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James, D. W.; Fullerton, T. M.; Rubink, W. L.; Garcia S., Hugo

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D. W. James
T. M. Fullerton
W. L. Rubink
Hugo Garcia S.

UTAH STATE UNIVERSITY

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D. W. James[1]
T. M. Fullerton[1]
W. L. Rubink[1]
Hugo Garcia S.[2]

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[1]Professor of Soils, Research Asso. Prof. of Soils, and former Graduate Research Assistant, Utah State University, Logan, Utah.

[2]Irrigation Engineer and Station Superintendent, Colombian Institute of Agriculture.

TABLE OF CONTENTS

Summary and Conclusions 2

Speculative Conclusions 3

Introduction 5
Observed Plant Growth Disorders 6

Summary of Field Experiments 7

Materials and Methods 8

Site Description 8
Soil Sampling and Analysis 9
Methods of Soil Physical and Chemical Analysis . . . 10

Results 11

Soil Morphology 11
Preliminary Chemical Analyses 12
Detailed Physical and Chemical Analyses Done at Logan, Utah . 12

Phosphorus and Heavy Metal Analyses 13

Phosphorus 13
Heavy Metals 15
Second Phase, Malambito Soil Sampling 16

Discussion 17

Definitive Conclusions 18
Speculative Results 18

Literature Cited 20
Tables 22
Figures 28
Appendix A 35
Appendix B 36

RESUMEN Y CONCLUSIONES

En el Distrito de Riego Atlántico No. 3 en Colombia, se llevó a cabo un Proyecto cooperativo sobre Investigación y Demostración de Manejo de Agua a nivel de Granja, desde Octubre de 1.971, hasta Octubre de 1.973. Las entidades involucradas fueron el Instituto Colombiano de la Reforma Agraria (INCORA), el Instituto Colombiano Agropecuario (ICA) y Utah State University. Los objetivos del proyecto fueron evaluar los potenciales de producción de cultivos bajo riego en el área, evaluar las interacciones de humedad del suelo con otros factores de crecimiento de los cultivos, y adaptar la tecnología moderna de riego a las condiciones de suelos y clima en el área del Proyecto Atlántico No. 3. Una prueba del proyecto se localizó sobre suelos de textura fina del distrito, en la Granja Malambito. En este informe se suministran los resultados de los análisis de las propiedades físicas y químicas efectuados a los mencionados suelos.

Catorce Ensayos fueron efectuados durante el estudio, con cultivos de maíz, ajonjolí, algodón, sorgo, soya, y arroz en tierras altas e inundadas. Con excepción del arroz (cuyos resultados se han reportado en otra parte) los cultivos fueron altamente variables en el campo, y hubo, relativamente bajas producciones.

Al comienzo de los ensayos de cultivos, se observó que los campos experimentales lo mismo que los de propietarios de los alrededores fueron altamente variables en cuanto a crecimiento de plantas y producción se refiere. Muchos intentos para la eliminación de ésta variabilidad fueron inútiles. Por consiguiente, los objetivos originales se modificaron con

el fin de encontrar la causa y la solución de las irregularidades del crecimiento de los cultivos y así lograr altas y uniformes producciones bajo manejo con riego.

Conclusiones Especulativas

1. Fósforo

El extraordinario suministro de fósforo fué causa de excesiva extracción por las plantas lo cual indujo o contribuyó a un desequilibrio de nutrientes.

2. Elementos Menores

Fe, Cu, y Zn, uno de ellos o varios en conjunto, estuvieron en exceso. Los niveles relativamente altos de Co y Ni extractables pudieron haberse involucrado en desórdenes nutricionales de la planta. Ninguna conclusión podría hacerse sobre manganeso por cuanto este fué afectado por el vapor para la esterilización de las muestras de suelo.

3. Recuperación

El alto contenido de fósforo y los elementos menores fueron suministrados por el material parental del suelo, y por cuanto estos materiales tienen solubilidad limitada la recuperación no puede ser lograda con procedimientos de rutina.

4. pH del Suelo

El pH del suelo estaba en el rango que se considera óptimo para el crecimiento de los cultivos.

5. Nitrógeno del Suelo

La deficiencia de nitrógeno no fué un factor limitante, porque aún donde no existía el requerido por la planta, este fué aplicado.

6. Potasio y Magnesio

Se aplicaron fertilizantes con K y Mg, pero no se observaron

beneficios en el cultivo. Los análisis de suelos indicaron niveles adecuados de dichos elementos.

7. Fósforo y Elementos Menores

El fósforo asimilable en el suelo fué de moderado a muy alto. El fósforo total fué extremadamente alto y el Fe, Cu, Zn, Co, y Ni extractables fueron altos a muy altos. Todos estos elementos provenían del suelo.

8. Características Físicas

a. Como consecuencia de las ondulaciones en la topografía, el área tenía depresiones superficiales que resultaron en drenaje superficial pobre. Esto podría corregirse por simples operaciones de nivelación de tierras.

b. Texturalmente la superficie del suelo era arcillosa a franco-arcillosa. El subsuelo tenía lentes de limo y arena comenzando desde los 0.8 m. A 1.5 m de profundidad la textura era arenosa definidamente. No se observaron problemas especiales con las condiciones físicas del suelo las cuales podrían ser manejadas con oportunas operaciones de preparación del suelo.

Summary and Conclusions

A cooperative On-Farm Water Management Research and Demonstration Project was conducted in the Atlantico #3 irrigation district of Colombia from October, 1971, to October, 1973. The agencies involved were the Colombian Institute of Agrarian Reform, the Colombian Institute of Agriculture, and Utah State University. The objectives of the project were to evaluate the irrigation crop production potentials in the area, evaluate soil moisture interactions with other crop growth factors, and to adapt modern irrigation technology to soils and climatic conditions of the Atlantico #3 area. One component of the project was located on the fine-textured soils of the district at Granja Malambito. Results from physical and chemical studies made on the fine-textured soils are reported here.

During the study a total of 14 cropping trials were conducted with corn, sesame, cotton, sorghum, soybeans, and both upland and inundated rice. With the exception of rice (the results of which have been reported elsewhere), the crops were highly variable in the field and relatively low yields were produced.

Upon initiating the cropping trials, it was observed that the experimental fields and also surrounding farmers' fields were highly variable in plant growth and yield. Many attempts to eliminate this variability were unsuccessful. Accordingly, the original objectives were modified to find the cause and the solution of the crop growth disorders in order to bring about uniform high yields under irrigation management.

Speculative Conclusions

1. Phosphorus

The extraordinarily large supply of soil phosphorus was causing excessive uptake by plants and as such was inducing or contributing to nutrient imbalances.

2. Heavy metals

Fe, Cu, and Zn, either singly or collectively, were in excess. The relatively high levels of extractable Co and Ni may have been involved in plant nutritional disorders. No conclusions could be made on Mn which was affected by steam sterilization of the soil samples.

3. Reclamation

The excessive phosphorus and heavy metals were indigenous to the soil parent material, and since these materials have limited solubility, reclamation cannot be achieved by routine procedures.

4. Soil pH

The measured soil pH was in the range considered to be optimum for plant growth.

5. Soil nitrogen

Nitrogen deficiency was not a factor even where no nitrogen fertilizer was applied.

6. Potassium and magnesium

K and Mg fertilizers were applied, but no crop benefits were observed. Soil analyses indicated adequate levels of K and Mg.

7. Phosphorus and heavy metal elements

Available soil P was moderate to very high. Total soil P was extremely high, and extractable Fe, Cu, Zn, Co, and Ni were high to

very high. All of these elements were indigenous.

8. Physical characteristics

a. Because of undulations in the topography, the area had shallow depressions that resulted in poor surface drainage. This could be corrected by simple land leveling operations.

b. Texturally the surface soil was clay to clay loam. The subsoil had silty and sandy lenses beginning at about .8 m. At 1.5 m depth the texture was distinctly sandy. No special problem was observed with the soil physical condition which could not be managed by timely soil tillage operation.

CHEMICAL AND PHYSICAL CHARACTERIZATION OF PROBLEM SOILS IN THE ATLANTICO #3 IRRIGATION DISTRICT, ATLANTICO, COLOMBIA

Introduction

The Atlantico #3 Irrigation Project is located in the southern part of the Department of Atlantico on the north coast of Colombia. It involves about 45,000 ha of land that was formerly marshy and subject to periodic flooding from the Magdalena River. Three experimental farms were located in the district so as to represent the principal soil types as described in a 1965 soil survey. Malambito, the second largest of the three, was created specifically to evaluate the capabilities of the fine-textured soils which occupy nearly 45 percent of the total project area.

A cooperative on-farm water management research and demonstration project was initiated in Atlantico #3 in 1971, involving the Colombian Institute of Agrarian Reform (INCORA), the Colombian Institute of Agriculture (ICA), United States Agency for International Development (USAID), and Utah State University. One component of this project was centered at Santa Lucia, which emphasized drainage and salty soil reclamation in the coarse-textured soils of the district. Another component was centered at Malambito, which was designed to evaluate the optimum combination of soil moisture and fertility for crop production on the fine-textured soils of the district. The drainage report was made by Olsen and Christiansen (10). A report on rice production at Malambito was made by Fullerton, et al. (6). The purpose of

this report is to present the results of physical and chemical analyses on fine-textured soils in an attempt to identify the reasons for the poor crop growth that was observed in both experimental plots and commercial fields.

Observed Plant Growth Disorders

Field experiments were carried out involving corn, cotton, sesame, sorghum and soybeans; but crop growth variability not related to controlled experimental variables obscured effects of irrigation and soil fertility treatments. The problems encountered were recognized previously, but only information of a qualitative nature was available. The nature of the problem may be described as follows: affected corn, sorghum, and sesame were generally chlorotic soon after emergence of the seedlings. The upper leaves of the young plants were deformed and tended to stick together. In later stages of growth, severe stunting was characteristic. Necrotic patches on the perimeter of the older leaves and general interveinal chlorosis were present. The corn grown on these areas reached only a fraction of the ordinary heights and produced very few ears. The corn died in some areas. Throughout the fine-textured soil areas of the district, it had previously been the general concensus among farmers that nothing except grasses would grow well. Growth disorders were also present in grasses but to a lesser extent. In the past, researchers and others had attributed the crop growth problems to saline, sodic, or degraded sodic soil conditions. Another explanation was that low soil fertility, brought about by excessive leaching of the soil in topographic depressions, induced poor crop growth. However, there were few attempts to correlate soil physical

Corn plots showing random response to treatment

and chemical analyses with crop performance.

Sorghum and cotton were produced more extensively than any other crop in the irrigation district at the time the water management program was established. Sorghum was generally planted first and rotated with cotton in a 1-2 sequence during the calendar year. Sesame was widely grown by irrigation district farmers during 1970 and 1971 but with little success. Fewer than 10 hectares of soybeans were under cultivation in this sector in late 1971 because of the general idea that this crop was unsuited to the area. Corn was produced throughout Atlantico #3 for home consumption but not as a cash crop. No rice was grown in the district at the time the project activities were initiated.

Summary of Field Experiments

Cotton, corn, soybeans, sorghum, sesame and both upland and flooded rice were grown in a series of 14 tests over the two-year period beginning in October, 1971. The detailed results of these trials were given in the project terminal report. Table 1 summarized the observed and expected yield results; of the six crops studied, only rice yielded at acceptable levels.

Although irrigation was the main factor studied in the crop trials, other factors tested in trying to overcome the yield deficiencies were N, P, K, S, B, Fe, Mn, Mg, Cu, gypsum and lime yield.

Yield increases were obtained with low rates of N fertilizer in some cases. In other cases no effects were seen from N. These modest results could be explained by an appreciable carryover of fertilizer N from previous seasons and also by the limited demand on soil N reserves by the deficient crops. It is clear, nevertheless, that N was not a part of the crop growth problem. No positive responses were obtained

to P fertilizer with any crop, but a significant decrease in sesame yield with a 50 kgm P_2O_5/ha treatment was observed. No effects were seen from K, S, lime, gypsum, B or foliar-applied Fe and Mg. One positive visual response was seen with foliar-applied Mn, but this evidently had no lasting effect on the crop.

A series of phytopathological tests were made to assay the role of disease organisms in the affected crops. One organism was identified in diseased sorghum plants. This was a bacterium, a species of Erwinnia, which can be present as a parasite or a saprophyte. Since no infection point was found, the organism was thought to be functioning as a saprophyte, and its presence was interpreted as being a secondary infection A Fusarium organism was tentatively identified in corn, but occurence of this pathogen was not related to variable crop growth in the area.

It was concluded that valid irrigation production information could not be developed until the cause of crop variability in the field could be determined and corrected, or unless alternative crops well-adapted to the conditions of the area could be found. The original objectives of the project were thus modified to include these considerations.

The purpose of this report is to present the results of an analytical program which was designed to characterize the chemical and physical properties of the soil. An attempt was made to relate these characteristics to crop growth.

Materials and Methods

Site Description

The site at Malambito has an undulating topography typical of

flood plain (alluvial) soils. The net difference in elevation across the 320 meter square study area was 1.5 meters, giving an average slope of about 0.5 percent. Vertical extremes within the area ranged from 10 to 20 cm. The undulations formed closed depressions which collected rain and irrigation water.

Typical vegetative cover (revegatation after initial clearing and disking) consisted principally of weeds such as Malva, Ipomea (and other trailing vines), Chenopodium, and some grasses. There were no recognizable relationships between weed growth and either the physical features of the soil or topography, but the weeds did show some growth disorders. Ipomea, Convulvaceae, and some Gramineae seemed to be most prevalent in the lower parts of the landscape, while Malva and Chenopodium inhabited the higher, seldom flooded portions.

Soil Sampling and Analysis

Soil sampling and analysis occurred in two phases. First, an area of approximately 8 ha was surveyed on a square grid system with the grids at 20 m intervals. Soil samples were collected at the grid intersections and analyzed for pH and ECe at Malambito. Additional soil samples were collected along transects within the general area to represent points that were known to vary widely in crop growth. These samples were taken to Utah State University at Logan for detailed analysis on pH, ECe, organic carbon, CEC and exchangeable cations. Some of these samples were analyzed for phosphorus and heavy metals also.

The other phase of sampling was especially for P and heavy metal analyses. A series of 12 composite soil samples was collected from control plots of a field corn trial. Plant samples were taken to estimate

the dry matter at each soil sampling point. Another group of samples were taken at various places to estimate vertical changes in soil properties.

All of the soil samples that were transported to Utah State University were subjected to autoclave steam sterilization at the USDA Plant Quarantine Station in Miami, Florida.

Methods of Soil Physical and Chemical Analysis

Particle size distribution was done by the Bouyoucos hydrometer method (1). Subsamples of 40 g were used for this analysis. Results are reported as percent sand, silt, and clay.

Measurements of soil pH were made using saturated paste, 1:1 soil-water and 1:2 soil-.01 $MCaCl^2$ systems. ECe was measured on the saturation extract. Oxidizable carbon was estimated by the micro-procedure of Chesnin (3). Exchangeable plus soluble cations were determined with an atomic absorption spectrophotometer after triple extraction of 5 g of soil with neutral, normal, ammonium acetate, using the procedure outlined by Jackson (8). Results are reported in milliequivalents per 100 g of oven-dry soil. Cation exchange capacity (CEC) was determined by the micromethod of Kinney and Bremner (7). Results for CEC are expressed in milliequivalents per 100 g of soil (meq/100 g).

Phosphorus analyses included both the Olsen test for available P (HCO_3-P) (12) and a perchloric acid digestion for total P (14). The Olsen test results are given as ppm and the perchloric acid digestion results are given as percent of total P in the soil.

Heavy metal analyses in the soils were done by extracting soil samples with DTPA according to the procedure given by Lindsay and Norvell

(9). The interpretation of DTPA soil analyses was given by Viets and Lindsay (16). Their work is summarized in Appendix A for comparison with the Malambito soils. An atomic absorption spectrophotometer was used to analyze for Cu, Co, Ni, Mn, Fe and Zn. The results for these elements are given as ppm in the soil.

There are several reports in the literature (4, 5, 15) which indicate that heat treating of soil (as in the steam sterilization process) sharply increases the level of extractable Mn. For purpose of comparison, therefore, a series of twelve Utah soil samples representing commercial irrigated fields in a four-county area of northern Utah were treated with DTPA before and after steam sterilization in an autoclave. The results of this series of analyses are given in Appendix B.

Results

Soil Morphology

Soil texture was slightly finer in the topographic lows. However, the difference in clay content was not great and all surface soil was classified as clay loam texture regardless of position. There was wide variability of subsoil texture because of silty or sandy lenses. In general, the texture was distinctly sandy below 1.5 m. The soil in this area is of recent alluvial origin; therefore, no genetic horizons exist. The vertical variations were related to depositional strata. The surface soil was darkened slightly by organic matter accumulations. A typical soil profile description follows:

1. 0-40 cm. Dark colored clay to silty clay, massive and hard when dry, little structure, plastic and very sticky when

wet, abundant roots, gradual transition to the next stratum.

2. 40-80 cm. Light colored silty clay, hard when dry, structureless, mottled, some roots, boundary uneven.
3. 80+ cm. Silty loam grading to sandy loam, structureless, non-plastic, few fine roots.

The water table fluctuated between 1 and 2 m of the surface, corresponding to the wet and dry seasons, respectively.

Preliminary Chemical Analyses

Laboratory results obtained in Atlantico indicated that soil pH was lowest as measured in the 0.01 m $CaCl_2$ system. The pH ranged from 5.5 to 6.5 in the surface 30 cm and increased gradually to a range of 6 to 6.8 at the lower depths. pH in the saturation extract was slightly higher. Table 2 shows the averages of soil pH at four depths by the three methods at 30 soil sampling points.

Horizontal concentration of salts varied continuously in the surface soils and increased with depth. Figure 1 demonstrates the horizontal variation in salt concentration in the sampling area. As indicated here, the ECe ranged as high as 1 mmho/cm. Subsoil ECe values (not shown) were much more variable, ranging as high as 9 mmhos at one point. However, the average ECe from 40 samples, representing the 30 to 95 cm depth range in two different transects, was 1.9. In two other sampling transects, the ECe was never above 1.5 at any depth.

Detailed Physical and Chemical Analyses
Done at Logan, Utah

A set of 30 soil samples of the 0-30 cm layer of soil, representing one transect through an area of good and bad crop growth, was

analyzed for 11 soil parameters. The results of these analyses are summarized in Table 3. The results for pH and ECe were analogous to those obtained in Colombia. The analyses for textural classifications substantiated the clay loam texture estimated in the field. None of the parameters given in Table 3 indicate that this soil was markedly different from arable productive soils for these particular measurements.

Correlations were run between the parameters given in Table 3 and corn plant height as observed at the 30 sampling points in the transect. The coefficient of determination from the linear regression analysis indicated that the $r^2 = 0.30$ between soluble plus exchangeable calcium and plant height and that $r^2 = 0.36$ for the ratio Ca/Mg + K + Na vs. plant height. Other coefficients of determination were much smaller and not worthy of note. The weak association between corn plant height and Ca, Mg, K and Na might indicate an imbalance of these nutrients; this possibility was, however, not substantiated during the actual crop trials. As stated previously, potassium fertilizer applications had little or no effect on the crop production and neither did applications of gypsum or lime.

Phosphorus and Heavy Metal Analyses

The first phase of sampling, represented by the 30 soil samples of Table 3, were anlayzed for HCO_3-extractable P, total P, and DTPA-extractable Co, Cu, Fe, Mn, Ni, and Zn. The results are summarized in Tables 4 and 5.

Phosphorus

For soils of pH 6.8 and above, 10 ppm of HCO_3-P would indicate P sufficiency for the crops tested (Table 1). Therefore, the range in

Table 4 of 6 to 77 ppm P indicates that available P was low to very high among the points sampled. The average soil test P (as would be obtained from a composite sample from the area) for the area (24.2 ppm, Table 4) would be interpreted as meaning no plant stress of any kind from available soil P.

The estimates for total P (Table 5) were probably conservative since the procedure used here underestimates P as compared with more thorough methods (14). The results for total P in the whole soil and the sand fraction were quite comparable (Table 5). It appears that the whole soil P is controlled by the sand, and ultimately therefore, the rock from which the sand originated. Brady (2) reported the results for total P analyses from three groups of 36 surface USA soils. These soils averaged .074 percent of P and ranged from .04 to 0.15 percent P among the different soil groups. The results in Table 5, therefore, are quite remarkable--indicating that the Malambito soils contained from 5 to 20 times as much P as the average of the 36 soils reported by Brady.

Available or HCO_3-P was strongly correlated with total P. Figure 2 illustrates this association. For normal soils total soil P bears no relationship to available P. This undoubtedly is due to the fact that total P is usually very low. Therefore, the results of Figure 2 portray another unusual, if not unique, finding for the Malambito soil. It may be inferred from the strong relationship between HCO_3-P and total P, that total P controls P availability to plants. If this is true, then HCO_3-P would have to be qualified as a direct indicator of P availability in this soil. It is possible that the excessive P availability could limit crop growth.

Heavy Metals

The results in Table 4 for the metal elements should be compared with Appendix A for estimates on relative availability and with Appendix B for estimates on the effect of steam sterilization on the amount of each element found in the soil extract. As indicated in Appendix B, the autoclave heat treatment of reference Utah soils increased Mn by about 22 fold. At the same time, Cu, Fe, and Zn decreased by 86 percent, 66 percent, and 79 percent, respectively. Extractable Cu and Ni could not be detected in the Utah samples. All of these metals compete on a mass action basis for ligands in the DTPA complex. It is apparent, therefore, that the relatively small decrease in extractable Cu, Fe, and Zn upon heating the Utah samples resulted from the large increase in Mn. Using the results of Appendix B as an indicator, it is evident that extractable Cu, Fe, and Zn in the Malambito soils would increase somewhat if they were not heated. Further, Mn would decrease to a very small fraction of the amounts observed. Whereas these observations leave some doubt as to the adequacy of available Mn at Malambito, the other metals were high to extremely high as compared to levels associated with nutrient deficiency. Ni, of course, is not a nutrient element but it may alter plant enzyme systems.

The Utah data showed no association among the extracted elements, probably because they came from widely separated sites and variable parent materials. On the other hand, the Malambito data indicate that 90 to 97 percent of the variability between Cu, Ni, Zn, and Fe were explained by simple linear regression (Table 6). The relationships are illustrated in Figures 3 and 4 for Ni vs. Fe and Zn vs. Fe. For

Co and HCO_3-P regression with Fe accounted for about 50 percent of the variability. No associations were found between Mn and the other elements probably because Mn changed so drastically on heating and because the absolute amount of extractable Mn was probably very low before soil heating.

Second Phase, Malambito Soil Sampling

The second phase samples comprised a total of 12 soil samples which were taken from control plots of an established corn trial. Regression analyses of the results are given in Table 7. Here it is apparent that the associations between HCO_3-P and Fe, Zn, and Cu, respectively, were somewhat reduced as compared to the first phase sampling. However, there was a rather striking relationship between plant dry weight and HCO_3-P and plant dry weight and DTPA-Fe. These results are illustrated in Figures 5 and 6. About 60 percent of the variability between plant weight and HCO_3-P were explained by the simple linear regression. Because of the relationships between plant weight and soil Fe and P (Table 5 and Figure 7), a multiple regression analysis was made with these two elements. This analysis indicated that the multiple R^2 for plant weight vs. Fe and P was 0.653, indicating that there was no probable interaction between Fe and P in these plant yield results.

Subsoil samples were obtained from four different points in the field to estimate variability of extractable elements with depth. These results are summarized in Table 8. As indicated, the heavy metals decreased in depth at every sampling point. Therefore, it is apparent that if any of these components were involved in the poor crop production, essentially all the effect was localized in the 0-20 or

0-30 cm soil layer.

Discussion

In June, 1975, 20 months after the field work had been terminated in this irrigation research project, we went back to the field site in an attempt to gain more information on the Malambito soil problems. But no crops were growing on the plot area and it was not possible to locate the bad spots.

Data that are given here on the physical and chemical nature of the fine-textured soils at Malambito strongly implicate plant nutrient imbalances or elemental toxicities as the cause of poor crop growth. Data obtained in the crop yield trials partly substantiate these implications. As already indicated, 14 field trials involving six different crops were conducted during the 2-year lifetime of the project.

Chemical analyses of plant tissue samples was limited to one set of leaf samples from one sesame trial. In this case higher leaf P concentrations were associated with a statistically significant decrease in yield. It was not feasible to obtain more plant analyses, but a large investment in this kind of work would be required to establish unequivacally the actual cause and affect relationships of the poor crop growth.

Several kinds of conclusions can be derived from the total program (considering data presented here and also the project terminal report and Fullerton et al. (6)). Some of these conclusions are definitive and some are, in varying degrees, speculative.

Definitive Conclusions

Plant pathogens Tests made for plant pathogens were all negative, indicating that the plant growth disorders had to be attributed to soil, chemical or nutritional stresses.

Soil moisture Erratic crop growth was seen both during the wet season and under irrigation during the dry season; therefore, soil moisture was not a factor.

Soil salts The total salt concentration in the main part of the root zone was below those levels known to cause osmotic stress in plants.

Soil pH The measured soil pH was in the range considered to be optimum for plant growth. Neither excessive Al because of low pH nor excessive Na associated with high pH were involved.

Nitrogen Soil N was not a factor even where no N fertilizer was applied. N deficiency symptoms were not expressed.

Potassium and magnesium K and Mg fertilizers were applied, but no crop affects were observed. Soil analyses done subsequent to the field trials would have predicted null responses to K and Mg.

Phosphorus and metal elements Total soil P was extremely high in some samples and extractable Fe, Cu, Zn, Co and Ni were high to very high. All of these elements were of geologic origin.

Speculative Results

It is hypothesized that the extraordinary supply of soil P resulted in excessive uptake by the plants and as such was inducing or contributing to nutrient imbalances.

Related to the excessive P were possible excesses of Fe, Cu, and Zn, either singly or collectively. The relatively high levels of

extractable Co and Ni may or may not have been involved.

Since all of the metals were extracted at the same time and by the same reagent, it is possible that the strong correlations were artifacts of the system. However, this possibility reduces to a small probability when the same analyses on other kinds of soils are considered.

With regard to Mn, the heat treatment of the Malambito samples undoubtedly altered this element beyond any point of reasonable interpretation. It is possible on one hand that this element was available in normal or adequate range so that it was not associated in any way with plant nutritional stress. On the other hand, if the hypothesis about excessive P, Fe, Cu, Zn, Co, and Ni is true, what might have been normal Mn nutrition otherwise could have been induced Mn deficiency because of altered coenzyme roles. This area clearly needs to be analyzed in detail.

The heat-released Mn also undoubtedly caused a reduction in extractable Fe, Cu, Zn, Co, and Ni. This increases the probability that these elements were present in excessive amounts in the untreated soil in the field.

If future work substantiates the hypothesis of excessive elements, no solution to the soil fertility problem is obvious. Rice may be the only alternative as already suggested (6) or other kinds of tolerant crops or cultivars may be found. Since the excessive elements are evidently of geologic origin, i.e., part of the indigenous soil mineral complex, reclamation cannot be achieved by routine procedures.

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Table 1. Expected yields, average experimental and commercial yields and estimates of production required to return investment in kilograms per hectare. Atlantico #3 Irrigation District, Colombia.[1]

Crop	Expected yields	Experimental yields Malambito 1971-1973	Production required to return investment[2]	Commercial yields[3] 1968-1972	
				Sta. Lucia region	Atlantico #3
Corn	4000	1475	1464	--	--
Cotton	1600	1393	710	1088	1335
Upland rice	3100	3951	--	--	--
Inundated rice	6200	7302	2583	--	--
Sesame	800	569	305	137	220
Sorghum	4000	2445	1470	973	1678
Soybeans	2200	1722	975	30	956

[1]Adapted from "Terminal Report, On-farm Water Management Research at Granja Malambito, Atlantico, Colombia. By T. M. Fullerton, Hugo Garcia S., and D. W. James.

[2]Estimates of production required to cover investment were based on 1970-72 cost data obtained from the INCORA Office of Statistics, Atlantico #3. The estimate for inundated rice was based on 1970 data of the Bolivar #1 district and does not include fixed costs.

[3]Weighted means representing two to five seasons of production. Growing seasons where complete crop loss was experienced were not utilized in calculating averages.

Table 2. Variations in soil pH by depth and method of measurement.

Depth-Cm	1:1, soil:water	1:2, soil .01 M:$CaCl_2$	Saturation extract
0- 30	6.40	6.05	6.63
30- 80	6.67	6.24	6.77
80-100	6.85	6.30	6.76
100-110	6.93	6.33	6.83

Table 3. Means and extremes of thirteen soil parameters observed in an intensively sampled area at Malambito.

	pH[a]	ECe	O.C. %	CEC	Soluble plus exchangeable cations Ca	Mg	K	Na	SAR	Ca/ Mg+K+Na	Clay %	Silt %	Sand %
				milliequivalents per 100 gms soil									
$\bar{Y}$	6.03	0.37	0.96	22.2	19.9	7.6	0.79	0.37	.08	2.3	50.0	37.7	12.3
$V(\bar{y})$	0.03	0.02	0.03	0.3	0.4	0.1	0.02	0.02	.002	--	0.7	0.3	0.9
Range	5.64-6.81	0.21-1.04	0.66-1.56	17.4-26.5	14.8-30.0	6.3-8.7	0.55-1.33	0.24-0.64	.07-.10	1.77-3.10	43.0-56.0	34.0-41.0	6.0-25.0

[a]As determined in .01 M $CaCl_2$.

Table 4. The means and extremes of soil extractable P, Co, Cu, Fe, Mn, Ni, and Zn from a transect of 30 soil samples.[a]

	Element--ppm						
	P	Co	Cu	Fe	Mn	Ni	Zn
Mean	24.2	0.68	4.45	46.32	40.61	2.11	5.52
Range	6.0-77.2	0.24-1.32	2.38-7.12	18.2-96.2	22.4-74.0	1.08-3.50	2.16-11.00

[a] HCO_3 extraction for P. DTPA extraction for metals.

Table 5. The means and extremes and regression values of total P in the sand fraction and whole soil

	Total P percent	
	Sand	Whole soil
Mean	.661	.698
Range	.40-1.51	.40-1.65

Soil total P = -.036 + 1.112 sand total P

r^2 = .981

Table 6. Linear regression analysis for P and metal elements from 30 soil sample transects.

	Regression Coefficients		Coefficient of determination
	b_0	b_1	r^2
Cu vs Fe	1.59	0.062	0.891
Ni vs Fe	0.850	0.027	0.905
Zn vs Fe	0.677	0.105	0.971
Co vs Fe	0.32	0.008	0.469
Fe vs STP	18.28	1.16	0.471

Table 7. Second phase soil and plant sampling: regression analysis for various combinations of parameters. 12 soil samples.

Comparison	Regression Coefficients		Coefficient of determination
	b_0	b_1	r^2
Plant wt vs Fe	591.9	-4.62	0.593
Plant wt vs HCO_3-P	510.9	-10.26	0.652
Fe vs HCO_3-P	25.42	1.98	0.878
Zn vs Fe	5.46	0.024	0.571
Cu vs Fe	7.42	-0.01	0.185

Table 8. DTPA extractable metals as related to soil sample depth and field location.

Field sample point	Depth cm	Fe ppm	Zn ppm	Cu ppm	Mn ppm	Ni
1	0-20	112	6.9	5.1	46	1.37
	20-46	51	3.0	3.8	17	0.72
	46-61	17	1.5	2.5	8	0.38
	61-76	15	1.3	1.4	7	0.05
	76-91	14	1.3	1.0	6	0.26
	91-107	18	1.5	1.2	9	0.31
	107-122	19	1.5	1.2	9	0.37
2	0-18	80	15.0	7.7	39	1.38
	18-36	35	5.3	5.7	25	0.61
3	0-18	78	7.0	6.6	34	1.59
	18-36	37	3.4	5.4	16	0.79
4	0-20	61	5.6	6.0	43	1.73
	20-40	24	2.8	4.4	31	0.88

(1-in rice plots; 2-sterile spot; 3-poor soil in multicrop test; 4-good soil in multicrop test.)

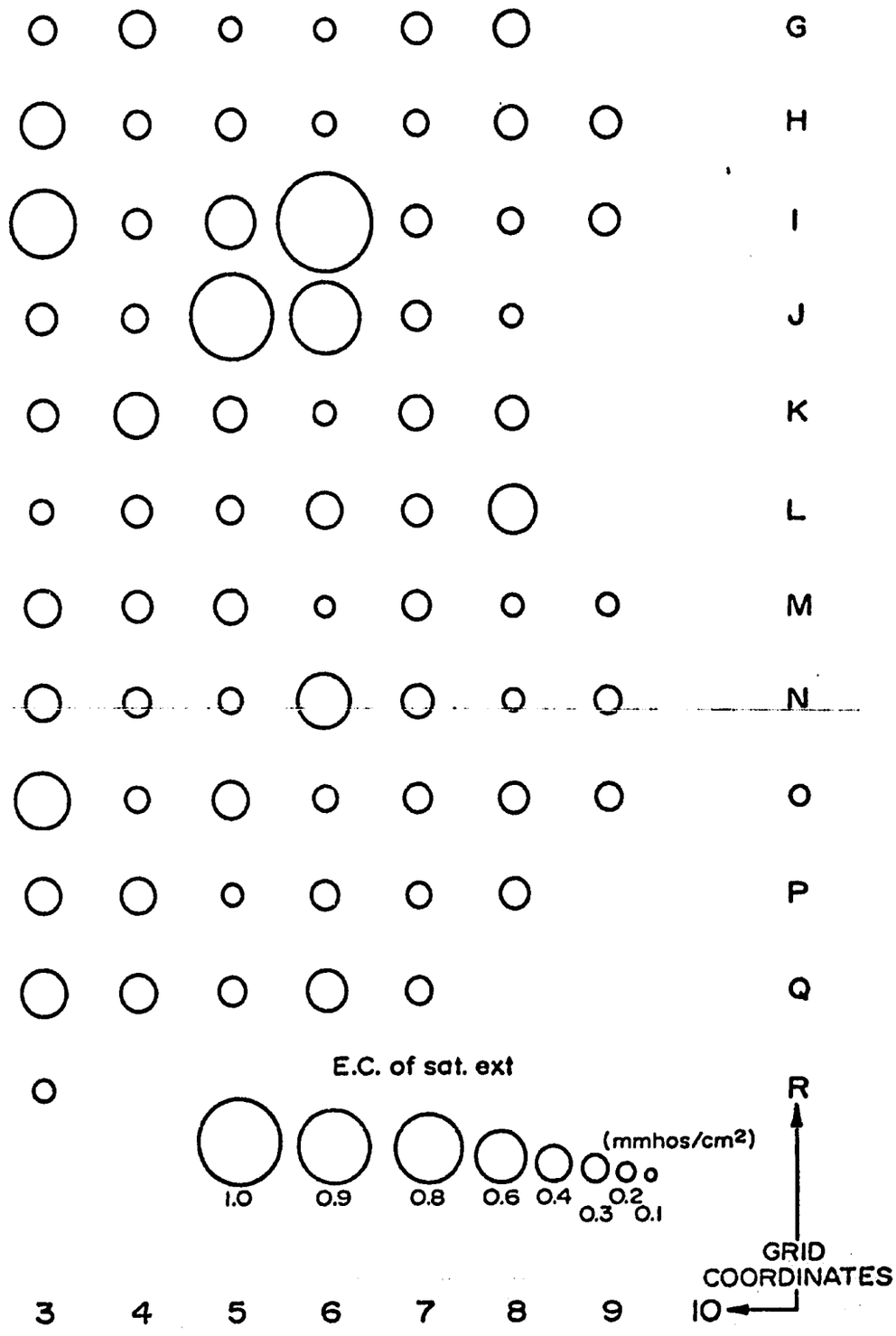


FIGURE 1. Field variability of salt concentration in the surface 30 cm of soil at the Malambito Experiment Farm study site. The grid lines are on 20 m intervals.

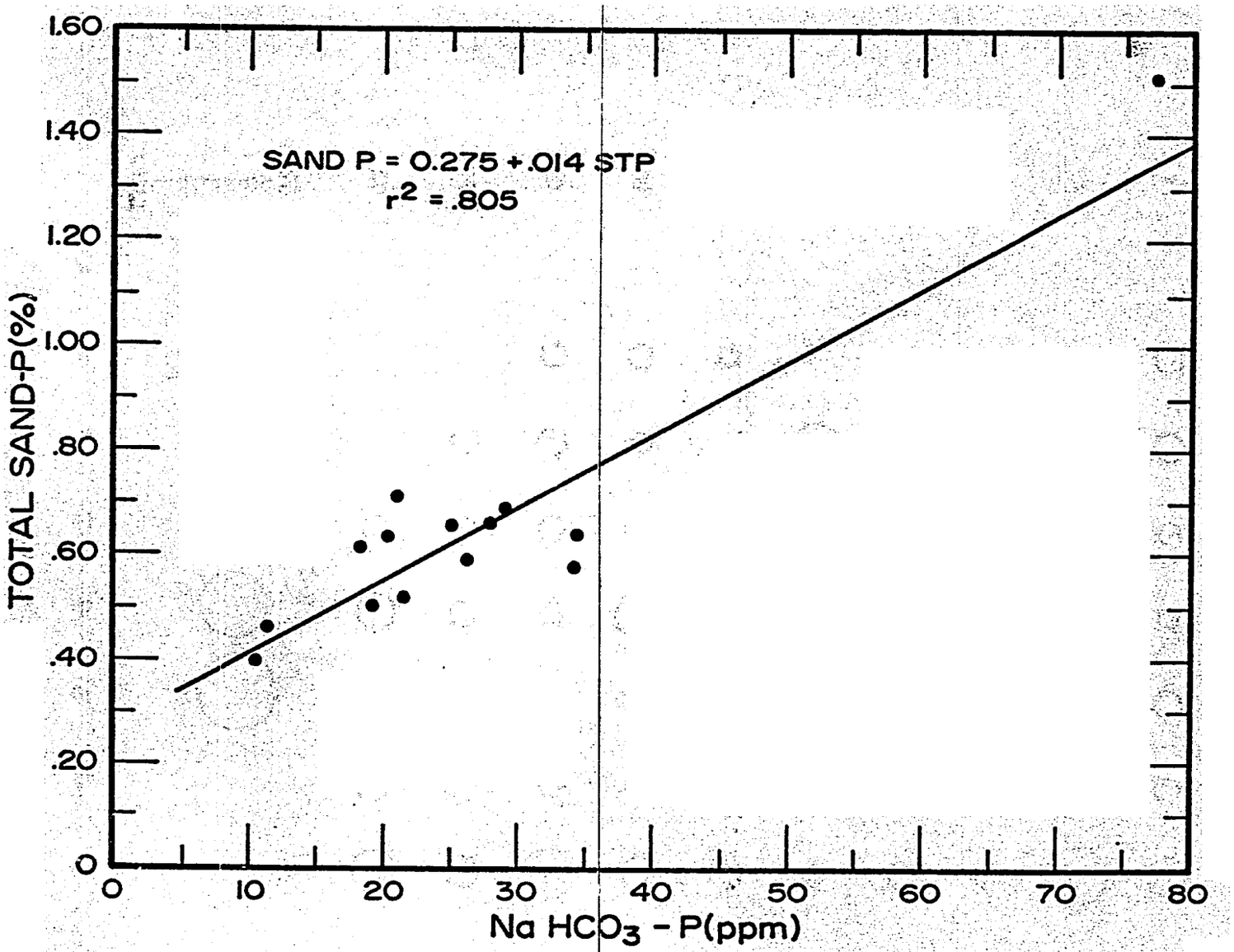


FIGURE 2. The relationship between total P in sand and HCO_3-extractable P in the whole soil: first sampling phase, Malambito.

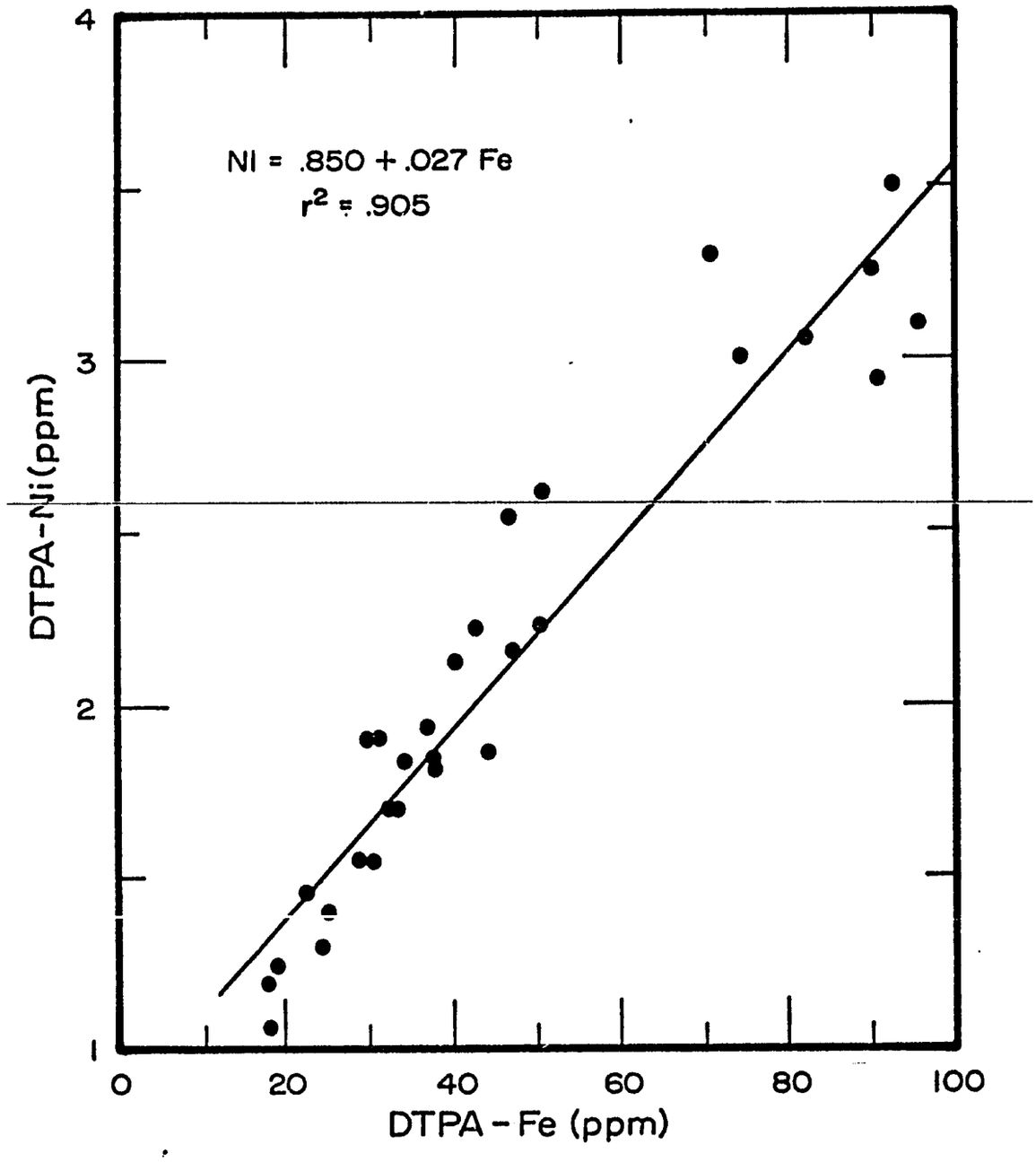


FIGURE 3. The relationship between DTPA-extractable Ni and Fe: first sampling phase, Malambito.

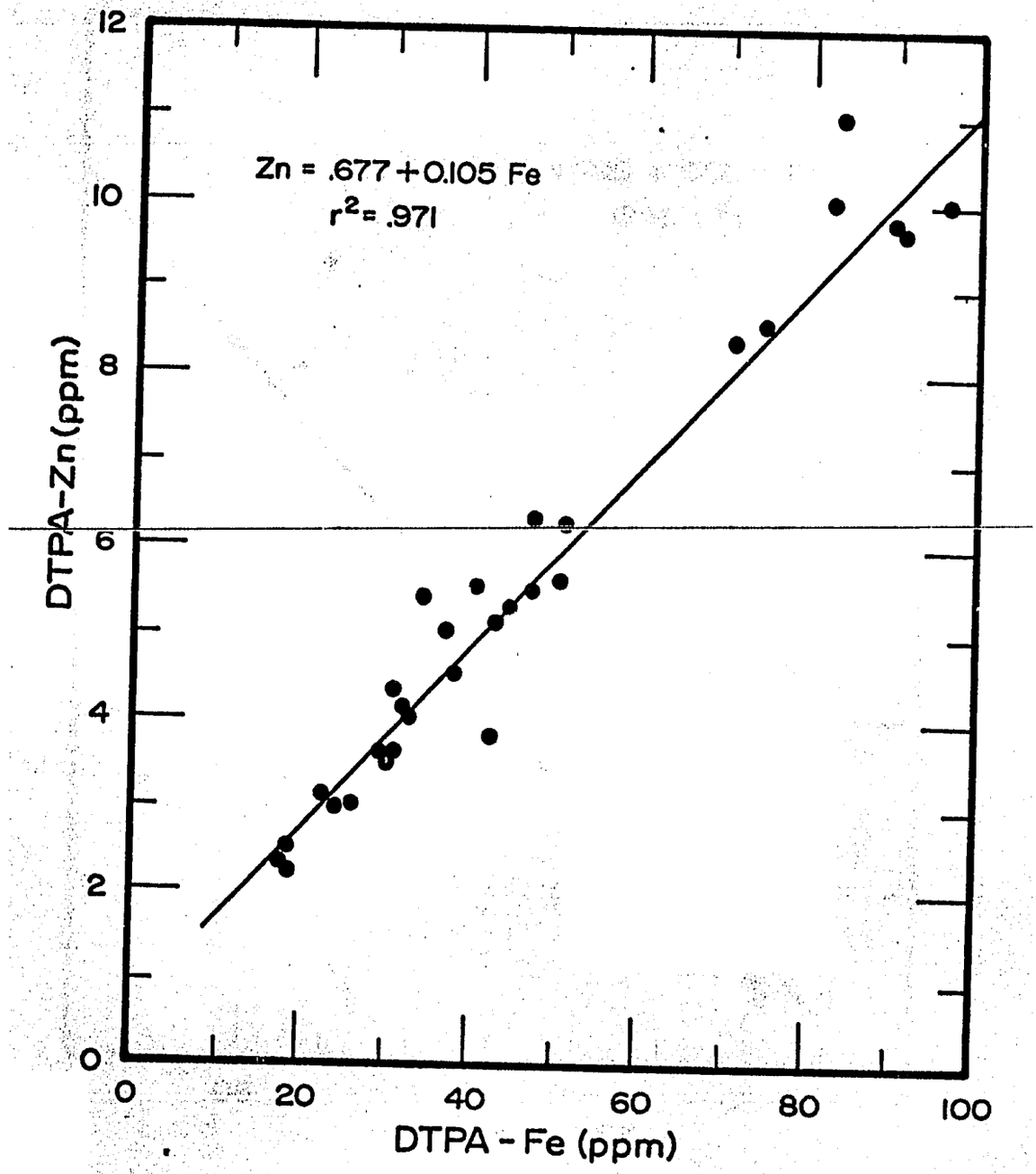


FIGURE 4. The relationship between DTPA-extractble Zn and Fe: first sampling phase, Malambito.

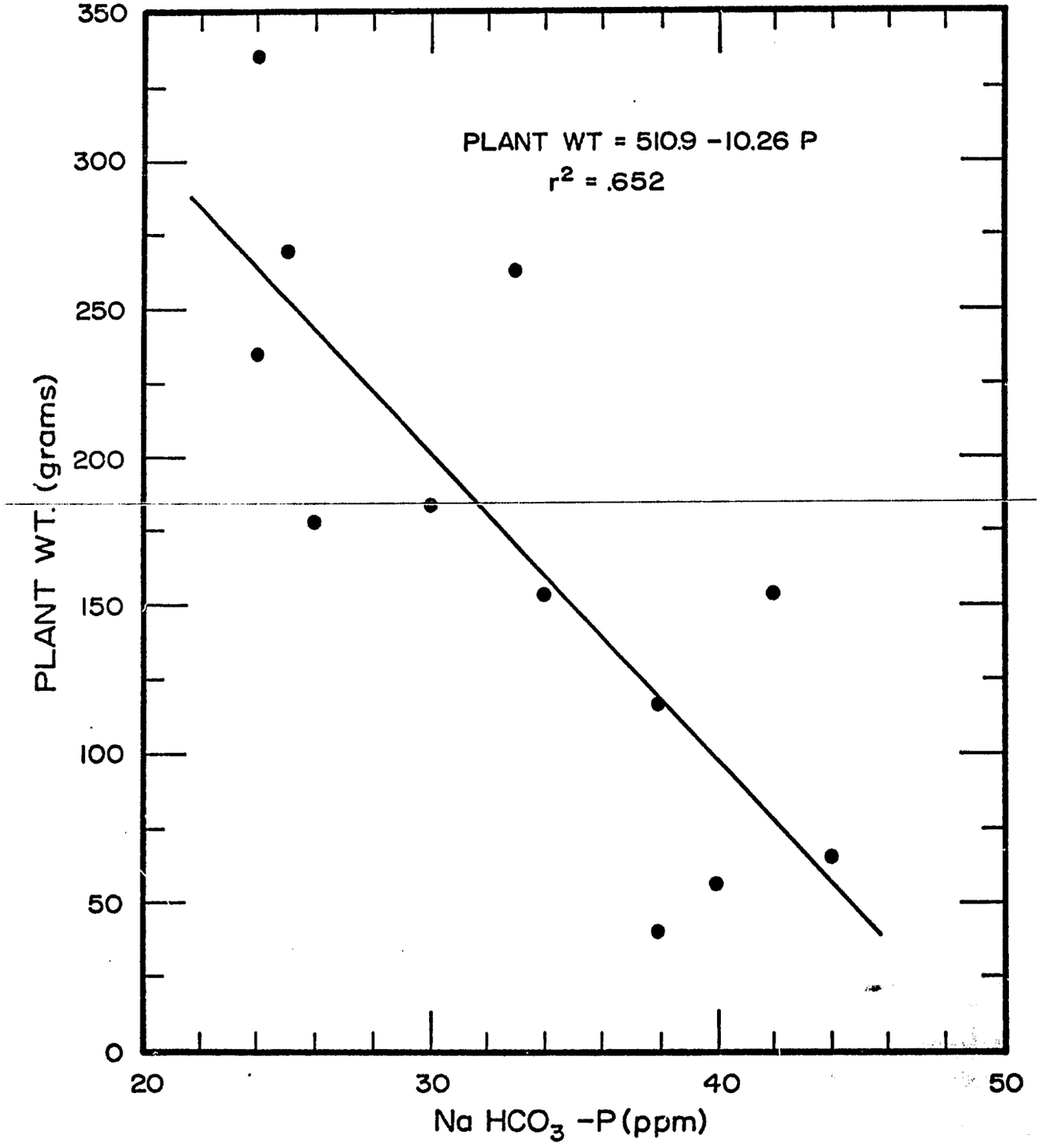


FIGURE 5. The correlation between corn plant sample weight and HCO_3-extractable P: second sampling phase, Malambito.

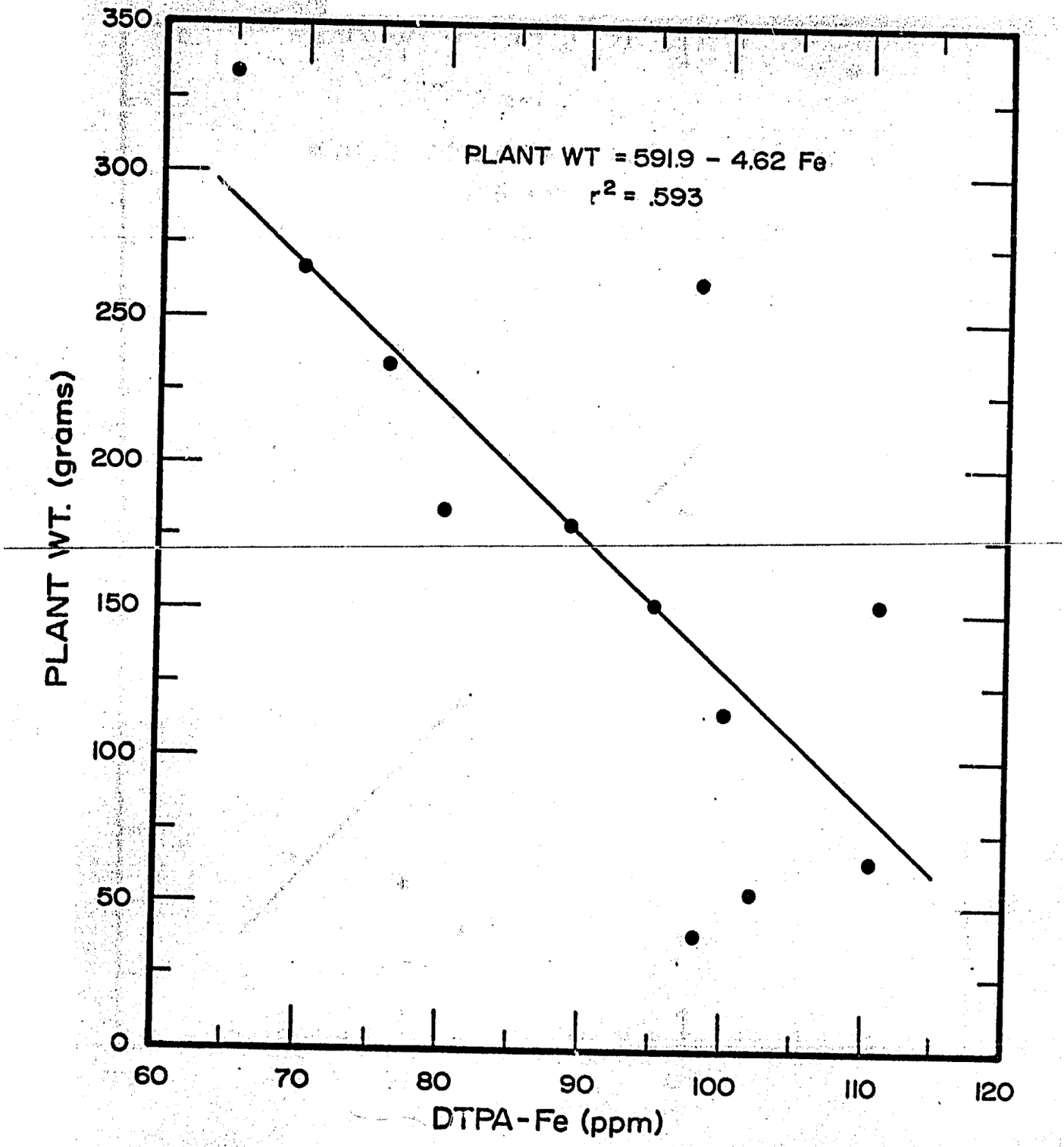


FIGURE 6. The correlation between corn plant weight and DTPA-extractable Fe: second sampling phase, Malambito.

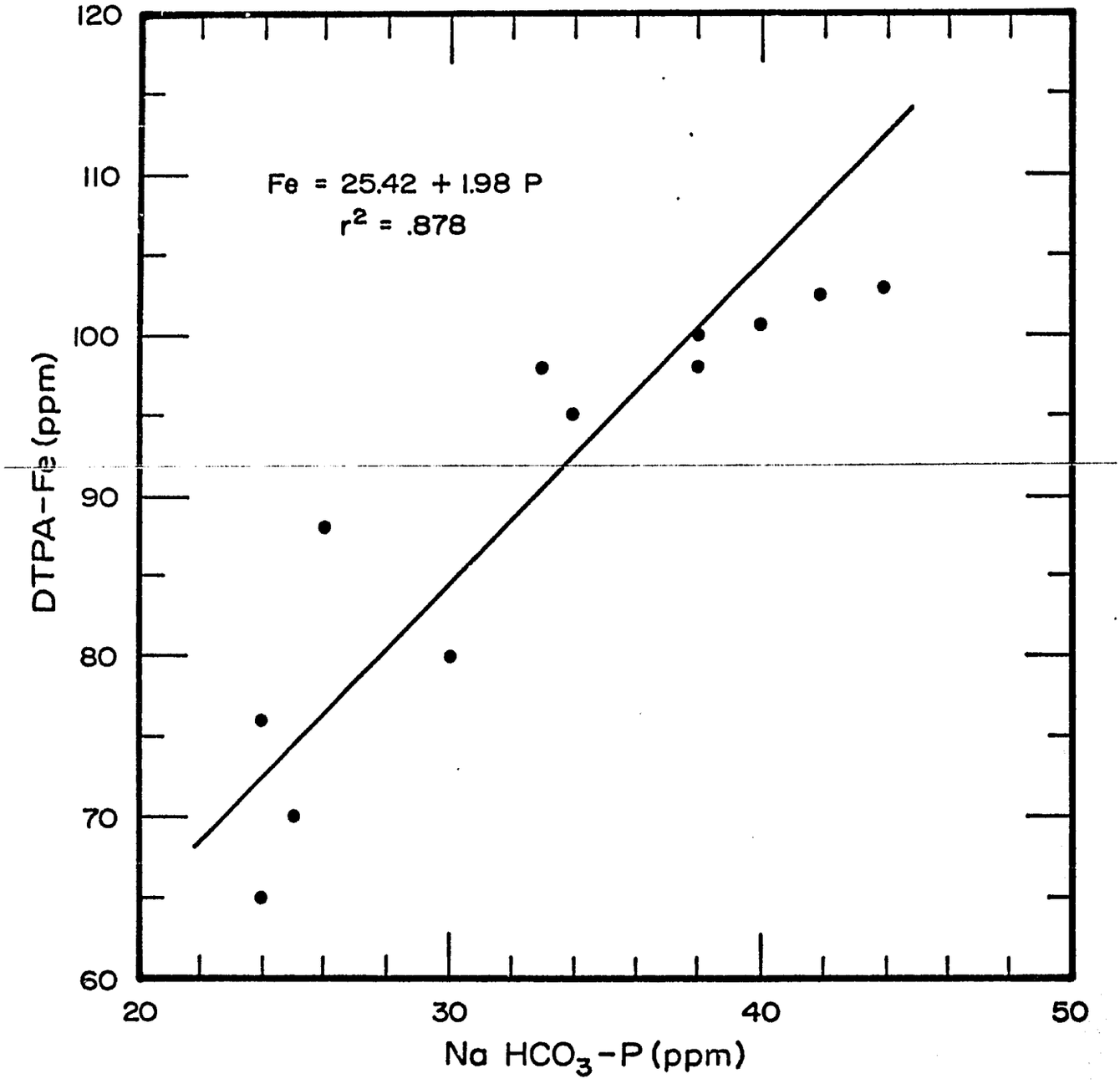


FIGURE 7. The relationship between DTPA-extractable Fe and HCO_3^--extractable P: second sampling phase, Malambito.

Appendix A

The following table is from Viets and Lindsay (16). It provides an interpretation of the DTPA diagnostic test for the soil fertility status of Cu, Fe, Mn, and Zn. The highest levels shown are the lower limits of the adequacy range. No information was available on possible toxicity levels of these elements as determined in the DTPA procedure.

Table A. 1. Critical levels of DTPA-extractable micronutrients for sensitive crops.

	ppm extracted from soils		
Nutrient	Deficient	Marginal	Adequate
Cu	<0.2	---	>0.2
Fe	<2.5	2.5-4.5	>4.5
Mn	<1.0	---	>1.0
Zn	<0.5	0.5-1.0	>1.0

Appendix B

It was necessary to steam sterilize the Colombian soil samples upon bringing them through the plant quarantine station to the USA. Since heat treatment drastically alters extractable Mn (4, 5, 15), a group of 12 Utah soils were analyzed for P and heavy metal elements before and after autoclave heat treatment. These soils represented commercial irrigated fields in a four-county area of northern Utah. These soils are not necessarily analogous to the Malambito soils, since they are from a semiarid region and contained some $CaCO_3$ in the surface and/or subsurface. The pH ranged from 7.5 to 8.2. Although the Malambito soils have no free $CaCO_3$ and are lower in pH, the level of soluble and exchangeable calcium in the Colombian soils is high enough to justify a broad comparison of the DTPA extraction effects. The soil extraction and analyses procedures were the same for both the Malambito and the Utah reference soil samples. The results for the Utah soils are given in Tables B.1 and B.2.

There was a slight reduction in HCO_3 extractable-P with heating. This change was probably independent of the changes seen in the other elements. The heat treatment possibly caused a reversion of dicalcium phosphate or similar compounds to less soluble forms. The small change in HCO_3- P upon heating was not large enough to cause a major change in the interpretation of the results.

Co and Ni were not detectable either before or after the heat treatment in the Utah samples. Cu, Fe, and Zn decreased in varying amounts, while Mn increased about 22-fold. Since these metals compete

for the ligands in the DTPA complex, it is evident that the mass action effect from the heat-released Mn decreased the amounts of Cu, Fe, and Zn found in the extracts.

Table B.2 shows that the elements that changed most upon heat treatment also had successively lower coefficients of determination. The regression equations for Cu and Zn could be used to predict the before-heating levels of these elements in the Malambito soils. The regression equation for Fe could be used but with less confidence. The regression equation for Mn would not be used because of its poor predictability.

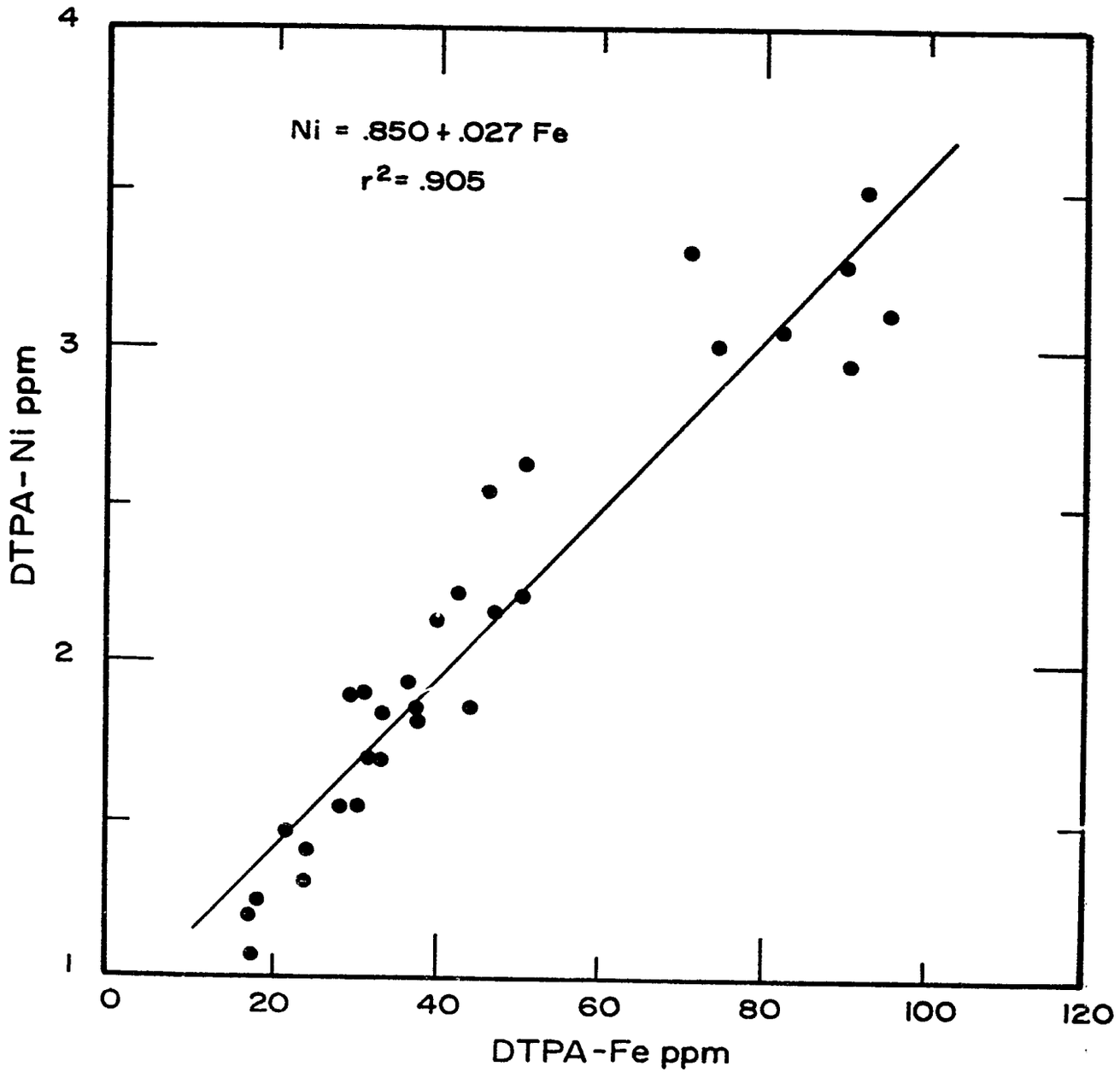
Table B. 1. Autoclave heat treatment effects on extractability of P, Co, Cu, Fe, Mn, Ni, and Zn in thirteen Utah reference soils.

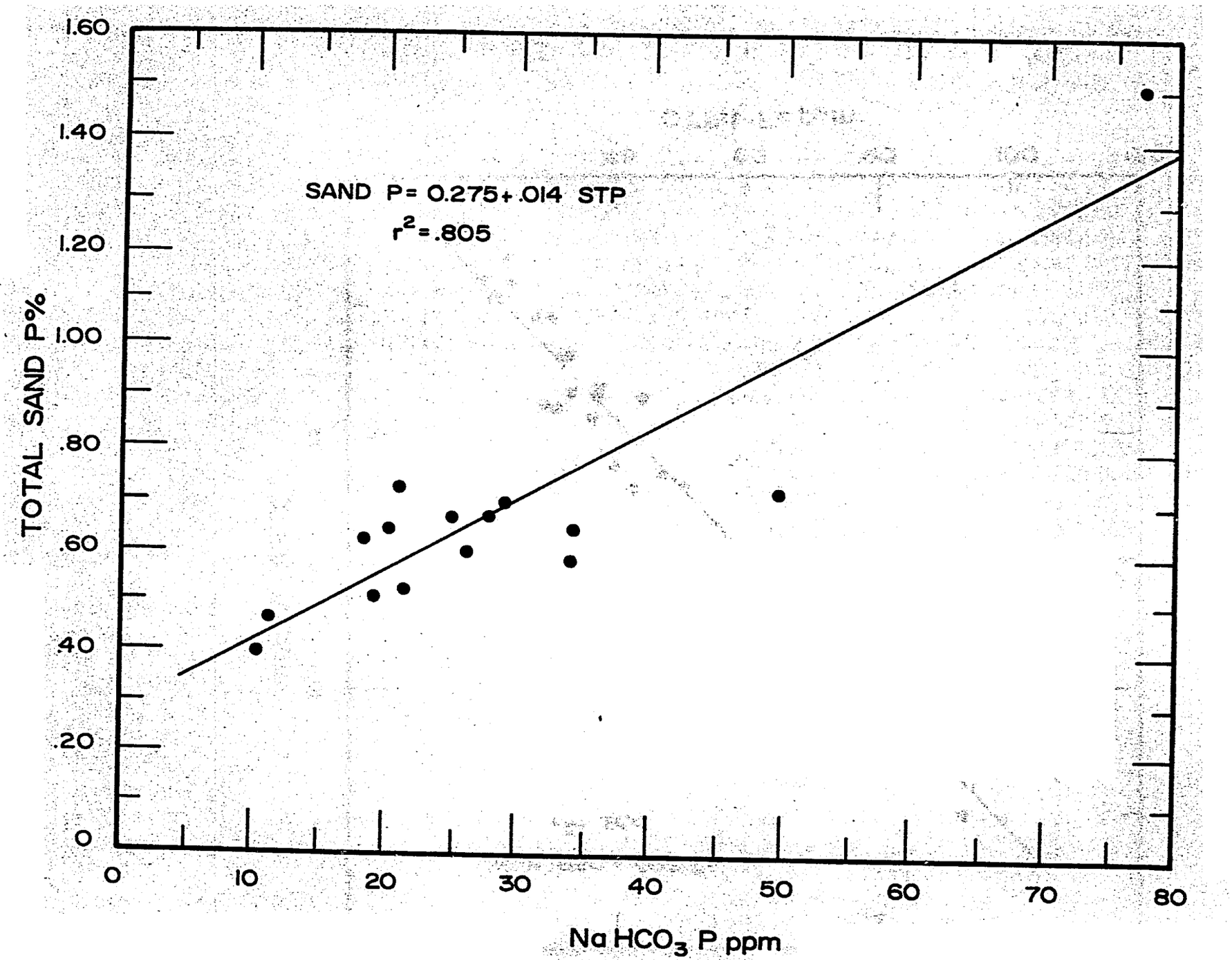
Element	No heat		With heat		Mean Ratio
	Range ppm	Mean ppm	Range ppm	Mean ppm	
P	7.0-66	19.08	6.0-50	18.23	0.955
Co	---	0.0	---	0.0	---
Cu	0.9-2.8	1.89	0.8-2.7	1.62	0.857
Fe	0.6-2.8	1.06	0.1-1.6	0.70	0.660
Mn	2.0-6.0	3.77	35.0-127.0	82.69	21.93
Ni	---	0.0	---	0.0	---
Zn	0.8-3.3	1.32	0.7-2.9	1.04	0.788

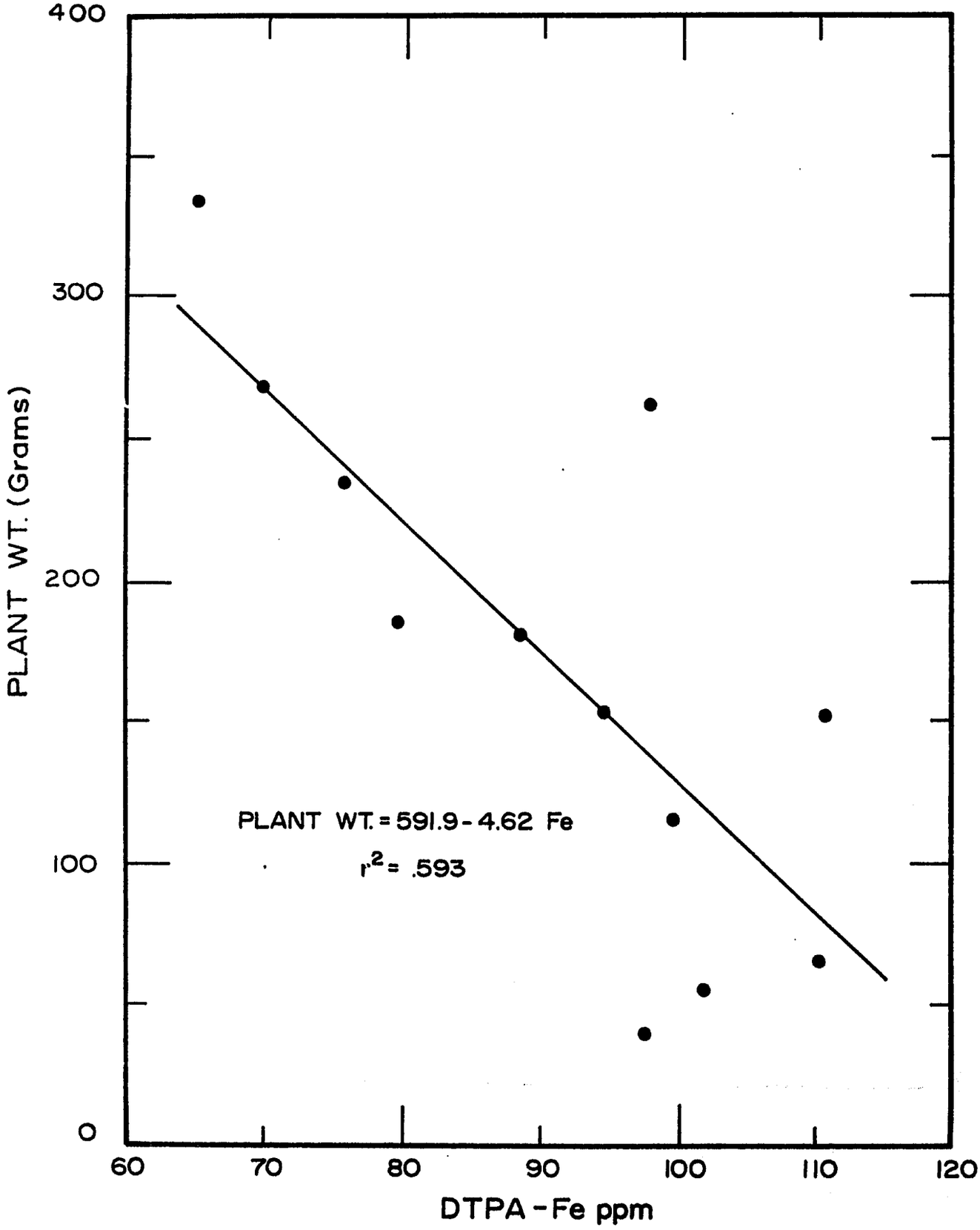
Table B. 2. Regression analysis of autoclave heat effects on element extractability from thirteen Utah reference soils.

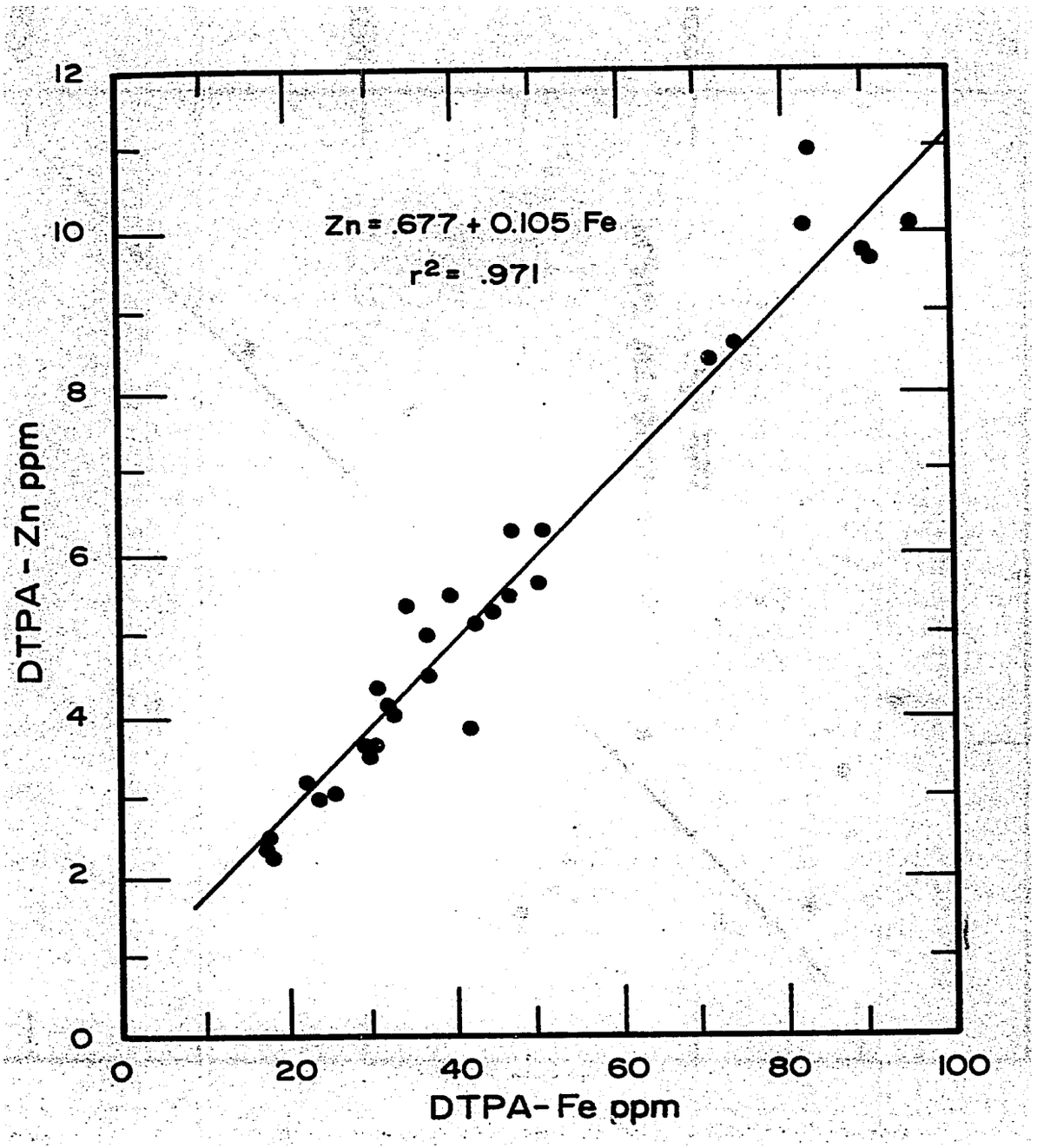
$$P^\circ = 4.04 + 0.744\ p^a,\ r^2 = 0.955$$
$$Cu^\circ = -0.24 + 0.985\ Cu,\ r^2 = 0.957$$
$$Fe^\circ = 0.164 + 0.505\ Fe,\ r^2 = 0.696$$
$$Mn^\circ = 54.01 + 7.61\ Mn,\ r^2 = 0.104$$
$$Zn^\circ = -0.067 + 0.836\ Zn,\ r^2 = 0.950$$

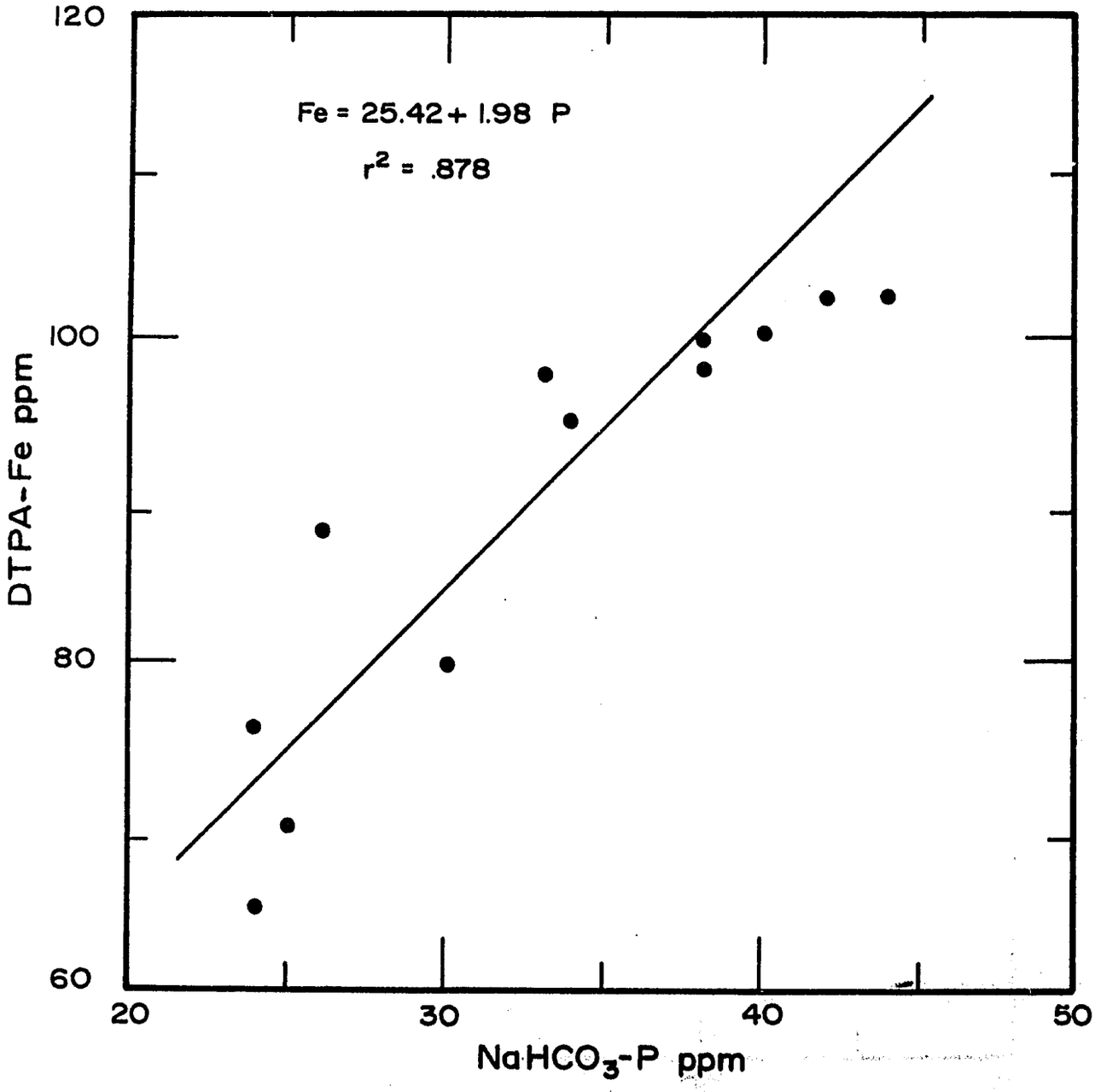
[a] e.g.: p° is autoclaved soil and P is no pre-treatment.

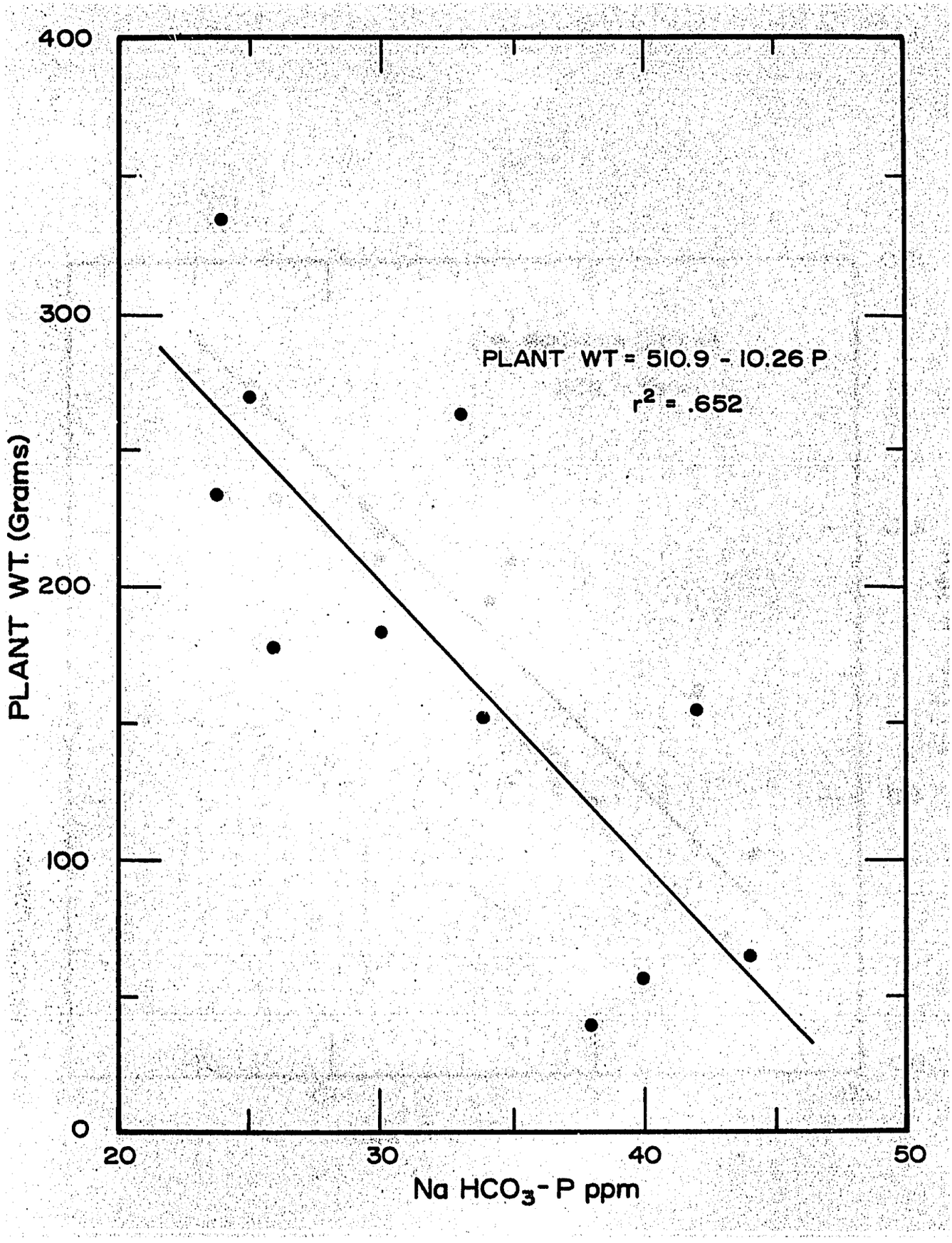

Ni = .850 + .027 Fe
r2= .905
DTPA-Ni ppm
DTPA-Fe ppm
4
3
2
1
0
20
40
60
80
100
120


SAND P= 0.275+.014 STP
r^2=.805
TOTAL SAND P%
1.60
1.40
1.20
1.00
.80
.60
.40
.20
0
0
10
20
30
40
50
60
70
80
Na HCO_3 P ppm


400
300
200
100
0
PLANT WT. (Grams)
PLANT WT. = 591.9 - 4.62 Fe
r² = .593
60
70
80
90
100
110
120
DTPA - Fe ppm


Zn = .677 + 0.105 Fe
r2 = .971
DTPA - Zn ppm
DTPA- Fe ppm
0
2
4
6
8
10
12
0
20
40
60
80
100


Fe = 25.42 + 1.98 P
r² = .878
120
100
80
60
DTPA-Fe ppm
20
30
40
50
NaHCO₃-P ppm


400
300
200
100
0
PLANT WT. (Grams)
PLANT WT = 510.9 - 10.26 P
r² = .652
20
30
40
50
Na HCO₃- P ppm