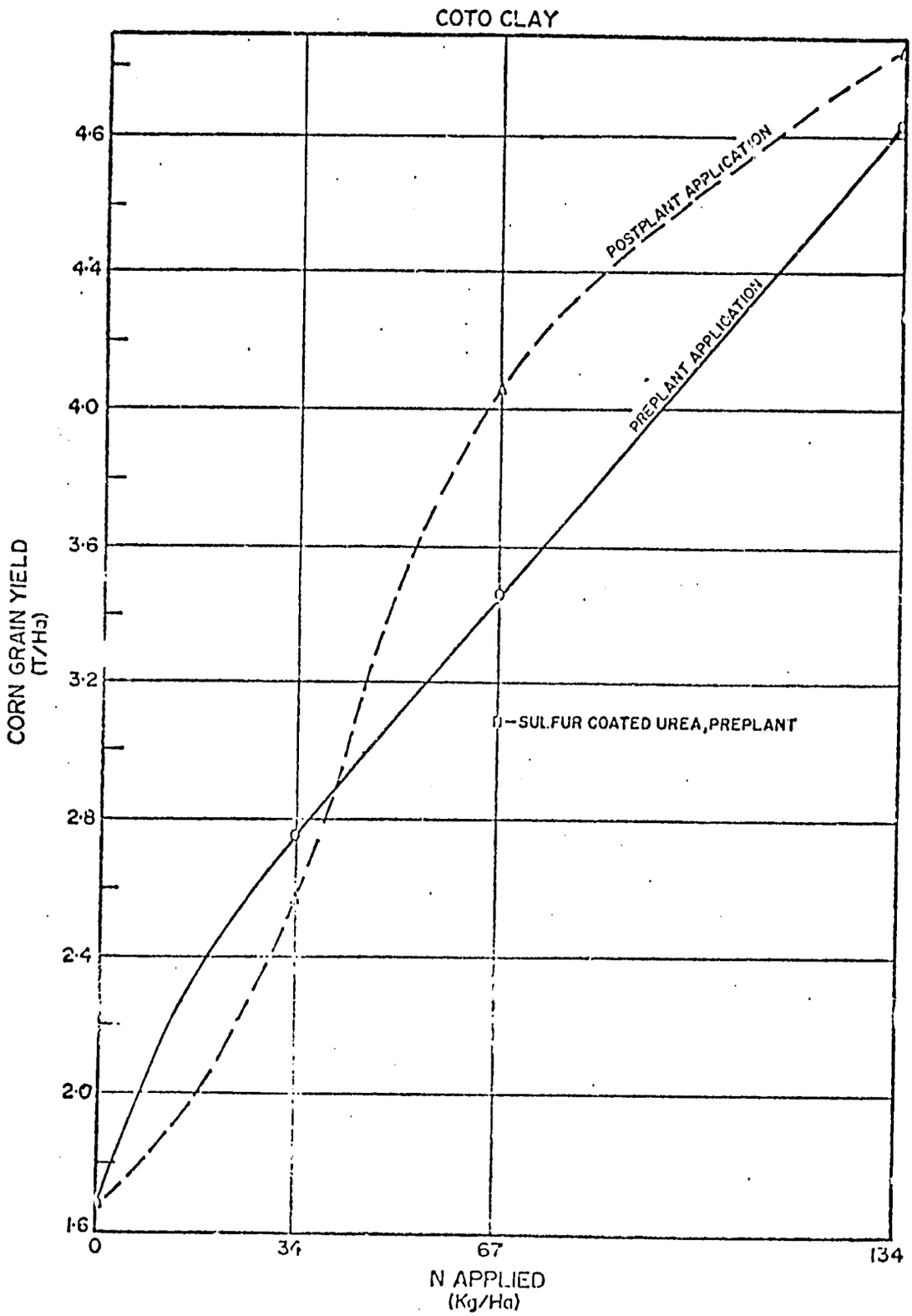

Fig. 4.- Effect of rate and time of application of fertilizer N on corn grain yield, Coto site.

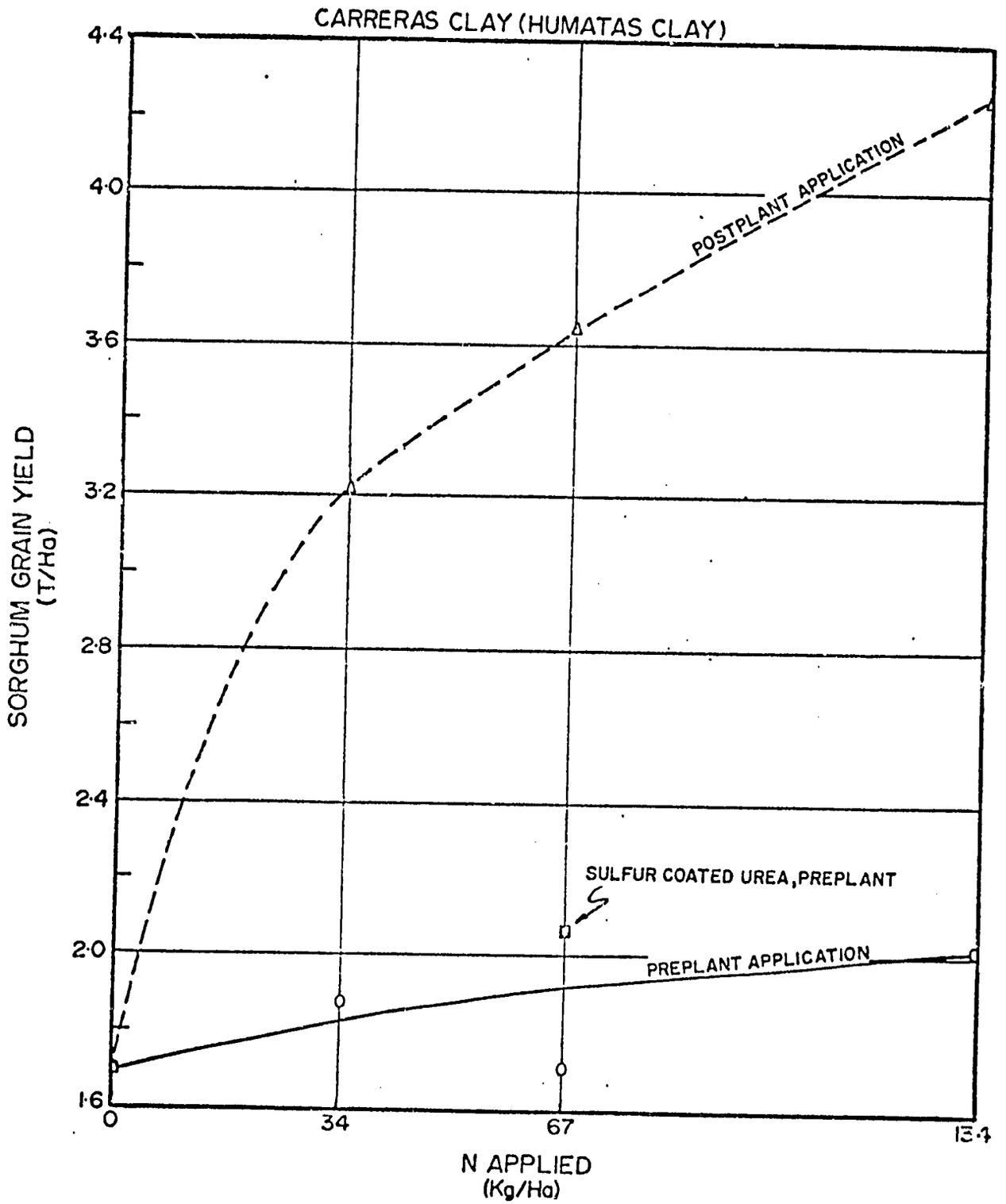

Fig. 5.- Effect of rate and time of application of fertilizer N on sorghum grain yield, Carreras site.

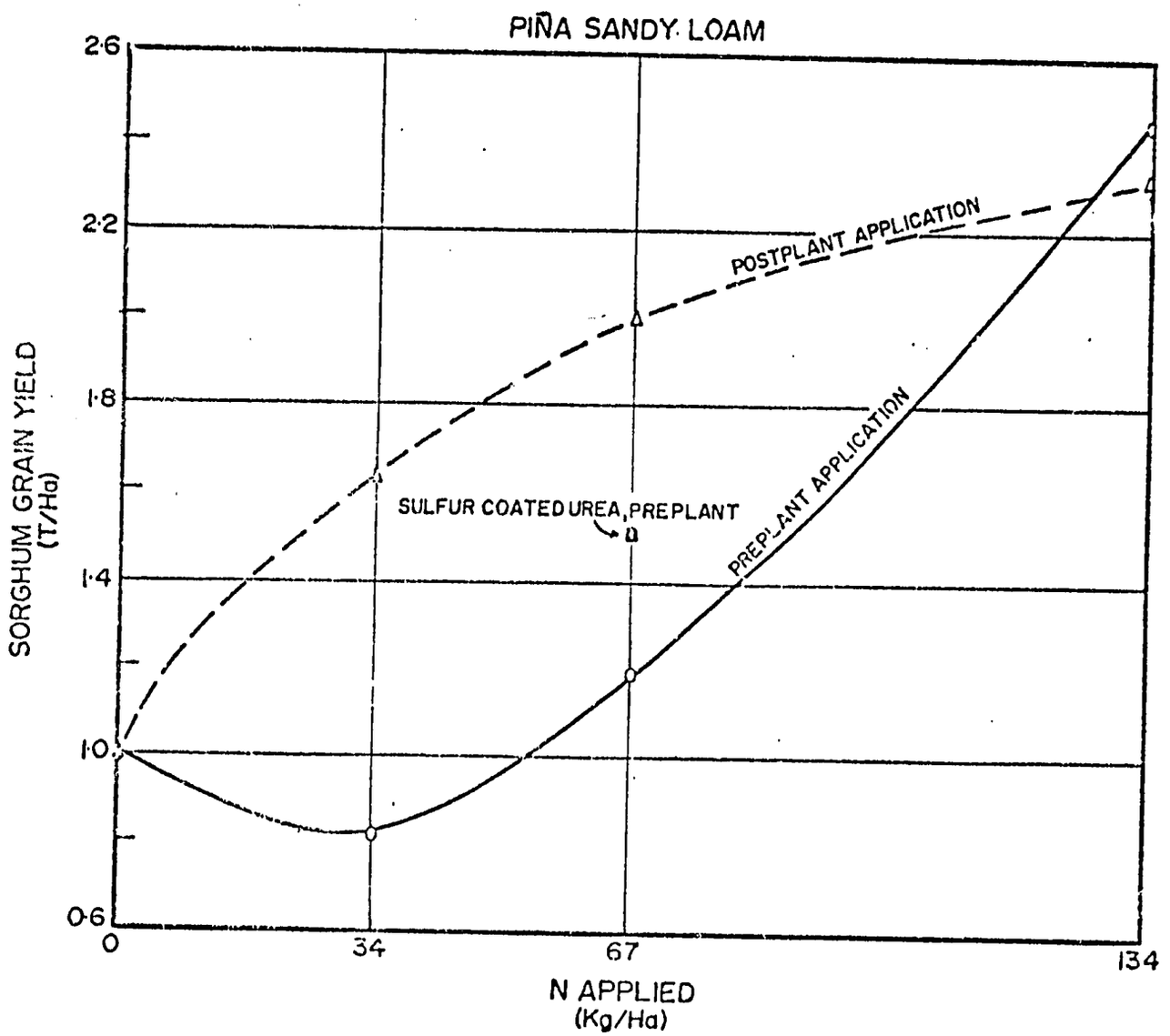

Fig. 6.- Effect of rate and time of application of fertilizer N on sorghum grain yield, Piñas site.

Table 2. Recovery of fertilizer N by crops grown in Coto, Carreras and Catalina clay (fertilized plant N minus check plant N/fertilizer N applied)

	Method of Application		
N Applied	Preplant plowdown	Postplant sidedress	Sulfur coated urea preplant plowdown
Kg/ha	% recovery		
34	43	52	
67	24	48	23
134	31	40	

Analysis of inorganic N content in the soil indicates that it has varied from a high of approximately 65 ppm in the top 30 cm, which was encountered in the first sampling of the Catalina site, to a low of approximately 10 ppm at all sites. The inorganic N content has varied throughout the year depending on the wet/dry cycle. Similar observations have been made by Cornforth (1971) and many others. The NH_4^+ content has remained relatively constant at 7 to 15 ppm and the variation has been in NO_3^- content.

There appears to be almost no accumulation of NO_3^- in the profile down to 90 cm even though a total of 400 kg/ha of N has been applied to some plots. It was not possible to determine if the N was lost by leaching or denitrification, or was incorporated into the organic matter.

A maize crop has recently been planted to determine the residual effect of the applied fertilizers and to correlate yield and N uptake with one of the chemical extraction procedures proposed by Lathwell et al. (1972) for estimating the N supplying capacity of these soils.

Conclusion

The most salient findings of the N fertilization field experiments with corn and sorghum in Puerto Rico have been: (1) postplant applications of N were much more effective than preplant applications in increasing grain yield and N fertilizer uptake, (2) sulfur coated urea was less effective than urea as a preplant application, (3) near maximum maize yields were generally obtained with only 67 kg/ha of N applied, (4) N fertility can be built up to such an extent in continuously cropped and fertilized Oxisols that yields of 5.8 T/ha of maize grain, and plant uptakes of 141 kg/ha of N have been observed on plots receiving no additional N, (5) a

maximum maize grain yield of 6.5 T/ha was obtained.

It should also be mentioned that the most serious problems encountered in producing maximum maize yields in Puerto Rico were drought, insects, nematodes and diseases, rather than lack of soil fertility.

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