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9. ABSTRACT

A comparison among eight surface and subsoils showed that yields on limed, fertilized, well-watered Los Guineos (Epiaquic Humoxic Tropohumult) surface soil, Carreras surface soil, Pina (Psammentic Haplorthox) surface soil, Los Guineos subsoil, Pina subsoil and Catalina (Tropeptic Haplorthox) surface soil were not significantly different. However, the yield on the least productive of two Catalina subsoils was only 64% of the yield on the Los Guineos surface soil. But with the addition of Zn and slightly over 1000 ppm P, yields on the two soils were essentially the same. It was found that the increased sorghum yields obtained when 2% dried, ground partially decomposed coffee leaves were added to limed Humatas (Typic Tropohumult) surface soil (fertilized with 96 ppm K, 96 ppm N, 10 ppm Mn, 5 ppm Fe, 2.5 ppm B, 5 ppm Zn, 0.5 ppm Cu and 0.1 ppm Mo) could be duplicated when the mineral fertilization was increased to 484 ppm N, 300 ppm P, 150 ppm K, 62 ppm S, 100 ppm Mg, 0.5 ppm B, 2.5 ppm Cu, 10 ppm Zn and 0.1 ppm Mo. The previously observed effect of the coffee leaves was probably related to increasing supply of available magnesium and phosphorus. It was concluded that the greenhouse pot productivity of surface soils and subsoils of the Ultisols and Oxisols studied can be brought to a high level without the addition of organic matter, provided adequate mineral fertilization, lime and water management are used.

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LIMITATIONS TO PRODUCTIVITY OF SOME OXISOL AND ULTISOL SURFACE AND SUBSOILS

KENNETH DALE RITCHEY

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LIMITATIONS TO PRODUCTIVITY OF SOME OXISOL AND ULTISOL SURFACE AND SUBSOILS

Kenneth Dale Ritchey, Ph.D.
Cornell University, 1973

Greenhouse experiments using maize and grain sorghum were carried out in Puerto Rico to see if the lower productivity of subsoils could be increased to that of surface soils with the use of mineral fertilizers and adequate watering techniques.

The use under tropical conditions of a simplification of the fiberglass wick automatic watering method of Dolar and Keeney (1971) was shown to significantly increase yields in greenhouse pots. The method maintained a larger supply of available water in the pots than would be present with conventional surface watering to field capacity, and permitted a sizable reduction in the time necessary for watering.

It was shown that an exposed subsoil of Nipe (a notoriously infertile Typic Acrorthox) was as productive as Carreras (Aquic Tropohumult) surface soil when N, K, micronutrients and 600 ppm P were added and the pots were watered by means of wicks.

Carreras subsoil, when limed and fertilized with N, K, 300 ppm P, 100 ppm Mg and 36 ppm Zn produced as well as Carreras surface soil, even though it contained only about one-third as much organic matter.

A comparison among eight surface and subsoils showed that yields on limed, fertilized, well-watered Los Guineos (Epiaquic Humoxic Tropohumult) surface soil, Carreras surface soil, Piña (Psammentic Haplorthox) surface soil, Los Guineos subsoil, Piña subsoil and Catalina (Tropeptic

Haplorthox) surface soil were not significantly different. However, the yield on the least productive of two Catalina subsoils was only 64% of the yield on the Los Guineos surface soil. But with the addition of Zn and slightly over 1000 ppm P, yields on the two soils were essentially the same.

It was found that the increased sorghum yields obtained when 2% dried, ground partially decomposed coffee leaves were added to limed Humatas (Typic Tropohumult) surface soil (fertilized with 96 ppm K, 96 ppm N, 10 ppm Mn, 5 ppm Fe, 2.5 ppm B, 5 ppm Zn, 0.5 ppm Cu and 0.1 ppm Mo) could be duplicated when the mineral fertilization was increased to 484 ppm N, 300 ppm P, 150 ppm K, 62 ppm S, 100 ppm Mg, 0.5 ppm B, 2.5 ppm Cu, 10 ppm Zn and 0.1 ppm Mo. The previously observed effect of the coffee leaves was probably related to increasing the supply of available magnesium and phosphorus.

It was concluded that the greenhouse pot productivity of surface soils and subsoils of the Ultisols and Oxisols studied can be brought to a high level without the addition of organic matter, provided adequate mineral fertilization, lime and water management are used.

LIMITATIONS TO PRODUCTIVITY OF SOME OXISOL AND ULTISOL SURFACE AND SUBSOILS

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University for the Degree of

Doctor of Philosophy

by

Kenneth Dale Ritchey

May 1973

BIOGRAPHICAL SKETCH

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The author is a member of Tau Beta Pi Science Honorary, the American Society of Agronomy, the Soil Science Society of America and the International Soil Science Society.

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GENERAL INTRODUCTION

The purpose of this investigation was to study the potential productivity of Oxisols and Ultisols of the humid tropics. In the fight to increase world food production it is important to know where the real limitations to production lie.

This study undertakes to investigate the not uncommon attitude that Ultisol and Oxisol subsoils are less productive than surface soils and that some Oxisols (e.g. Nipe) are inherently unproductive.

Many subsoils in the Tropics have good structure, but it is observed that plant roots do not fully explore this subsoil area and therefore do not make use of the reserves of moisture and nutrients present. This limitation on plant growth is often caused by low pH or low fertility. This study was undertaken specifically to investigate the fertility limits involved, with the expectation that micronutrient deficiencies might be of particular significance. In situations where subsoils are exposed by land-leveling or erosion, knowledge of what fertility factors may be retarding full production is especially important.

The experiments were carried out in pots in the greenhouse to permit the study of a number of soils at the same time and to allow auxiliary experiments aimed at gaining some understanding about the interplay of factors affecting productivity on the lower yielding soils. Greenhouse studies may say little about the field problems of disease, insect and bird damage, variations in rainfall, difficulties of cultivation,

and economic constraints, but they can clearly indicate whether the fertility limitations of a soil can be overcome or not, and what fertilizers are needed to accomplish this.

The thesis is divided into four sections. In the first, results of yield comparisons among Ultisol and Oxisol surface and subsoils are presented. The second section discusses the results of trials on an improved method of watering greenhouse pots which reduces water stress and eliminates differences in experimental yields arising from variations in the ability of soils to supply water to plants growing in pots. The third section discusses a series of experiments carried out to see if a leaf striping symptom observed in the maize cultivar grown was related to any nutrient deficiency in the soils and if it was related to reduced yields. The fourth section describes investigations carried out to see if increased yields reported associated with high organic matter contents could be duplicated with mineral fertilizers.

The first two sections have been written with the aim of submitting them for publication in journals of tropical agriculture. In some cases where an experiment investigated several nutrient interactions simultaneously, the overall experiment is described in one of the last two sections and the results of relevant treatments are given in the sections to be submitted for publication.

SECTION ONE

LIMITATIONS TO PRODUCTIVITY OF SOME ULTISOL AND OXISOL SUBSOILS

INTRODUCTION

As population and agricultural land use pressure increase, both erosion and land-leveling expose more subsoil to potential cultivation. Lower yields often observed on subsoils sometimes create the impression that subsoils are irremediably inferior to surface soils.

Reported instances of cases where subsoil productivity is lower than the productivity of the surface soil include that of Abruña-Rodríguez and co-workers (1970) who found in Puerto Rico plot experiments that tobacco yields on Corozal subsoil (Aquic Tropudult) were at least 23% lower than those on Corozal clay surface soil at comparable base saturations and rates of applied fertilizer.

Pangola grass growing on Alonso clay (Orthoxic Tropohumult) subsoil at Adjuntas, Puerto Rico gave a yield of 75% the yield obtained on the surface soil (Abruña-Rodríguez, personal communication).

A Coto subsoil (Tropeptic Haplorthox) at Isabela, Puerto Rico, although exposed for many years, remained practically barren. The infertility of the subsoil was apparently due to Zn deficiency. Maize plants not sprayed with zinc sulfate stopped growing after reaching a height of 30 cm, while Zn-sprayed plants in the next row matured normally (Cornell University, 1971).

In greenhouse tests on Carreras surface and subsoil (an Aquic Tropohumult formerly called Humatas), and Cialitos surface and subsoil (Orthoxic Tropohumult), the dry weights of bean tops grown on the surface

soils were twice as large as those grown on the subsoils with complete fertilization including micronutrients (Cornell University, 1970).

Lathwell et al. (1972) studied the nitrogen-supplying potential of 10 tropical Ultisols and Oxisols from Puerto Rico. After fertilizing with N, P, K, Mg, and micronutrients, the greenhouse yield for five crops of corn and sorghum on the least productive soil, Nipe (Typic Acrorthox), was 42% of that the most productive, Carreras (Typic Tropohumult); additional experiments indicated that these results may have been due to high phosphorus fixing capacity in the Nipe soil (Lathwell, personal communication).

This study undertakes to find out exactly what fertility factors are responsible for preventing maximum growth on some Puerto Rican subsoils. In addition to conventional pot watering a new method of watering which reduces the possibility of moisture stress was used, to see if previously reported depressed pot yields on subsoils could be partially attributed to ineffective conventional pot watering techniques.

GENERAL METHODS

Soils were collected from the Cornell-AID plots near Jayuya (Los Guineos), Manati (Piña), Barranquitas (Catalina) and Corozal (Carreras, formerly called Humatas). The Nipe soil was collected from Las Mesas near Mayaguez. Surface soils were collected from the plow layer (0-20 cm) and the subsoils from 20 to 50 cm depth. Details are given in the Appendix.

The thoroughly mixed air-dry soils described in Tables 1 and 2 were ground in a Quaker City Mill to 4 mm or less, mixed with liming materials and fertilizers, and placed in 2000 and 3000 ml capacity white plastic pots with 4 holes in the bottom (diameter of pot tops 15 or 20 cm). Where density of the soils differed greatly, equal volumes rather than equal weights of soil were used. A layer of fiberglass was used to line the bottoms of the pots.

Modifications of the wick-watering method of Dolar and Keeney (1971), described in Part II, were used on a number of pots. A hole was melted through the bottom of the pot with a red-hot 1.4 cm diameter iron pipe. A wick was inserted which extended halfway up through the center of the pot and down into a container of water below the pot. A preliminary trial of the method using USP cotton fiber for wicks was made in Experiment I. For the remaining experiments fiberglass wicks 27 cm long and 1.3 cm in diameter were used (Type 4608, Atlas Asbestos Co., North Wales, Pa.).

Table 1. Chemical properties of soils used and their classification under the U.S. Soil Taxonomy system.

Soil	Depth	N	pH*	Ca	Mg	K	Al	OM
	cm	%		me/100 g+				%
Carreras	0-20	0.14	5.0	6.10	0.86	0.320	1.54	4.88
Aquic Tropohumult; clayey, kaolinitic, isohyperthermic	33-43	0.09	4.5	1.59	0.35	0.200	7.54	1.80
Los Guineos	0-15	0.65	5.0	4.86	1.71	0.366	1.06	10.66
Epiaquic Humoxic Tropohumult; clayey, kaolinitic, isothermic	17-35	0.27	5.0	2.36	0.99	0.187	1.49	5.27
Piña	0-15	0.07	5.3	1.00	0.18	0.080	0.37	1.81
Psammentic Haplorthox; sandy, isohyperthermic	20-40	0.06	4.75	0.48	0.24	0.026	1.06	2.03
Catalina	0-12	0.31	5.8	5.48	0.68	0.420	0.00	6.04
Tropeptic Haplorthox; clayey, oxidic, isohyperthermic	20-50	0.22	5.4	3.72	0.88	0.640	0.00	3.60
Nipe	Exposed Subsoil	0.14	4.8	2.28	1.31	0.187	0.00	3.22
Typic Acrorthox; clayey, oxidic, isohyperthermic								

*1:2 soil:water.

+Exchangeable Ca, Mg and K with ammonium acetate; exchangeable Al with potassium chloride.

Table 2. Available zinc, available phosphorus and phosphorus requirements of soils used.

Soil		Available Zinc 0.1N HCl	Double acid	DTPA TEA	P*	P requirement+
		ppm				µg/g
Carreras	Surface	0.6	1.0	0.4	1.8	100-150
	Sub	0.4	0.7	0.1	4.2	440-480
Los Guineos	Surface	2.2	3.5	2.1	6.3	740-800
	Sub		0.6		1.8	650-700
Piña	Surface	0.6	0.8	0.3	133.0	0
	Sub				53.9	0
Catalina	Surface	2.0	2.8	2.8	4.2	--
	Sub		2.0		1.4	640-860
Nipe	Exposed Subsoil				1.4	750-850

*Available phosphorus by Bray No. 2.

+Micrograms P per gram soil necessary to obtain 0.2 ppm P in equilibrium solution after six days by method of Fox and Kamprath (1970).

All other pots were watered conventionally. They were brought to field capacity by sprinkling water on the surface one to three times daily.

Distilled water was used in all experiments except Experiment I.

In all experiments ammonium nitrate, potassium nitrate and monocalcium phosphate were used as sources of N, P and K, except in Experiment III, where potassium sulfate was used.

Split applications of nitrogen fertilizer through the growing period were made by injecting concentrated ammonium nitrate solution into the wicks with a hypodermic needle or adding it to the conventionally watered pots with irrigation water.

Ten to 12 seeds of maize (Zea mays L. cv. Pioneer Tropical Hybrid X-306) were planted and thinned to four plants per pot. In some of the trials an effort was made to reduce fungus infection (especially severe in Carreras subsoil), by using seeds which had been germinated between moist paper towels. For the final 24 hours of the three-day germination period, a 0.5% suspension of Chloroneb systemic fungicide (1,4-dichloro-2,5-dimethoxybenezene) was used to moisten the towels. Plants were sprayed as necessary with Diazinon to control insects.

The plants were grown in the greenhouse under natural light. After two to three weeks of growth (measured from the initiation of germination), plant tops were harvested, dried to constant weight at 70 C, and weighed.

EXPERIMENT I

This experiment was designed to see if the soil productivity differences between Nipe subsoil and Carreras surface soil which were observed by Lathwell et al. (1972) would persist at high phosphorus rates and continuous water supply.

Methods

Treatments of 0, 600 and 1800 ppm P (600 mixed in plus 1200 banded) were applied to 2000g Nipe subsoil, and a treatment of 600 ppm P was applied to 1600 g Carreras surface soil. The banded monocalcium phosphate was divided into six parts. One part was placed in the center of the pot and the other five placed in 2 cm long glass tubes of 6 mm inside diameter and distributed around the pots, in order to provide a concentrated phosphorus source with a minimum possibility of soil fixation. The soils were limed to pH 5.5-6.0. Each soil received a 200 ppm K, 300 ppm N and a micronutrient solution supplying 10 ppm Mn as $MnCl_2 \cdot 4H_2O$, 5 ppm Fe as sodium ferric diethylenetriamine pentaacetate, 2.4 ppm B as H_3BO_3, 0.5 ppm Cu as $CuSO_4 \cdot 5H_2O$, 5 ppm Zn as $ZnSO_4 \cdot 7H_2O$ and 0.1 ppm Mo as $H_2MoO_4 \cdot H_2O$.

To test the feasibility of using wick-watering methods and because the Nipe soil has a low available water content, two treatments using wick-watering were included: Nipe with 1800 ppm P and Carreras with 600 ppm P.

Results and Discussion

The oven-dry weights of the plant tops which were harvested 24 days after planting are shown in Table 3. When water supply was adequate (wick-watering) and high amounts of phosphorus were added, the productivity of the Nipe subsoil equalled that of the Carreras surface soil. With Nipe the addition of 1200 ppm P in a banded application to the 600 ppm mixed-in had no effect on yield, but there was a considerable increase in phosphorus content of the leaves.

The previously reported low yields on Nipe subsoil in greenhouse experiments were probably due mainly to insufficient application of phosphorus. Phosphorus adsorption isotherm measurements [using the methods described by Fox and Kamprath (1970)] showed that approximately 800 micrograms P/gram of soil were necessary to maintain an equilibrium solution concentration of 0.20 ppm P, regarded as sufficient for plant growth in pots. In this experiment 600 ppm apparently provided sufficient P in the pots, as 1800 ppm gave no higher yields.

The rates of P applied to satisfy phosphorus requirements are far higher than those necessary in the field. Baker and Woodruff (1963) observed in pot experiments with maize that a disproportionately large increase in rates of P fertilization was necessary as pot size was decreased. Fox and Kamprath (1970) attributed this to interception of plant roots by the container walls causing "piling-up" of the roots which results in reducing their effectiveness for phosphorus uptake. Because of this observed amplification of P requirements in pots one can expect to reach plateau levels of P response in the field with much lower levels of P fertilization than were necessary here.

Table 3. Yield and foliar phosphorus content of maize grown on Nipe subsoil and Carreras surface soil at various phosphorus rates with conventional and wick watering in Experiment I.

Soil	Applied P	Watering	Replications	Yield*	Foliar P
	ppm			g/pot	ppm
Nipe	0	conv	4	2.72 a	0.12
Nipe	600	conv	4	10.42 b	0.39
Nipe	1800	conv	4	10.48 b	0.74
Nipe	1800	wick	2	13.00 b c	0.45
Carreras	600	wick	3	11.57 c	0.54
Carreras	600	conv	4	12.82 b c	

*Yields not followed by the same letter are significant different at the 5% probability level according to Duncan's Multiple Range Test as modified by Kramer for unequal replication (Steel and Torrie, 1960).

There was a 24% increase (although it was not significant) in yield in the Nipe with the use of the automatic wick-watering method to maintain a continuous supply of easily available water. Roberts (1942) described the naturally occurring Nipe soil as "not sterile, but extremely infertile . . ." and it is apparent that the low available water capacity of the soil is a factor of importance.

EXPERIMENT II

In a nitrogen experiment described by Fox (1972), marked differences in productivity at the same level of nitrogen had been observed on different areas of a field of Carreras soil varying according to the amount of subsoil mixed in with the surface soil (R. H. Fox, personal communication).

A preliminary experiment on surface soils, a partially exposed cropped subsoil, and a buried subsoil from the field showed that the yield relationships observed in the field could be reproduced in the greenhouse. All the soils received 300 ppm N, 300 ppm P, 200 ppm K, 50 ppm Mg, 5 ppm Zn and micronutrients. The pot yield on the pure subsoil was only 69% of the yield on the surface soil. Yields were proportional to both soil organic matter content and Bray No. 2 available P. In the preliminary experiment the addition of 2% dried, partially decomposed coffee leaves increased yields on the pure subsoil by 18%. Foliar analysis indicated that Mg, Zn, and P might be insufficient.

This experiment was carried out to see if the differences in productivity on a low organic matter subsoil could be eliminated with mineral amendments or if organic matter additions were also necessary.

Methods

Three levels of phosphorus (100, 200, and 300 ppm P) were applied to a 1600 g Carreras subsoil receiving zero or 36 ppm Zn. An organic

matter treatment of 300 ppm P, 36 ppm Zn and 1% dried ground partially decomposed coffee leaves was included. For comparison, Carreras surface soil with and without added Zn was included. All soils were limed to pH 5.1-5.5, fertilized with 300 ppm N and 200 ppm K, and all but Treatment 10 received 100 ppm Mg as magnesium sulfate. Three replicates per treatment, all wick-watered, were arranged in Random Complete Blocks, and the experiment was harvested 24 days after the initiation of germination.

Results and Discussion

The results (shown in Table 4 and Figure 1) indicate that phorphorus and zinc levels are more important to yield than organic matter. When 300 ppm P and 36 ppm Zn were added to the pure subsoil, the yield was as good as that obtained on surface soil with Zn or on subsoil plus organic matter. The response to zinc, particularly at high phosphorus level, was striking, exceeding 100%. (See Figure 1.) There was also a marked response to the application of zinc in the surface soil. It is clear that both Zn and P are needed to maximize yields in this soil.

The subsoil showed no significant response to added copper, nor to the addition of 1% dried ground partially decomposed coffee leaves.

The results of foliar analysis are shown in Table 5. These emission spectroscopy measurements were unreplicated so the possibility of error cannot be eliminated. The phosphorus content was erratic in the zinc-deficient plants but in the zinc-sufficient treatments P content increased with applied phosphorus to 0.30% P at 300 ppm P added, which is within the sufficient range for maize according to Jones (1967). Zinc content was deficient at all levels of phosphorus when no zinc was applied, but at 36 ppm Zn the plant content was sufficient at the 200 and 300 ppm P treatments.

Table 4. Treatments and yields on Carreras surface and subsoils in Experiment II.

Treatment Number	Treatment Zn	P	Cu	Yield*			
	ppm			g/pot			
Subsoil							
1	0	100	21	4.60	a		
2	0	200	21	5.60	a		
3	0	300	21	6.97	a		
4	36	100	21	6.63	a		
5	36	200	21	11.23		b	
6	36	300	21	14.23		b	c
7	36	300	21	13.33		b	c
	plus 1% coffee leaves						
8	36	300	0	15.27			c
Surface Soil							
9	0	300	21	7.70	a		
10	36	300	21	14.30		b	

*Yields not followed by the same letter are significantly different at the 5% probability level by the Duncan's New Multiple Range Test.

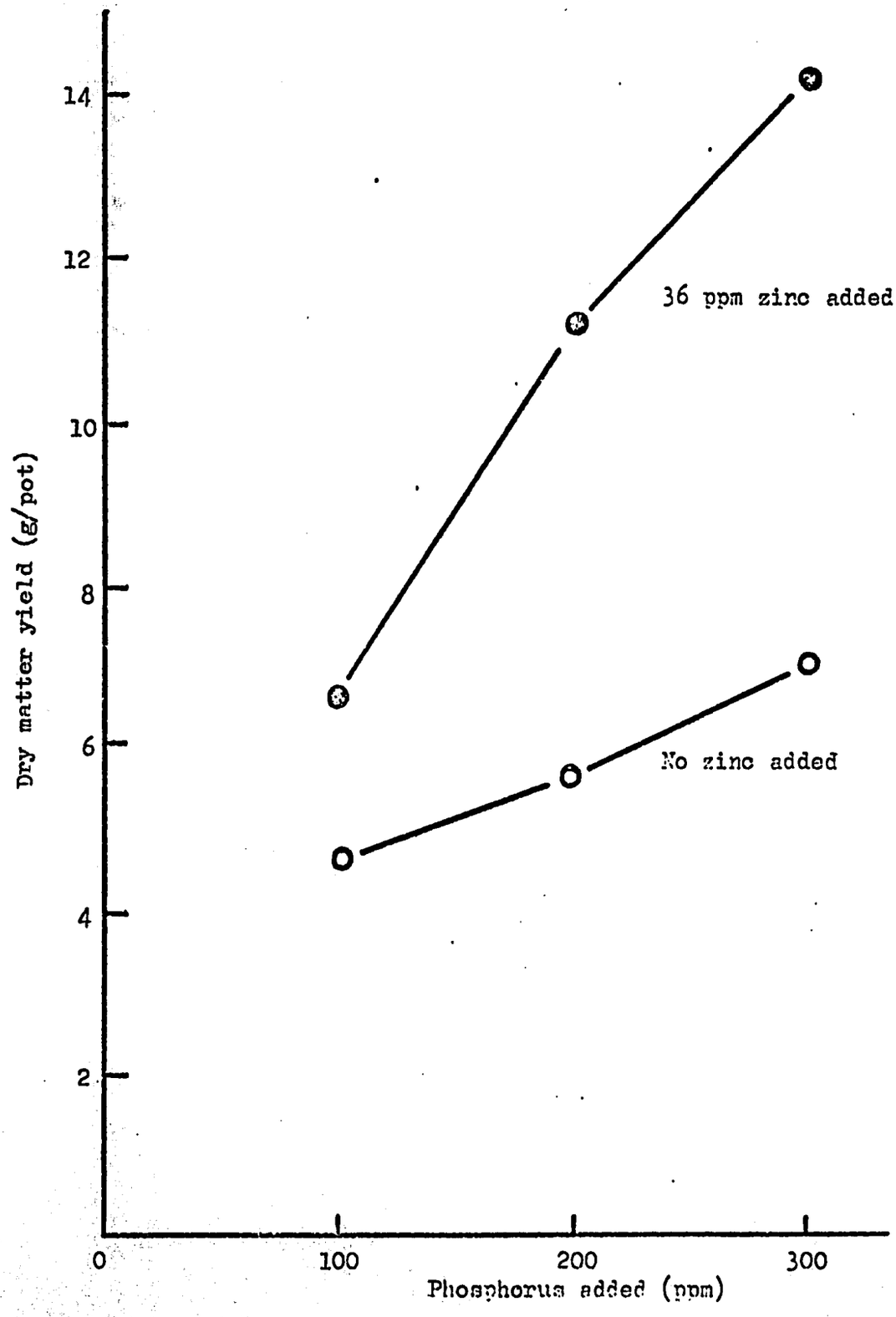

Figure 1. Relationship between phosphorus application and dry matter yield of maize with and without added zinc on Carreras subsoil.

Table 5. Foliar analyses of maize plants from Experiment II.

Treatment Number	Yield	N	P	K	Ca	Mg	Mn	Fe	B	Cu	Zn	Al	Mo
		%					ppm						
1	4.60	2.9	0.12	4.69	0.65	0.05	69	57	8	7	8	62	2.1
2	5.60	3.5	0.31	4.70	1.36	0.17	106	106	15	19	10	84	2.2
3	6.97	3.2	0.20	5.79	0.52	0.04	51	41	9	4	7	44	1.8
4	6.63	2.7	0.09	3.86	0.25	<0.01	21	36	5	3	12	53	1.7
5	11.23	2.3	0.19	3.77	0.62	0.06	57	93	15	12	56	71	2.1
6	14.23	2.0	0.30	3.39	0.35	0.04	41	69	13	10	46	48	2.1
8	15.27	2.1	0.21	3.43	0.46	0.04	46	72	12	9	54	48	1.8
9	7.70	2.9	0.34	2.73	0.75	0.29	119	236	14	19	13	64	1.8
10	14.30	2.5	0.24	1.61	0.34	0.12	40	98	12	11	46	57	2.1

In spite of the addition of 100 ppm Mg as magnesium sulfate the magnesium content was unusually low in all the subsoil treatments. The plants from the highest yielding treatment, number 8, contained 0.04% Mg which is in the deficiency range for maize according to Jones (1967). At these low levels of Mg, however, the results of emission spectroscopy are not extremely accurate because the precision of the instrument is only ± 0.02% for Mg. Unusually low magnesium contents in Pioneer X-306 maize growing in field plots have been observed by other workers in Puerto Rico (R. H. Fox and F. Abruña, personal communication).

EXPERIMENT III

Trial One

The differences in productivity thus far tested had disappeared completely with sufficient mineral fertilization. In an effort to find additional cases where a marked difference in productivity existed the following were compared: surface and subsoil of Los Guineos (Humoxic Tropohumult), surface soil of Carreras (Aquic Tropohumult), surface and subsoil of Piña (Psammentic Haplorthox), and surface and two subsoils of Catalina (Typic Haplorthox).

Methods

The basic fertilizer treatment applied to each soil (1600 g per pot) included Zn where a zinc deficiency was suspected, 270 ppm N, 200 ppm K and 350 to 400 ppm P (Table 6). Piña surface and subsurface soil (2000 g per pot) received 320 ppm N and 200 ppm K but no P. No blanket micronutrient treatment was applied. Where necessary, soils were limed to a pH between 5.1 and 5.7 with an equimolar mixture of magnesium and calcium hydroxides. Two watering regimes were used to ensure adequate water supply. Three wick-watered and three conventionally watered pots per treatment were arranged in a Completely Random Design.

Because of the variable emergence due to inadequate initial watering of the soil, the plants were harvested 13 days after the average plant height per pot reached 13.2 cm (20 to 22 days after the initiation of germination). At harvest the plants were 50 to 71 cm high.

Table 6. Watering method, fertilizer treatment and yield of maize on eight soils surveyed in Experiment III, Trial One.

Soil		Watering	Treatment P	Treatment Zn	Treatment Lime*	Yield+	
			ppm	ppm	ppm	g/pot	
Los Guineos	Surface	wick	350	0	1906	15.33	g
		conv	350	0	1906	12.73	cdef
Carreras	Surface	conv	400	18	1119	14.73	fg
		wick	400	18	1119	11.27	abcd
Piña	Surface	conv	0	18	241	14.00	efg
		wick	0	18	241	13.30	defg
Los Guineos	Sub	wick	400	18	1906	13.67	defg
		conv	400	18	1906	9.30	a
Piña	Sub	wick	0	18	393	13.37	defg
		conv	0	18	393	10.43	abc
Catalina	Surface F	wick	400	0	0	13.07	defg
		conv	400	0	0	12.87	def
Catalina	Sub BP	wick	400	0	1184	12.63	cdef
		conv	400	0	1184	11.67	bcde
Catalina	Sub F	wick	400	0	659	9.80	a
		conv	400	0	659	9.17	a

*Equimolar mixture of magnesium hydroxide and calcium hydroxide.

+Yields not followed by the same letter are significantly different by Duncan's New Multiple Range Test.

This procedure allowed growth rate to be measured and eliminated the effect of initial emergence differences.

Results and Discussion

Table 6 shows that in the first trial all the soils except Catalina subsoil location F and Catalina subsoil location BP produced yields within 15% of the Los Guineos surface soil yield (which was the highest yielding) under the watering regime most effective for that soil. Wick-watering was superior for all the soils except Carreras and Piña surface soils, where low hydralic conductivity at low moisture contents may have reduced the availability of water during high transpiration periods.

Trial Two

Methods

A further experiment was made comparing the lowest and highest yielding of the eight soils surveyed in the previous group.

Four levels (0, 300, 300 banded, and 600 ppm) of phosphorus were applied to 1600 g of the lowest yielding, the Catalina subsoil F. Since the Catalina subsoil had not previously received any zinc, 36 ppm Zn were added to each treatment. Two levels of phosphorus (300 and 600 ppm) were applied to the highest-yielding soil of the previous trial, the Los Guineos surface soil, to see if phosphorus fertilization was optimal. The soils were limed with an equimolar mixture of $Ca(OH)_2$ and $Mg(OH)_2$ to pH 5.4-5.7, and received 360 ppm N and 100 ppm K. The plant tops were harvested 23 days after planting.

Results and Discussion

The oven-dry weights given in Table 7 show that there was a strong response to phosphorus. Banding the 300 ppm phosphorus application was no more effective than mixing. The yield of Catalina subsoil receiving 600 ppm was almost identical to that of the Los Guineos surface soil receiving 300 ppm P, but significantly less than the Los Guineos with 600 ppm P.

Trial Three

Methods

It was clear that both soils were still responding to phosphorus applications. Therefore another trial was run, using the same soils, which were dried, pooled, and repotted after the addition of 1025 ppm P, 205 ppm K and 47 ppm Mg to the Catalina subsoil and 1132 ppm P, 226 ppm K and 52 ppm Mg to the Los Guineos surface soil.

Results and Discussion

Results of this trial, which was part of a larger experiment, showed that response to phosphorus in both soils was now at or near plateau level, and that the yields on the two soils were not significantly different. Catalina subsoil yielded 20.7 g/pot, and Los Guineos surface soil yielded 21.6 g/pot after 22 days of growth.

This effectively demonstrated that the previously low subsoil yield could be brought to the level of a highly fertile surface soil by the addition of phosphorus and zinc.

Table 7. Treatments and yields of maize on Catalina subsoil and Los Guineos surface soil in Experiment III, Trial Two.

Soil	Number of Replicates	Treatment P	Treatment Zn	Yield+	
		ppm	ppm	g/pot	
Catalina Subsoil	3	0	36	3.20	a
	3	300	36	12.57	b
	3	300*	36	13.33	b
	3	600	36	16.77	c
Los Guineos Surface Soil	4	300	18	16.90	c
	4	600	18	21.15	d

*Phosphorus was banded.

+Yields not followed by the same letter are significantly different at the 5% probability level according to Duncan's New Multiple Range Test as modified by Kramer for unequal replication (Steel and Torrie, 1960).

CONCLUSION

This study shows that differences in productivity of soils observed in previous experiments were not due to inherent limitations of the subsoils, but arose because of their higher requirements for phosphorus, zinc and available water.

As the requirements of mechanized agriculture increase the amount of land-leveling and subsequent exposure of subsoils in the tropics, there is a growing need to be able to obtain maximum yields on these soils. The results of this study indicate that with careful water management, liming and fertilization (with P and Zn especially) the Oxisol and Ultisol subsoils tested can be as productive as the surface soils. It will be necessary to conduct field experiments to determine how high the rates of P fertilization must be in order to reach near-maximum yields but it can be assumed it will be less than the 1000 ppm P required in the greenhouse pots (Fox and Kamprath, 1970).

SUMMARY

Greenhouse experiments with maize were carried out to see if the reported infertility of some subsoils could be improved with mineral fertilization and efficient watering.

It was shown that Nipe exposed subsoil was as productive as Carreras surface soil when N, K, micronutrients and 600 ppm P were added and the pots were watered by means of wicks.

Carreras subsoil, when limed and fertilized with N, K, 300 ppm P, 100 ppm Mg and 36 ppm Zn produced as well as Carreras surface soil, even though it contained only about one-third as much organic matter.

A comparison among eight surface and subsoils showed that yields on limed, liberally fertilized, well-watered Los Guineos surface soil, Carreras surface soil, Piña surface soil, Los Guineos subsoil, Piña subsoil and Catalina surface soil were not significantly different. However, the yield on the least productive of two Catalina subsoils was only 64% of the yield on the Los Guineos surface soil. But with the addition of Zn and slightly over 1000 ppm P, greenhouse pot yields on the two soils were essentially the same. Field experiments will be necessary to determine optimum P rates under field conditions.

It was concluded that the productivity of subsoils of the Ultisols and Oxisols studied can be as high as the surface soils, provided adequate mineral fertilization (including Zn and high P rates), lime and water management are used.

SECTION TWO

USE OF WICK-WATERING FOR GREENHOUSE POTS IN THE TROPICS

INTRODUCTION

In tropical and subtropical regions a great deal of experimentation is done with plants growing in pots in the greenhouse. The high evapotranspiration rates that occur during periods of intense solar radiation make it difficult to maintain a supply of water sufficient for the plant's needs, especially when small pots are used.

Adding water to partially-dried pots often causes leakage out the bottom of the pot, leaching of soluble nutrients, and increased variability in the experiment. It is sometimes necessary to water pots three or more times per day which involves a considerable amount of time.

The method of watering with a fiberglass wick described by Dolar and Keeney (1971) offers a way to reduce some of these problems. A comparison of conventional watering with a simplified modification of Dolar and Keeney's method was made in Puerto Rico in a series of experiments on 10 Oxisol and Ultisol surface and subsoils over a period of 18 months. Oxygen diffusion rate measurements were made in an effort to assess the availability of oxygen to plant roots under the two systems.

MATERIALS AND METHODS

Wick-watered Pots

In the interest of low cost and flexibility, the methods proposed by Dolar and Keeney were modified so that the equipment used was as simple as possible.

The pots used were 15 or 20 cm diameter at the top, rigid white plastic pots of 2000 and 3000 ml capacity with four small holes in the bottom. An additional hole was melted through the center of the bottom of the pot with a red-hot 14 mm galvanized iron pipe. A disk of fiberglass insulation blanket was cut with a knife to fit the bottom of the pot and an X-shaped cut made in the center. Fiberglass wicks 1.3 cm in diameter and 27 or 33 cm long for the two pot sizes were prepared (Wick Type 4608, Atlas Asbestos Co., North Wales, Pa.). In order to prevent fraying of the wick ends when the individual lengths of wick were cut off the roll, two pieces of transparent tape were wrapped side by side around the wicking and the cut made between them.

The pot to be filled was placed on top of a large-mouth jar for support, the fiberglass insulation disk placed in the bottom, the wick inserted through the X-shaped cut in the disk and the preweighed soil poured into the pot while the wick was held in position with one hand. The wick extended to about 5 cm from the surface of the soil. After the pot was filled with soil it was placed on two

rods lying across the top of a No. 10 tin can (a cylinder 15 cm in diameter and 17 cm high), so that the wick extended down into the can which was lined with several polyethylene bags, one inside the other.

In order to easily fill the cans and maintain the level of distilled water, a plastic pail equipped with a long watering hose was used. To make the hose, the end of a length of plastic Tygon tubing was placed in a flame so that the plastic expanded to form a flange. The other end of the tubing was then pulled through a small hole cut in the bottom of a 10 liter plastic pail so that the expanded collar could be sealed in place against the inside of the pail with silicone sealant. This pail was also used to add water directly to the soil surface during periods of extremely high evapotranspiration rates.

Because the hydraulic conductivity drops rapidly as soil dries out, it is important to keep the moisture level in the wick-watered pot reasonably high, or else the flow of water from the soil near the wick to the soil around the roots will be seriously impaired. Under hot, dry conditions a great deal of water is transpired by large plants in the greenhouse. Thus, when plants are large, and greenhouse temperatures 35 C or greater, it is sometimes necessary, particularly for heavy clays, to supplement the water supplied by wicks by adding water from above, although with much less frequency than is needed in conventional watering. It is also important that the level of water in the cans be kept high during these periods. Several methods can be used to monitor the water status of the wick pots. The most reliable is to weigh the pots in the mid-morning to see if water content has fallen

below normal levels and if surface irrigation will be needed before water uptake rates increase to critical levels. Observing the amount of guttation in the early morning will also indicate which pots have an ample supply of water and which may be deficient.

Planting was carried out by placing the seeds in dry soil and watering from above for several days before putting water in the can under the pot. This method reduced the possibility of salt damage to seedlings when high rates of fertilizer were used.

Another method used in certain instances was to put distilled water in the can and let the entire pot of soil become moist before planting. This minimized the breakdown of unstable soil granules because water was never added from above.

The conventionally watered pots were watered to field capacity one to three times daily as necessary. As the crop grew, allowance was made for the additional weight of the plants in the pots. Field capacity was measured by placing air dry soil in an open-ended 6 cm diameter cylinder 14 cm long, adding water to the top, covering the top with plastic film, and measuring the water content of the center of the wetted section after 15 hours.

Split applications of nitrogen were added at intervals through the growing period by injecting a concentrated ammonium nitrate solution with a syringe into the wick at the bottom of the pots.

After harvesting, the plant tops were oven-dried at 70 C to constant weight and the weights recorded.

Soil Preparation

The soils (all were clays except the Piña sandy clay loam) were ground in a Quaker City mill so that the largest particles were 4 mm in diameter and about 40% of the soil was silt-size or smaller. The percentage of fine particles was desirable because if the amount was too low, there was not enough contact between soil particles and water transport through the soil was reduced.

Oxygen Diffusion Rate Measurement

An apparatus for measuring oxygen diffusion rate (ODR) was constructed according to the plans of Lemon and Erickson (1955). The platinum microelectrode was 0.644 mm in diameter and 3.9 mm in length. It was sealed in a glass tube according to the procedure outlined by Letey and Stolzy (1964) and the platinum-glass joint coated with epoxy glue. A carbon electrode was used in place of the saturated calomel cell, as suggested by Wengel (1971). A potential of 1.065 volts was applied across the two electrodes, and the current read after 5 minutes.

To establish a value for very low aeration conditions, oxygen diffusion rate current measurements were made in a completely water-saturated clay soil stored in an air-tight container. While the highest individual readings observed in conventionally watered, well-aerated open-structured soils were 16 to 19 microamperes, the average current in the reduced soil was 3 microamperes.

RESULTS AND DISCUSSION

Yields

Table 8 shows the yields obtained from a number of otherwise identical treatments when wick-watered and conventionally watered.

Wick-watering gave significantly higher yields in six cases and in one case conventional watering was superior. There was no significant difference between the two methods in the remaining 17 comparisons. The instance where conventional watering gave greater yields most likely arose because supplemental surface watering necessary during periods of high evapotranspiration rates was inadequate.

The improved growth observed in the wick-watered pots probably arises from increased availability of water during periods of water stress. Acevedo et al. (1971) observed that expansion of maize leaves was severely reduced at soil-water tensions of -0.8 bar, which are certainly frequently encountered in conventionally watered pots. In wick-watered pots, however, the free water level varies from 17 to 27 cm below the surface of the soil, and water tension in the pots will be only -0.02 bar when the soil is in equilibrium with the water below, a situation most likely to occur at night when transpiration is minimal. During the daytime water tension will be greater. Water content measurements made on soil samples removed from 20 cm pots immediately after harvesting in the late morning showed that water content ranged from 70% of field capacity in the top of the pot to 141% of field capacity in the bottom center of the pot (Table 9).

Table 8. Effect of wick and conventional watering on yields of maize and sorghum grown during 18 months in the greenhouse.

Soil	Crop	Growing Period	Average Yield* Wick Watering	Average Yield* Conventional Watering
		days	g/pot	g/pot
Carreras Surface	Maize	26	20.13 (3)	13.80 (1)+
Los Guineos Sub	Maize	20	13.67 (3)	9.30 (3)+
Carreras Sub (exposed & cropped)	Maize	26	17.83 (3)	14.20 (1)
Carreras Surface	Maize	26	19.97 (3)	17.00 (1)
Piña Sub	Maize	20	13.37 (3)	10.43 (3)+
Los Guineos Surface	Maize	20	15.33 (3)	12.73 (3)+
Nipe Sub (exposed)	Maize	24	13.00 (2)	10.48 (4)
Carreras Sub + 1% coffee leaves	Maize	26	15.80 (3)	14.10 (1)
Catalina Surface	Maize	20	12.63 (3)	11.67 (3)
Humatas Surface + 2% coffee leaves	Sorghum	19	3.40 (4)	2.45 (4)+
Humatas Surface	Sorghum	19	2.95 (2)	2.10 (2)+
Humatas Surface + 15% vermiculite	Sorghum	19	3.25 (2)	2.60 (2)
Catalina Sub	Maize	20	9.80 (3)	9.17 (3)
Humatus Surface + 2% coffee leaves	Sorghum	19	2.80 (4)	2.28 (4)
Humatas Surface + carbon powder	Sorghum	19	2.90 (2)	2.55 (2)
Catalina Surface	Maize	20	13.07 (3)	12.87 (3)
Carreras Sub	Maize	26	13.03 (3)	12.90 (1)
Carreras Surface	Maize	26	19.53 (3)	19.50 (1)
Humatas Surface	Sorghum	19	0.78 (4)	0.98 (4)
Humatas Surface + 2% coffee leaves	Sorghum	25	7.18 (4)	7.68 (4)
Humatas Surface	Sorghum	25	2.68 (4)	2.88 (4)
Piña Surface	Maize	20	13.30 (3)	14.00 (3)
Carreras Surface	Maize	24	11.57 (3)	12.82 (4)
Carreras Surface	Maize	20	11.27 (3)	14.73 (3)‡

*Numbers in parentheses refer to the number of replicates per treatment.

+Wick-watering significantly superior at the 5% probability level.

‡Conventional watering significantly superior at the 5% probability level.

Table 9. Water contents and field capacity of Carreras surface soil, subsoil and subsoil plus organic matter from various parts of wick-watered pots in the late morning.

Location in Pot	Water Content		
	Surface Soil	Subsoil	Subsoil + 2% Coffee Leaves
	%		
Top, halfway between wick and wall	21	33	33
Center, halfway between wick and wall	33	39	39
Bottom, near wall	35	40	40
Bottom, near wick	41	43	48
Field capacity of soil	29	35	37

Apparently having some areas of the pot with water contents greater than field capacity is not harmful. Yu et al. (1969) found that maize, sunflower and barley planted in soil in 43 cm deep cylinders grew better when the cylinder was half full of water than when it was maintained at field capacity, although the differences were not significant.

To further investigate the effects of high water contents on availability of oxygen, oxygen diffusion rate comparison measurements were made for the two types of watering.

Oxygen Diffusion Rate Measurements

Measurements made on pots in the greenhouse several hours after watering the conventionally watered pots are presented in Table 10. It can be seen that only a slight difference exists between conventional and wick pots. However, there is indication that the wick pots have an area of slightly lower oxygen availability near the center of the pot at 6 to 9 cms depth. This seems reasonable since some aeration would be provided in the extreme lower portions by the holes in the bottom of the pot.

It was originally thought that comparisons with published values of ODR could be made. The calculated value of the oxygen diffusion rate, in units of 10^{-8} g cm^{-2} min^{-1} is 6.1 times the microampere reading, as derived from the working relationship given by McIntyre (1970):

$$ODR = \frac{60\ Mi}{n\ F\ A} \times 10^{-6}\ g\ cm^{-2}\ min^{-1}$$

where

i = current in microamperes

M = molecular mass of oxygen (32 g per mole)

Table 10. ODR current comparisons among eight wick and conventionally watered pots.

Soil and Crop	Watering	Depth	Number of Readings	Average Current
		cm		μa
Humatas surface soil sorghum	wick	6-10	6	10.4
	conv	6-10	7	14.1
Los Guineos surface soil maize	wick	4-15	8	14.4
	conv	7-13	7	13.3
Los Guineos surface soil maize	wick	3-11	10	8.2
	conv	5-11	12	10.5
Catalina subsoil maize	wick	2-15	12	12.7
	conv	4-9	8	14.2

n = number of equivalents per mole of oxygen (4)

F = 96,500 coulombs per equivalent

A = area of electrode in cm^2.

The measurements in the wick-equipped and conventionally watered pots range from 27 to 116 x 10^{-8} $g \cdot cm^{-2}$ min^{-1} and are well above the critical minimum values of 10 x 10^{-8} g cm^{-2} min^{-1} for root growth for corn cited by Letey, Stolzy and Valorous (1965) and most are above the value of 40 x 10^{-8} g cm^{-2} min^{-1} quoted for maximum root growth. However, Kristensen (1966) pointed out that the plateau in the current vs. voltage graph which Lemon and Erickson (1955) observed in 2-phase solid-liquid suspensions was not present in a 3-phase soil system. This means that the current will be significantly affected by the effective voltage. But because of the resistance of the soil between the two electrodes the effective voltage acting at the platinum electrode is somewhat less than the applied voltage measured across the two electrodes, and unless the effective voltage is known, the current reading will not have much meaning. McIntyre (1970) states that no comparisons with published values can be made because none of the published critical minimum ODR measurements specify these essential parameters.

In view of the relatively high currents observed with both types of watering, and the increased growth generally present in the wick-equipped pots, it seems clear that little danger of insufficient aerarion exists while a healthy crop is growing in the pot and evapotranspiration rates are high.

On one occasion a 20 cm wick-equipped pot of heavy clay soil with very poor structure was left unplanted with the wick in water for

60 days. It developed an area of gleyed soil in the shape of a doughnut, about 2 cm up from the bottom of the pot. This was the only observation of any such problem.

Hewitt (1966) attributed the lack of success of previous wick-watering methods to the fact that the wicks used (cotton wool, blotting paper or asbestos) became fouled and clogged and could not supply water at a high rate. These problems were not observed in these experiments, perhaps because the fiberglass wick is a more efficient water conductor.

CONCLUSION

Plants grown with the wick-watering technique generally are larger than those conventionally watered, probably because they suffer less water stress during periods of high evapotranspiration rates.

Because watering is essentially automatic it is only necessary to add water to the cans beneath the pots once a day. During very hot periods when plants are large in relation to the pot size it is also occasionally necessary to add water directly to the pots. Since conventional techniques require weighing and watering each pot one to three times daily, the wick-watering method permits a considerable saving of time, up to two-thirds of what would be necessary with conventional methods. The number of times the pot needs to be moved is also greatly reduced and resulting damage to the plant and soil structure is much less likely.

While slightly more time is needed for setting up wick-watering pots and ensuring that the soil particle size distribution is more or less uniform from pot to pot, the improvements in yield and the great savings of time (especially when the evapotranspiration rate is high) make the method very appealing.

SUMMARY

The use of a simplified modification of the wick-watering method of Dolar and Keeney (1971) was shown to increase maize yields in greenhouse pots over those obtained with conventional watering, presumably by increasing the supply of available water. Water contents in various parts of the pots ranged from 70% of field capacity to 141% of field capacity. Oxygen diffusion rate measurements indicated that sufficient oxygen was available to the plant roots. The method permits a considerable reduction in the time necessary for watering.

SECTION THREE

POSSIBLE CAUSES OF LEAF STRIPING OBSERVED IN PIONEER X-306 MAIZE

INTRODUCTION

An interveinal leaf striping of varying intensity occasionally appeared in Pioneer Hybrid X-306 maize plants grown in greenhouse pots and in the field. In accordance with the original purpose of the investigation, to discover what limits to productivity were present in the surface soils and subsurface soils being studied, a series of experiments was carried out to see if the striping might be indicating some nutrient deficiency or imbalance.

EXPERIMENT IV

Interveinal striping was observed in an early greenhouse experiment, and similar striping was observed in apparently vigorous maize plants growing in a nitrogen experiment field in Carreras soil at Corozal, Puerto Rico. The stripes were light yellow in color and occurred between the veins. The striping was most pronounced in the newest leaves and more prominent near the base of the leaf. In general the bands were most marked in the section of the leaf midway between the rib and the leaf margins.

Spectrographic analysis of a striped leaf from a field plant showed it contains 0.03% Mg. According to Jones (1967), less than 0.10% magnesium in maize ear leaves indicates deficiency. Key et al. (1962), found a similar value for 30 day old maize plants. All the other elements were present in normal concentrations except K, which was excessive (4.14%). Assuming that the values given by Jones apply to younger leaves, the most obvious possible cause of the striping appeared to be magnesium deficiency exacerbated by excess K.

Methods

The first series of treatments studied the effects of various K-Mg fertilization ratios on Carreras subsoil. Plants receiving these treatments were grown concurrently with plants receiving the treatments described in Experiment II in Section One, and the combined treatments

statistically analyzed as a whole. The details of the treatments are shown in Table 13. Planting dates, etc., are presented in Table 11.

The magnesium was supplied as Epsom salts.

Results and Discussion

In the presence of 100 ppm Mg as Epsom salts ($MgSO_4 \cdot 7H_2O$), the addition of only 50 ppm K supplied enough potassium for near-maximum yields. When no magnesium was added there was a tendency towards reduced yields, and the yield on the treatment receiving 300 ppm K and no added Mg was significantly lower than the yields on treatments receiving Mg (Table 12).

Leaf analysis of plants from a pot receiving 100 ppm Mg and 200 ppm K (Table 13) showed that foliar Mg was still extremely low (0.04%). It may be that 100 ppm Mg in the form of Epsom salts was not an effective source of Mg in this soil, at least in terms of greatly increasing foliar content. Phosphorus levels were erratic in the zinc-deficient plants but in the zinc-sufficient treatments P content increased with applied phosphorus to 0.30% at 300 ppm P added, which is within the sufficient range for maize according to Jones (1967). Zinc content was deficient at all levels of phosphorus when no zinc was applied, but at 36 ppm Zn the plant content was sufficient at the 200 and 300 ppm P treatments. It is interesting to note that the treatment with 0 Mg, 300 ppm K and 300 ppm P (treatment 8) had a phosphorus content in the deficiency range and the treatment receiving 200 ppm P, 0 Zn and 100 ppm Mg (Treatment 10) showed excessive calcium content. These emission spectroscopy measurements were unreplicated so the possibility of error can not be eliminated.

Table 11. Details of planting and fertilization for Experiments IV, V, VI and VII.

	Experiment			
	IV	V	VI	VII
Starting Date	29 Feb. 1972	25 Sept. 1972	6 Oct. 1972	22 Nov. 1972
Growing Period, Days*	24	23	22	22
Soil Used per Pot, g	1600	1600	Los Guineos 1415 Catalina 1565	1565
Experimental Design+	RCB	CRD	CRD	CRD
Incubation Period, Days‡	22	5	0	0
Seeding	pregerminated	direct	direct	direct
Replicates (all wick watered)	3	Los Guineos 4 Catalina 3	4	2
Blanket Fertilizer Applications				
N, Split, ppm	330	360	Los Guineos 463 Catalina 418	188
P, ppm	varied	varied	varied	147
K, ppm	varied	100	205	185
Mg as Epsom salt, ppm	Treatment 10 0 Others 100	0	47	
$Ca(OH)_2$, ppm	Top none Sub 2770	Los Guineos 1600 Catalina 368		
$Mg(OH)_2$, ppm		Los Guineos 1250 Catalina 290		

*Measured from planting or initiation of germination where pregerminated seed was used.

+RCB = Random Complete Block; CRD = Completely Random Design.

‡Number of days fertilized soil was kept moist before planting.

Table 12. Effect of fertilizer treatment on yield and leaf striping of maize grown on Carreras surface and subsoil in Experiment IV.

Treatment Number	Fertilizer Mg	K	P	Zn	Cu	Striping*	Yield+
	ppm						g/pot
Subsoil							
1	100	0	300	36	21	8	12.73 defg
2	100	50	300	36	21	3	14.80 g
3	100	200	300	36	21	4	14.23 fg
4	100	200	300	36	0	4	15.27 g
5	0	0	300	36	21	1	10.93 cdef
6	0	100	300	36	21	1	10.87 cdef
7	0	200	300	36	21	6	12.93 defg
8	0	300	300	36	21	5	9.63 bcd
9	100	200	100	0	21	P-def	4.60 a
10	100	200	200	0	21	Zn-def	5.60 a
11	100	200	300	0	21	Zn-def	6.97 ab
12	100	200	100	36	21	P-def	6.63 ab
13	100	200	200	36	21	3	11.23 def
14	100 plus 1% dried coffee leaves	100	300	36	21	2	13.33 efg
Surface Soil							
15	0	100	300	36	21	4	14.30 fg
16	100	100	300	0	21	Zn-def	7.70 abc

*0 = no striping; 9 = severe striping.

+Yields not followed by the same letter are significantly different at the 5% probability level according to Duncan's New Multiple Range Test.

Table 13. Foliar analyses of maize from Experiment IV.

Treatment Number	N	P	K	Ca	Mg	Mn	Fe	B	Cu	Zn	Al	Mo
	%					ppm						
3	2.0	0.20	3.39	0.35	0.04	41	69	13	10	46	48	2.1
4	2.1	0.21	3.43	0.46	0.04	46	72	12	9	54	48	1.8
5	2.2	0.21	3.53	0.57	0.03	49	80	9	11	57	67	1.8
8	2.4	0.10	4.27	0.16	0.01	14	33	8	7	13	40	1.5
9	2.9	0.12	4.69	0.65	0.05	69	57	8	7	8	62	2.1
10	3.5	0.31	4.70	1.36	0.17	106	106	15	19	10	84	2.2
11	3.2	0.20	5.79	0.52	0.04	51	41	9	4	7	44	1.8
12	2.7	0.09	3.86	0.25	<0.01	21	36	5	3	12	53	1.7
13	2.3	0.19	3.77	0.62	0.06	57	93	15	12	56	71	2.1
15	2.5	0.24	1.61	0.34	0.12	40	98	12	11	46	57	2.1
16	2.9	0.34	2.73	0.75	0.29	119	236	14	19	13	64	1.8

The severity of leaf striping increased when high rates of potassium were applied to soils not receiving magnesium, but it was still present in the zero potassium, 100 ppm Mg treatments. The intensity of leaf striping did not seem to be related to yield.

EXPERIMENT V

A second experiment was carried out, again comparing the effects of fertilizer K:Mg ratios on X-306 maize, this time in the absence of added Cu.

Methods

The soil used was Catalina subsoil. Additional treatments (described in Section One, Experiment III, Trial Two) comparing the effects of Zn and phosphorus were included. The results of the whole experiment are presented in Table 14. Planting details are described in Table 11. The magnesium in this experiment was provided as magnesium hydroxide in the liming material rather than Epsom salts.

Results and Discussion

Table 14 shows that the use of a high Mg:K fertilizer ratio had essentially no effect on reducing striping or increasing yield. Emission spectroscopy values for foliar analysis (Table 15) show a Mg level of 0.55%, which should be more than adequate. Apparently magnesium hydroxide is an effective source of Mg on this soil.

A strong response to phosphorus is evident on both soils. There was less striping on the very stunted phosphorus-deficient No. 12 treatment. Increasing the amount of zinc applied on the 300 ppm P treatment from 36 to 55 ppm Zn did not reduce striping.

Table 14. Treatments, yields and striping of maize in Experiment V.

Treatment	Fertilizer Mg	K	Zn	P	Striping+	Yield‡	
	ppm					g/pot	
Catalina Subsoil							
1 0 Mg-2K	0	200	36	300	3	11.47	b
2 1 Mg-1K	121	100	36	300	3	12.57	b
3 2 Mg-0K	242	0	36	300	5	11.63	b
4 3 Zn-0P	121	100	36	0	1	3.2	a
5 3 Zn-3P*	121	100	36	300*	3	13.33	b
6 3 Zn-6P	121	100	36	600	4	16,77	c
7 5 Zn-3P	121	100	55	300	4	12.43	b
Los Guineos Surface Soil							
8 LG-3P	524	100	18	300	4	16.90	c
9 LG-6P	524	100	18	600	5	21.15	d

*Phosphorus was banded.

+0 = no striping; 9 = severe striping.

‡Yields not followed by the same letter are significantly different at the 5% probability level according to Duncan's New Multiple Range Test as modified by Kramer for unequal replication (Steel and Torrie, 1960).

Table 15. Foliar analyses of maize plants from Experiment V.

Treatment	P	K	Ca	Mg	Mn	Fe	B	Cu	Zn	Al	Mo
	%				ppm						
1 0 Mg-2K	.19	2.28	.40	.12	130	100	21	17	45	90	3.5
3 2 Mg-0K	.18	1.16	.40	.57	186	145	12	19	53	103	4.7
4 3 Zn-0P	.14	3.02	.55	.35	202	92	12	18	78	90	3.6
6 3 Zn-6P	.20	1.25	.46	.28	226	100	10	15	40	124	3.9
8 LG-3P	.28	1.59	.24	.36	83	102	18	22	47	86	3.9
9 LG-6P	.26	1.36	.32	.52	65	103	14	16	41	78	3.9

The results of this experiment tend to indicate that varying the Mg:K ratio does not reduce striping, nor does increasing Zn from 36 to 55 ppm.

EXPERIMENT VI

Because varying the magnesium level did not reduce striping it seemed that the symptom might be more directly related to another element. Therefore treatments of B, Fe, Cu, $Ca(OH)_2$, and P were applied to Catalina subsoil. One pot planted with Puerto Rico Mayorbella maize was included to see if striping would develop on it.

Methods

The soils from the previous pots were pooled and repotted. The Catalina subsoil had received in the previous trial 300 ppm P, 100 ppm K, 121 ppm Mg, and 36 ppm Zn, and the Los Guineos 450 ppm P, 100 ppm K, 524 ppm Mg, and 18 ppm Zn.

After adding a new blanket treatment of 512 ppm P, 205 ppm K (as K_2SO_4), and 47 ppm Mg (as Epsom salts) to the Catalina subsoil, five treatments designed to clarify the cause of the interveinal yellowing were imposed: 0.6 ppm boron as boric acid; 38 ppm iron as sodium ferric diethylenetriamine pentaacetate; 2.6 ppm copper as copper sulfate; 1405 ppm $Ca(OH)_2$; and 512 ppm phosphorus additional as monocalcium phosphate monohydrate.

The Los Guineos surface soil received a blanket application of 226 ppm K (as potassium sulfate), 52 ppm Mg (as Epsom salts) and two P treatments: 556 ppm and 1132 ppm P.

Results and Discussion

Table 16 shows that the phosphorus response of both soils is near plateau level.

The interveinal striping was exacerbated by iron chelate and high levels of phosphorus. Apparently it did not interfere with high yields, since the striping was severe in the high-yielding high phosphorus treatment. But the application of iron chelate reduced the yield.

The cause of the striping may have been related to a genetic peculiarity of Pioneer X-306 since it was not observed in the Mayorbella maize cultivar receiving essentially the same treatment.

Table 16. Treatment, yield, pH and striping observed on maize in Catalina subsoil location F and Los Guineos surface soil in Experiment VI.

Treatment	P added ppm	Yield* g/pot		pH	Striping
Catalina Subsoil F					
Fe (38 ppm)	520	17.82	a	5.25	9
$Ca(OH)_2$ (1406 ppm)	520	18.75	ab	5.90	5
Cu (2.6 ppm)	520	19.45	abc	5.20	5
B (0.6 ppm)	520	20.22	abc	5.04	5
P	1025	20.70	bc	5.31	9
Mayorbella Maize‡	600	17.10		--	1
Los Guineos Surface Soil					
LG-5	566	20.74	bc	5.25	2
LG-11	1132	21.59	c	--	2

*Yields not followed by the same letter are significantly differen at the 5% probability level according to Duncan's New Multiple Range Test as modified by Kramer for unequal replication (Steel and Torrie, 1960).

+0 = no striping; 9 = severe striping.

‡One replicate of Puerto Rico cultivar Mayorbella. All other pots were planted with Pioneer Tropical Hybrid X-306.

EXPERIMENT VII

From the key to nutrient deficiency symptoms presented by Krantz and Melsted (1964), deficiencies of Zn, Fe, B, or Mn seemed possible causes of the striping. Since additions of zinc, iron, and boron did not cure the symptoms, this experiment was carried out to see if an application of manganese would reduce the chlorosis.

Methods

The pots from the iron and phosphorus treatments of the previous experiment were used. These treatments showed the highest incidence of striping.

The soil was broken up in the pots and seeds of Pioneer X-306 tropical hybrid maize planted. Half the pots in each of the previous two treatments received 4 ppm Mn as $MnCl_2 \cdot 4H_2O$, added with the nitrogen in the irrigation water.

On the eighth day after planting 147 ppm P and 185 ppm K were added to each pot as KH_2PO_4. Fourteen days after planting a 2% $MnCl_2 \cdot 4H_2O$-1% lime suspension was sprayed on the leaves of the Mn treatment pots.

Results and Discussion

The final observations (shown in Table 17) were made 22 days after planting. At that time all plants showed a moderate amount of

Table 17. Height and striping of Pioneer X-306 maize plants in Experiment VII.

Previous Treatment	Mn Addition	Striping*	Height
	ppm		cm
38 ppm Fe	4	5	73.9
38 ppm Fe	0	4	75.2
1025 ppm P	4	4	76.2
1025 ppm P	0	7	73.5

*0 = no striping; 9 = severe striping.

striping. No clear-cut difference emerged as a result of the Mn applications.

This was not a definitive test however. While 4 ppm Mn applied to the soil is a recommended rate, it is valid only if banded. Murphy and Walsh (1972) indicate that broadcast applications should be roughly ten times higher. It would also have been better to have used a chelated manganese source for the foliar applications and to have started spraying the plants at an earlier stage.

CONCLUSIONS

The striping observed in X-306 hybrid maize occurred most strongly when levels of phosphorus fertilization were high or chelated iron was added to the soil. Large applications of magnesium and high rates of zinc fertilizer did not alleviate the striping.

The exact cause of the striping is unclear but appears to be a peculiarity of this maize cultivar as it did not occur in Puerto Rico Mayorbella maize. Since it is apparently not associated with reduced yields, further research into its cause is probably unwarranted.

SUMMARY

Interveinal yellowing of new leaves on Pioneer X-306 maize plants was observed in the field and greenhouse. Foliar analysis showed low Mg (0.04%) and high K (4.14%) content in the affected leaves of the field plants. An experiment on Carreras subsoil showed that yields were reduced when 300 ppm K and no magnesium was added but that striping still existed in plants growing on soil receiving 100 ppm Mg as magnesium sulfate and no K. Foliar magnesium content remained very low in these leaves, indicating that magnesium sulfate might be an ineffective Mg source.

When Pioneer X-306 maize was grown on Catalina subsoil, which has 107 ppm exchangeable Mg (2.5 times as much as the Carreras subsoil), varying the K:Mg ratio from 200:0 to 0:242 increased striping slightly. The leaf Mg content was 0.57%, so apparently the striping in the upper leaves was not related primarily to Mg deficiency.

Subsequent trials on the same soils showed that striping increased greatly when 38 ppm Fe in chelated form or 1000 ppm P as calcium monophosphate was added to the soil. The iron addition caused a significant yield decrease. The addition of 2.6 ppm Cu, 4 ppm Mn, 0.6 ppm or sufficient calcium hydroxide to raise the pH to 5.90 did not alleviate the striping.

However, little striping was observed in a Puerto Rican maize

cultivar, Mayorbella, and since very high yields were obtained from the maize growing on Catalina subsoil receiving 1000 ppm P, perhaps the striping is a genetic peculiarity of X-306 maize of relatively little importance.

SECTION FOUR

INVESTIGATION OF THE ROLE OF ORGANIC MATTER IN SOIL PRODUCTIVITY

INTRODUCTION

A certain mystique exists about the role of organic matter in tropical agriculture.

The use of 2% partially decomposed coffee leaves greatly increased productivity on a Humatas surface soil in greenhouse experiments (Santiago, 1972). The productivity of Los Guineos (Epiaquic Humoxic Tropohumult) surface soil (10.7% organic matter) is regarded as unusually high, and is locally attributed to the possible presence of plant-stimulating hormones.

Subsoils generally have a lower organic matter content than surface soils. When subsoils are exposed, either through land-leveling or erosion, a considerable period of time is required to build up the organic matter level. In some clayey subsoils water management is difficult, but in many cases where there is a high iron and aluminum sesquioxide content the structure is good. In such soils it is particularly important to know if the increased productivity usually associated with organic matter can be obtained with mineral fertilizers alone.

Therefore several experiments were carried out to investigate the possible relationship of high organic matter content to increased yields, and to attempt to duplicate the effects of organic matter with mineral fertilizers, with the expectation that micronutrients might be of particular significance.

EXPERIMENT VIII

Five Carreras soils were collected from the Corozal, Puerto Rico site used in the Cornell-AID project. In a nitrogen experiment described by Fox (1972), marked differences in productivity at the same level of nitrogen had been observed on different areas of a field varying according to the amount of subsoil mixed in with surface soil (R. H. Fox, personal communication). The purpose of this experiment was to ascertain what factors were causing the low yields on the exposed cropped subsoil. Characteristics of the soils are shown in Table 18.

Because the subsoil had low Bray No. 2 phosphorus and low organic matter, phosphorus was added to the soils. Pure subsoil and pure subsoil mixed with 2% dried ground partially decomposed coffee leaves were included in the experiment.

Methods

Four pots of each soil were prepared following the procedure described under General Methods in Section One. The plain soil was limed with 2770 ppm calcium hydroxide and the subsoil plus organic matter received 2450 ppm calcium hydroxide (less was used because of the neutralizing power of the coffee leaves). A blanket micronutrient application was made which supplied 4.7 ppm Fe as sodium ferric diethylenetriamine pentaacetate, 2.3 ppm B as boric acid, 4.7 ppm Zn as zinc sulfate, 8 ppm Mn as manganese chloride, 5 ppm Cu as copper chloride

Table 18. Characteristics and greenhouse maize yields on three Carreras surface soils, Carreras exposed cropped subsoil, buried subsoil and buried subsoil plus 2% coffee leaves.

Soil	Field Productivity	Previous Fertilizer* N	P	K	Mg	Initial pH	Available+ P	OM	Yield‡	
		kg/ha					ppm	%	g/pot	
Surface Soil Location										
#1	High	440	20	280	112	5.4	23.8	4.04	19.52	a
#2	High	430	310	308	168	5.7	20.3	3.46	19.22	a
#3	Medium	231	310	308	168	5.4	24.5	3.66	18.55	a
Subsoil										
Exposed cropped subsoil	Low	231	310	308	168	5.4	14.6	3.07	16.92	ab
Buried subsoil + 2% coffee leaves	—	—	—	—	—	—	—	—	15.38	bc
Buried subsoil	—	—	—	—	—	4.4	2.1	1.48	13.00	c

*Amounts of fertilizer added to the field during the previous 18 months.

+Bray No. 2 available phosphorus.

‡Yields not followed by the same letter are significantly different at the 5% probability level according to Duncan's New Multiple Range Test.

and 0.09 ppm Mo as ammonium paramolybdate. In addition, 50 ppm Mg were supplied as Epsom salts.

Three replicates were wick-watered, according to the technique described in Section Two of this thesis. The remaining pot was conventionally watered to field capacity. Details of planting are given in Table 19.

Results and Discussion

Plant top weights are shown in Table 18. The yields on the three surface soils were similar and all significantly higher than the yield on the subsoil. The yields on the exposed cropped subsoil, and the subsoil plus coffee leaves were intermediate between the pure subsoil and topsoil yields.

Yields were roughly proportional to both amount of organic matter and Bray No. 2 phosphorus in the original soil.

Plants in all the treatments showed "white heart" symptoms of zinc deficiency (a bleached area in the lower half of the leaf, visible as the young leaves come out of the whorl), although in the three pure surface soils the symptoms were not well developed. The pure subsoil and subsoil plus organic matter plants also had a strongly developed leaf striping in the upper leaves.

While the zinc contents for the subsoil treatments, shown in Table 20, are not particularly low, the presence of "white heart" symptoms suggested that the application of 5 ppm Zn may have been insufficient and that zinc deficiency might be reducing yields in the subsoils. Lutz and Jones (1971) noted zinc deficiency symptoms in

Table 19. Details of planting and fertilization for Experiments VIII, X, XI and XII.

	Experiment			
	VIII	X	XI	XII
Starting Date	13 Oct. 1971	15 Sept. 1972	12 Oct. 1972	21 Nov. 1972
Growing Period, Days	26	19	25	19
Soil Used per Pot, g	3200*	1350	1350	ca.1175
Experimental Design+	RCB	CRD	CRD	CRD
Incubation Period, Days‡	0	9	4	0
Seeding	direct	direct	direct	direct
Replicates conventionally watered	1	2	2	OM_2 4[a] OM_o 2
Replicates wick-watered	3	2	2	OM_2 4 OM_o 2
Blanket Fertilizer				
N, split, ppm	300	318	224	484
P, ppm	300	0	0	300
K, ppm	200	96	0	150 as sulfate
Mg as $MgSO_4 \cdot 7H_2O$, ppm	50	0	varied	100

*Pot size 20 cm diameter.

+RCB = Random Complete Block; CRD = Completely Random Design.

‡Number of days fertilized soil was kept moist before planting.

[a]OM_2 = 2% dried partially decomposed coffee leaves added; OM_o = no organic matter added.

Table 20. Foliar analyses of maize plants from Experiment VIII.

Soil	P	K	Ca	Mg	Mn	Fe	B	Cu	Zn	Al	Mo
	%				ppm						
Surface soil #1	0.41	4.32	0.29	0.16	133	160	31	9	24	101	2.2
Exposed cropped subsoil	0.34	4.02	0.37	0.12	97	93	23	17	32	53	2.2
Buried subsoil + 2% coffee leaves	0.33	5.34	0.69	0.22	246	113	28	13	28	57	1.9
Buried subsoil	0.24	3.93	0.87	0.17	183	124	36	16	36	57	1.9

maize plants at silking on plants growing on a Typic Hapludult, Tatum silt loam. Foliar analysis showed that the symptoms occurred in plants with 27 ppm Zn. This value is somewhat higher than the "low" value of 11-20 ppm given by Jones (1967).

Conclusions

This experiment indicated that yield relationships observed in the field could be reproduced in the greenhouse.

In a succeeding investigation, Experiment IV, described in Section Three, the yield on the pure subsoil increased to that of the surface soil when 300 ppm P, 100 ppm Mg and 36 ppm Zn were added. The typical zinc deficiency symptoms disappeared in the high zinc treatment but the striping in the upper leaves persisted.

The yield increases observed with the addition of 2% dried coffee leaves (which contained enough Zn, Mg and P to supply 44 ppm P, 60 ppm Mg and 0.7 ppm Zn to the soil) was probably related to increasing the amounts of these elements available to the plants.

EXPERIMENT IX

Cachaza (filter-press cake or filter-press mud) is a by-product of the sugar cane industry produced in large quantities each year. Samuels and Landrau (1955) reported that it contains on the average 2.19% N, 1.21% P, 0.36% K, 2.18% Ca, 0.30% Mg, 0.11% Mn, 0.73% Fe, 0.003% B, and 39.5% organic matter.

Landrau and Samuels (1955) reported that 20 tons per acre of cachaza significantly improved yields of Plamar tomatoes on Coto clay (Tropeptic Haplorthox) even when 99 kg/ha P, 189 kg/ha K, and 114 kg/ha of N were also added. Samuels and Landrau (1955) studied responses to cachaza and found that filter press cake plus mineral fertilizer increased yields of taniers (Xanthosoma atrovirens) on Lares clay (Aquic Tropohumult), and peppers on Juncos clay (Inceptisol), compared to mineral fertilizer alone, but that in nine other instances there was no significant response to the addition of cachaza.

Cachaza is regarded as a valuable soil amendment, particularly by the home gardener.

Methods

To see if any yield improvements would be observed in the very low organic matter Piña subsoil (Psammentic Haplorthox), a small comparison was run concurrently with Experiment III, Trial One described in Section One, using the same procedures. Three wick-watered pots

of Piña subsoil (2.03% organic matter) treated with 2% dried filter press cake, were compared with three pots of plain subsoil. Both sets of pots received 18 ppm Zn and 80 ppm Mg as magnesium hydroxide, as well as 320 ppm N and 200 ppm K.

Results and Discussion

The yield on the cachaza-treated pots averaged 13.7 gm/pot, while on the plain soil the yield was essentially the same, 13.4 g/pot.

The effects of cachaza observed by the other workers may have been caused by a change in the physical structure of the soil which would have raised the water-holding capacity, or may have arisen from increased supply of some micronutrient deficient in the original soil. Apparently neither of these improvements was necessary in the Piña subsoil.

This agrees with the results of Lugo-López et al. (1956) who found that on several Oxisols (Catalina clay (Tropeptic Haplorthox) Coto clay (Tropeptic Haplorthox) and Bayamón silty clay (Tropeptic Eutrorthox)), which were thought to be in organic matter equilibrium, the addition of filter-press cake was only beneficial in reducing erosion.

EXPERIMENT X

In order to investigate the beneficial effect (56% greater yield) of organic matter on sorghum grown on Humatas surface soil observed by Santiago (1972), an initial trial was set up to test the effect of watering with different methods (wick and conventional) to see if water deficiency may have reduced yields in pots not receiving organic matter.

Methods

Humatas surface soil (Typic Tropohumult, clayey, kaolinitic, isohyperthermic) was collected from the same site as the soil used by Santiago and received approximately the same blanket fertilizer that he used (96 ppm K as potassium nitrate, 96 ppm N as ammonium nitrate and potassium nitrate, and a micronutrient solution supplying 10 ppm Mn as $MnCl_2 \cdot 4H_2O$, 5 ppm Fe as sodium ferric diethylenetriamine pentaacetate, 2.5 ppm B as H_3BO_3, 5 ppm Zn as $ZnSO_4 \cdot 7H_2O$, 0.5 ppm $CuSO_4 \cdot 5H_2O$, and 0.1 ppm Mo as $H_2MoO_4 \cdot H_2O$). The plain soil treatments (OM_o) were limed with 2850 ppm $Ca(OH)_2$ and the organic matter treatments (OM_2) were limed with 2140 ppm $Ca(OH)_2$ and also received 2% organic matter (the same dried ground partially-decomposed coffee leaves used by Santiago). The pH of both soils was approximately 5.0 after harvesting.

To gain further information about the role of organic matter, the original soils which had received these treatments and were used

in Santiago's experiment in 1971 were removed from the pots, dried, broken up by hand, and placed in wick-equipped pots. Just before planting, 330 ppm N, 100 ppm P, and 135 ppm K, as KH_2PO_4 and ammonium nitrate in solution form were added to each pot. Ten days after planting an additional 114 ppm N was applied. These soils made up treatments OM_o-'71 and OM_2-'71.

In each of these trials 12 seeds of grain sorghums (Sorghum bicolor (L.) Moench cv. RS671) were planted and later thinned to six plants per pot. In an effort to ascertain the cause of interveinal striping observed after 8 days in Treatment OM_o pots, 200 ppm Mg as Epsom salts were added to half the pots of the conventionally watered OM_o treatment and half the pots in the OM_o-'71 treatment.

Results and Discussion

As shown in Table 21, wick-watering had little effect compared to the effect of organic matter. Organic matter addition increased yields by 317%.

Presumably this effect was not related to phosphorus fertilization because both the replanted treatments originally used by Santiago (OM_o-'71 and OM_2-'71) received 100 ppm P for the first time in this experiment and still the pots receiving organic matter greatly outyielded the plain soil.

Published foliar analyses for estimating deficiencies are less available for sorghum than for maize. Owens and Furr (1967) published foliar contents for five cultivars of forage sorghum growing on Pullman silty clay loam of medium fertility and pH 7.2 with and without small

Table 21. Treatments and yields of sorghum grown on Humatas topsoil with and without added coffee leaves in Experiments X and XI.

Treatment		Experiment X			Experiment XI				
		pH After Harvest	Yield	Mean+	$Ca(OH)_2$	Aqueous Coffee Leaf Extract	pH	Yield	Mean+
			g/pot	g/pot	ppm			g/pot	g/pot
OM_o-conv	a	4.95*	.7		1245	0	5.60	1.8	
	b	4.90*	1.0		0	0	4.92	3.5	
	c	4.90	1.1		0	0	4.85	2.8	
	d	4.92	1.1		1245	0	5.71	3.4	
				0.98 a					2.88 a
OM_o-wick	a	5.03	0.6		1245	0	5.71	3.8	
	b	5.00	0.8		1245	0	5.62**	1.8	
	c	5.09	1.1		0	0	4.85	2.5	
	d	5.10	0.6		0	Yes	4.96	2.6	
				0.78 a					2.68 a
OM_o-'71 wick	a	4.79	1.3		1421	0	5.02	3.3	
	b	4.75	.7		0	Yes	4.92	2.2	
	c	4.69*	.5		1421	0	4.80	3.9	
	d	4.64*	.5		0	0	4.80***	1.6	
				0.75 a					2.75 a
OM_2-conv	a	5.00	2.1		0	0	5.08	7.5	
	b	4.94	2.6		0	0	5.02	7.6	
	c	4.92	1.8		0	0	5.03	8.1	
	d	—	2.6		0	0	5.06	7.5	
				2.28 b					7.68 b

Table 21. Continued.

Treatment		Experiment X			Experiment XI				
		pH After Harvest	Yield	Mean+	$Ca(OH)_2$	Aqueous Coffee Leaf Extract	pH	Yield	Mean+
			g/pot	g/pot	ppm			g/pot	g/pot
OM_2-wick	a	5.10	2.4		0	0	4.70	8.3	
	b	5.08	3.0		0	0	4.82	7.0	
	c	5.10	2.6		0	0	4.82	6.9	
	d	5.11	3.2	2.80 b	0	0	4.72	6.5	7.18 b
OM_2-'71-wick	a	4.70	3.4		0	0	4.30	2.9	
	b	4.63	2.0		0	0	4.22	2.4	
	c	4.72	3.6		0	0	4.35	3.8	
	d	4.58	2.5		0	0	4.01	1.6	
				2.88 b					2.68 a

*200 ppm Mg as Epsom salts added ten days after planting.

**100 ppm S as potassium sulfate added four days before harvesting.

***0.7 ppm B as boric acid added four days before harvesting.

+Means in the same column not followed by the same letter are significantly different at the 5% probability level according to Duncan's New Multiple Range Test.

additions of chelated micronutrients. They reported that the additions had no effect on yield or foliar mineral content, but that variations due to cultivars were important. The highest and lowest of these published values are shown in Table 22, along with spectrographic analyses of sorghum plants grown in Experiment X. Also presented are the spectrographic analyses obtained by Santiago (private communication) for sorghum plants grown on Humatas soil receiving treatments similar to those applied to the soils in Experiment X. In addition, the levels for deficiency and excess in maize cited by Jones (1967) are included for comparison. The maize values are for the ear leaf at silking.

The higher yielding organic matter treated plants showed higher contents of Mg, K, Mn and Mo. The likelihood that Mn deficiency was causing the difference seems slight as the level of manganese was high compared to that of the published maize and sorghum values. Potassium values were likewise relatively high compared to the values for maize.

The addition of Epsom salts to supply 200 ppm Mg late in the first trial had, if any, a depressing effect on yield. The same pots showed no special change in the second trial either. It would appear that no response to magnesium or sulfate existed, unless the magnesium sulfate was not very available.

The lack of response to Mg is somewhat surprising because the foliar analyses indicated that the level of Mg in the leaves was low and was inversely proportional to the yield. The average Mg content of sweet sorghum fodder given by Morrison (1948) is 0.31% Mg. None of the OM_o treatment leaf contents was even one-third of this.

Table 22. Foliar analyses of grain sorghum plants from Experiment X, grain sorghum plants grown by Santiago on soils receiving similar treatments, forage sorghum plants (Owens and Furr, 1967) and maize plants (Jones, 1967).

Crop	N	P	K	Ca	Mg	Mn	Fe	B	Cu	Zn	Al	Mo
	%					ppm						
Grain Sorghum												
OM_o - wick c		0.26	2.62	0.47	0.09	112	106	12	17	80	46	2.2
OM_o-'71 a		0.27	2.48	0.37	0.07	154	105	20	19	73	75	3.0
OM_o-Santiago		0.26	3.98	0.60	0.13	239	147	23	11	106	154	2.5
OM_2 - wick d		0.25	3.15	0.36	0.16	200	143	11	17	61	67	3.4
OM_2-'71 c		0.27	3.44	0.38	0.20	245	98	15	23	92	78	3.8
OM_2-Santiago		0.20	3.69	0.46	0.16	276	101	20	7	81	90	2.6
Forage Sorghum												
Range from	1.19	0.13	1.65	0.18	0.20	35	137		11	22		
to	1.30	0.17	2.42	0.23	0.22	43	178		13	31		
Maize												
Deficient	2.45	0.15	1.25	0.10	0.10	15	10	2	2	10		never
Excess	3.75	0.50	2.50	0.90	0.55	200	350	35	50	100	400	

Adams and Henderson (1962) found that Sudangrass (Sorghum vulgare) growing on low cation exchange capacity soils where Mg made up less than 4% of the exchangeable cations was magnesium deficient. In Santiago's soil, only 3% of the exchangeable cations were Mg, although the total exchangeable magnesium content was several times larger than that in the soils used by Adams and Henderson.

McColloch et al. (1957) found that citrus became chlorotic due to Mg deficiency when the soil ratio of exchangeable K to exchangeable Mg exceeded 0.4 to 0.5. The ratio in the original soil used by Santiago was 1.47 (0.47 me K/0.32 me Mg in 100 g soil) while in the soil receiving organic matter (where greatly increased yields were observed) the ratio was 0.43 (0.37 me K/0.85 me Mg).

In a study of Ca:Mg ratio effects on maize, Key et al. (1962) grew plants in a sand and exchange resin mixture for 28 days. The exchangeable Mg contents closely approximated those in Santiago's work. When the exchangeable Mg content was increased from 0.50 to 1.50 me/100 g, magnesium deficiency symptoms disappeared. Santiago (1972) observed that the addition of 2% organic matter increased the exchangeable Mg content from 0.32 to 0.85 mg/100 g, and that the yield of sorghum almost doubled. See Table 23.

These considerations indicate that Mg supplied by coffee leaves may have been an important factor in increasing the yields in the OM_2 treatments.

However, if there was a Mg deficiency in the OM_0 soil, it is not clear why the addition of 200 ppm Mg (1.6 me/100 g) as Epsom salts would not have caused a yield increase. But there is some indication that $MgSO_4$ is not an efficient source of Mg at low pH.

Table 23. Effect of soil exchangeable Ca:Mg ratio on maize reported by Key et al. (1962) and change in sorghum yield and soil exchangeable Ca:Mg ratio resulting from coffee leaf application observed by Santiago (1972).

Crop	Soil			Leaf		Growth Effect
	Mg exchangeable	Ca exchangeable	Ca:Mg	Mg	Ca	
	mg/100 g soil			%		
Maize (Key et al., 1962)	0.50	2.5	5:1	0.10	0.09	Mg deficient
	1.50	1.5	1:1	0.16	0.08	No symptoms
Sorghum (Santiago, 1972)	0.32	8.68	26:1	0.13*	.60*	Low yield
	0.85	8.75	10:1	0.16*	.46*	Yield increases by 56%

*Emission spectroscopy values (Santiago, personal communication).

McCart and Kamprath (1965) found that for cotton growing on a soil of 2.2 me/100 g CEC, limed to pH 5.5 with calcitic lime, the addition of 0.30 me/100 g Mg as $MgSO_4$ did not increase the yield, but that there was an indication that when soils were limed to pH 5.5 with dolomite (which raised the exchangeable Mg from 0.09 to 0.45 me/100 g) the growth of cotton was greater. They also found that Mg uptake from $MgSO_4$ was half as efficient at pH of 6.0 than at pH 6.5.

Milam and Mehlick (1954) found that Crotalaria Striata, growing on Portsmouth sand (8 me/100 g CEC and 3.6% OM) at pH 4.8 was severely Mg-deficient when the soil exchangeable Mg level was 0.2 me/100 g, while at pH 6.1 and the same exchangeable Mg content, the yield was nearly double and there were no deficiency symptoms.

Similarly Munk (1961) found that powdered dolomitic lime was a better source of Mg than $MgSO_4$ at pH levels below 5.5.

The clear indication is that at the low pH values at which these experiments are run, soil Mg requirements are considerably higher than they would be at a pH of 6.5.

All the OM_o treatments plants showed a widespread incidence of red staining in the oldest two leaves, probably caused by fungus. Plant disease could be causing the lower yields observed in the plain soil plants, or the higher incidence of disease could be due to lowered resistance of these plants caused by some nutritional unbalance.

EXPERIMENT XI

The previous experiment confirmed the beneficial effect of coffee leaf additions in both the new and the 1971 pots. A second trial was undertaken to test the effect of pH and aqueous coffee leaf extract.

Methods

The soils were dried and 1240 ppm $Ca(OH)_2$ were added to half the OM_o pots, which increased the pH to 5.7. Half the pots in Treatment OM_o-'71 received 1490 ppm $Ca(OH)_2$ each. To see if the beneficial factor in the coffee leaves was water-soluble, 104 g leaves were soaked 24 hours, filtered, the leaves washed, and the combined clear-brown filtrates (650 ml) added to one OM_o pot and one OM_o-'71 pot.

Four days before harvest 100 ppm S (as K_2SO_4) were added to one OM_o pot and 0.7 ppm B (as boric acid) were added to one OM_o-'71 pot to see if any immediate change in plant appearance would result.

Results and Discussion

The OM_o yields did not respond at all to a pH increase of 0.7 units to 5.7 (Table 21). While the pH in Treatment OM_o-'71 inexplicably increased little on liming there was a tendency toward increased yield. However, the yields did not approach the level observed in Treatment OM_2. The aqueous extract of coffee leaves had no effect.

There was no yield increase in the pots which had received 200 ppm Mg during the first trial. Nor was there any visible change in

foliar appearance during the four days after the additions of boron and potassium sulfate.

In this trial, yields on Treatment OM_2-'71 fell to the level of the pots not receiving organic matter addition. This was probably due to Al toxicity accompanying the decrease in pH (to 4.2) caused by heavy applications of ammonium nitrate. Santiago had observed that when pH fell below 4.4, sorghum yields were severely reduced due to Al toxicity.

By the 20th day after planting many of the new leaves emerging from Treatment OM_o plants showed a pale green color and cells in and along the veins became completely translucent, causing a water-soaked appearance very similar to the initial symptoms of bacterial streak disease (Xanthomonas holicola) of sorghum described by Doggett (1970). However, a plant pathologist observing the leaves said the symptoms were not caused by disease. The phenomenon was particularly strong in wick-watered pots. There was a tendency for the affected pots to show lower yields. Almost all the plants also had crinkling of leaf margins.

The leaf symptom was most likely related to the nutrition of the plain soil plants. According to Krantz and Melsted (1964), sorghum deficiency symptoms are similar to those of maize. If the information provided for maize can be assumed applicable to sorghum it is possible to make the following tentative deductions. Since the lower leaves of the affected plants remained dark green and healthy-looking, deficiencies of N, K, Mg, or P are unlikely to be the cause of the disorder since these elements are relatively mobile and symptoms usually develop first in the older leaves. Molybdenum deficiency causes leaf tips to die

first. Copper is described as causing yellowing of the younger leaves. Probably neither of these was responsible for the symptoms.

Zinc, iron, manganese or boron are more likely. However, because the chlorosis occurred along, rather than between, the veins, it is less likely that the cause of the stripes was iron or manganese. The leaf stripe symptoms of the affected plants are not exactly like any described by Krantz and Melsted, but are close to those of zinc or boron deficiency.

EXPERIMENT XII

Methods

When no effects of liming or aqueous coffee leaf extract were observed on the Treatment OM_o pots, all the OM_o soils were removed, dried, and thoroughly mixed together. The Treatment OM_2 soils (excluding OM_2-'71) were similarly pooled. The pooled soils received 484 ppm N (as ammonium nitrate), 300 ppm P (as monocalcium phosphate monohydrate), 150 ppm K (as potassium sulfate), 107 ppm Mg (as Epsom salts) and 0.5 ppm B (as boric acid), 2.5 ppm Cu (as copper sulfate), 10 ppm Zn (as zinc sulfate) and 0.1 ppm Mo (as molybdic acid).

To four of the Treatment OM_o pots were added 4 mg/pot Disyston pellets (0,0-Diethyl S-(2(ethylthio)ethyl) phosphorodithiolate 15%), a systemic insecticide used on the coffee plantation from which the coffee leaves were obtained, which reportedly greatly increased the N uptake of the trees. Four other pots each received an acetone extract of 24 g dry coffee leaves obtained by soaking 96 g ground leaves in 500 ml acetone, collecting the decantate, repeating this twice, and evaporating the combined decantate on 150 cc finely ground activated carbon powder. The remaining four pots were mixed with 15% (volume/volume) expanded vermiculite to see if the effect of coffee leaves might have been physical in nature.

Results and Discussion

The yields obtained after pooling the Treatment OM_o soils and fertilizing them increased remarkably, nearly to the level of the Treatment OM_2 soils (Table 24). The Disyston, vermiculite, and acetone extract of coffee leaves treatments had little effect.

The main differences in fertilization of this treatment were:

1. For the first time P (300 ppm) was added to the new soils. (However, the OM_o-'71 and OM_2-'71 soils had both received 100 ppm P in Experiment X and no equalization of yields occurred.)
2. Somewhat higher rates of zinc and copper were added. (The micronutrient solutions used were individually and freshly prepared. The solution used previously in Experiment X and by Santiago was prepared in 1970.)
3. Magnesium (100 ppm) was added to all treatments. (However several pots in Experiment X had received 200 ppm Mg and did not show any improvement in that or in the following experiment.)
4. Sulfur (62 ppm) as potassium sulfate was added to all treatments for the first time. (However, in Experiment XI, one pot had received 100 ppm S as potassium sulfate four days before harvest with no visible effect, and 260 ppm S as magnesium sulfate had been added with the 200 ppm Mg treatments mentioned above.)

From the data available it is not possible to implicate a deficiency of any one element as the likely cause of the lower yields observed

Table 24. Sorghum yields in Experiment XII.

Treatment		Watering	Number of Replicates	Yield* g/pot	
OM_o	Disyston	wick	2	2.93	b c d
		conv	2	2.10	a
OM_o	Acetone extract of coffee leaves	wick	2	2.90	a b c d
		conv	2	2.55	b c
OM_o	Vermiculite	wick	2	3.25	c d
		conv	2	2.60	a b c
OM_2		wick	4	3.40	d
		conv	4	2.45	a b

*Yields not followed by the same letter are significantly different at the 5% probability level according to Duncan's New Multiple Range Test as modified by Kramer for unequal replication (Steel and Torrie, 1960).

in the plain Humatas soils, although it certainly appears that the use of a magnesium-calcium hydroxide mixture for liming would be a good initial step in any further investigation.

It may be that several elements were deficient at the same time. Sulfur was probably not one of these. Table 25 shows the acetate-soluble sulfur contents in coffee-leaf-treated and plain soil do not differ appreciably and are much higher than the level in a sulfur deficient soil. Owens and Furr (1967) found that the sulfur level in five cultivars of forage sorghum ranged from 0.10% to 0.12%, and Volk et al. (1945) reported that pot-grown sorghum plant tops with 0.04% sulfur were S-deficient while 0.13% sulfur was sufficient. The levels found in plants from both OM_o and OM_2 treatments were well above these levels, as shown in Table 26.

It may be that phosphorus and magnesium were both deficient and additions of one without the other were ineffective.

Zinc or copper might also have been deficient although the leaf analysis values are high.

The most likely cause for the increased yields observed in the coffee-leaf-treated soils and in all the soils in the last experiment is that some element or elements supplied in the fertilizer used in the last experiment were also supplied or made available by the coffee leaf additions. (The coffee leaf addition supplied 46 ppm S, 44 ppm P, 64 ppm K, 504 ppm Ca, 60 ppm Mg, 18 ppm Mn, 20 ppm Fe, 1.5 ppm B, 0.4 ppm Cu, 0.7 ppm Zn, 40 ppm Al and 0.2 ppm Mo.)

The possibility of a disease factor should not be overlooked. Since the weather was cooler and cloudier during the last experiment,

Table 25. Acetate-soluble sulfate* in original soils used by Santiago, after three weeks incubation at field capacity and 18 months air-dry storage.

Soil	Treatment		Acetate-Soluble Sulfur*
	$Ca(OH)_2$	OM	
	ppm	%	mg/g soil
Humatas	2990	0	710
	2220	2	672
	740	8	766
Coamo+ (Mollisol)			10 or less

*According to the method presented by Bardsley and Lancaster (1965).

+Sulfur-deficient soil (plants grown on this soil responded when sulfur was added).

Table 26. Total sulfur content of sorghum plant tops grown on Humatas surface soil with and without added coffee leaves.

Soil	Total Sulfur	Yield Level
	%	
OM_o	0.23	Low
OM_o-'71	0.29	Low
OM_o vermiculite plus mineral fertilizer	0.32	High
OM_2	0.38	High

there may have been a reduction in some deleterious process that might have affected the plants in the non-treated soils. For example, if the addition of coffee leaves altered the microbiological balance in the rhizosphere so that plants in those pots were less susceptible to root disease, it is possible that cool, cloudy weather would reduce the transpiration requirements of the disease-affected plants in the non-treated soils and allow their yields to reach the same level. However, the possibility of these two factors acting simultaneously seems remote.

CONCLUSION

The last experiment definitely showed that the beneficial effect of coffee leaves in improving reduced yields observed on untreated Humatas surface soil could be duplicated with mineral fertilizers. The exact deficiency or deficiencies were not unequivocally identified, but magnesium and phosphorus seem possible.

SUMMARY

Several investigations were made of cases where the addition of organic matter to subsoils or surface soils had been shown to increase productivity.

The effect of a 2% addition of ground, dried, partially decomposed coffee leaves in raising yields on Carreras subsoil could be duplicated by the addition of 36 ppm Zn, 100 ppm Mg and 300 ppm P.

The application of cachaza (filter-press cake), which has been reported to significantly increase yields on various Puerto Rican soils, was found to have no effect on a Piña subsoil concurrently receiving N, K, Zn and Mg.

Santiago (1972) observed a marked increase in sorghum yields grown on Humatas surface soil when partially decomposed coffee leaves were added. The soils had received lime, N, K and a mixture of micronutrients. The increase could not be accounted for by increased pH.

In order to see if the beneficial effect of the organic matter might have been due to increasing water availability, the experiment was repeated with two types of irrigation, conventional watering to field capacity and wick-watering. On soil that had been previously cropped by Santiago and on new soil from the same source there was no effect of watering, but the addition of 2% organic matter increased yields by 317%. Foliar analysis indicated that the low-yielding sorghum plants might be magnesium deficient, but the addition of 200 ppm Mg as magnesium sulfate to two pots had not increased yields.

In a second experiment it was shown that neither the addition of an aqueous extract of coffee leaves nor raising the pH to 5.7 increased yields to the level of the soil receiving organic matter. The cells in and along the veins of the upper leaves of the plants growing on the plain soil had become translucent and took on a watersoaked appearance. This might have been due to a nutritional imbalance in the plants.

Finally, the treated and untreated soils were removed from the pots, dried, mixed and repotted after the addition of N, K, 100 ppm Mg, 10 ppm Zn, 2.5 ppm Cu, and 300 ppm P. The yields on the plain soils increased to near the level of the yields on the organic matter treated soil. The cause of the low yields on the plain soil was not positively identified, but may have been a deficiency of magnesium or phosphorus or both.

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APPENDIX

DETAILS OF SOIL COLLECTION

The Nipe and Carreras (formerly called Humatas) soils used in the first experiment were collected by Lathwell. The Nipe was collected from an exposed subsoil terrace at Las Mesas near Mayaguez, Puerto Rico. The Carreras was collected from an uncropped portion of the northern edge of the Cornell-AID experimental plot for nitrogen response at the Corozal Substation. Further details are given by Lathwell et al. (1972)

The Carreras soils used in Experiments II, III, IV and VIII were collected on 9 September 1971 on the Cornell-AID plots at the Corozal Substation. Surface soil #3 (0-20 cm) came from the northeast corner of Plot Treatment 6, Block I, in the nitrogen experiment field. The buried subsoil (33-43 cm) came from the same location. The exposed subsoil (0-10 cm) came from the northwest corner of Plot Treatment 6, Block II. Surface soil #2 (0-20 cm) came from the northwest corner of Plot Treatment 4, Block IV. Surface soil #1 was from an adjacent field, about 25 meters away, used for studying phosphorus response. The top 10 cm of soil were taken from the southwest corner of Plot Treatment 7, Block III.

The Los Guineos soils used in Experiments III, V, VI and VII were collected at 27 April 1972, six meters north (downslope) of the Cornell AID plot at Jayuya, Puerto Rico, under pasture grass. The surface soil (0-15 cm) was brown, friable and had many earthworms. The subsoil (17-35 cm) was yellow, had few roots and no earthworms.

The Catalina surface soil (0-12 cm) and subsoil Location F (20-50 cm) were collected 25 April 1972, 1.3 meters north (upslope) of the Cornell-AID nitrogen experiment plot, between the weather station and the rain gauge. The land had been fallow for several years. The Catalina subsoil Location BP was collected under the direction of Eduardo Brennes and Raul Pérez Escolar from near the liming experiment plot.

The Piña soil was collected 11 May 1972, four meters east of the Cornell-AID nitrogen experimental plot and four meters south of the James Wolf water permeability testing site at the Fundador Farm, Manati, Puerto Rico. The surface soil (0-15 cm) collected was dry, sandy and cemented. The subsoil (20-40 cm) was more moist, and had a few roots growing in animal burrows.