EFFECT OF THE USE OF LIME AND OTHER SOIL AMENDMENTS ON AMORPHOUS AND DIFFERENTIALLY CRYSTALLIZED SUBSOIL OF THE AKAKA SERIES

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INTRODUCTION

While calcium has long been known as an essential macro-nutrient for plants, it has had the distinction of having been used as a soil ameliorating agent from the very beginning of organized soil husbandry (Thompson, 1957).

Calcium is ascribed several roles in plant nutrition, among which is its role in the formation of cell wall constituents, that of nitrogen metabolism and as activator of several enzyme systems. (Meyer et al., 1960). Even so, Fried and Peech (1946) discussing calcium as a nutrient, came to the conclusion that supplying calcium as such was not important, on the probable assumption that most well-cultivated agricultural soils have a sufficient supply of calcium for nutritional purposes.

Thus, it is no surprise that most of the work done with calcium has been on its role as a soil ameliorating agent, or as a liming material on acid soils, for promoting the growth of certain crops. Under the general term of lime, many materials, such as calcium carbonate, hydrated lime, dolomitic limestone, silicic slags of various descriptions, crushed serpentine rocks, cement kiln dusts, etc., have been included.

Numerous reasons have been adduced by several workers for the ameliorating effect of these soil amendments in relation to the growth of specific plants on these acid soils. Among these, some of the more important

are:

a) Promotion of more favorable soil physical conditions (Coleman et al., 1958).

b) Improvement in the fixation of nitrogen by improved soil microbial activity (Black, 1957).

c) Beneficial effect of phosphorus release from the breakdown of organic phosphates (Ghani & Aleem, 1942).

d) Reduction of phosphorus fixation in soils (Mitscherlich, 1947).

e) Reduction of toxic levels of manganese and aluminum in soils (Mulder & Gerretsen, 1952).

f) Increasing the general effectiveness of other elements (Truog, 1953).

The literature also gives ample evidence of injury to crops due to overliming (Richardson, 1951; Russel, 1961). In tropical soils, while a great deal of research has been concentrated on the amelioration and utilization of leached-out acid soils, nevertheless many gaps as in a "jigsaw puzzle" yet remain to be filled. This situation is best illustrated in the words of Schmehl et al., (1950) " . . . the poor plant growth associated with acid soils is a complex function of many contributing factors, all of which may be modified by liming. Not until the relative importance of the different beneficial effects of liming acid soils is fully evaluated will it be possible to make the most intelligent use of lime . . ."

As for the research findings reported in this thesis, it must be pointed out that much work has already been done on the amelioration with lime of these Akaka soils (Monteith, 1961; King, 1961; Rixon, 1962; Clements, 1962, 1963; Reddy, 1964; Rana, 1964). The present work is thus an extension of the work already done, in which Akaka subsoil (2-5 feet depth) has been investigated. The main areas where the work to be reported here would contribute to additional knowledge are:

a) The laboratory study of the progressive dehydration of these soils from the state of field moistness to complete dryness, with respect to certain chemical, physical, as well as mineralogical changes.

b) Use of these soils at three different moisture levels (moist, 50% moist, dry)[1] for studying their response to liming. This is the first time that an intermediate moisture level has been investigated in fertility studies in these soils.

c) An investigation concerning the physical mixing of the moist and dry soils in varying proportions with respect to response to lime and plant growth.

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[1] Moist - State of field moistness (376% moisture on O.D. basis).

50% Moist - Dehydrated to 50% of field moistness (193% moisture on O.D. basis).

Dry - Sun-dried to constant weight from state of field moistness (21% moisture on O.D. basis).

d) The use of crushed Olivine Sand as a soil amendment, since this material is found occurring in abundance in the Hawaiian islands. It would prove to be an economic soil amendment if found efficacious. In addition to crushed Olivine sand, crushed coral rock and calcium silicate (TVA) was also investigated.

REVIEW OF LITERATURE

DESCRIPTION OF SOILS

The Akaka soil used in this study has been classified by Cline et al. (1955) as belonging to the Hydrol Humic Latosol great soil group. Soils developed in the humid tropics have been subject to such extremely intense weathering conditions that these soils have lost practically all their bases and silica. The Hydrol Humic Latosols of Hawaii are no exception and according to Sherman (1958), weathering has proceeded to such a stage in these soils that he considered them potential commercial sources of aluminum ore. These soils, therefore, also tend to be quite acidic. Reddy (1964) and Rana (1964), for instance, recorded as low pH values as 3.8 on the surface horizons. These soils are also characterized by a low bulk density and low particle density. These soils are also reported to dry irreversibly and in so doing change from an amorphous hydrated state to a crystalline one (Sherman, 1957). King (1961) working with Akaka subsoils, reported a loss of about 70 per cent of both the weight and volume of the soil upon drying. Kanehiro and Chang (1956) also observed a sharp drop in the cation exchange capacity of these soils on drying.

SOIL ACIDITY AND PLANT GROWTH

The literature is replete with controversies on soil-plant inter-relationships.

This is true for relationships involving the growth of crops on acid soils as well as on non-acid soils. Though theoretically soils below a pH of 7 can be regarded as acidic in reaction, it has been recognized for a long time that problems in the cultivation of most agricultural crops do not arise until the soil pH value drops to about 5 or below.

At least three different concepts on soil acidity vis-a-vis plant growth may be considered to be quite pertinent with reference to the different views held on this subject by different workers. One school of thought has it that injury to plants on acid soils is due to a high concentration of H ions per se. While this may be expected at low pH values of around 3, Arnon & Johnson (1942) in their work with higher plants under controlled conditions, have demonstrated that so long as adequate nutrition was provided, pH fluctuations from 4-8 were tolerated. On evidence such as this, one could well dismiss the idea of H ion injury to plants, since most cultivated soils are seldom allowed to reach pH values of 3 or 4. Yet soil acidity problems are encountered in agricultural soils with pH values around 5.

Another view about soil acidity is that by Albrecht and his co-workers (1941), who consider that soil acidity is nothing short of nutrient deficiency, particularly of calcium. This view was shared by Mehlich and Colewell (1943) who appear to agree to the extent that the major benefit of liming is increased calcium availability.

The third and currently most acceptable view is that calcium deficiency is of less importance than the problem of Al and also of Mn toxicity in agricultural soils of around pH 5. Among several workers who hold this view, those of Schmehl et al. (1950), Fried and Peech (1946) and Vlamis (1953) may be mentioned. That excessive aluminum and not a deficiency of calcium necessarily was the primary cause of crop failure in these so-called H-ion systems, had in fact been demonstrated by Paver and Marshall (1934) as early as in 1934. The work of Paver and Marshall was supported in 1955 by McAuliffe and Coleman (1955), who concurred that acid soils are in reality H-Al clays.

MECHANISM OF ALUMINUM TOXICITY

On the subject of the mechanism of aluminum toxicity, the literature reveals a host of divergent views. While Coleman et al. (1958) stated that the mechanism of aluminum toxicity was not known, numerous other workers have advanced one or more views.

Addoms (1927) attributed aluminum toxicity in plants to the lethal flocculation and coagulation of plant protoplasm as a result of the rapid penetration of Al ions into the cells of root hairs when in contact with aluminum solutions of sufficiently high concentration. Other workers, such as Schmehl et al. (1950) and Chernov and Belyaneva (1946), attributed aluminum toxicity to serious interference with the uptake and accumulation of calcium, especially

when aluminum in the growing medium is at fairly high concentrations. Certain other workers, Evans and Cate, Jr. (1962), McLean and Gilbert (1928) and Trenel and Alten (1934) seem to have inferred from their work that aluminum toxicity came about as a result of direct injury to plant roots when in contact with sufficiently high concentrations of aluminum ions or salts of aluminum. In addition to all the foregoing views, probably the major concensus of opinion today connects aluminum toxicity with interference in the uptake and translocation of phosphorus within the plant. Russell et al. (1950), Wright (1943) and Pierre and Stewart (1933) share this view. Besides these several views, Anderson and Evans (1956) working with snap beans have attributed aluminum toxicity to an inhibition of the isocitric dehydrogenase and malic enzyme activities.

ALUMINUM IN PLANTS

Plants appear to vary over very wide ranges in their sensitivity to aluminum toxicity or one might say in their tolerance of aluminum concentrations. Thus, it becomes quite necessary to take due cognizance of this factor when it comes to the amelioration of those soils, in which aluminum contributes to soil acidity. In this regard as a general rule legumes are recognized as being more intolerant of excessive aluminum than grasses. However, even among grasses Hartwell & Pember (1918) found barley to be extremely sensitive to aluminum in contrast to rye. In a slightly later study, McLean and Gilbert (1926) classified a few crops with reference to aluminum sensitivity as follows--lettuce, beets, and timothy as being very sensitive;

radishes, sorghum, cabbage, oats and rye as being moderately sensitive; and corn, turnips, and red tops as being least sensitive. It is interesting to note that these same authors--McLean and Gilbert--considered aluminum as being stimulating to plants at low concentrations and toxic only at high concentrations. In this regard, several species are known to take up very high concentrations of aluminum with no apparent ill effects. For instance, Moomaw et al. (1959) investigating the flora on some high aluminous soils, report certain Pteridophytes as containing from 3000 to 9000 ppm of aluminum. Again Chernery (1955) in a preliminary study of aluminum in the tea bush, reported high concentrations of 5000 to 16, 000 ppm in the old leaves.

LIMING OF SOILS

Soils are most often limed when they reach a state of acidity that the pH is considered too low for the successful cultivation of some particular crops. The lime requirement itself is calculated with the use of buffer solutions, (Woodruff, 1947) or with the aid of titration curves (Matsusaka & Sherman, 1950).

Coleman et al. (1958) in their recent review of liming, attributed the response of crops to liming to any one or more of the following changes in soil environment:

a) Insolubilization of toxic substances.

b) Supplying of calcium and magnesium.

c) Making phosphate and potassium more available.

d) Influencing the solubilities and availabilities of micro-nutrients.

e) Promoting of soil micro-biological activities.

Where much work has been carried out with liming of soils, Engels (1936) of Germany concluded that the beneficial effects of lime were due to the prevention of the formation of iron and aluminum phosphates. Gerricke (1951) reviewing German work on liming showed that lime increased phosphate availability in strongly acid soils, but not in soils with a pH value higher than 6. He considered that lime corrected certain "unfavorable" conditions for plant growth, thus enabling the plant to utilize less available forms of phosphate.

From a physiological point of view, Jacobson et al. (1961) have demonstrated the influence of calcium on cation absorption with reference to the greater uptake of potassium as opposed to sodium and lithium. Again Epstein (1961) showed similar effects of calcium, this time in the uptake of rubidium as opposed to sodium and before that demonstrated (1960) the influence of calcium on the uptake of lithium.

RATES OF LIMING

Most often the aim in liming agricultural soils is to raise their pH to a condition of slight acidity or neutrality since the great majority of agricultural crops are known to perform best at or around this soil reaction, provided there are no other liming conditions. With the Akaka soils, for instance, Monteith and Sherman (1963) showed increased yields of sudan grass upon liming, provided the soil pH remains below 6.8.

Richardson (1951) draws attention to need for caution in the liming of tropical soils, in order to avoid causing micro-nutrient deficiencies. Forsee (1954) has demonstrated deficiencies of manganese on certain organic soils, when the soil pH was raised to 6 with lime. Again Mulder and Gerretsen (1952) have shown manganese deficiency with liming which they attributed to changes in the oxidation state of manganese. Fujimoto and Sherman (1946), too, have related manganese availability to the oxidation-reduction state of this element. In addition to manganese the solubilities of copper, iron, and zinc are also believed to decrease upon overliming of soils. Rogers and Wu (1948) refer to decreased zinc content of oats with liming. Gilbert (1952) in reviewing the role of copper in nutrition concludes that though liming may reduce copper availability, yet on soils high in organic matter, liming may result in the liberation of bound copper to more available forms. As for iron, Brown and Holmes (1956) were of the opinion that iron deficiency only occurs in calcareous soils. Liming, of course, has a completely opposite effect with molybdenum and Davies (1956) showed increased molybdenum availability with liming. The dangers of overliming are probably best appreciated in the words of Thompson (1957) " . . . too much lime may be worse than not enough . . ."

SOURCES OF LIME CARRIERS

The sources of lime most often employed are calcite ($CaCO_3$) and dolomitic limestone ($CaMg(CO_3)_2$). The pure forms of these two compounds

have neutralizing values of 100 and 109, respectively. Calcium oxide as well as the hydroxide are at times used as liming materials and so are basic slags (by-products of smelting operations) which consist largely of calcium silicate often admixed with impurities in the form of phosphorus, micro-nutrients, etc.

The soil amendments used in this research were coral rock (high in $CaCO_3$), Calcium silicate, and Olivine sand (about 47% magnesium silicate). Even though olivine sand may not be properly classified as a lime carrier, it is defined as such under this heading.

Coral Rock. This amendment being very high in $CaCO_3$, can be regarded as a standard lime carrier and would not need any further review over and above what has already been reviewed under liming.

Calcium Silicate. Both the pure form and the various slags of calcium silicate have been used for some time as liming materials and the literature has different views both to its mode of action as a soil amendment and also to its efficiency in comparison with the more conventional forms of calcium.

While Taylor (1960) discusses four types of silicon-bearing materials of agronomic value, Miller (1938) contends that this element as far as the physiology of the plant is concerned is either non-essential or required only in very minute amounts. Dewan and Hunter (1949), on the other hand, refer to three possible roles that silicon may play in the promotion of increased plant yields. They enumerate these three roles as follows:

a) Role of silicon in possibly substituting for and thereby economizing on the use of phosphates by the plant (Loew, 1903).

b) Role of silicon in either directly or indirectly increasing the assimilation of phosphates by plants (Toth, 1939).

c) Role of silicon in the improvement of soil physical conditions and thereby increasing crop yields (Hartwell & Pember, 1920).

While one or all of these three roles may lead to increased plant yields often observed, opinion seems to be mostly crystallized on its role in increasing phosphorus availability in soils and thereby increasing phosphorus assimilation, by plants. Anionic exchange is suggested as the mechanism, whereby the orthosilicate and the polysilicate ions increase the availability of adsorbed or precipitated soil phosphorus. This concept has also been more or less borne out by the work of Akhromeiko (1934), who refers to a hastening of the diffusion of phosphorus into the plant as a SiO_2/P_2O_5 complex formed at the soil solution-root interface. Sherman et al. (1954), too, have demonstrated a direct relationship between the uptake of silicon by the plant and the concentration of plant phosphorus. Hall and Morrison (1955) also have shown an increased SiO_2/P_2O_5 ratio with silicate application.

There appears to be divergent views on the comparative efficiency of the silicates and the conventional formes of lime. While Hartwell and Pember (1920) found no difference between dicalcium silicate and limestone, other workers such as Scheidt (1917) and Taranovskaya (1941) reported the

silicates to be more effective than the carbonates and hydrates of lime.

These divergencies of findings may very well be due to different responses stemming from different plant species and from different soil conditions. Dewan and Hunter (1949) have observed that increased phosphorus assimilation with silicates may depend on plant species and age of sampling. Toth (1939) for instance refers to sudan grass as a high silica plant as opposed to soybean and rape. To illustrate the differential response to silica as a function of soil, Sherman et al. (1954), Suehisa (1961), Ikawa (1956) have all had responses on Humic Latosols, but not on certain other soil types, such as Low Humic Latosols, Humic Ferruginous Latosols, Dark Magnesium Clays, etc.

As to the role of silicon in increasing the availability of soil phosphorus, it is interesting to note the claim of Bromfield (1959) where he reported that the siliceous material in rice hulls increased the solubility of aluminum phosphate and also inhibited the absorption of phosphorus by aluminum oxides.

Olivine Sand. The literature as far as the writer was able to discover, was quite meager with reference to the use of Olivine sand as a soil amendment. In Hawaiian soils at least, it was probably used for the first time, in this research, as a possible soil amendment. Olivine sand used in this research consisted of about 47 per cent magnesium silicate, and the literature does have a few instances of the use of magnesium silicate. For instance, Taranovskaya (1941) reported that calcium silicate and magnesium silicate

were more effective than lime in mobilizing phosphorus and reducing the soluble aluminum content. Toth (1939), however, referred to decreased absorption of calcium, and increased uptake of magnesium by all plants grown on magnesium silicate-treated soils. He further goes on to say that the small yield of rape with magnesium silicate was due to an unfavorable ratio of exchangeable CaO to exchangeable MgO. Dewan and Hunter (1949), too, reported, comparable yields of soybean and sudan grass with magnesium silicate and calcium silicate, but recorded nil yields with soybean and low performance of sudan grass with olivine.

THE PLACE OF PHOSPHORUS IN THE LIMING OF ACID SOILS

A review of the liming of acid soils would not be complete without discussing its influence on phosphorus. As has already been brought out earlier in this review, one of the more significant responses to the liming of acid soils is claimed to be the greater release of phosphorus. Ayres (1934) has made the observation that most of the Hawaiian soils tested were capable of fixing phosphates. In some of the great soil groups of Hawaii, Chu and Sherman (1952) also reported the fixation of 90 per cent added phosphorus within 24 hours. Chu and Sherman (1952) in the same work also reported less than 30 per cent fixation of phosphates if the oxides of iron and aluminum were removed. A similar observation is also made by Coleman et al. (1960) of reduction in phosphate fixation with the removal of exchangeable aluminum.

Younge and Moomaw (1960) on the other hand, advocated a different approach--saturating the phosphate fixation complex of the soil with heavy rates of phosphorus applications, leaving phosphorus over and above that which is fixed for plant utilization.

There are a number of reviews on phosphorus fixation in the literature and one of the more recent is that by Hemwall (1957). He defines phosphorus fixation as " . . . phosphorus which has been rendered insoluble that is defined as 'fixed' . . . "

Three major mechanisms of phosphate fixation are generally recognized. These three mechanisms are:

a) Chemical adsorption or surface reaction--a phenomenon whereby phosphorus concentrates at the solid-liquid interface of the soil system and is subject to fixation. The phosphorus thus fixed is supposed to be readily exchangeable (Mattson, 1931; Scarseth, 1935; Coleman, 1944).

b) Chemical precipitation--a phenomenon whereby phosphorus is subject to fixation by ionic iron and aluminum compounds. Phosphorus thus fixed is said to be very sparingly available to plants and according to Truog (1938) is the main cause of phosphorus fixation.

c) Anion exchange--the replacement of one anion on the exchange complex by another as a result of a greater concentration or a stronger tendency to hold its position on the exchange complex. Dean and Rubins (1947)

considered this a major factor in phosphorus fixation, though Hemwall (1957) concludes that " . . . for the most part the anion exchange theory of phosphate fixation today has very few supporters . . ."

Besides these mechanisms of phosphorus fixation under acid soil conditions, it is well to bear in mind that Cole et al. (1953) also referred to phosphate sorption by calcium carbonate. On the same subject, Scarseth and Tidmore (1934) also discussed the formation of Tricalcium phosphate where phosphorus is applied to heavily limed soils, which have not equilibrated fully with the soils.

MATERIALS AND METHODS USED

SOILS

Subsoil of the Akaka series belonging to the Hydrol Humic Latosol great soil group was used in this study. These soils were obtained from a locality known as Kaiwiki situated in the Hilo coast of the island of Hawaii. The soil was collected from a two to five foot depth (approximately) by cutting into a road bank. The predominant vegetation covering the soil was staghorn fern. The soils were transported to Honolulu in polyethylene-lined, well-secured jute bags to keep to an absolute minimum losses in soil moisture.

PROCESSING OF SOIL

The soil on arrival in Honolulu was stored in a sheltered area and was subsequently screened through a 1/4 inch mesh screen to remove stones, roots, etc. Thereafter those portions of the soil which needed to be dried down to 50 per cent moisture of the initial soil and to complete dryness, were put out in the sun in thin layers on cartridge paper and dried down to the desired moisture levels. About 3 days of sun-drying were required to bring the soil to air (constant weight) dryness, whereas only about 8 to 10 hours of sun-drying were required to bring the soil to a 50 per cent moist condition. Whereas King (1961), Reddy (1964), Rana (1964) referred to air drying, that

part of the soil dried in the research reported here, was in reality sun-dried. For convenience in reporting, however, the soils will hereafter be referred to as Akaka moist, Akaka 50 per cent moist, and Akaka air-dried (A.D.). In some plates, Akaka moist has also been referred to as soil at field capacity (F.C.).

SOIL AMENDMENTS

Coral Rock. Fragments of coral rock were collected near Keehi Lagoon in a locality off the former Honolulu International Airport. These fragments were washed, dried in the sun, and subsequently ball-milled to 100 mesh fineness.

Calcium Silicate. The source of this material was the TVA Mix 398, Electric Phosphorus furnace slag. This material was practically of 100 mesh fineness.

Olivine Sand. A small quantity of Olivine sand was obtained for this investigation from Dr. Gordon MacDonald, Professor of Geology, University of Hawaii. This material contained admixtures of calcite-like material and also what appeared to be crystals of magnetite. Practically all the whitish calcite-like material was removed by treatment with 6 N hydrochloric acid several times, until there was no more reaction. The material was then washed free of hydrochloric acid with distilled water. Then the material was dried and as much as possible of the magnetite-like material was removed with the use of a magnet. Finally, the material was ball-milled to 100 mesh fineness.

The neutralizing power of the three soil amendments described above was determined as was also their chemical composition with respect to total calcium, total magnesium, total phosphorus and total manganese (Table 1).

A spectroscopic analysis was also made of the three soil amendments and the main features are as follows:

Coral rock showed very strong peaks for strontium, but was less intense in $CaSiO_3$ and absent in olivine sand.

All three materials showed peaks for iron, which were the most prominent in the case of olivine sand. Olivine sand also displayed a prominent peak for nickel.

Of the other elements -- Cr, Mn, Co, Zn--these were either present in trace amounts or were absent.

The high strontium content of coral rock must necessarily raise a speculation, with regard to the poor response of sudan grass to coral rock when compared to $CaSiO_3$.

NUTRIENTS USED IN SOIL-PLANT INVESTIGATIONS

All treatments received N P K while certain treatments received a micro-nutrient supplement as well. Nitrogen and phosphorus were applied as NH_4H_2PO4. In all the soil-plant investigations, phosphorus was a variable applied at two rates--250 and 750 pounds P per acre. To make up for the

TABLE 1.

PARTIAL CHEMICAL COMPOSITION OF THE SOIL AMENDMENTS

Soil Amendments	Neutralizing Power	Ca %	Mg %	P %	Mn ppm
Coral Rock	83	39.1	1.62	0.09	49
Calcium Silicate	74	33.8	1.43	0.93	294
Olivine Sand	66*	0.9	15.59	0.15	686

* After standing for 3 weeks. Initial neutralizing power was only 12.

extra nitrogen in the P_2 treatments, an adjustment for nitrogen was made in the P_1 treatments with Ammonium nitrate. The nitrogen applied amounted to 336 pounds N per acre. Potassium was also applied to all the treatments in the form of potassium chloride at the rate of 350 pounds K per acre.

The micro-nutrient supplement applied to certain treatments consisted of:

Manganese sulphate ($MnSO_4 \cdot H_2O$)	20 lb/A
Copper sulphate ($CuSO_4 \cdot 5H_2O$)	10 lb/A
Ammonium molybdate ($(NH)_6Mo_7O_{24} \cdot 4H_2O$)	2 lb/A
Boric acid (H_3BO_3)	2 lb/A
Zinc sulphate ($ZnSO_4 \cdot H_2O$)	25 lb/A

GREENHOUSE EXPERIMENTAL PROCEDURE

For the soil-plant investigations, 1-gal. cans, 6 inches in diameter and 7 inches in depth were used. These were lined with polyethylene bags in order to maintain a closed system. Into each pot, 2100 grams of soil were weighed. In the treatments to be limed, the requisite amount of soil amendment was applied on a surface area basis and the amendment was thoroughly mixed with the soil. Then the mixed soil in each pot was brought up to a pre-determined field capacity state of soil moisture and allowed to incubate for 4 weeks at room temperature, with the soil securely contained within the polyethylene bags. During the 4 weeks of incubation, the soils were stirred twice.

At the end of the incubation period, the soils were treated with the rest of the nutrients, applied as solutions, and thoroughly mixed.

Immediately after, sudan grass seed (Sweet Sudan Grass Premium Variety) was sown at the rate of 40 seeds per pot, covered lightly with soil, and set in the greenhouse. The seeds germinated in 2 days time. The seedlings were thinned to 25 per pot, 10 to 14 days after germination. The pots were watered twice a day with tap water in an attempt to maintain the soils at field capacity. Representative pots were weighed daily and all pots were weighed weekly in the attempt to maintain the soils at Field Capacity. Estimated allowances were made for plant growth differences.

Though it was planned to harvest the plant crop at 6 weeks or around first flowering, some of the treatments produced such heavy growth that it became necessary to harvest the plant crop at 5 weeks from sowing.

One ratoon crop was taken -- the ratoon crop receiving 200 pounds nitrogen and 100 pounds potassium per acre as ammonium nitrate and potassium chloride. The micro-nutrient supplement, too, was applied to the relevant treatments. As in the case of the plant crop, all the nutrients to the ratoon crop were also applied as solutions. The ratoon crop was harvested 4 weeks after the harvest of the plant crop. The greenhouse phase of the soil-plant investigation lasted from August 9, 1963 to October 11, 1963. At the end of the period of cropping, the soil in the pot was tied up in the

polyethylene bag and left covered, till it was processed for soil analysis.

The plant tops after harvest were placed in paper bags, dried for a number of days in a draft oven at 65 to 70° C. and the weight determined and recorded as dry matter yields per individual treatment. Then the plant material was ground to 40 mesh in a Wiley mill for analytical study.

ANALYTICAL METHODS

A. Plant Analysis

Due to extremely low yields in certain treatments, it was found necessary to composite the dry matter yields of the replicates. Even then, some of the treatments did not have sufficient plant material for the analysis of such elements as zinc.

In the plant analysis, eight elements were determined--silica, phosphorus, aluminum, calcium, magnesium, potassium, zinc, and manganese. Whenever there was sufficient plant material, determinations were carried out in duplicate and the technique of bringing the elements into solution was by dry ashing. The elements phosphorus, aluminum, and potassium were determined in separate ashings. An interesting observation in dry ashing was that ashings from calcium-silicated treatments were not as clean as the ash from other treatments.

For the determination of phosphorus, aluminum and potassium, 1 g of oven-dried plant material was weighed into a porcelain crucible and then

wetted with 5 ml of an alcoholic solution of 25 per cent $MgNo_3$. The material was then ignited, and then the crucibles were placed in a muffle furnace at a temperature of 550^{o} C. overnight. Then the ash was collected in 10 ml of 2 N Hydrochloric acid, warmed over a low bunsen flame to dissolve the residue, and filtered through a SS 581 White Ribbon filter paper. The residue was washed a few times, and the filtrate plus washings was made up to a volume of 50 ml in volumetric flasks. The determinations for phosphorus, aluminum, and potassium were made as follows:

Phosphorus. The method employed was the Vanadomolybdophosphoric yellow color method as described by Jackson (1962). Ten ml of aliquot was placed in a 50 ml volumetric flask, 10 ml of the Vanadomolybdate reagent added, made up to volume with distilled water, mixed well and read in the Klett Summerson colorimeter at 470 mu after standing for 30 minutes. The concentration of phosphorus was calculated with reference to a standard curve.

Aluminum. The colorimetric method by Chernery (1948) was employed. A 5 cc aliquot was placed in a beaker, diluted to 20 ml with distilled water, 2 ml of (1 + 100) thioglycollic acid added, followed by 10 ml of aluminon reagent. This mixture was then adjusted to pH 4.2, transferred to a 50 cc volumetric flask and warmed over a boiling steam bath for 12 minutes. Then the flasks were allowed to cool to room temperature (at least for 1-1/2 hours) made to volume with distilled water and the color concentration read in a Klett

Summerson colorimeter at 540 mu. Again the aluminum concentration was calculated with reference to a standard curve.

Potassium. Potassium was determined by reading off its concentration directly in a Beckman DU flame photometer. The exact concentration was again determined with reference to a standard curve.

For the determination of silica, calcium, magnesium, manganese and zinc, a separate plant sample of 1.5 g was weighed into a porcelain crucible and ashed overnight in a blast furnace at a temperature of 550° C. The ash was again taken up in 10 ml of 2 N hydrochloric acid, warmed over a low bunsen flame to dissolve the ash and filtered through an acid washed SS 581 white ribbon filter paper. The residue was washed with warm 2 N hydrochloric acid thrice, keeping the filtrate and washings to about 25 ml, all of which was used to determine zinc to start with. The determinations of zinc as well as the other four elements were made as follows:

Silica. The residue left on filtration was accepted as the total plant silica and was determined by first drying the filter paper plus residue in an oven at 105° C. and thereafter causing it to be ignited at a temperature of about 800° C. under a strong meeker flame in a weighed porcelain crucible. The crucibles so ignited were allowed to cool in a dessicator and then re-weighed to determine the amount of siliceous ash.

Zinc. The plant zinc was determined by the zincon method (Jackson and Brown, 1956). A resin column was first washed with 50 ml of .05 N hydrochloric

acid. These washings were discarded and then the approximately 25 ml of plant ash solution taken up in 2 N hydrochloric acid was passed through the resin column. The resin column was now washed in turn with 50 ml of N hydrochloric acid an 10 ml of N potassium chloride. The filtrate and these washings were now set aside for the determination of manganese, calcium, and magnesium. Now the resin column was washed with 20 and 10 ml portions of .05 N hydrochloric acid. This filtrate was then transferred into a 50 ml volumetric flask, and treated with 5 ml of a buffer solution and 3 ml of a zincon reagent. Then the contents of the flask were brought to volume with distilled water, thoroughly mixed and the color read in a Klett Summerson colorimeter at 620 mu between 20 and 40 minutes of color development.

Manganese. The filtrate and washings set aside in the zinc determination were made up to 100 ml and a 50 ml aliquot was used to determine manganese, which was carried out by the periodate method as described by Jackson (1962). The characteristic pink color developed was read off in a Klett Summerson colorimeter at 540 mu and the actual manganese concentration determined with reference to a standard curve.

Calcium and Magnesium. These two elements were determined on a 20 ml aliquot of the same solutions from which the aliquot for manganese was taken. Calcium was determined titrimetrically with .05 N potassium permanganate, after having been first converted to the oxalate salt. Magnesium

was determined gravimetrically after being converted to magnesium pyrophosphate. Both these methods were as described by Piper (1944).

B. Soil Analysis

The soil left in the pots after the growth of sudan grass was passed through a 1/4 inch mesh screen to eliminate plant roots. Then the replicates of each treatment were composited, and quartered. Representative samples from the composites were placed in polyethylene bags and well secured for chemical analysis to be carried out.

These soils were first tested for their pH and then the chemical determinations for the following were carried out--.02 N H_2SO_4 extractable phosphorus, exchangeable Al, exchangeable Ca, exchangeable Mg, exchangeable K, exchangeable Mn and reducible Mn.

Soil pH Determinations. These were carried out using a Beckman pH meter, with a 1:1 soil-water mixture on a volume basis. This mixture was allowed to stand overnight with occasional stirring and the actual pH itself was recorded on the stirred suspension. The pH determinations as well as the other soil analyses were carried out in duplicate.

Soil Extractable Phosphorus. Soil phosphorus was determined colorimetrically by the molybdenum blue color method described by Jackson (1962). The extracting solution was the modified Truog as used by Ayres and Hagihara (1955). Two g of soil on a regular basis were extracted with 200 cc of 0.02 N H_2SO_4 containing ammonium sulphate as a buffer at the rate of 3 g for litre. The soil was subjected to mechanical shaking with the extracting solution for half

an hour, then filtered and a 5 ml aliquot transferred into a 50 ml volumetric flask for the determination of phosphorus. The pH of the aliquot was adjusted to 3 with the use of 2, 4 dinitrophenol indicator as described by Jackson (1962). Then 2 ml of ammonium molybdate--sulphuric acid mixture--were added, the volume made up with extracting solution and the color developed with freshly prepared stannous chloride and read after between 4 and 12 minutes of color development. The final concentration was worked out by reference to a standard curve, and converted to an oven-dry basis, by the use of a moisture factor calculated for each soil sample.

Soil Aluminum. Exchangeable soil aluminum was determined by the method described by Chernery (1948). The extracting agent was normal ammonium acetate with 0.2 barium ions as barium chloride per litre of extracting solution, adjusted to pH 4.8. Ten g of soil were treated with 50 ml of extracting solution and left overnight. Then the suspension was filtered in a Buchner filter apparatus, using a further 50 ml of extracting solution in 5 to 10 ml installments to wash the soil. Then an aliquot of 1 ml of this 100 ml filtrate was used to determine exchangeable aluminum according to the same procedure as outlined for the determination of plant aluminum. The final values were corrected on an oven-dry basis.

Exchangeable Calcium, Magnesium, and Potassium. Exchangeable forms of calcium, magnesium, and potassium were determined on a single soil

sample of 25 g, treated with 200 ml of normal ammonium acetate and left overnight with occasional shaking. These soil suspensions were subjected to Buchner filtration, using a further 200 ml of extracting solution to wash the soil in three to four installments. The 400 ml of filtrate were then brought to volume, and a 200 ml aliquot used to determine exchangeable calcium and magnesium.

The 200 ml aliquot was evaporated to complete dryness to remove the acetates, treated with 10 per cent hydrogen peroxide to destroy any organic matter and the residue was taken up in 1:1 hydrochloric acid. From this point on, as in the instance of plant calcium and magnesium, calcium was determined titrimetrically as the oxalate using .05 N potassium permanganate and magnesium was determined gravimetrically as its pyrophosphate salt, by the methods described by Piper (1944). The values for calcium and magnesium were also converted to an oven-dry basis.

Using a little of the filtrate left after the determination of exchangeable calcium and magnesium, exchangeable potassium was determined using the Coleman flame photometer. Here again the values were converted to the oven-dry basis.

Soil Manganese-Exchangeable and Reducible. Both these forms of manganese were determined by the periodate method. Exchangeable manganese was determined by the procedure outlined by Jackson (1962), while reducible manganese was determined by the method described by Sherman et al. (1942),

both with a few modifications.

Twenty-five g of soil were treated with 250 ml of normal ammonium acetate and shaken in a mechanical shaker for 15 minutes and then subjected to immediate Buchner filtration, so that the total time of shaking and filtration was confined to about 30 minutes. This filtrate was then evaporated to complete dryness to remove the acetates, digested for 30 minutes with a mixture of concentrated nitric acid and 30 per cent hydrogen peroxide to destroy any organic matter and then again evaporated to dryness. The residue was now boiled with concentrated phosphoric acid, cooled and diluted with water and the color developed with periodate as described by Jackson (1962). The color was read in a Klett Summerson colorimeter at 540 mu and the final values determined on an oven-dry basis.

In determining reducible manganese, the soil, left on the filter paper after filtration for exchangeable Mn, was further treated with 250 ml of normal ammonium acetate containing 0.2 per cent of hydroquinone. This again was shaken for 15 minutes in a mechanical shaker and immediately subjected to Buchner filtration so that once more shaking and filtration was completed in about 30 minutes. The filtrate was treated with 10 ml of 1:1 H_2SO_4, 30 ml of concentrated HNO_3 and digested for about 1-1/2 to 2 hours until the dark brown color of the filtrate became pale orange, indicating the destruction of most of the hydroquinone. Then the filtrate was evaporated on the hot plate until the evolution of H_2SO_4 fumes and at this stage, the sulphuric acid itself

was taken to complete dryness over a moderate Bunsen flame.

The residue minus any traces of hydroquinone was collected in 1:4 sulphuric acid, and color developed by boiling with periodate without the use of phosphoric acid. The color was again read in a Klett Summerson colorimeter at 540 mu and the reducible manganese concentration calculated with reference to a standard curve and converted to an oven-dry basis.

EXPERIMENTAL RESULTS AND DISCUSSION

EXPERIMENT 1 - SOIL DEHYDRATION STUDIES

In addition to the main soil-plant interrelationships that were studied in four separate greenehouse experiments, using moist, 50 per cent moist and dry Akaka subsoils, a separate greenhouse laboratory study was also made with this Akaka subsoil. This study concerned itself with the progressive day by day dehydration of this soil, when exposed to sunlight under greenhouse conditions.

This study devolved itself on:

a) The sequential loss of both weight and volume of the soil, due to loss of moisture on drying. This loss of moisture was irreversible even after 24 hours drying, since even after this period of drying, the soil did not re-wet to the initial moisture level. Of interest in this study was the more or less constant weight/volume ratio at any moisture level. This was of interest in the greenhouse pot experiments, since equal weights of moist, 50 per cent moist, as well as dry soils, occupied more or less the same volume in the cans. As would be expected, the weight/volume ratio on an oven-dry basis, increases characteristically with drying. The relationship is curvilinear. This also reveals the greater amount of mineral matter that a dry soil would have over and above a wet Akaka soil--both occupying the same volume. The data on dehydration are tabulated on Table 2.

TABLE 2.

LABORATORY STUDIES - PROGRESSIVE DEHYDRATION OF AKAKA SUBSOIL

Initial Moisture Content on O.D. Basis						376%
Initial Weight of Soil Taken						200 g
Approximate Volume of Soil Sample						315 ml
	Weight	Volume	Weight/Volume		Per cent Moisture	
Soil Sample	g	ml	Regular	O.D. Basis	On Dehydration	Initial Moisture
Initial	200	315	0.63	0.13	--	100
1 day's drying	178	273	0.65	0.15	324	86
2 days' drying	164	260	0.63	0.16	291	77
3 " "	143	230	0.62	0.18	248	66
4 " "	123	203	0.61	0.21	193	51
5 " "	103	160	0.64	0.26	145	39
6 " "	74	110	0.67	0.38	76	20
7 " "	64	80	0.80	0.53	52	14
8 " "	55	70	0.79	0.60	29	08
9 " "	53	70	0.76	0.60	26	07
10 " "	52	70	0.74	0.60	21	06

b) A partial chemical characterization with progressive drying. This chemical characterization was carried out with respect to cation exchange capacity, exchangeable aluminum, extractable phosphorus and the soil pH.

These data are presented in Table 3. It is interesting to note the very sharp drop in CEC with only two days drying at which time 77 per cent of the initial moisture remained. Kanehiro and Chang (1956) reported a similar drop in CEC from a condition of field moistness to a state of air dryness. However, these data seem to reveal that this break takes place with the very initial losses in soil moisture, with not much change thereafter.

There was not much change in exchangeable aluminum and pH, too, decreases only but slightly on dehydration.

The extractable phosphorus falls very distinctly with drying.

c) A mineralogical (X-ray diffraction, differential thermal analysis) study of the differentially dried soils. The X-ray diffraction patterns and the DTA curves are seen on Figures 1 and 2. While the gibbsite peaks in the 25 per cent moist and dry Akaka are quite prominent in both the X-ray diffraction data and the DTA curves, at higher moisture levels these peaks fade off very rapidly. Even so, the gibbsite peaks in the DTA patterns of the dry soils correspond only to about 10 per cent of gibbsite.[2] This amount of gibbsite appears to be quite low when compared to a figure of 29 per cent

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[2] This quantitative evaluation was made with reference to certain standard curves of Mr. Matsusaka of the Department of Agronomy and Soils, University of Hawaii.

TABLE 3.

PARTIAL CHEMICAL CHARACTERIZATION OF AKAKA SUBSOIL DRIED TO DIFFERENT MOISTURE LEVELS*

	CEC (me/100 g)	Exch:Al (ppm)	Extr. P (ppm)	pH
Moist Soil	103.6	378	35.9	5.3
77% Moist	41.0	393	25.2	5.4
66% Moist	37.3	460	24.6	5.5
51% Moist	36.2	379	22.0	5.3
20% Moist	37.1	291	11.2	5.3
Completely Dried (in sun - 6% Moist)	37.2	390	8.1	5.1

* All the data are expressed on an O.D. Basis.

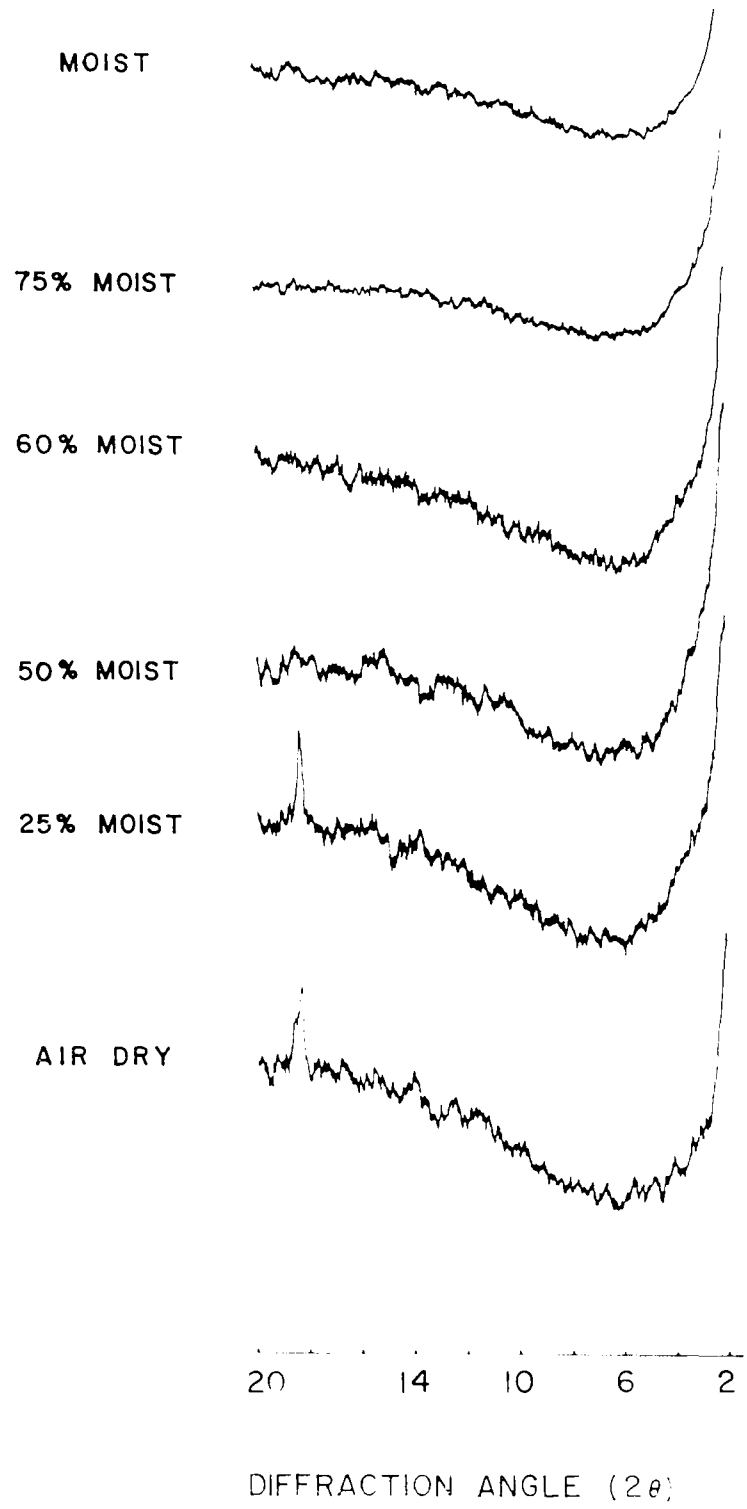

FIGURE 1. X-RAY DIFFRACTION PATTERNS OF AKAKA SUBSOIL WITH PROGRESSIVE DEHYDRATION

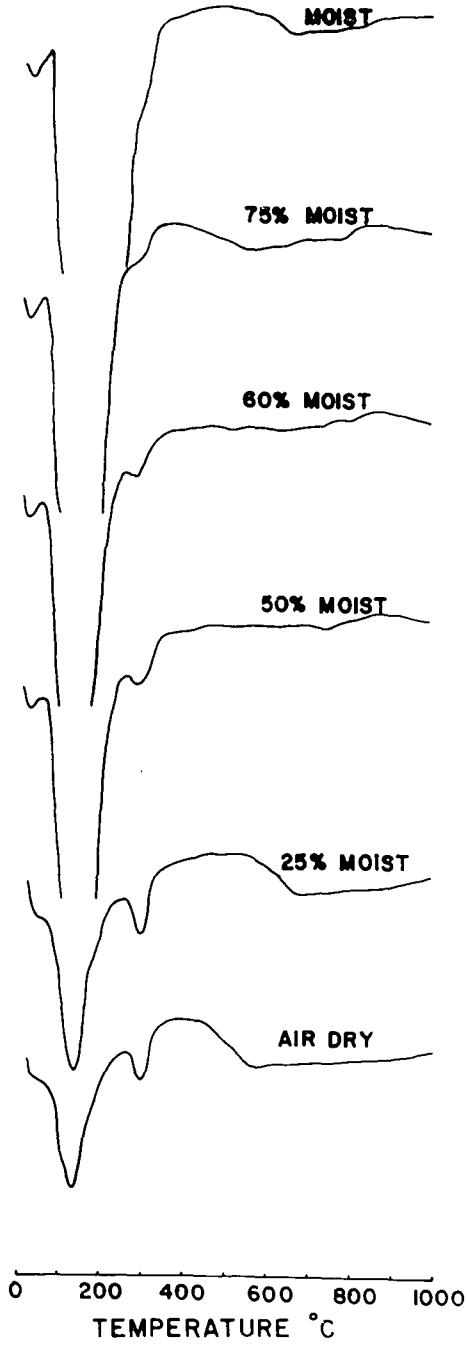

FIGURE 2. DIFFERENTIAL THERMAL ANALYSIS PATTERNS OF AKAKA SUBSOIL WITH PROGRESSIVE DEHYDRATION

gibbsite indicated for Akaka subsoils by Tamura et al. (1953). As to this variation in gibbsite, there is good evidence that even in the so-called subsoil the gibbsite content changes tremendously from layer to layer of the Akaka profile. Howard Tenma (personal communication) working on the same soil has found very prominent X-ray diffraction peaks for gibbsite at the 20 inch depth and beyond the 60 inch depth in the profile but not much gibbsite in between. The present study involved depths between 2 to 5 feet where probably rich gibbsite layers are lacking.

These horizons also appear to vary tremendously in soil reaction. King (1961) working on these subsoils recorded a pH for moist Akaka of 6.5, whereas the pH of the moist Akaka in the soils discussed in this thesis was only 5.4.

Coming back to the formation of gibbsite crystals, mineralogical data seem to indicate the breaking point around 50 to 60 per cent of the initial soil moisture. The very first yellowish gibbsite crystals are even visually evident at the 50 to 60 per cent moisture stage of dehydration (Plate 1). Mineralogically the data appear to suggest an increase in the concentration of gibbsite with dehydration.

EXPERIMENT 2

This experiment consisted of a pot experiment to compare the three lime carriers at three different rates of application with two different levels of phosphorus on Akaka moist (amorphous) and Akaka dry (crystalline) soils.

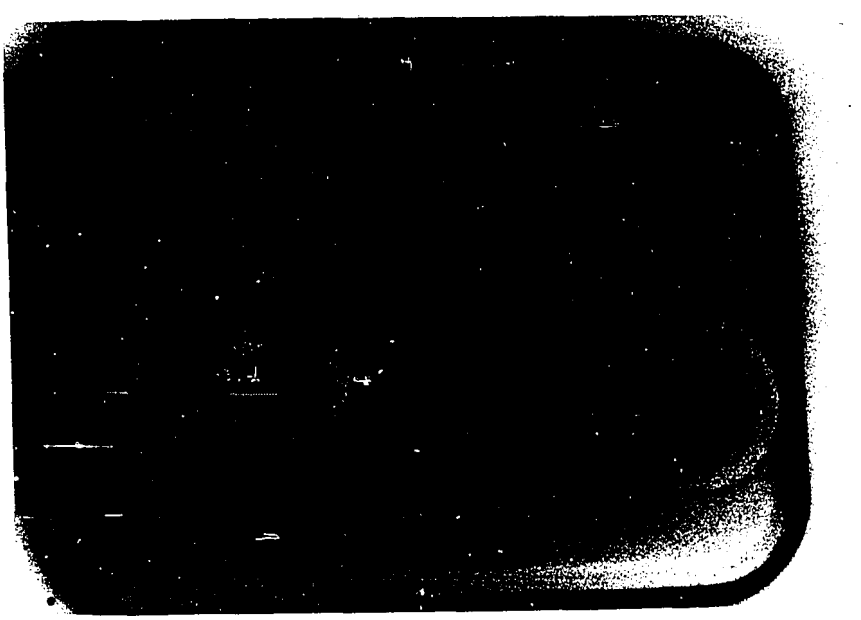

PLATE 1. PROGRESSIVE DEHYDRATION OF AKAKA SUBSOIL. D AND E SHOW INCIPIENT GIBBSITE FORMATION, WITH LOSS OF ABOUT 50 TO 60 % OF SOIL MOISTURE

The experiment was thus a four factor factorial as follows:

1. Lime Carriers
    a) Coral Rock
    b) Calcium Silicate
    c) Olivine Sand
2. Rates of Application
    a) 0
    b) 10, 000 lb/A (20 g/pot)
    c) 20, 000 lb/A (40 g/pot)
3. Phosphorus
    a) 250 lb/A (1.9 g $NH_4H_2PO_4$/pot)
    b) 750 lb/A (5.7 g $NH_4H_2PO_4$/pot)
4. Soils
    a) Akaka Moist (2100 g/pot)
    b) Akaka dry (2100 g/pot)

A total of 36 treatment combinations were replicated thrice.

Results

The results of this experiment left many a thing to be desired. In the first instance, the olivine-treated pots completely failed. In fact, in this instance, the controls were superior to all the olivine-treated pots. Secondly, even in the case of coral rock, the rates of application (5 and 10 tons per acre)

were found to be not the best. As will be seen in Experiment 4, coral rock at these rates actually depressed growth.

Some measure of response to the soil amendments were observed only in the instance of calcium silicate, where the rate of 5 tons per acre was seen to be markedly superior to both the control pots and the 10 tons per acre rate. With calcium silicate as well, data in Experiment 3 showed that the rate of application of 2.5 tons per acre was significantly superior to the other rates.

The mean dry matter yields of sudan grass for the untreated controls as well as for the soil amendment-treated soils are reported below. The means for the untreated controls are the average value for the unlimed pots for all the amendments. Those for the soil amendments are the average value for both rates of application on both moist and dry Akaka subsoil at both levels of P.

	Untreated Control	Coral Rock	Calcium Silicate	Olivine Sand
Sudan grass yields (g dry matter/pot)	1.87	1.88	6.84	0.31

The above figures as well as Plates 2 and 3 convey the hopelessness of trying to make any comparisons of sudan grass yields in this experiment. In fact as Plates 2 and 3 reveal, some of the treatments were so poor at the time of the plant crop harvest that 33 pots out of a total of 108 failed to produce any ratoon crop.

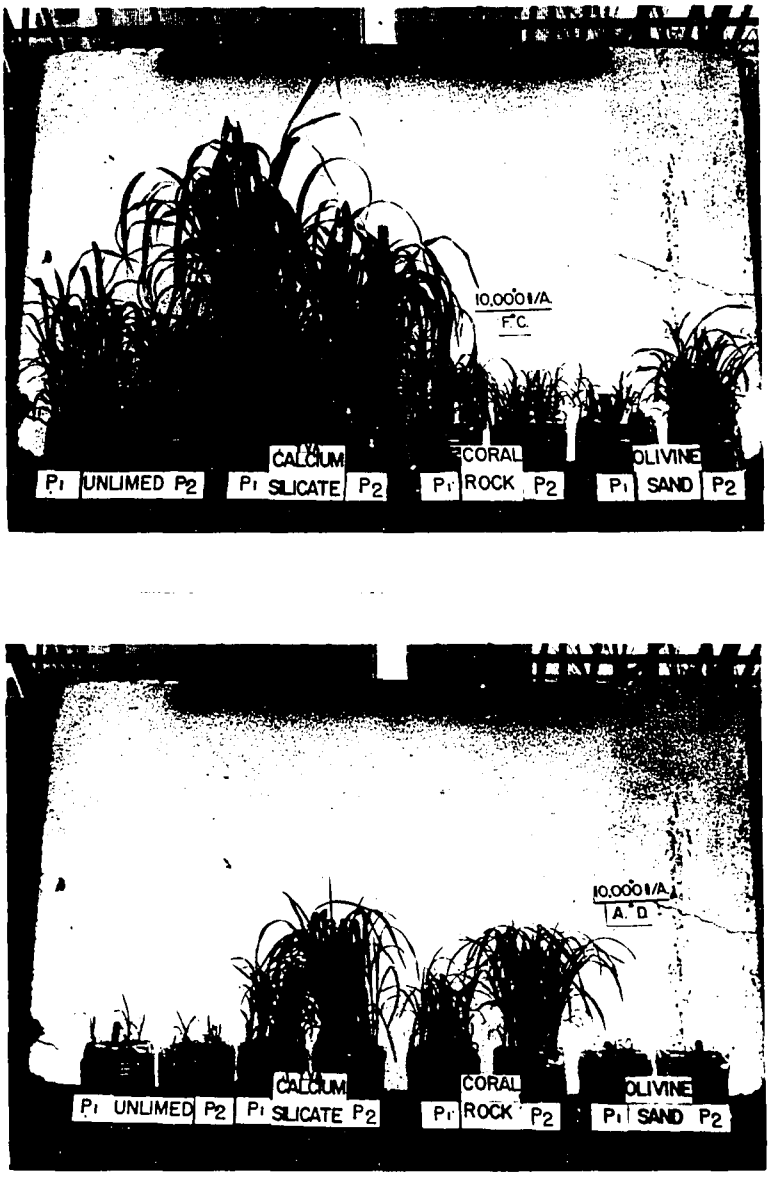

PLATE 2. RESPONSE OF SUDAN GRASS TO THE 3 SOIL AMENDMENTS AT 5 T/A ON AKAKA MOIST (F.C.) AND AKAKA DRY (A.D.) SUBSOIL WITH 250 and 750 LB P/A (P_1 AND P_2)

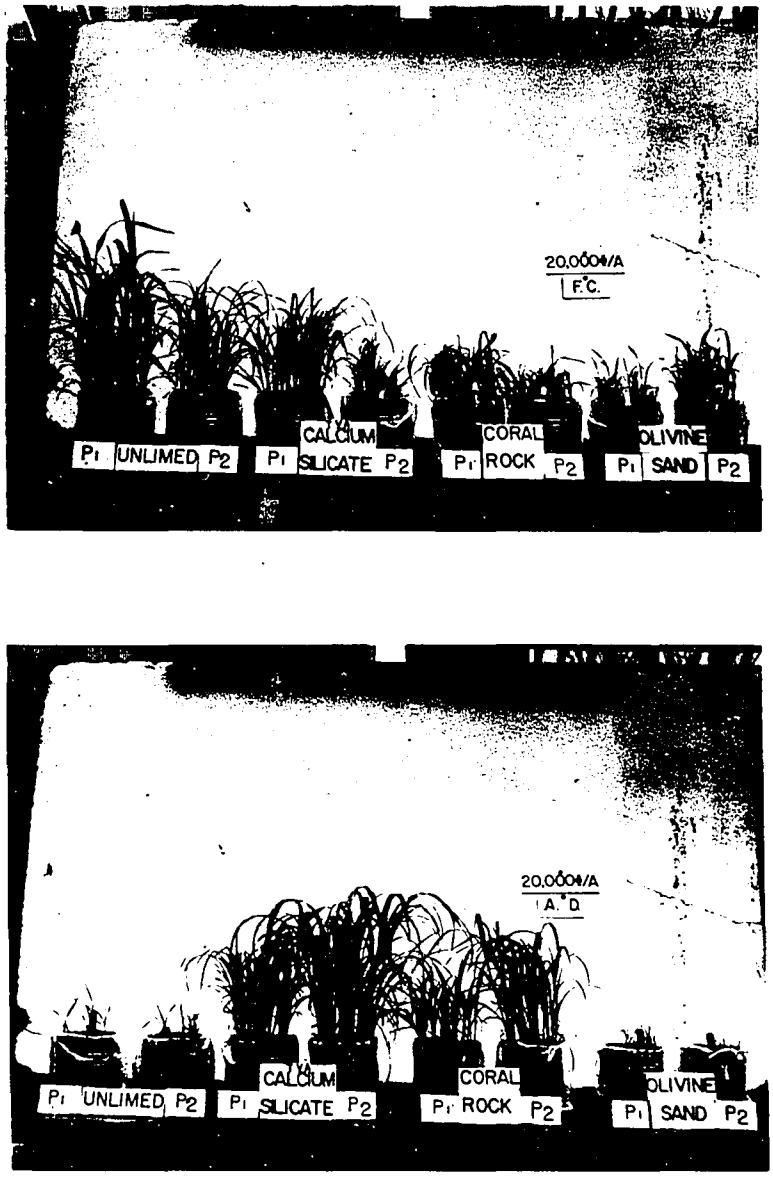

PLATE 3. RESPONSE OF SUDAN GRASS TO THE 3 SOIL AMENDMENTS AT 10 T/A ON AKAKA MOIST (F.C.) AND AKAKA DRY (A.D.) SUBSOIL WITH 250 AND 750 LB P/A (P_1 AND P_2)

Under these circumstances it is not proposed to discuss the results of the dry matter yields or plant composition data relating to this experiment. All the same the entire run of data for the plant crop as well as for the ratoon crop are presented in Tables A and B of the Appendix.

However, the results of the soil analytical data in respect of this experiment, which is more comparable are reported below.

Soil Analytical Data

The following data gives the mean extraction values for the soil elements investigated. These values are averages for the amendment-treated soils (both Akaka moist and dry) at both levels of P.

	Coral Rock	Calcium Silicate	Olivine Sand
Extractable P (ppm)	329	206	31
Exchangeable Al (ppm)	459	450	604
Exchangeable Ca (%)	1.05	0.98	0.03
Exchangeable Mg (%)	0.03	0.02	0.18
Exchangeable K (%)	0.06	0.04	0.06
Exchangeable Mn (ppm)	0.61	1.10	2.50
Reducible Mn (ppm)	1.83	2.27	2.69

With respect to the three soil amendments, the above data reveal some interesting general trends, which no doubt had a bearing on their influence on sudan grass yields.

Both coral rock and calcium silicate-treated soils have given similar magnitudes of exchangeable Ca and Mg. With regard to extractable P and exchangeable K, the slightly lower extractability in the case of calcium silicate-treated soils, must no doubt have been contributed by a greater uptake of these nutrients, due to superior plant growth in some of these calcium silicate-treated soils. Both exchangeable and reducible Mn were appreciably higher in calcium silicate-treated soils, while both coral rock and calcium silicate were equally efficient in depressing exchangeable Al.

Olivine sand as a soil amendment has had no effect on extractable P or exchangeable Ca, while its efficiency in depressing exchangeable Al was also poor. As to be expected Olivine sand-treated soils have a much higher magnitude of exchangeable Mg, when compared to coral rock and calcium silicate-treated soils. The magnitude of exchangeable K too in Olivine sand-treated soils is similar to that of soils treated with the other two amendments. Olivine sand-treated soils also have appreciably higher exchangeable and reducible Mn when compared to the soils treated with coral rock and calcium silicate.

In addition to these general trends, Figures 3 and 4 are illustrative of the behavior of these soil elements, both as a function of dehydration of Akaka subsoil and as influenced by increasing rates of the three soil amendments.

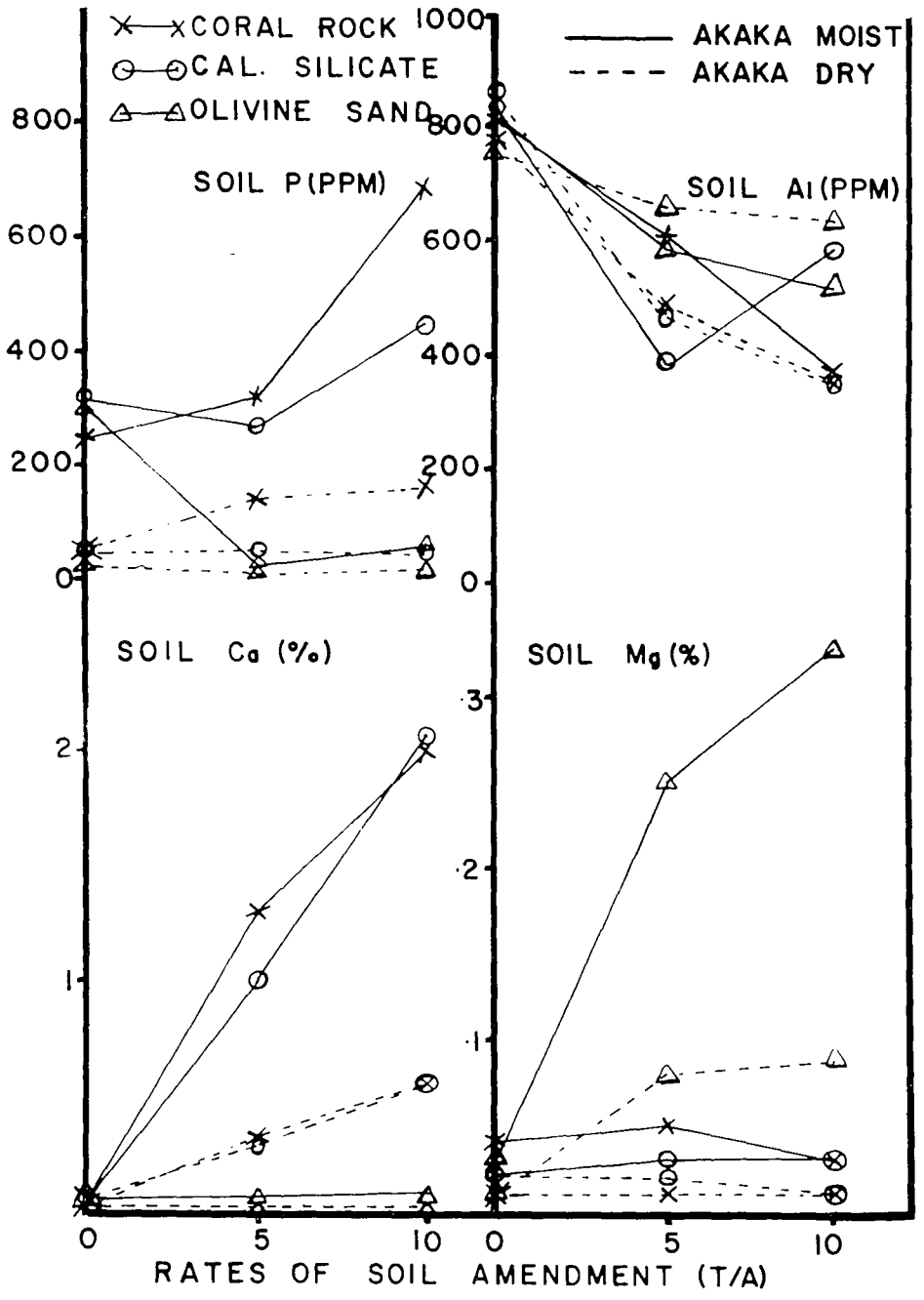

FIGURE 3. EFFECT OF INCREASING RATES OF $CaSiO_3$, CORAL ROCK AND OLIVINE SAND ON EXTRACTABLE P, AND EXCHANGEABLE Ca, Mg, AND Al IN AKAKA MOIST AND AKAKA DRY SUBSOIL

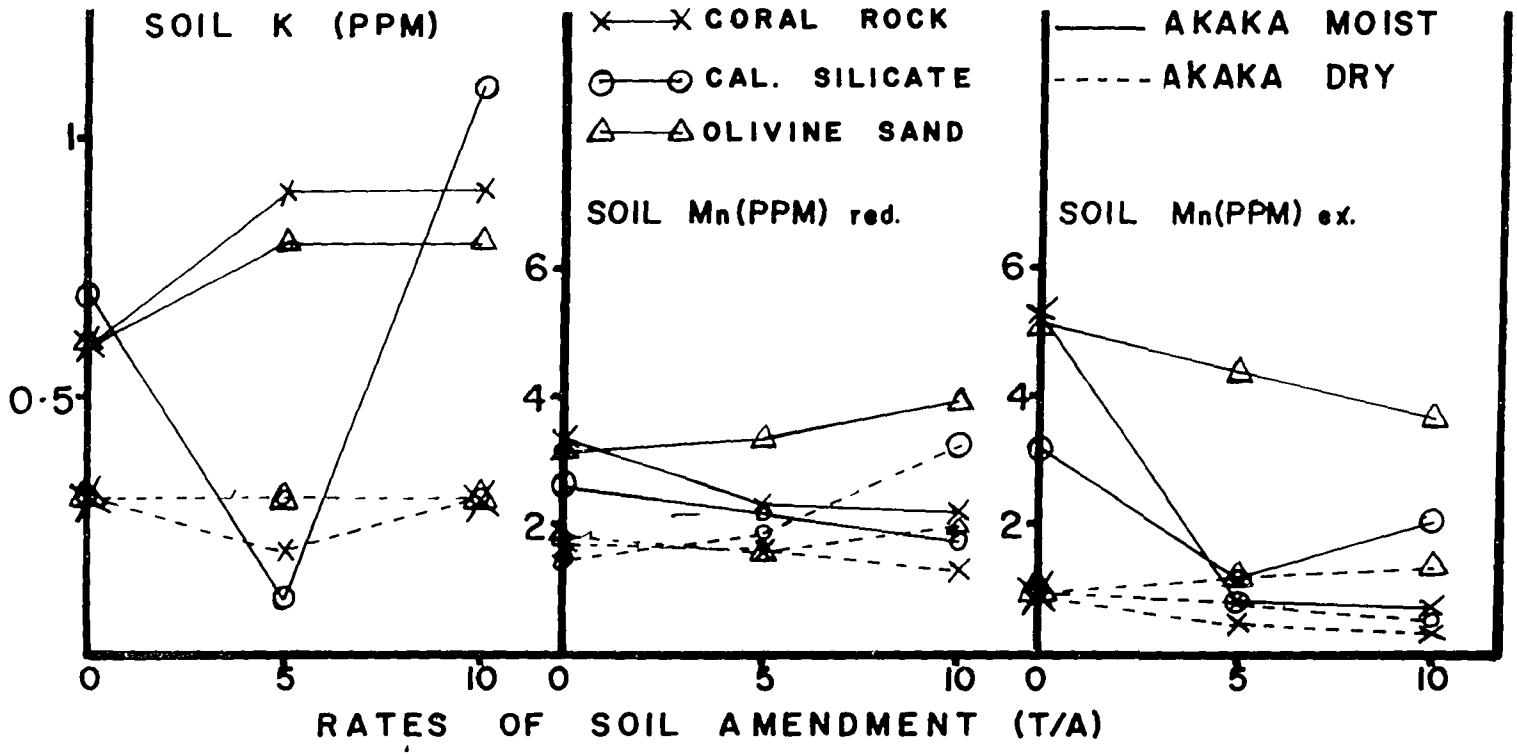

FIGURE 4. EFFECT OF INCREASING RATES OF $CaSiO_3$, CORAL ROCK AND OLIVINE SAND ON EXCHANGEABLE K, Mn AND REDUCIBLE Mn IN AKAKA MOIST AND AKAKA DRY SUBSOIL

Figures 3 and 4 indicate that with the exception of exchangeable Al, the dehydrated soils generally give consistently less extractable and exchangeable nutrients than the moist soils.

In the light of the poor response to Olivine sand in this experiment and in view of the fact that the other two soil amendments have been further investigated in Experiments 3 and 4, it is not proposed to run any statistical analysis on the plant yield data of this experiment.

Discussion

The low extractability of the elements in the dry Akaka soils needs explanation. In the instance of those elements that were applied to the soil either as amendments or as nutrients on a surface area basis, it might be said that the dry soil having 3.4 times more soil on the oven-dry basis than the moist soil, contained smaller amounts of extractable elements. Good as this premise might be, in most instances the extractability of elements in moist Akaka was at least of the order of 4 times that of the extraction in dry Akaka. Therefore, it might well be that the low extractability of the several elements in the dry Akaka soil may be something more than a simple relationship between amount of element applied and amount extracted. In this respect, Fried and Shapiro's (1961) views on soil-plant relationships in ion uptake are quite interesting. They view the availability of soil nutrients to plants as a capacity factor and that the greater the amount of an element in the soil, the more easily would it be released to the soil solution and, therefore,

rendered available for plant nutrition. They contended that the greater the amount of nutrient supplied to a soil, the more easily would it be available. On the other hand, if a nutrient was in short supply, it would be so tightly held to the soil colloids, that its availability would be drastically reduced. If, therefore, one were to apply this theory to the difference in extractability of elements between Akaka moist and Akaka dry, one might say that the Akaka dry having less nutrients applied on a oven-dry matter basis, had a low capacity facotr. This, in turn, would have yielded smaller amounts of elements to the extracting agents when compared with the moist Akaka soils, having apparently a larger capacity factor.

The above thinking ties in also with that of Hsu (unpublished paper of the Pennsylvania State University), who has reported a similar view in the fixation of phosphorus at a soil pH above 5. Hsu contended that P fixation above pH 5 was mainly a phenomenon of surface reaction or adsorption by amorphous iron and or aluminum compounds and not precipitation by ionic Al^{+++} or Fe^{+++}. The latter he contended was important only under more acid conditions. His contention was that when the adsorbing surface was nearly saturated with P, then the absorbed P is highly available. On the contrary, he contended that when a small amount of P was adsorbed by a large amount of adsorbent, then the P was difficultly available. The work of Monteith and Sherman (1963) also revealed considerably less extraction of P and Ca from

a Puhi soil as compared to a Akaka soil, P and Ca having been applied on a surface area basis.

With reference to the three liming materials in this experiment, the poor performance of Olivine as a soil amendment becomes quite obvious in the low extractable P and exchangeable Ca values. Besides, its efficiency in reducing exchangeable Al is also low. It also contributes to an extremely low exchangeable Ca/Mg ratio in the soil. All these adverse factors no doubt contributed to its poor status as a soil amendment in this investigation. In respect to exchangeable K, it is comparable to the other two amendments. It also yields higher levels of both exchangeable and reducible Mn which can be explained by its higher content of Mn as compared to coral rock and calcium silicate (see Table 1).

Calcium silicate and coral rock are quite comparable in their yield of extractable and exchangeable elements. Two peculiarities with calcium silicate may require some explanation though. The first is with regard to exchangeable K, in which case there is a characteristic drop at the 5 ton rate of application. This could well be due to a higher plant yield at this point and a consequently a greater uptake of K. The other point in need of discussion would be the upswing in exchangeable Al at the 10 ton rate of application. The only explanation the writer can offer is the probability of resolubilization of Al at high pH values as reported by Magistad (1925), who

reported this tendency at pH values greater than 7.8. At this level of treatment, in this investigation, post incubation pH values up to 8.1 and post harvest pH values of 7.6 and 7.7 were recorded.

EXPERIMENT 3

This investigation was an inquiry on soil-plant interrelationships with various levels of calcium silicate, using sudan grass as the indicator crop. Four levels of calcium silicate were originally intended to be investigated. However, in view of Reddy's (1964) and Rana's (1964) report of a depression of yield with high levels of lime, it was decided to include another treatment to check on the possibility of micro-nutrient deficiencies with high levels of liming. Therefore, in addition to the four levels of silicate, a fifth treatment comprising a micro-nutrient supplement plus the highest level of lime was incorporated into the experiment. Since this would upset the statistical orthogonality of the design, the experiments have been statistically analyzed in two components.

The experiment itself was a 3 factorial experiment as follows:

1. Calcium Silicate

    a) 0

    b) 2.5 tons/A (10 g/pot)

    c) 5 tons/A (20 g/pot)

    d) 10 tons/A (40 g/pot)

    e) 10 tons/A + micro-nutrient supplement

2. Degrees of Dehydration of Akaka subsoil

   a) Moist (2100 g/pot)

   b) 50 per cent moist (2100 g/pot)

   c) Dry (2100 g/pot)

3. Phosphate

   a) 250 lb P/A (1.9 g/pot as $NH_4H_2PO_4$)

   b) 750 lb P/A (5.7 g/pot as $NH_4H_2PO_4$)

A total of 30 treatments were replicated thrice, in a randomized block layout.

Results

Table C of the Appendix gives a complete picture of the dry matter yields of sudan grass together with the data on plant composition and soil analysis. In addition, Figure 5 gives a histogram of the interaction of calcium silicate x soil dehydration x phosphorus.

For purposes of statistical analysis of the plant yield data, the experiment was considered as two discrete setups, viz:

1. The comparison of four levels of soil amendment (0, 2.5, 5, and 10 tons per acre) x degree of soil dehydration (moist, 50% moist, dry) x two levels of P (250 and 750 lb/A).

2. The comparison of 10 tons of soil amendment per acre with and without the micro-nutrients supplement x degree of soil dehydration (moist, 50% moist, dry) x two levels of P (250 and 750 lb/A).

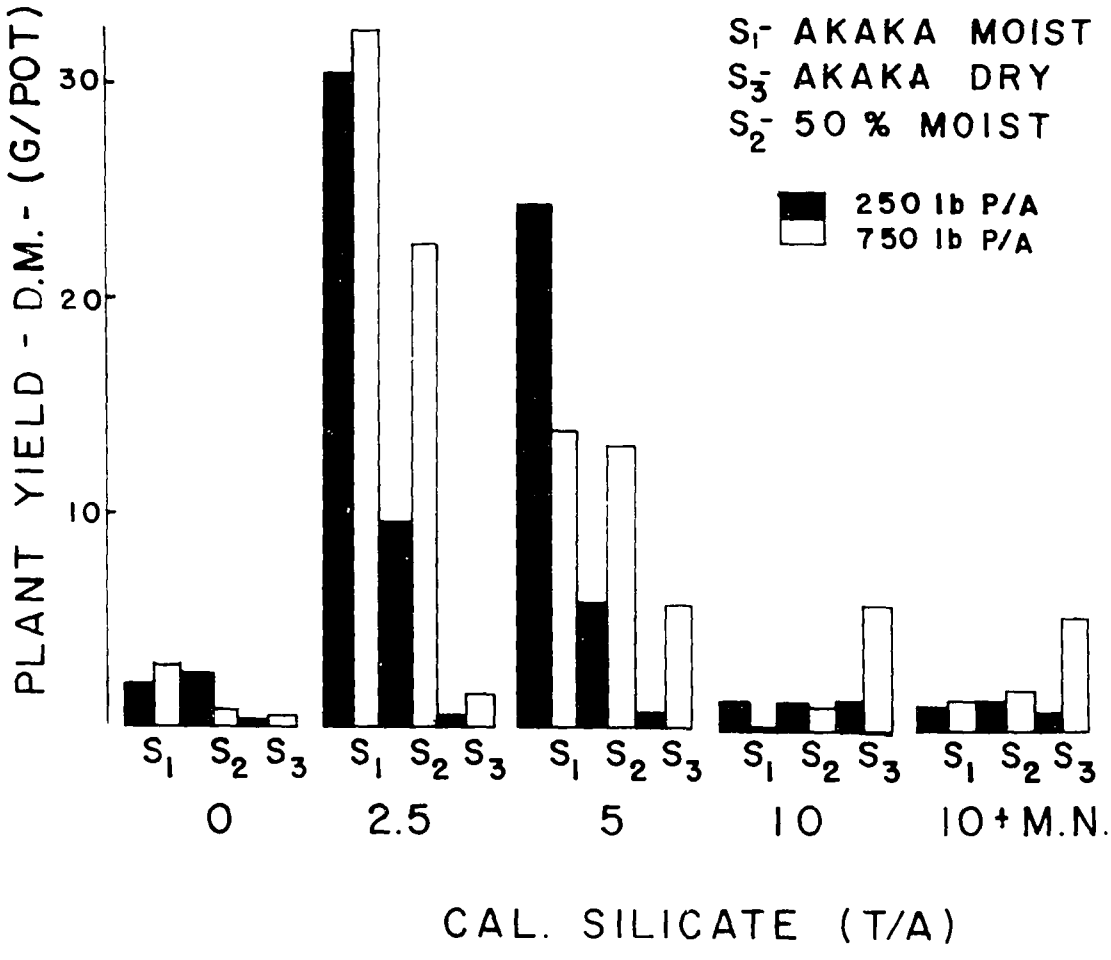

FIGURE 5. INTERACTION OF VARYING RATES OF $CaSiO_3$ X DEGREE OF DEHYDRATION OF AKAKA SUBSOIL X TWO LEVELS OF PHOSPHORUS

Table 4 gives a summary of the variance analysis on the plant yields for the first component of the experiment. All the main effects and the interactions are significant at the 1 per cent level of probability.

The differences in the mean yields of the main treatments are reported below.

CALCIUM SILICATE (Ton/A)

	0	2.5	5	10
Sudan grass yields (g dry matter/pot)	1.49	16.26	10.81	1.99

D (5% level) = 3.73

DEGREE OF DEHYDRATION OF SOIL

	Akaka Moist	50% Moist	Air-Dry
Sudan grass yields (g dry matter/pot)	13.59	7.14	2.13

D (5% level) = 3.39

PHOSPHATE (Lb/A)

	250	750
Sudan grass yields (g dry matter/pot)	6.78	8.49

D (5% level) = 2.51

It is interesting to note that even though the variable P was significant, yet no difference can be demonstrated between the two means. This may be due to insufficient replication.

TABLE 4.

SUMMARY OF VARIANCE ANALYSIS DATA ON SUDAN GRASS YIELDS (DRY MATTER) IN A THREE FACTORIAL EXPERIMENT WITH FOUR LEVELS OF CALCIUM SILICATE - TVA SLAG - (0, 2.5, 5 AND 10 T/A) x THREE DEGREES OF SOIL DEHYDRATION (MOIST, 50% MOIST, DRY) x TWO LEVELS OF PHOSPHORUS (250 AND 750 LB/A)

Variates	D.F.	Calculated "F" Values	Table "F" Values 5%	1%
Replicates	2	0.55	3.20	5.10
Calcium Silicate (C)	3	314.51**	2.81	4.24
Soils (S)	2	267.59**	3.20	5.10
Phosphate (P)	1	17.88**	4.05	7.21
C x S	6	113.90**	2.30	3.22
C x P	3	10.70**	2.81	4.24
S x P	2	26.12**	3.20	5.10
C x S x P	6	17.54**	2.30	3.22
	46			
TOTAL	71			

With calcium silicate the best combination of effects appear to be a rate of application of 2.5 tons per acre on moist Akaka subsoil. The higher level of P does not influence the plant yield to any great extent (See Figure 5).

Table 5 gives a summary of the variance analysis on the plant yield data for the second component of this experiment. In this instance, only the main effects--soil and phosphate--and their interaction are significant at the 1 per cent level. Calcium silicate x soil interaction is only significant at the 5 per cent level.

The differences in mean yields of the two significant main effects are reported below.

DEGREE OF DEHYDRATION OF SOIL

	Akaka Moist	50% Moist	Air-Dry
Sudan grass yields (g dry matter/pot)	1.18	1.61	3.50

D (5% level) = 1.07

PHOSPHORUS (Lb/A)

	250	750
Sudan grass yields (g dry matter/pot)	1.43	2.77

D (5% level = 0.88

The above data reveal two rather interesting points. First, that at this level of calcium silicate (10 tons per acre), the depression in yield with

TABLE 5.

SUMMARY OF VARIANCE ANALYSIS DATA ON SUDAN GRASS YIELDS (DRY MATTER) IN A THREE FACTORIAL EXPERIMENT HAVING CALCIUM SILICATE AT 10 T/A (WITH AND WITHOUT A MICRO-NUTRIENT DRESSING) x THREE DEGREES OF SOIL DEHYDRATION (MOIST, 50% MOIST, DRY) x TWO LEVELS OF PHOSPHORUS (250 AND 750 LB/A)

Variates	D.F.	Calculated "F" Values	Table "F" Values 5%	1%
Replicates	2	0.19	3.44	5.72
Calcium Silicate (C)	1	1.59	4.30	7.94
Soil (S)	2	67.48**	3.44	5.72
Phosphate (P)	1	60.00**	4.30	7.94
C x S	2	5.73*	3.44	5.72
C x P	1	3.70	4.30	7.94
S x P	2	82.37**	3.44	5.72
C x S x P	2	2.33	3.44	5.72
	22			
TOTAL	35			

increasing levels of calcium silicate is not counteracted by application of micro-nutrient elements. Even if micro-nutrients are involved, other factor(s) appear dominant.

Even though the yields per pot are not high, the other interesting point that emerges is that, at this level of calcium silicate, the response shifts from moist Akaka to dry Akaka. Plates 4 and 5 illustrate the response of sudan grass to the various interactions.

Plant and Soil Analysis

The soil analysis data in this experiment, too, show a considerably reduced extractability of P, Ca and K as a function of dehydration. The extractability of Al and Mg is hardly affected by dehydration while in the instance of Mn, the dry Akaka has a slightly higher extractability than the moist and the 50 per cent moist Akaka. The yield data also show a very distinct trend of yield depression with dehydration, which is well matched by the reduced extractability of P, Ca and K on dehydration.

The trends in plant composition in its relation to plant yield are not well defined. However, a few observable trends with respect to the several elements analyzed are as follows: The Figures 6 - 13 show the interrelationships between plant yield versus soil and plant analysis.

Phosphorus. (Figure 6) In the case of Akaka moist and 50 per cent moist, there is marked depression at calcium silicate levels of 2.5 tons per acre and 10 tons per acre. Concentration of plant P in dry Akaka was quite

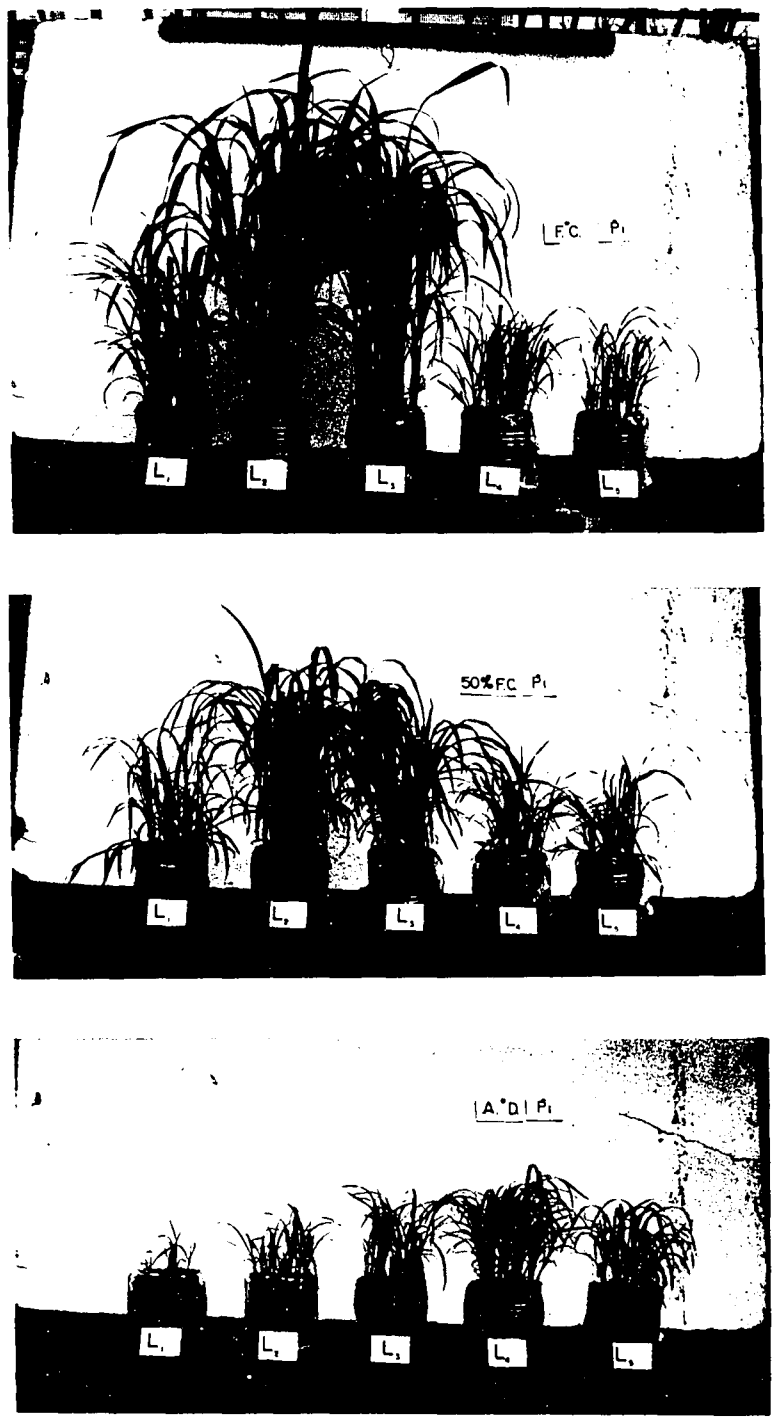

PLATE 4. RESPONSE OF SUDAN GRASS TO $CaSiO_3$ LEVELS--L_1 TO L_5--(0, 2.5, 5, 10, AND 10 T/A + MICRO-NUTRIENTS), ON AKAKA SUBSOIL DEHYDRATED TO DIFFERENT DEGREES WITH P AT 250 LB/A

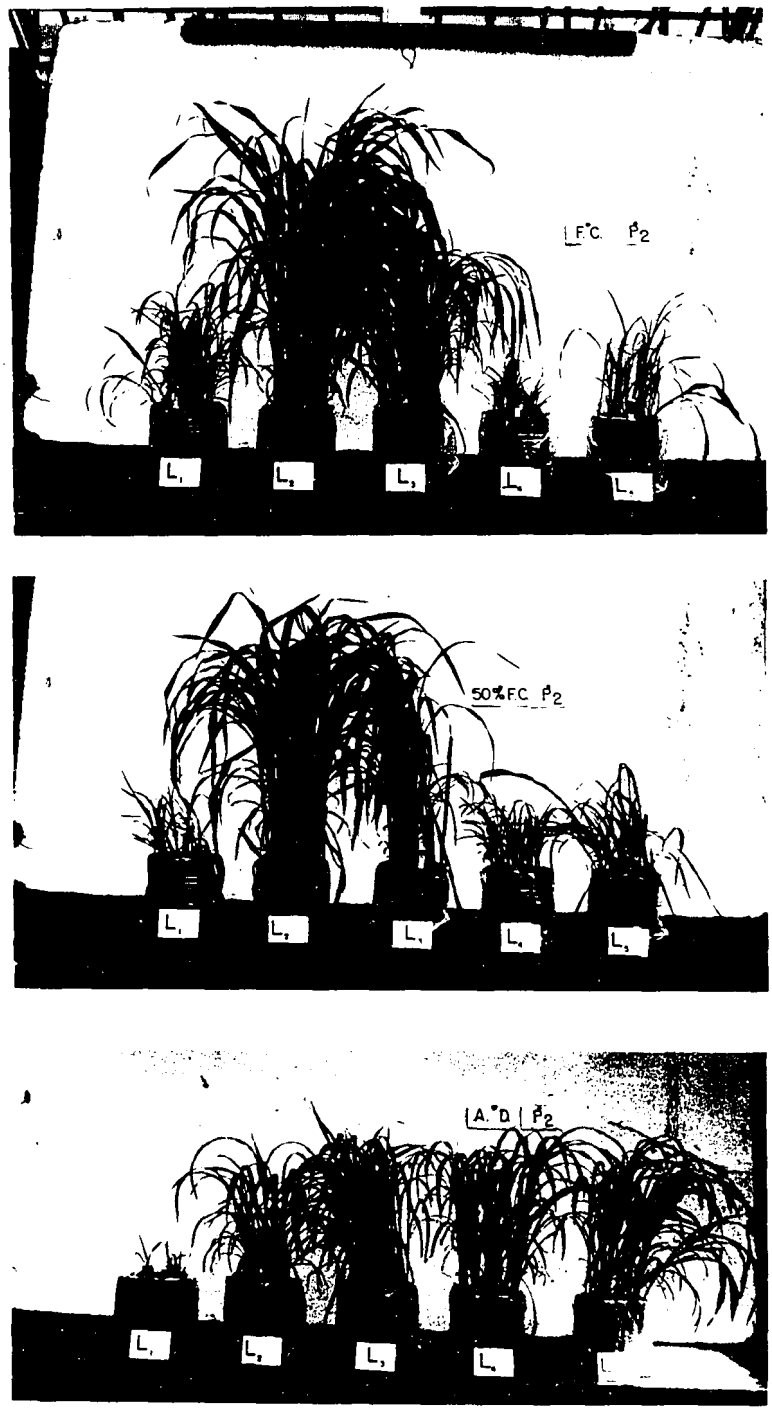

PLATE 5. RESPONSE OF SUDAN GRASS TO $CaSiO_3$ LEVELS--L_1 TO L_5--(0, 2.5, 5, 10, AND 10 T/A + MICRO-NUTRIENTS), ON AKAKA SUBSOIL DEHYDRATED TO DIFFERENT DEGREES WITH P AT 750 LB/A

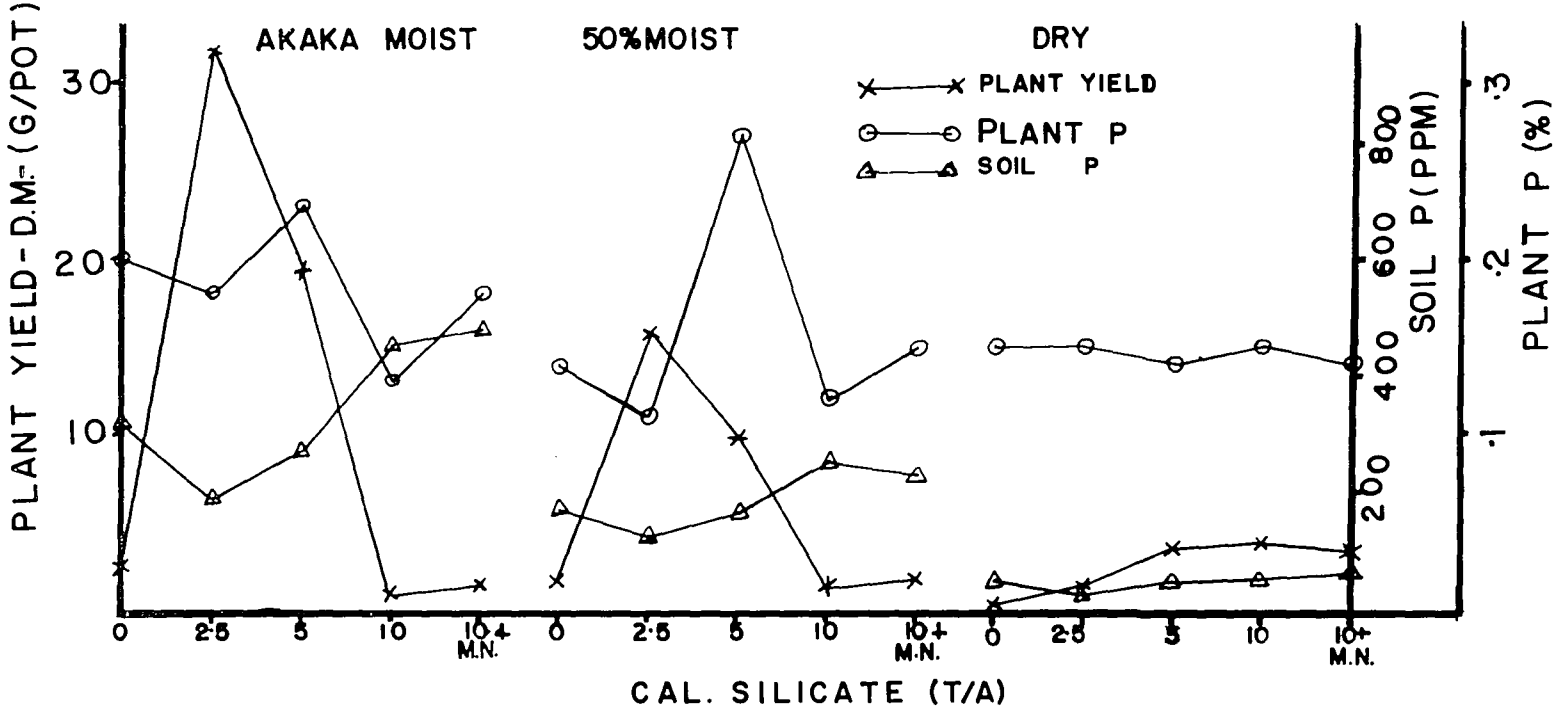

FIGURE 6. SUDAN GRASS YIELD IN RELATION TO EXTRACTABLE SOIL P AND PLANT P WITH INCREASING RATES OF $CaSiO_3$, ON AKAKA MOIST, 50% MOIST AND AKAKA DRY SUBSOIL

Aluminum. (Figure 7) Plant concentration remains more or less constant irrespective of treatment.

Calcium. (Figure 8) Plant concentration seems to level off from the first level of calcium silicate.

Magnesium. (Figure 9) A depression of plant Mg is observable with increasing levels of calcium silicate.

Potassium. (Figure 10) Plant K more or less levels off from the first level of calcium silicate, except in 50 per cent moist Akaka, where the trend is erratic.

Manganese. (Figure 11) Plant Mn falls with increasing levels of calcium silicate, but the Mn concentration noticeably picks up with the micro-nutrient treatment.

Zinc. (Figure 12) There is again a depression of plant Zn with a very steep increase in concentration at 10 tons per acre of calcium silicate both with and without the micro-nutrient supplement.

Silicon. (Figure 13) A very characteristic depression of plant silicon is observed at the highest level of calcium silicate.

Discussion

The following data with reference to soil dehydration will show the very direct relationship that extractable P and exchangeable Ca and K have to dry matter yields.

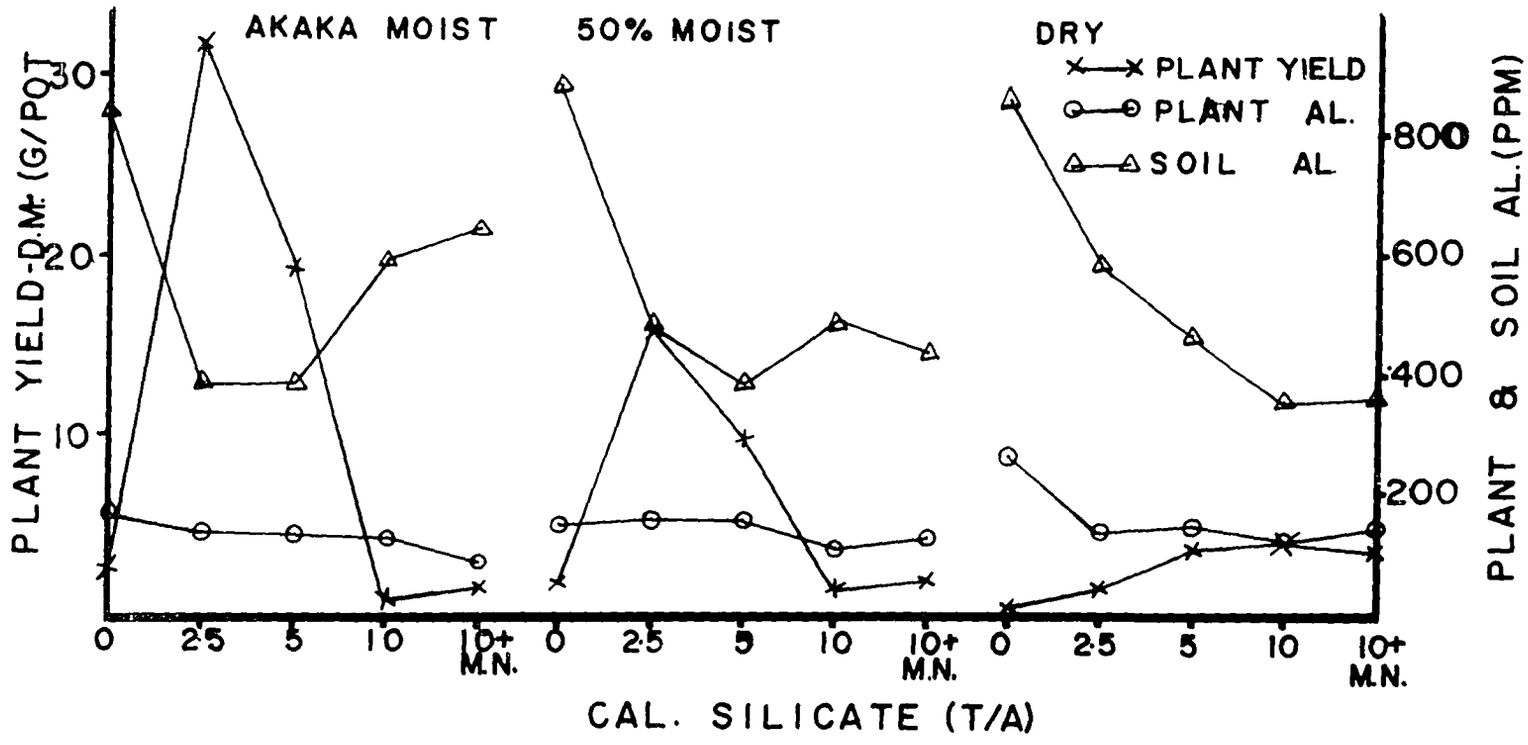

FIGURE 7. SUDAN GRASS YIELD IN RELATION TO EXCHANGEABLE SOIL A1 AND PLANT A1, WITH INCREASING RATES OF $CaSiO_3$, ON AKAKA MOIST, 50% MOIST AND AKAKA DRY SUBSOIL

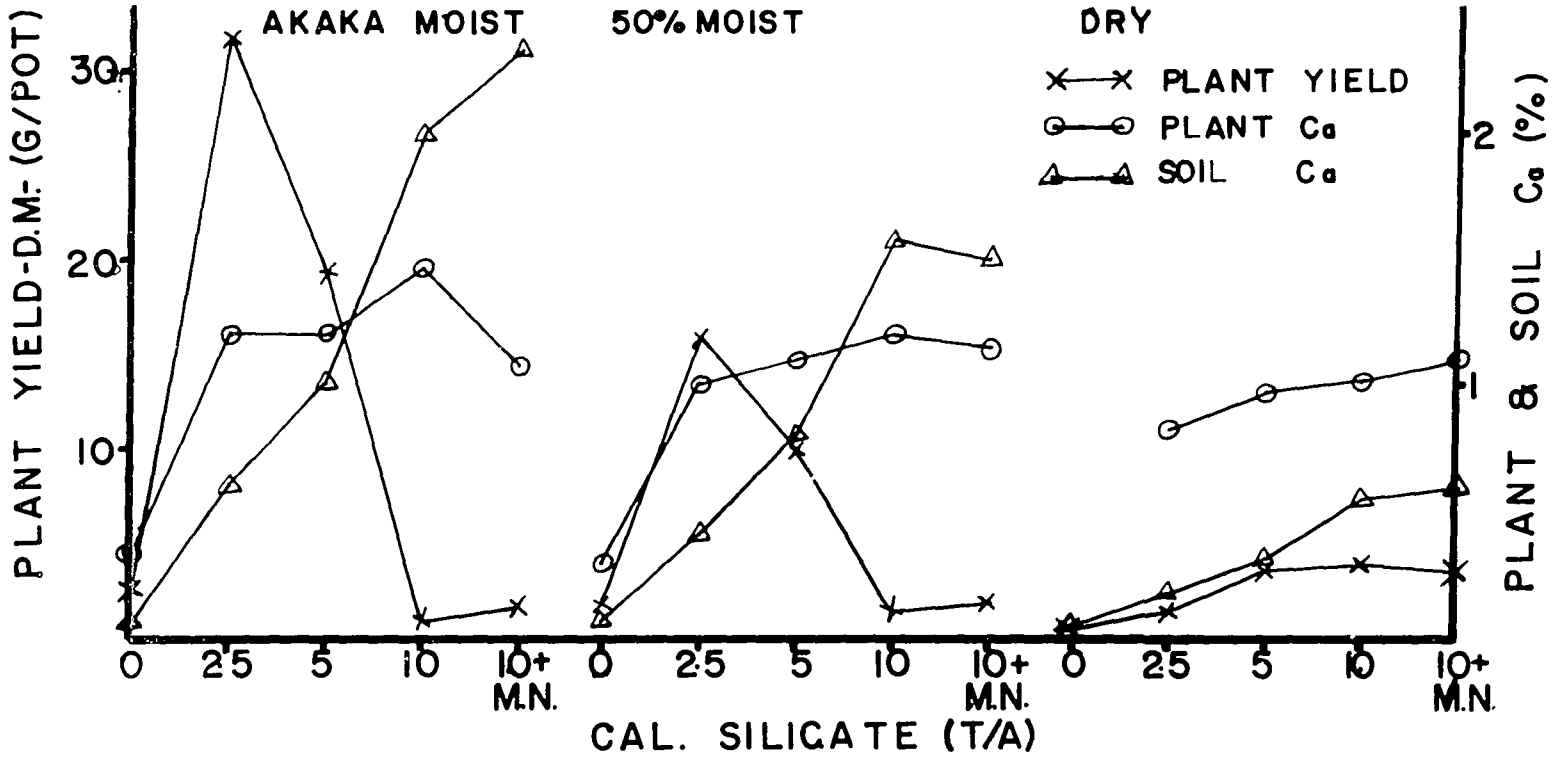

FIGURE 8. SUDAN GRASS YIELD IN RELATION TO EXCHANGEABLE SOIL Ca AND PLANT Ca WITH INCREASING RATES OF $CaSiO_3$ ON AKAKA MOIST, 50% MOIST, AND AKAKA DRY SUBSOIL

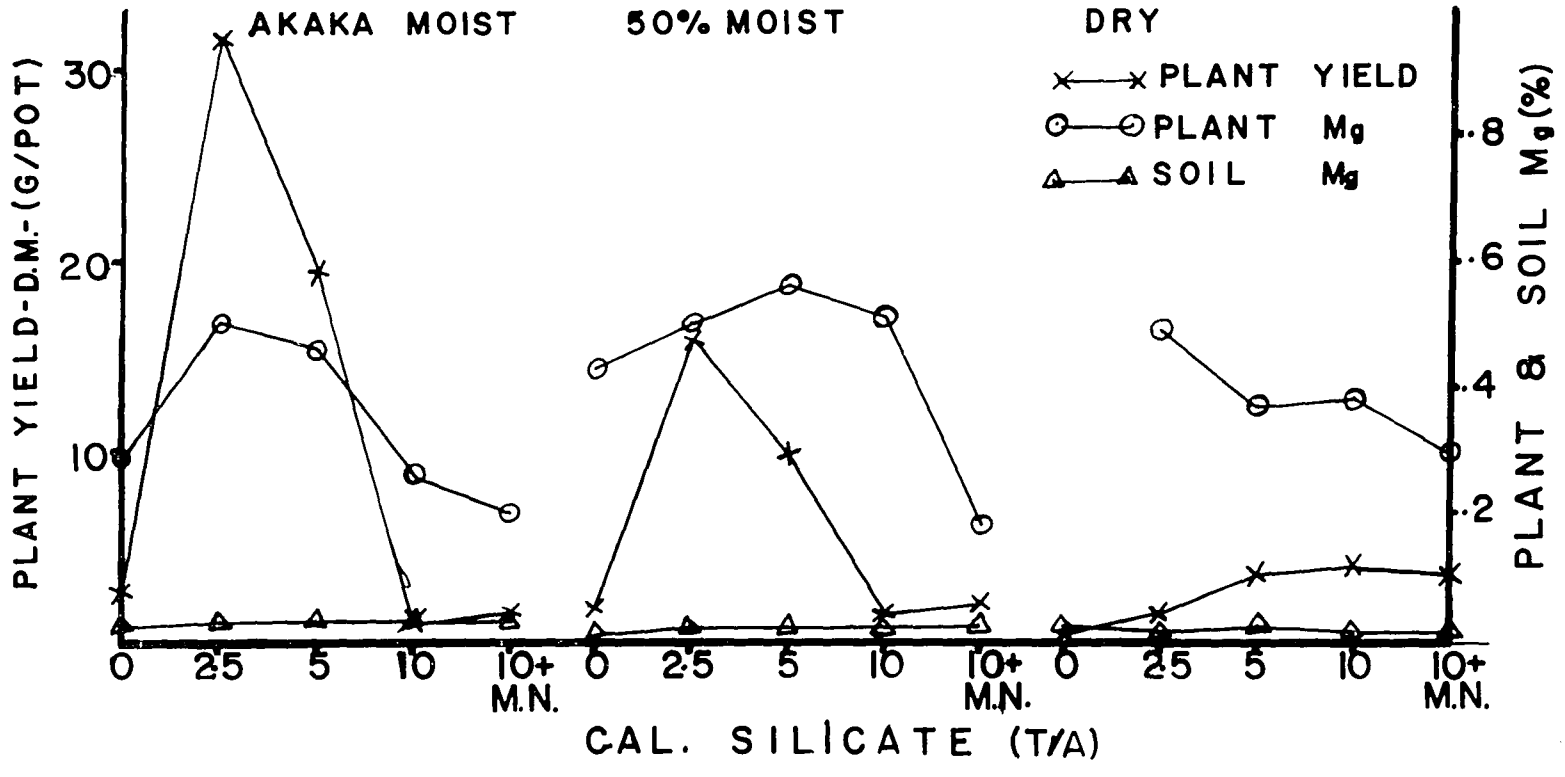

FIGURE 9. SUDAN GRASS YIELD IN RELATION TO EXCHANGEABLE SOIL Mg AND PLANT Mg WITH INCREASING RATES OF $CaSiO_3$ ON AKAKA MOIST, 50% MOIST, AND AKAKA DRY SUBSOIL

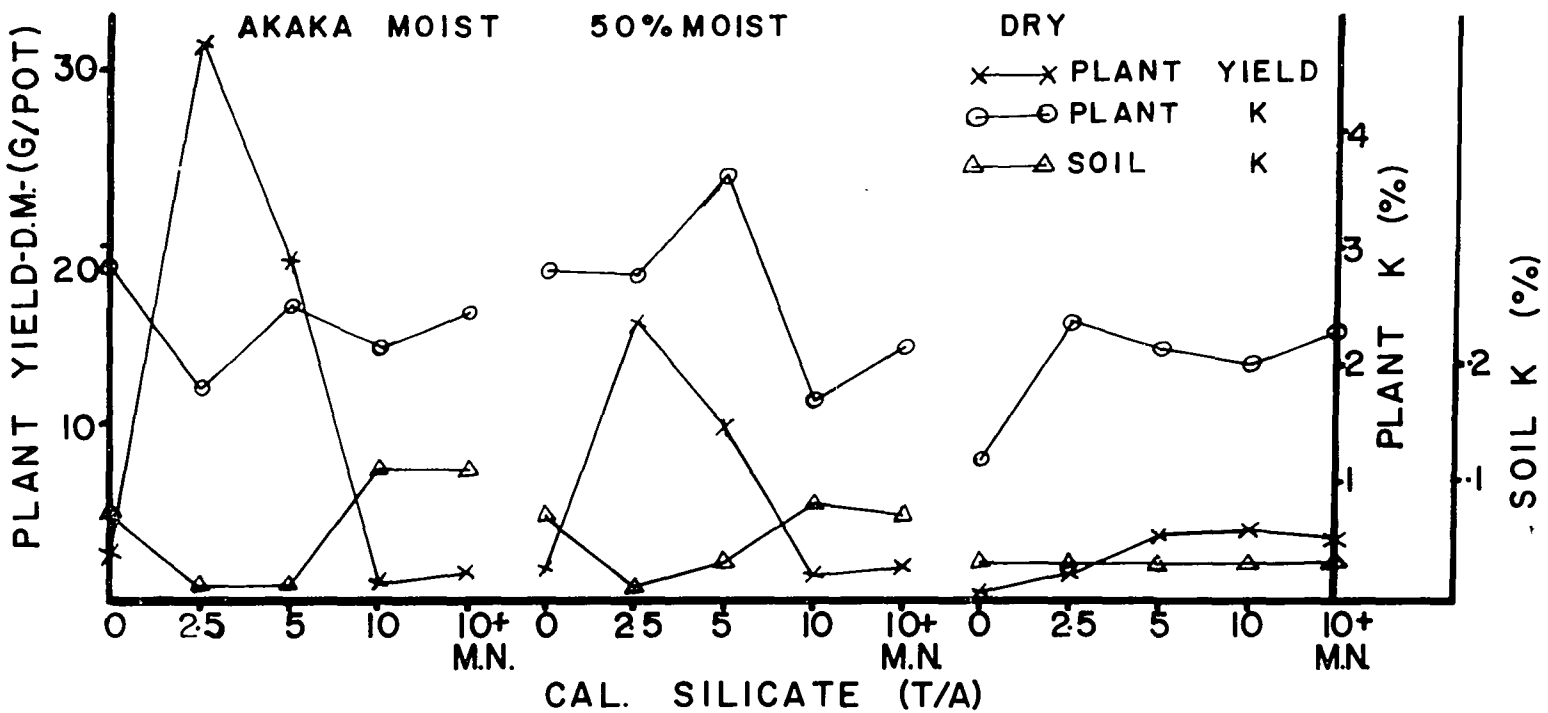

FIGURE 10. SUDAN GRASS YIELD IN RELATION TO EXCHANGEABLE SOIL K AND PLANT K WITH INCREASING RATES OF $CaSiO_3$, ON AKAKA MOIST, 50% MOIST AND AKAKA DRY SUBSOIL

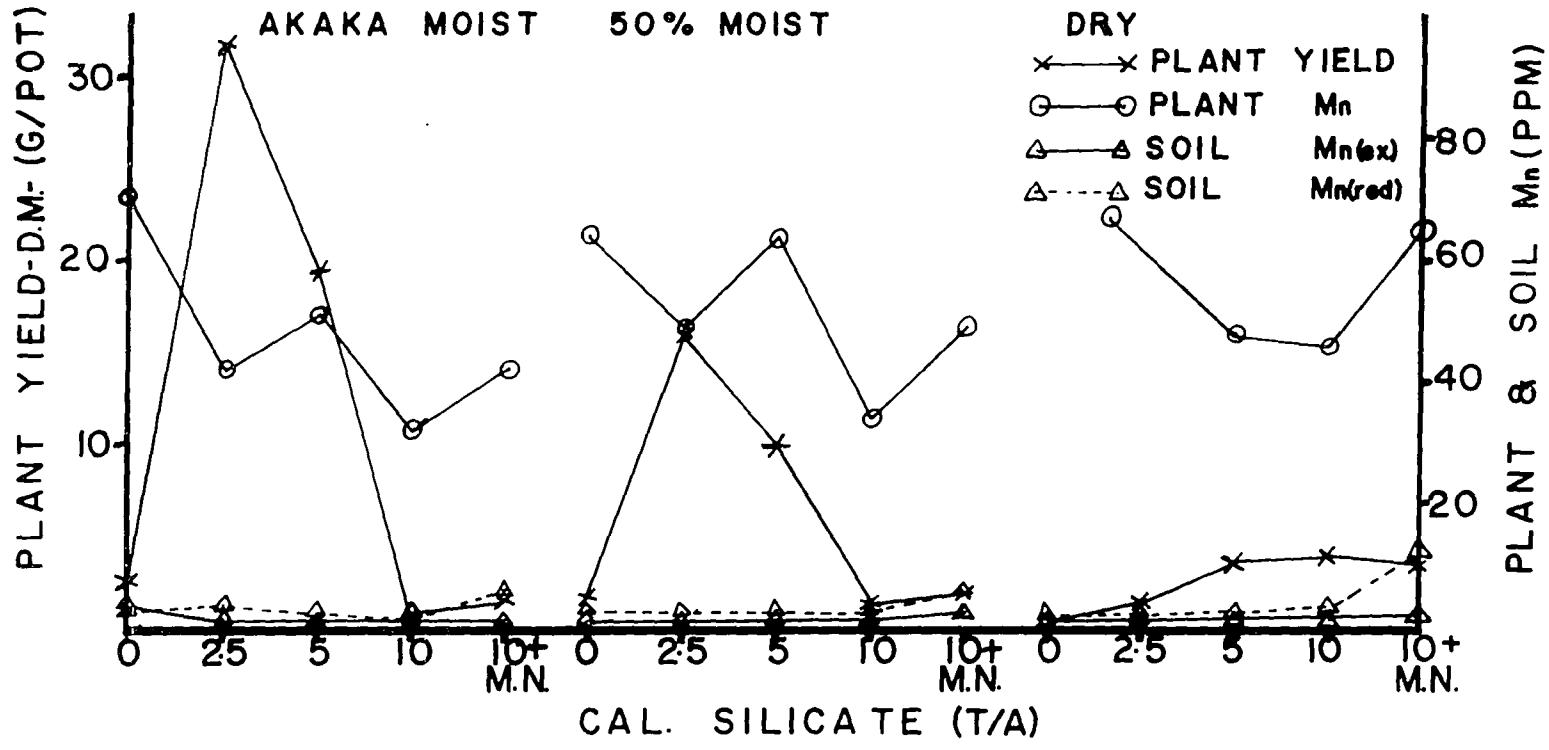

FIGURE 11. SUDAN GRASS YIELD IN RELATION TO EXCHANGEABLE AND REDUCIBLE SOIL Mn AND PLANT Mn WITH INCREASING RATES OF $CaSiO_3$ ON AKAKA MOIST, 50% MOIST AND AKAKA DRY SUBSOIL

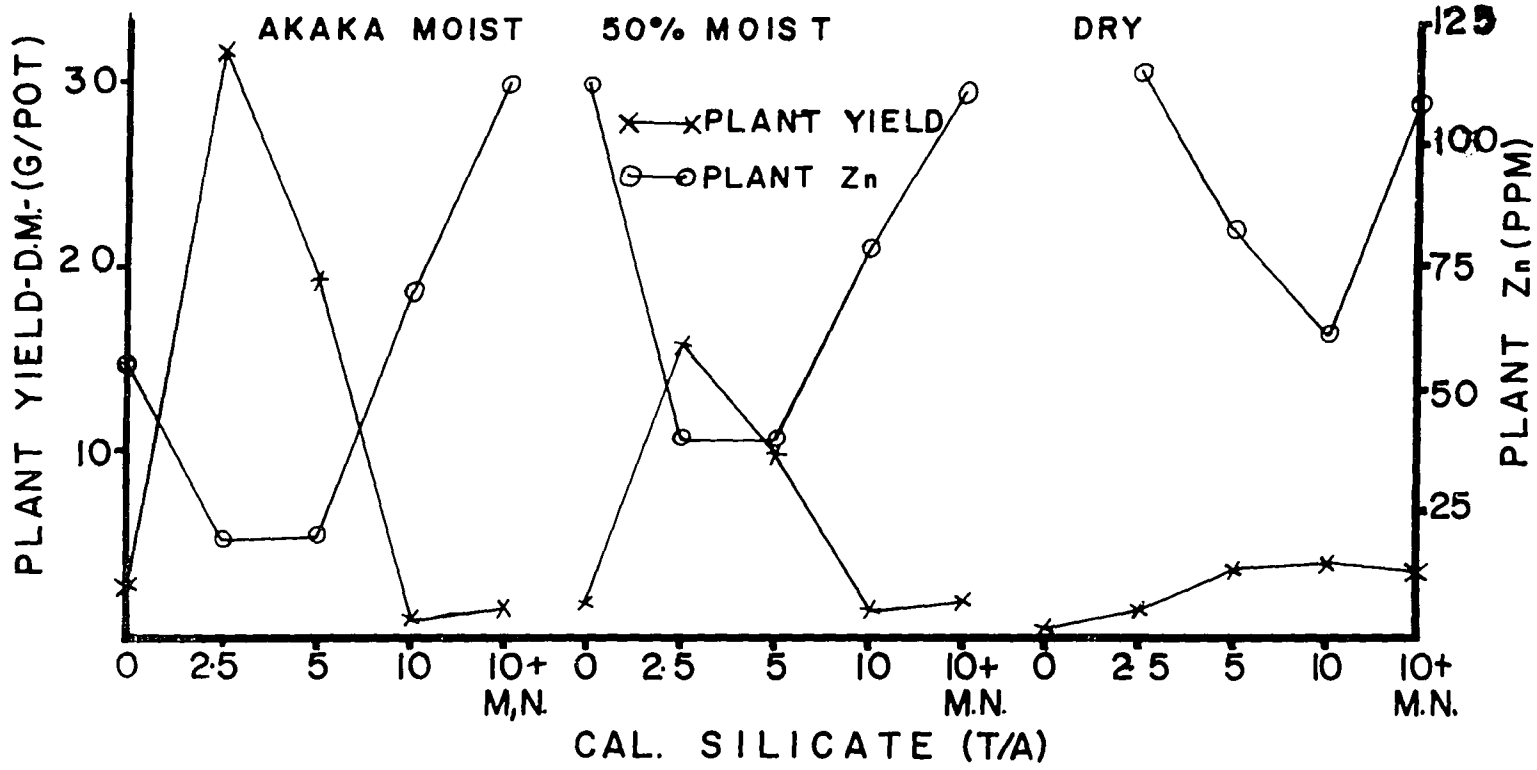

FIGURE 12. SUDAN GRASS YIELD IN RELATION TO PLANT Zn WITH INCREASING RATES OF $CaSiO_3$ ON AKAKA MOIST, 50% MOIST AND AKAKA DRY SUBSOIL

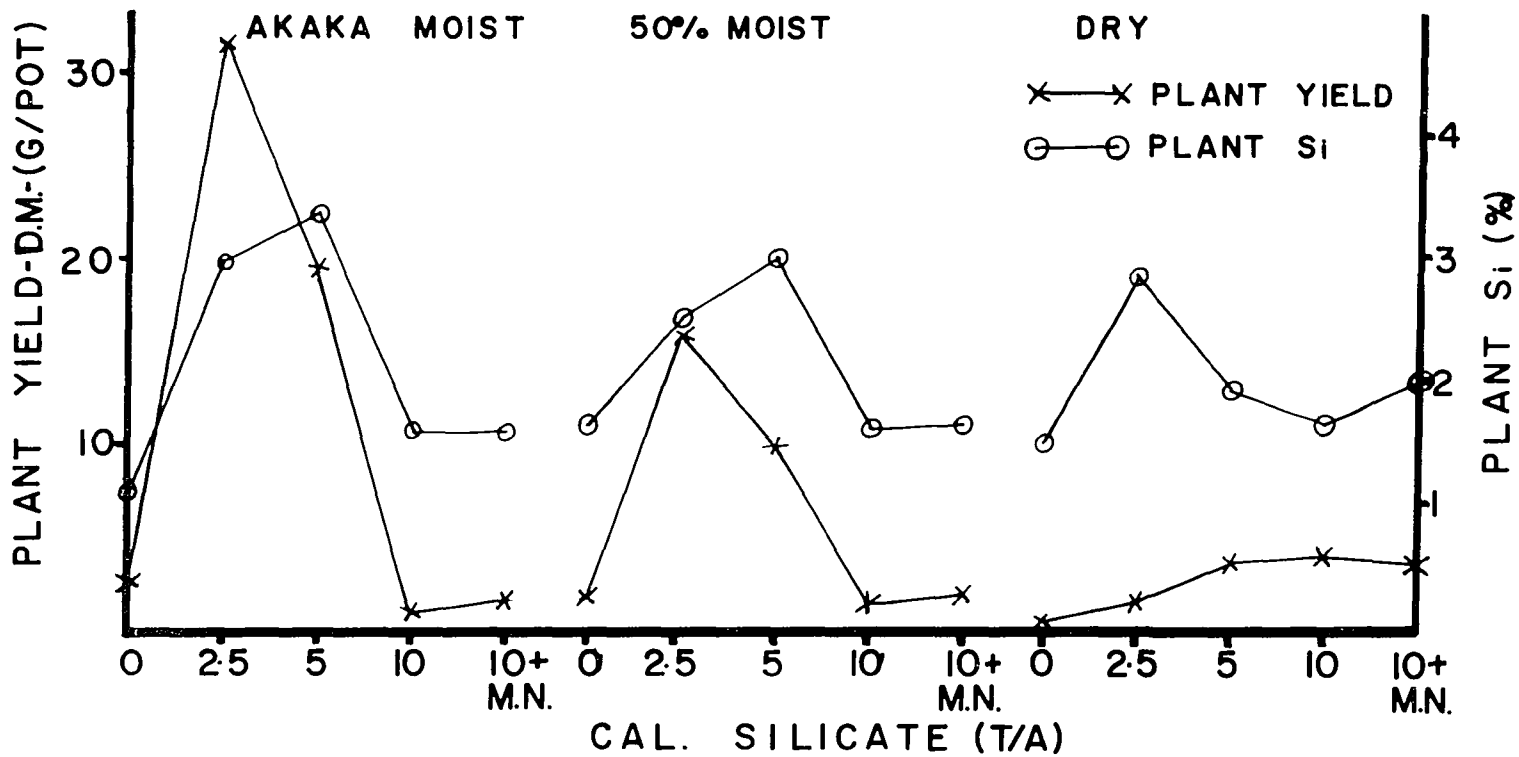

FIGURE 13. SUDAN GRASS YIELD IN RELATION TO PLANT Si WITH INCREASING RATES OF $CaSiO_3$ ON AKAKA MOIST, 50% MOIST AND AKAKA DRY SUBSOIL

	P (ppm)	Ca (%)	K (%)	Plant Yield (g/pot)
Akaka Moist	341.0	1.20	.063	11.17
Akaka 50% Moist	190.4	0.87	.051	6.09
Akaka Air-Dry	47.9	0.32	.027	2.39

While P extractability is affected most by dehydration, the availability of exchangeable Ca and K is also considerably affected.

It is the identical trend as in Experiment 2 and the same explanation is offered. In this case the plant yield data confirms the evidence of low extractability. To those who would yet contend that the lower yields and lower extractability of the dehydrated soil is due to a lesser amount of applied nutrients, such as P and Ca, to the dry soils, the following data should indicate that there is something more to it than such a straightforward explanation.

	Plant Yields (g/pot)
Akaka Moist (2.5 tons $CaSiO_3$/A + 250 lb P/A)	30.64
Dry Akaka (10 tons $CaSiO_3$/A + 750 lb P/A)	6.06

Since on a oven-dry soil basis, Akaka dry pots had 3.4 times more soil than Akaka moist, at least in respect to P and $CaSiO_3$, one would expect comparable conditions in the above two treatments. Yet the Akaka moist registers a five-fold increase over Akaka dry. Thus, it appears to be more than a straightforward relationship in terms of amount of nutrients added. In addition to the explanations offered in Experiment 2, another plausible one

may be with reference to the soil moisture regime in Akaka dry versus Akaka moist. The Akaka dry soil by virtue of its physical properties would be expected to hold and retain much less moisture than the moist Akaka soil. Such a situation no doubt would contend against effective nutrient uptake by plant roots. The same physical properties of the Akaka dry soil would also contribute to less root-soil contact which could also mean less efficient nutrient uptake.

Contrary to the research reported in this thesis, King (1961) working on Akaka subsoils, reported significantly higher yields with Akaka dry than on Akaka moist soils. Whether these divergent results could be the outcome of differences in the intensities of drying (air-drying as against sun-drying), or due to differences in soil sampling (while King worked on soils with an initial pH of 6.5, the soils reported in this thesis had a pH of 5.4) has to be left to speculation.

With reference to the intensity of drying, an observation has to be made. In the course of this research, there was evidence of what appeared to be rather distinct differences in the physical state of sun-dried when compared to air-dried Akaka soils. The segregation of Gibbsite crystals in the air-dried Akaka subsoil appeared to be more complete than in the sun-dried specimens. When both specimens were subjected to X-ray analysis however, no mineralogical basis for the apparent physical differences could

be established. It appears, however, that further investigation on this aspect of drying may be warranted.

Coming to a discussion of the plant composition trends, as already reported, the plant Al stayed within very narrow limits irrespective of soil or other treatment effects. However, soil Al decreased more or less linearly with increasing levels of calcium silicate, except in the case of 10 tons $CaSiO_3$/A, in moist Akaka, where there was an upward swing as was also observed and explained in Experiment 2.

As to plant P, the concentration hardly varied with increasing $CaSiO_3$ in dry Akaka. The depression of plant P concentration at 2.5 tons $CaSiO_3$/A on both Akaka moist and 50 per cent moist is explained on a basis of dilution with increased yield. At these same treatments the extractable soil P also drops, due probably to a greater plant uptake. The drop in plant P, however, at 10 tons per acre of $CaSiO_3$ with an increasing extractable P in both Akaka moist and 50 per cent moist soils is not too straightforward in explanation. But all the same, it must be recorded that in the case of the Akaka moist soils, the decrease in plant P concentration was evident even earlier in the form of very severe P deficiency symptoms. One explanation that could be offered is that P was subject to fixation at the time of sowing of the seed, due to the very high post-incubation pH values (up to 8.1), that these soils were at. This situation so weakened the plants, that they were not able to make use of the soil P even when it was probably more available at a later stage. In fact, the plant crop

was so weak, that these treatments hardly gave a ratoon crop. Clements (1958) in his work with the crop log on sugar cane makes a similar observation also in regard to P but in a different context. Pierre and Browning (1935) have also reported yield depressions of alfalfa and corn with high lime applications and have demonstrated that a P stress was responsible for the lower yields. They referred to this phenomenon as temporary overliming injury. The more recent researches of Hagen and Hopkins (1955) also seem to support the possibility of such a P stress with overliming. These workers demonstrated the competitive inhibition on the plant uptake of both forms of the orthophosphate ions ($H_2PO_4^-$ and HPO_4^{--}), by the hydroxyl (OH^+) ions. Since liming soils to pH values above 7 result in higher concentrations of OH^- ions, one could on the basis of the work of Hagen and Hopkins, expect a P stress in plants growing on overlimed soils.

With both plant Ca and K the more or less leveling off in concentration from the first installment of $CaSiO_3$ seems to suggest that sudan grass is not a luxury consumer of Ca and that neither does Ca tend to suppress the uptake of K. In the instance of Ca, another interesting observation is that while plant Ca levels off, exchangeable Ca linearly increases with increasing rates of $CaSiO_3$. Another interesting point with these curves is with reference to soil dehydration. While in the case of Akaka moist and 50 percent moist soils, the soil Ca curve overtakes the plant Ca curve, in the case of Akaka dry it falls way short of the plant curve. With poor extractability of both Ca and P in these

soils, one wonders as to the possibility of the formation of relatively unavailable forms of calcium phosphates in the dry Akaka. King (1961) in his P fractionation studies, reported on the greater amount of P fixed in dry Akaka as calcium phosphate.

The depression of plant Mg with increasing levels of $CaSiO_3$ is of considerable interest, especially in view of the very low levels of exchangeable Mg recorded. Magnesium deficiency to a greater or a lesser extent may have affected sudan grass yields and may have need for future investigation in liming studies.

The response to the micro-nutrient supplement reflected by higher plant concentrations in Mn and Zn, even in combination with the highest level of silicate application, was interesting. These higher plant concentrations of Zn and Mn were not, however, reflected in any significantly higher plant yields. Thus, even though these micro-nutrients may have been limiting, yet other more critical elements like P, might well have masked any such deficiencies.

The very characteristic depression of plant silicon at the highest level of calcium silicate is quite intriguing. Normally, one would not expect this depression, especially with increasing pH. In the case of Akaka moist and 50 per cent moist, this depression was also tied up with an equally characteristic depression of plant P as well as dry matter yield. This similar behavior of P and Si, probably further confirms the close relationship that has been observed between these two elements in plant nutrition, even though Si is not regarded as being essential.

EXPERIMENT 4

In this experiment were investigated the same plant-soil inter-relationships as in Experiment 3 but using coral rock instead of calcium silicate. Again a micro-nutrient supplement was introduced as a variable together with the highest level of coral rock. Also, as in Experiment 3, the dry matter yields were analyzed in two components in order to maintain the statistical orthogonality of the experiment.

The experiment, which was a three factorial one, was comprised of the following combination of variables:

1. Coral Rock
    a) 0
    b) 2.5 ton/A (10 g/pot)
    c) 5 ton/A (20 g/pot)
    d) 10 ton/A (40 g/pot)
    e) 10 ton/A + micro-nutrient supplement
2. Degrees of dehydration of Akaka subsoil
    a) Moist (2100 g/pot)
    b) 50 per cent moist (2100 g/pot)
    c) Dry (2100 g/pot)
3. Phosphate
    a) 250 lb P/A (1.9 g/pot as $NH_4H_2PO_4$)
    b) 750 lb P/A (5.7 g/pot as $NH_4H_2PO_4$)

A total of 30 treatments were replicated thrice, in a randomized block layout.

Results

Table D in the Appendix gives a complete breakdown of the dry matter yields of sudan grass together with the data on plant composition and soil analysis for the various treatments. Figure 14 gives a histogram of the interaction of coral rock x soil dehydration x phosphorus.

Again as in Experiment 3, for purposes of statistical analysis, the experiment was considered in two components:

1. Investigation of the four levels of coral rock (0, 2.5, 5 and 10 tons per acre) x degree of dehydration of Akaka subsoil (Moist, 50% Moist, Dry) x two levels of P (250 and 750 lb P/A).

2. The evaluation of the highest level of coral rock with and without the micro-nutrient supplement x degree of dehydration of Akaka subsoil (Moist, 50% Moist, Dry) x two levels of P (250 and 750 lb P/A).

Table 6 gives the summary of the variance analysis for the first component of the experiment. Again as in the instance of Experiment 3, all the main effects as well as the interactions a e significant at the 1 per cent level. The mean yields of the main effects are reported below.

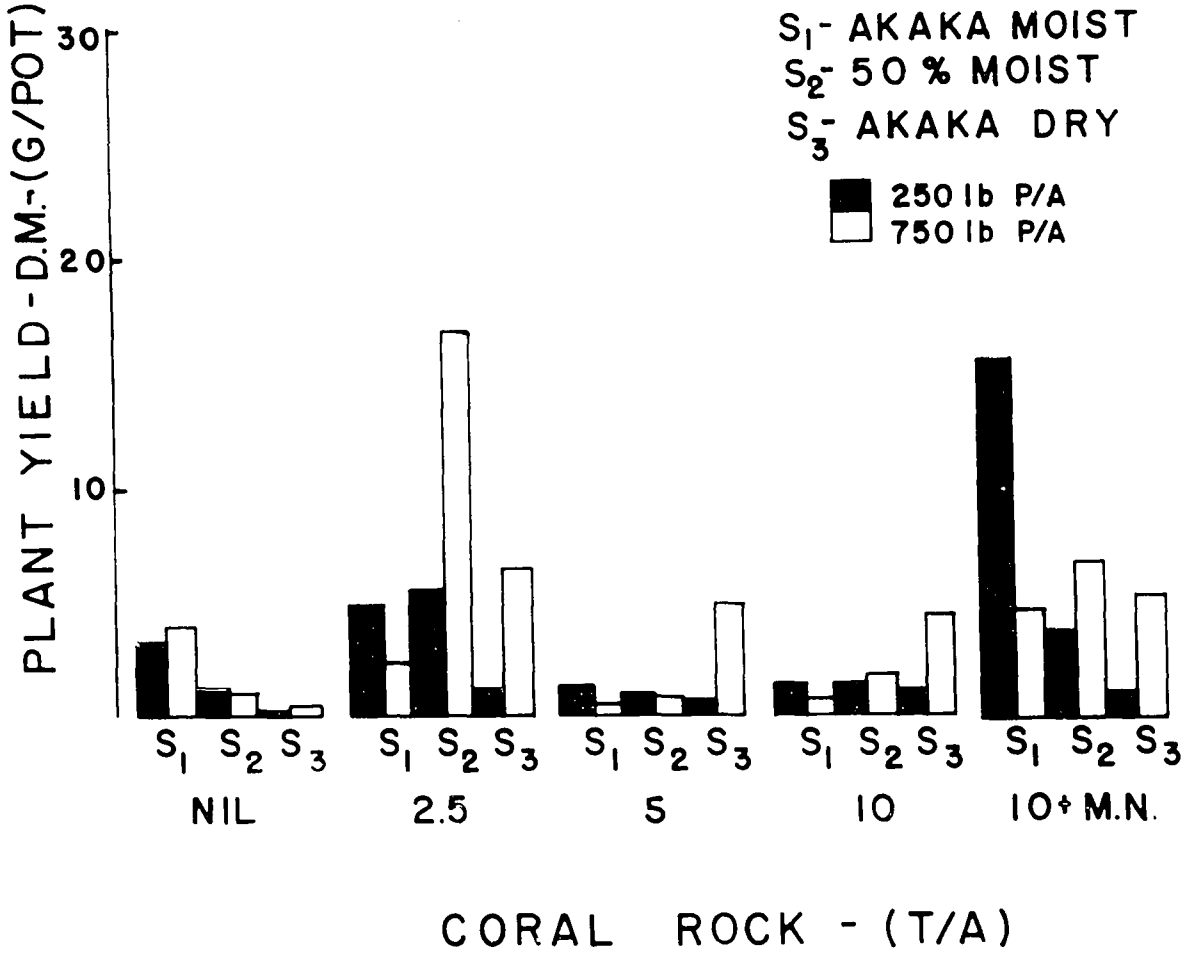

FIGURE 14. INTERACTION OF VARYING RATES OF CORAL ROCK x DEGREE OF DEHYDRATION OF AKAKA SUBSOIL x TWO LEVELS OF PHOSPHORUS

TABLE 6.

SUMMARY OF VARIANCE ANALYSIS DATA ON SUDAN GRASS YIELDS (DRY MATTER) IN A THREE FACTORIAL EXPERIMENT WITH FOUR LEVELS OF CORAL ROCK (0, 2.5, 5 AND 10 T/A) x THREE DEGREES OF SOIL DEHYDRATION (MOIST, 50% MOIST, DRY) x TWO LEVELS OF PHOSPHORUS (250 AND 750 LB/A)

Variates	D.F.	Calculated "F" Values	Table "F" Values 5%	1%
Replicates	2	2.35	3.20	5.10
Coral Rock (C)	3	41.08**	2.81	4.24
Soil (S)	2	6.30**	3.20	5.10
Phosphates (P)	1	23.32**	4.05	7.21
C x S	6	18.26**	2.30	3.22
C x P	3	7.61**	2.81	4.24
S x P	2	13.26**	3.20	5.10
C x S x P	6	9.11**	2.30	3.22
	46			
TOTAL	71			

CORAL ROCK (TON/A)

	0	2.5	5	10
Sudan grass yields (g dry matter/pot)	1.60	6.26	1.54	1.80

D (5% level) = 3.32

DEGREE OF AKAKA SUBSOIL DEHYDRATION

	Moist	50% Moist	Air-Dry
Sudan grass yields (g dry matter/pot)	2.31	3.71	2.39

D (5% level) = 3.01

PHOSPHORUS (LB/A)

	250	750
Sudan grass yields (g dry matter/pot)	1.93	3.67

D (5% level) = 2.51

As in the case of Experiment 3, one is again confronted with the situation of being unable to demonstrate significant differences in means, even through these exist. This is in the case of both soils and phosphorus. As for coral rock treatments, the rate of 2.5 ton per acre is significantly superior to the other levels, even though the response at this level is much less than that of calcium silicate in Experiment 3. An acute depression in yield also takes place at 5 tons per acre, which with calcium silicate in Experiment 3, occurred only at 10 tons per acre.

Table 7 gives the summary of the analysis of variance for the second component of this experiment. In this case, only two of the main treatments (coral rock at 10 tons per acre, with and without micro-nutrients and soils) together with the third order interaction and two second order interactions C x S and S x P, gave highly significant (1% level) yield responses.

The differences in mean yields of the two significant main effects are reported below.

CORAL ROCK (10 TON/A)

	With Micro-Nutrient	Without Micro-Nutrient
Sudan grass yields (g dry matter/pot)	6.20	1.80

D (5% level) = 2.78

DEGREE OF DEHYDRATION OF SOIL

	Akaka Moist	50% Moist	Air-Dry
Sudan grass yields (g dry matter/pot)	5.65	3.42	2.94

D (5% level) = 3.45

Here, too, in the case of soils, one is unable to demonstrate significant differences in means.

The data in the second component of this experiment have provided very convincing evidence of a highly significant response to micro-nutrients by sudan grass, with high levels of liming. In fact, it may be that even at the level of

TABLE 7.

SUMMARY OF VARIANCE ANALYSIS DATA ON SUDAN GRASS YIELDS (DRY MATTER) IN A THREE FACTORIAL EXPERIMENT HAVING CORAL ROCK AT 10 T/A (WITH AND WITHOUT A MICRO - NUTRIENT DRESSING) x THREE DEGREES OF SOIL DEHYDRATION (MOIST, 50% MOIST, DRY) x TWO LEVELS OF PHOSPHORUS (250 AND 750 LB/A)

Variates	D.F.	Calculated "F" Values	Table "F" Values 5%	1%
Replicates	2	1.33	3.44	5.72
Coral Rock (C)	1	61.18**	4.30	7.94
Soils (S)	2	8.86**	3.44	5.72
Phosphate (P)	1	0.05	4.30	7.94
C x S	2	20.87**	3.44	5.72
C x P	1	4.08	4.30	7.94
S x P	2	27.85**	3.44	5.72
C x S x P	2	13.39**	3.44	5.72
	22			
TOTAL	35			

2.5 tons of coral rock, there might have been a micro-nutrient stress, which kept the yields down very considerably as opposed to calcium silicate at the same level.

Plates 6 and 7 illustrate the response of sudan grass to the interactions in this experiment.

Plant and Soil Analysis

The plant and soil analysis findings very closely parallel those of Experiment 3 with calcium silicate. The identical reduced extractability of P, Ca and K (Figures 15, 16, 17) is seen as a function of dehydration, while Al and Mg (Figures 18 and 19) extractability are not affected by soil dehydration. Exchangeable and reducible Mn (Figure 20) are low irrespective of dehydration. The yield data also conform to the pattern of reduced extractability of nutrients with dehydration. At 2.5 tons per acre, however, the moist soil fails to respond in comparison to the same treatment with 50 per cent moist Akaka. Another interesting feature with reference to plant yield versus dehydration is the consistent response of Akaka dry soils, the lesser response of the Akaka 50 per cent moist soils and the least response of the Akaka moist soils (sometimes a yield depression, which is difficult to explain) to the higher level of P. This same trend was also evident in Experiment 3 with calcium silicate. This evidence appears to favor the capacity factor theory in plant nutrition, referred to earlier.

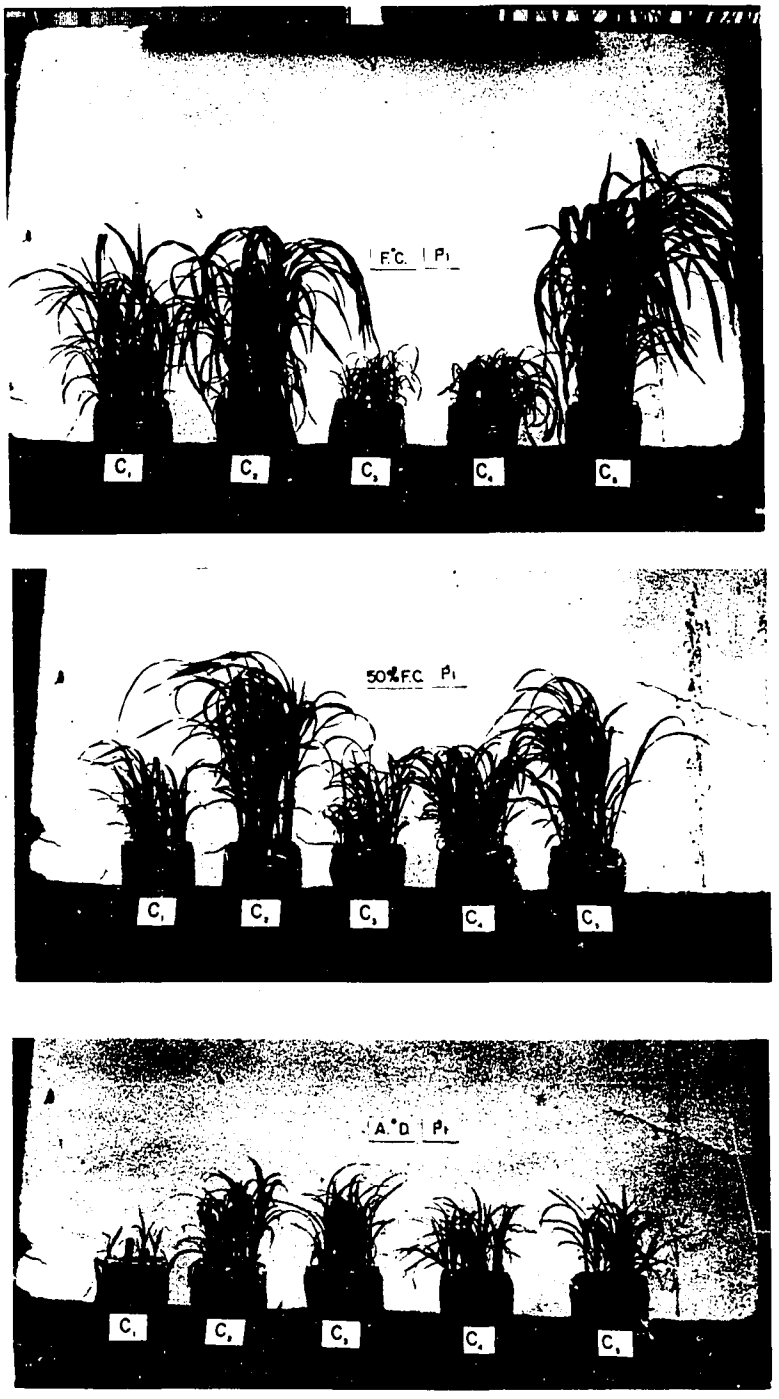

PLATE 6. RESPONSE OF SUDAN GRASS TO CORAL ROCK LEVELS--C_1 TO C_5--(0, 2.5, 5, 10, AND 10 T/A + MICRO-NUTRIENTS), ON AKAKA SUBSOIL DEHYDRATED TO DIFFERENT DEGREES, WITH P AT 250 LB/A

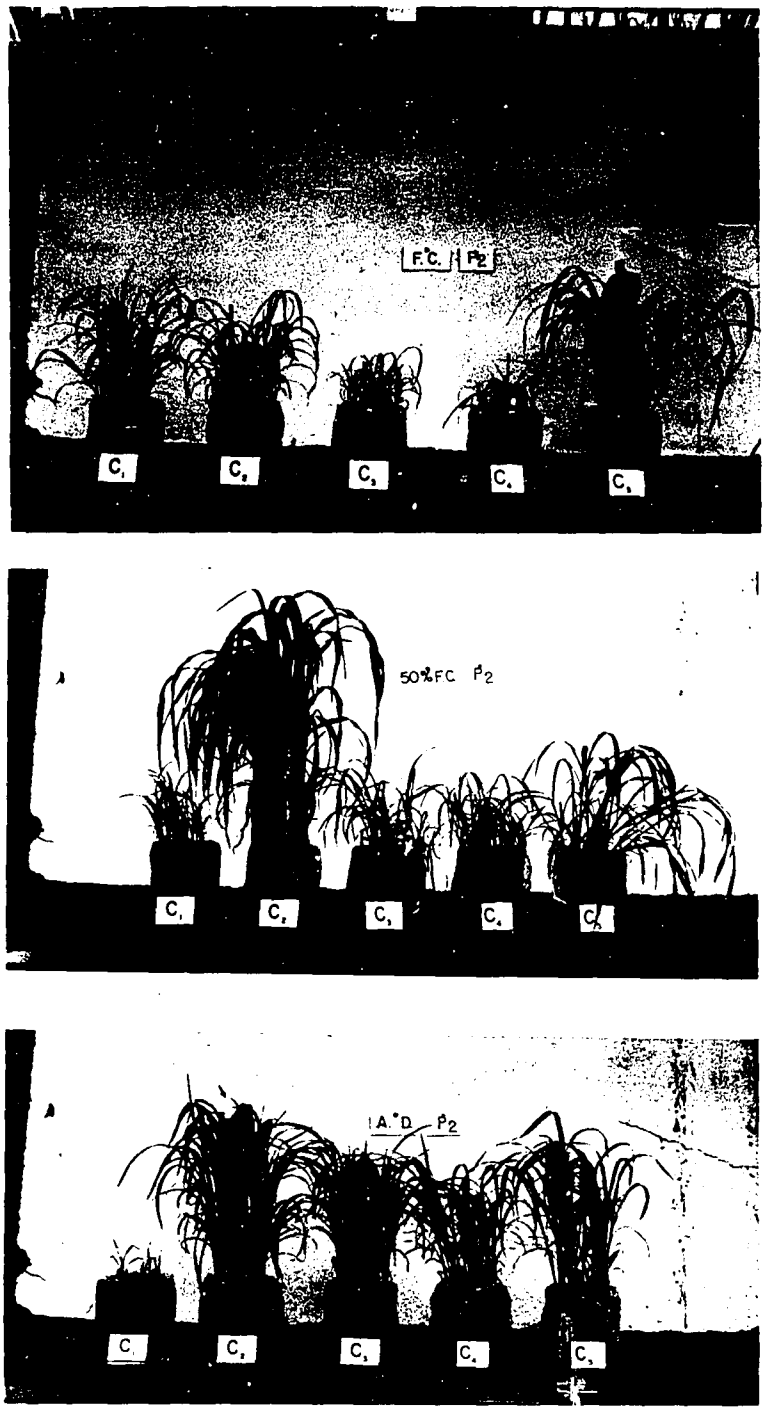

PLATE 7. RESPONSE OF SUDAN GRASS TO CORAL ROCK LEVELS--C_1 TO C_5--(0, 2.5, 5, 10, AND 10 T/A + MICRO-NUTRIENTS), ON AKAKA SUBSOIL DEHYDRATED TO DIFFERENT DEGREES WITH P AT 750 LB/A

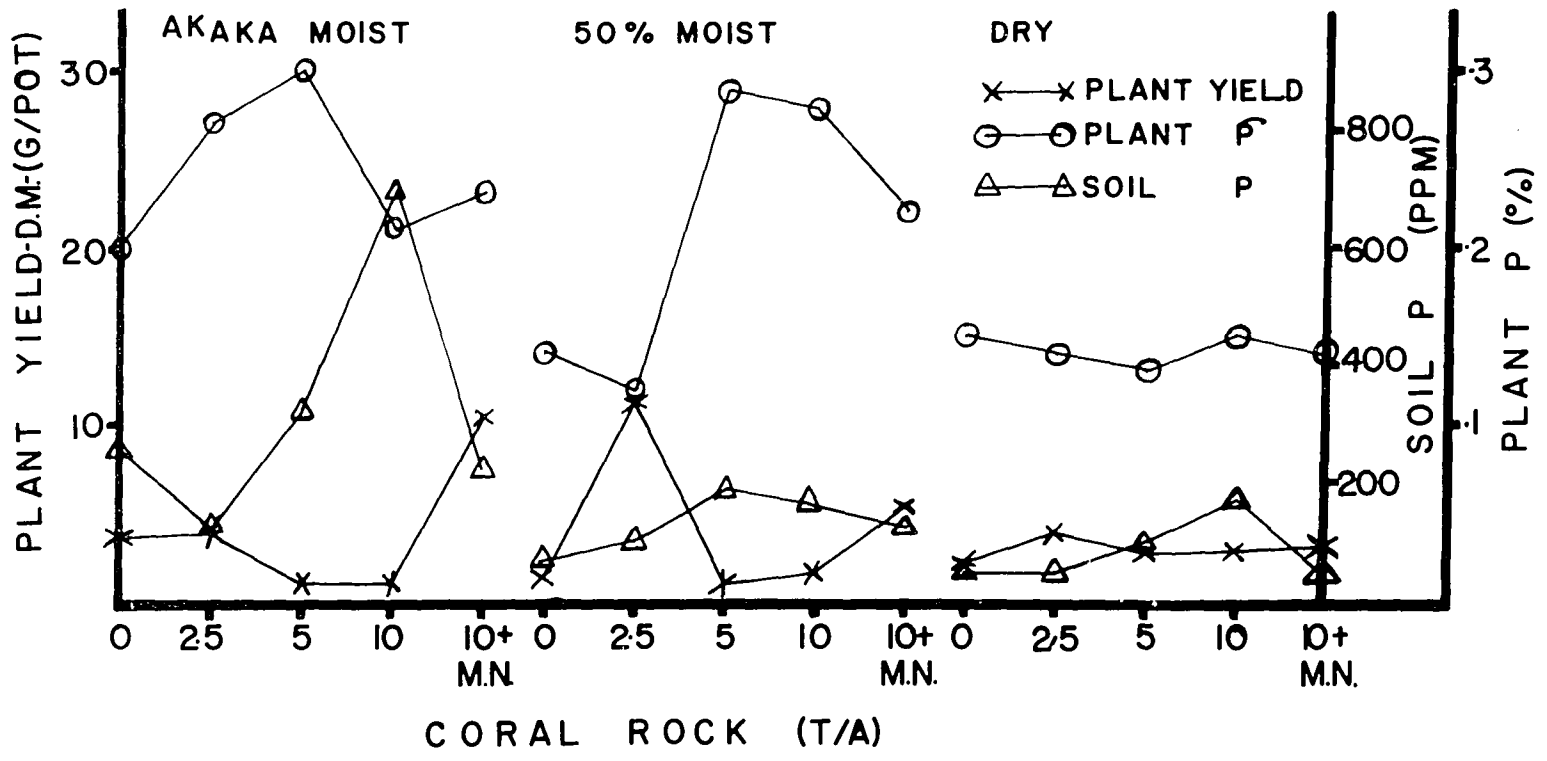

FIGURE 15. SUDAN GRASS YIELD IN RELATION TO EXTRACTABLE SOIL P AND PLANT P WITH INCREASING RATES OF CORAL ROCK ON AKAKA MOIST, 50% MOIST AND AKAKA DRY SUBSOIL

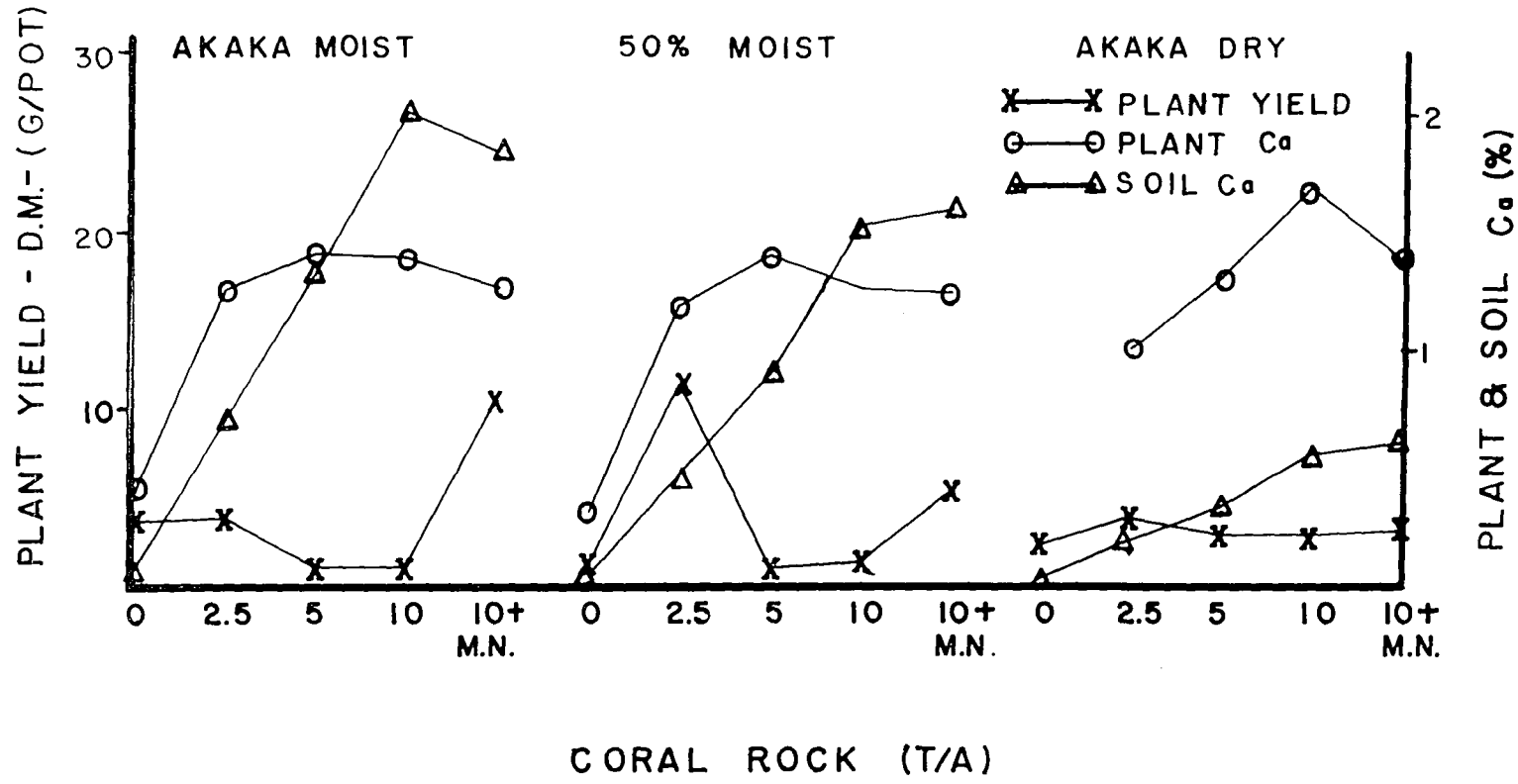

FIGURE 16. SUDAN GRASS YIELD IN RELATION TO EXCHANGEABLE SOIL Ca AND PLANT Ca WITH INCREASING RATES OF CORAL ROCK ON AKAKA MOIST, 50% MOIST AND AKAKA DRY SUBSOIL

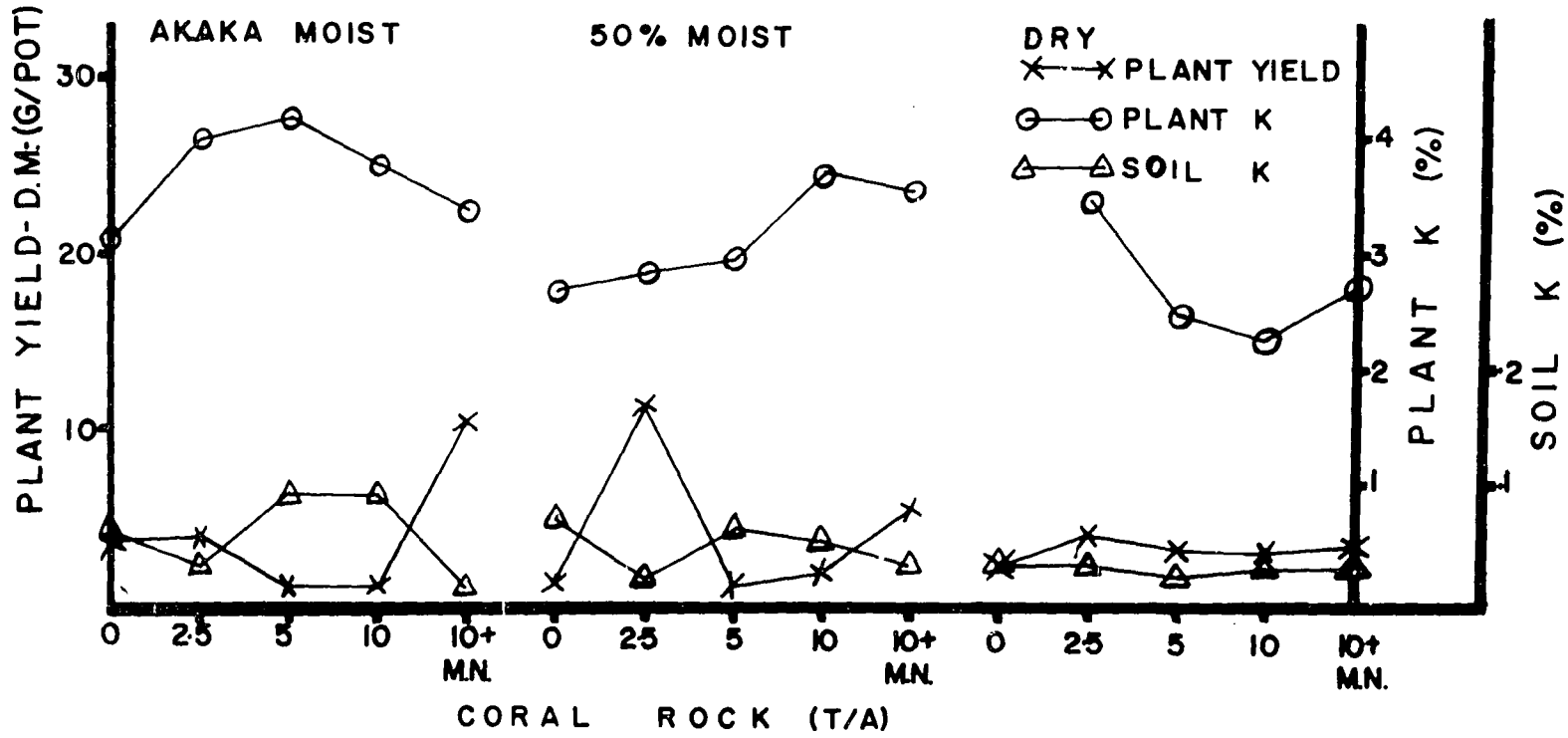

FIGURE 17. SUDAN GRASS YIELD IN RELATION TO EXCHANGEABLE SOIL K AND PLANT K WITH INCREASING RATES OF CORAL ROCK ON AKAKA MOIST, 50% MOIST AND AKAKA DRY SUBSOIL

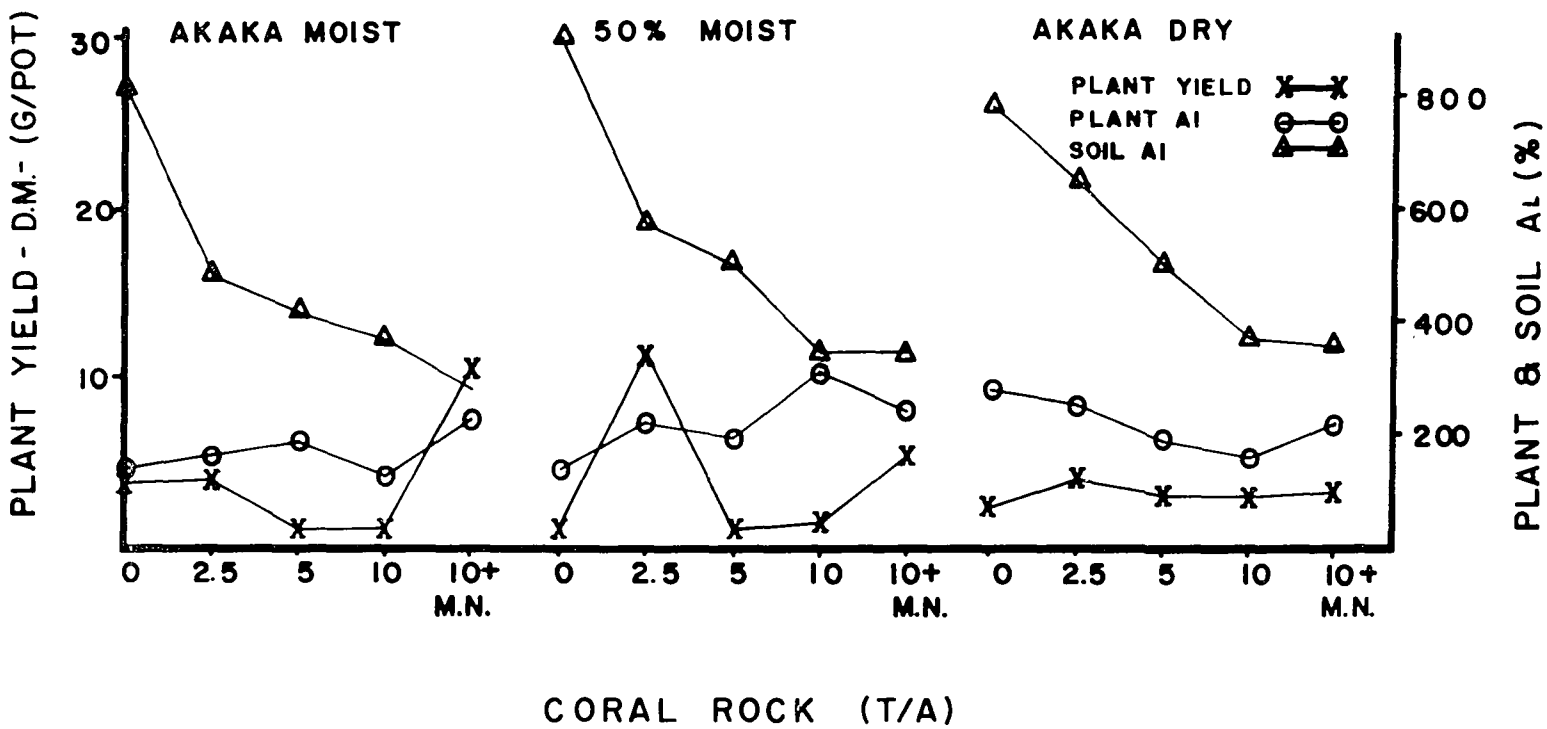

FIGURE 18. SUDAN GRASS YIELD IN RELATION TO EXCHANGEABLE SOIL Al AND PLANT Al WITH INCREASING RATES OF CORAL ROCK, ON AKAKA MOIST, 50% MOIST AND AKAKA DRY SUBSOIL

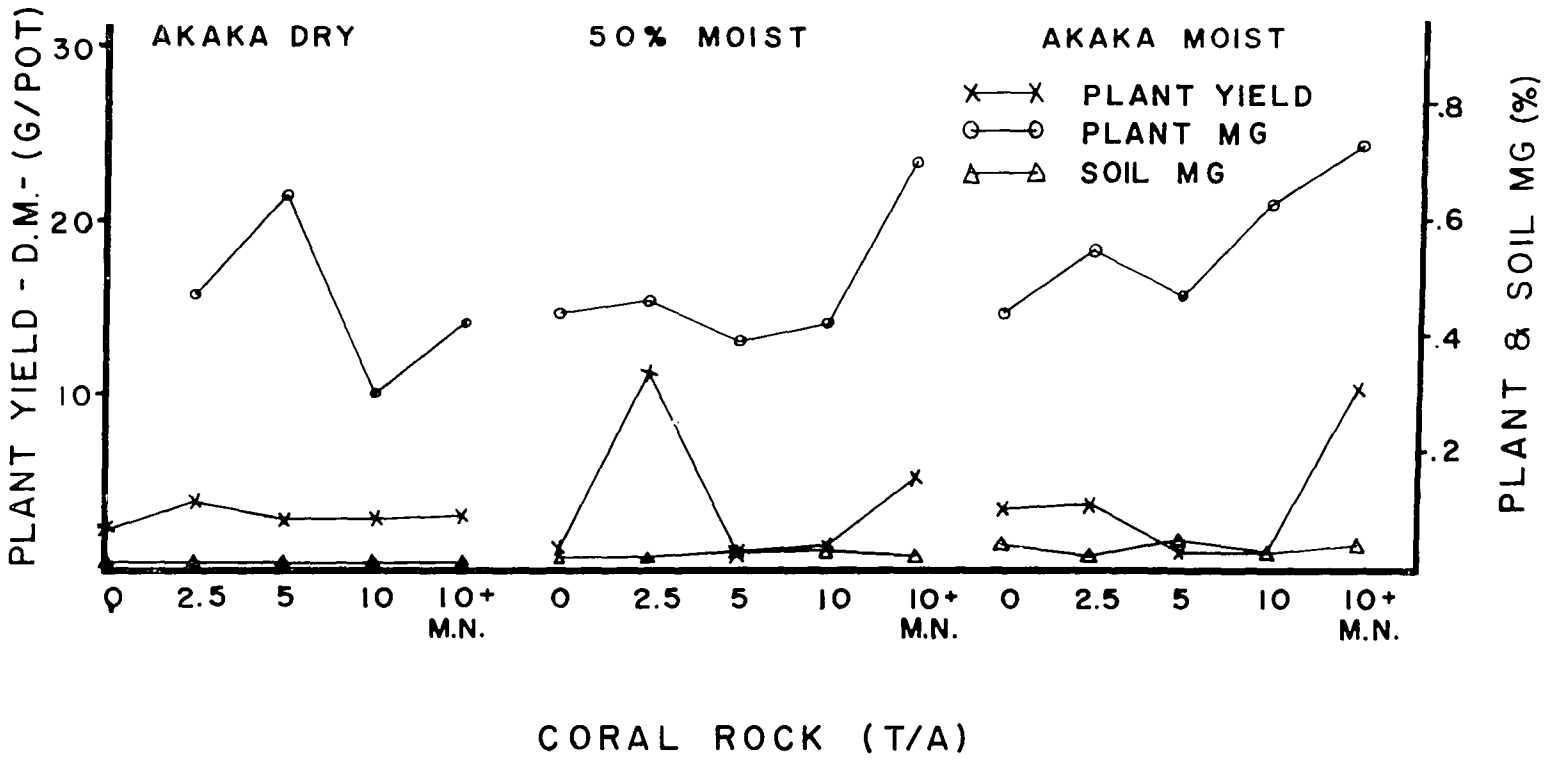

FIGURE 19. SUDAN GRASS YIELD IN RELATION TO EXCHANGEABLE SOIL Mg AND PLANT Mg WITH INCREASING RATES OF CORAL ROCK ON AKAKA MOIST, 50% MOIST AND AKAKA DRY SUBSOIL

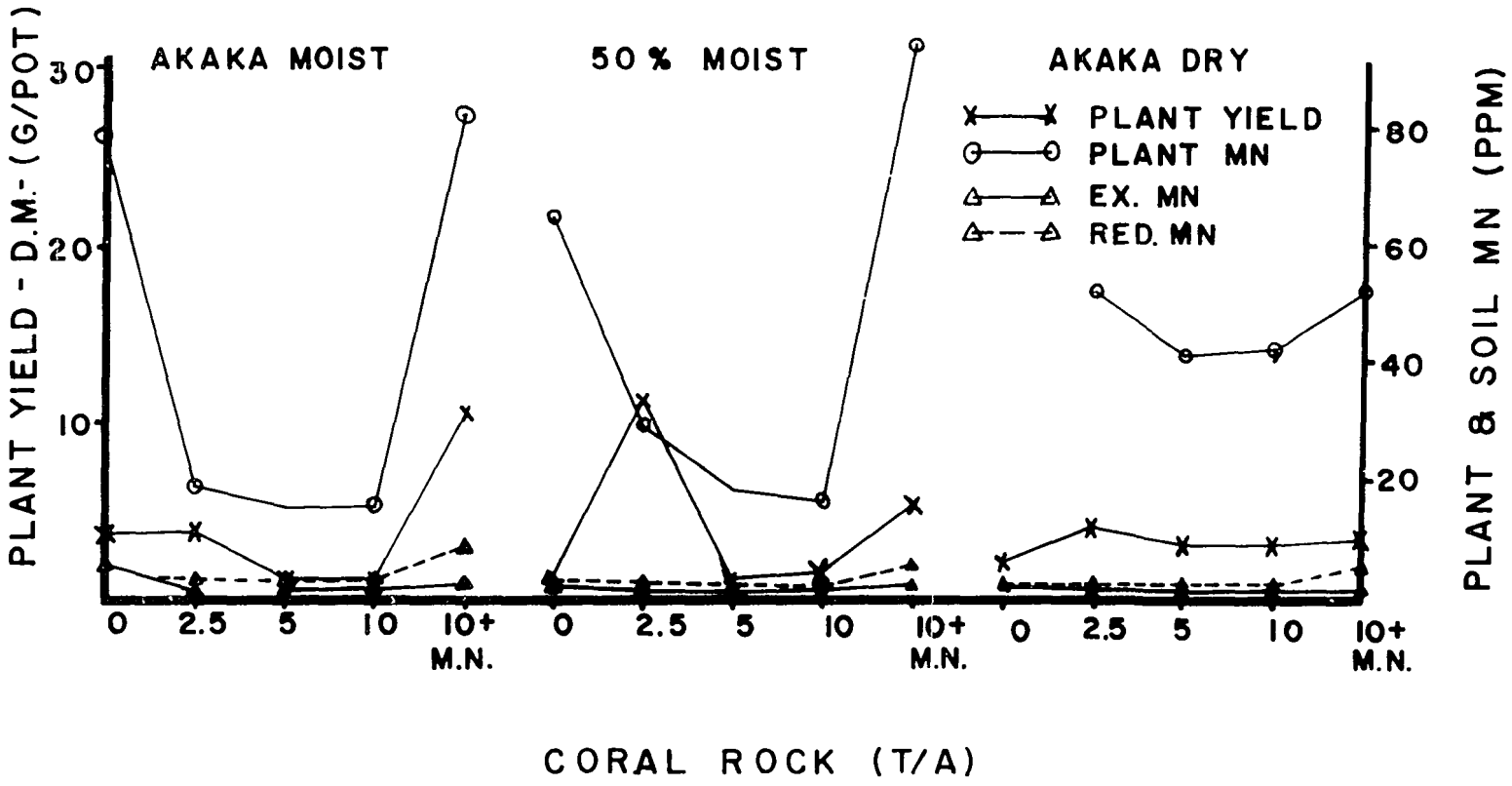

FIGURE 20. SUDAN GRASS YIELD IN RELATION TO EXCHANGEABLE AND REDUCIBLE SOIL Mn AND PLANT Mn WITH INCREASING RATES OF CORAL ROCK ON AKAKA MOIST, 50% MOIST AND AKAKA DRY SUBSOIL

In this experiment the trend in plant and soil P, Ca and K were almost identical with that observed in Experiment 3.

Plant Al, too, was not affected to any degree by any of the treatments. Soil Al, however, decreased almost linearly with increasing levels of coral rock. There was no upward swing of the Al curve at the higher rates as observed with calcium silicate.

Plant Mg, Zn (Figure 21), or Si (Figure 22) did not show any particular trends.

The picture with plant Mn, however, proved to be quite interesting. With the Akaka moist and 50 per cent moist soils not only was there a marked increase in uptake of Mn with the application of micro-nutrients, but this increased plant Mn was also reflected in significantly (1% level) higher plant yields.

Discussion

In the instance of nutrients, P, Ca and K, the trends being so close to those of Experiment 3, need hardly any further elaboration.

Soil Al, of course, behaves differently in that there is no evidence of an upward swing of the curve at the 10 ton/A rate as occurred with calcium silicate on both the moist and the 50 per cent moist soil. That this phenomenon with calcium silicate may have been a pH-induced one seems to be further documented in this experiment. The pH values for coral rock and calcium silicate recorded below may justify the above speculation.

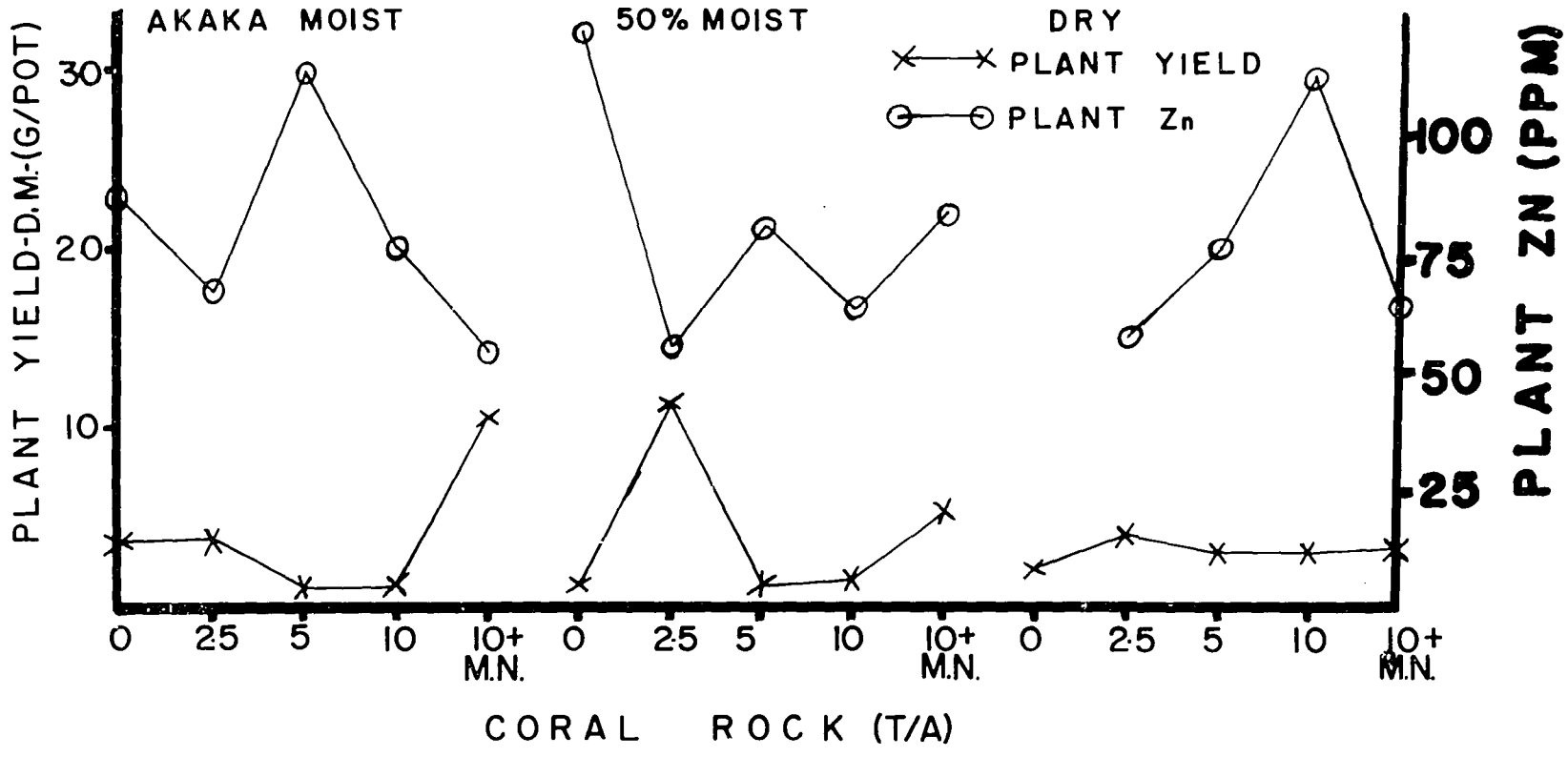

FIGURE 21. SUDAN GRASS YIELD IN RELATION TO PLANT Zn WITH INCREASING RATES OF CORAL ROCK ON AKAKA MOIST, 50% MOIST AND AKAKA DRY SUBSOIL

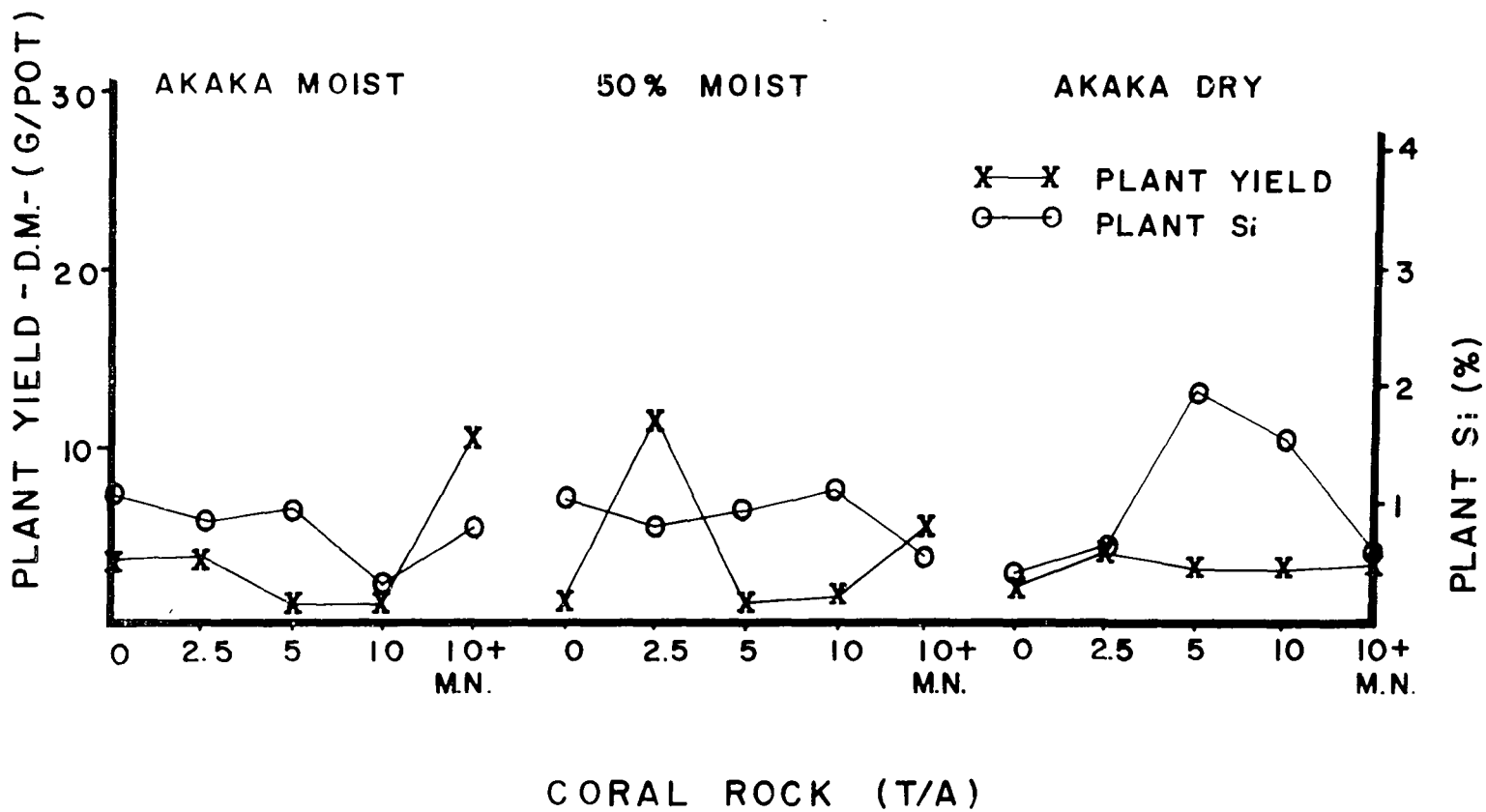

FIGURE 22. SUDAN GRASS YIELD IN RELATION TO PLANT Si WITH INCREASING RATES OF CORAL ROCK ON AKAKA MOIST, 50% MOIST AND AKAKA DRY SUBSOIL

	CALCIUM SILICATE (10 TON/A)			CORAL ROCK (10 TON/A)		
	Moist	50% Moist	Dry	Moist	50% Moist	Dry
Post Incubation pH	8.1	7.7	7.3	7.6	7.5	7.5
Post Harvest pH	7.7	7.3	6.5	7.5	7.4	6.7

The statistically significant yield increase with micro-nutrients and the trend in plant Mn with and without micro-nutrients seem to leave no doubt of the critical role of Mn in this experiment.

Acid soils are often thought of as containing excessive amounts of soluble Mn. In fact, as reviewed earlier, one of the beneficial effects of liming acid soils is believed to be amelioration of Mn toxicity. However, in the soil investigated in these experiments, the level of both exchangeable and reducible Mn was very low indeed. The exchangeable Mn ranged from about a maximum of 5 ppm in untreated soils to as little as 0.34 ppm in limed soils. The status with regard to reducible Mn was no higher ranging from as low as 1.25 ppm in limed soils to about 3.5 ppm in unlimed soils. These values would seem to fall well below the critical limits of 3 and 25 ppm for exchangeable and reducible Mn, respectively, as proposed by Sherman et al. (1942). These workers contended that soils may become deficient in Mn below these levels.

That Mn was deficient was evidenced in this experiment where acute and typical gray speck disease was observed at the rate of 5 and 10 tons per acre of coral rock. The drastic yield depression was also at these levels of coral

rock. The micro-nutrients, in fact, restored plant yields to the same level recorded for 2.5 tons per acre of coral rock.

The plants showing acute Mn deficiency symptoms at 5 and 10 tons per acre of coral rock had a Mn concentration of 15 ppm. The plants growing on moist Akaka treated with 2.5 tons per acre of coral rock had a Mn concentration of only 19 ppm. Although these plants did not exhibit any deficiency symptoms, from a study of the data it might appear as if the unusually low yield of sudan grass with this treatment might have been contributed by a Mn stress. Willis (1931) reports Mn deficiency with liming at pH values as low as 6.4 on Mn deficient soils, while Mehlich (1957) reported such deficiency symptoms even at pH values of 5.8 in the presence of Al^{+++} and Fe^{+++} salts. Thus, in this investigation, the plant yields on moist Akaka treated with 2.5 tons per acre of coral rock could very well have been a Mn stress, even through the soil pH values ranged from 6.6 to 6.8 in these treatments.

Dehydration of soils has been claimed to increase the availability of soil Mn (Fujimoto and Sherman, 1946). This seems to be evident with Akaka soil dehydrated to 50 per cent of the moisture content, where with 2.5 tons per acre of coral rock, the plant Mn rises to 28 ppm accompanied by a very significant increase in plant yield.

Even though the writer has not been able to ascertain the critical Mn requirements of sudan grass, it appears from this work that plant concentrations

of around 25 ppm or less may be in the region of deficiency for sudan grass.

It may not be out of place to bring out the fact that with calcium silicate-treated soils, plant Mn was always well above 25 ppm, even at the highest rates of silicate application. The reason for this probably lies in the fact that calcium silicate had a manganese concentration six times that of coral rock. The lack of a response to Mn in the calcium silicated-soils could have been due to the appreciable percentage of Mn that was already present in the calcium silicate itself.

EXPERIMENT 5

The main purpose of this experiment was to investigate the plant response on these Hydrol Humic Latosols, when subjected to physical modifications. These physical modifications were effected by mixing the Akaka moist and the Akaka dry subsoil in three different proportions, with the moist and the dry soils themselves serving as end members of such a series. In addition, three levels of calcium silicate (as a soil amendment) constituted a second factor, while two levels of P served as a third factor. The macro-nutrients, N and K, were applied as blanket applications as in the earlier experiments. Sudan grass was again the indicator crop.

This experiment was also a factorial with 3 factors as follows:

1. Soil Combinations

    a) Moist soil (2100 g/pot)

b) 2/3 Moist soil + 1/3 Dry soil (1400 g moist + 700 g dry/pot)

c) 1/2 Moist soil + 1/2 Dry soil (1050 g moist + 1050 g dry/pot)

d) 1/3 Moist soil + 2/3 Dry soil (700 g moist + 1400 g dry/pot)

e) Dry soil (2100 g/pot)

2. Calcium Silicate

a) 0

b) 5 tons/A (20 g/pot)

c) 10 tons/A (40 g/pot)

3. Phosphorus

a) 250 lb/A (1.9 g/pot as $NH_4H_2PO_4$)

b) 750 lb/A (5.7 g/pot as $NH_4H_2PO_4$)

A total of 30 treatments was replicated thrice and laid out in a randomized block layout.

Results

Table E in the Appendix gives the complete data on this experiment in respect to dry matter yields of sudan grass, the plant composition and the soil analysis. In addition, Figure 23 gives a histogram of the interaction of the three factors in the experiment.

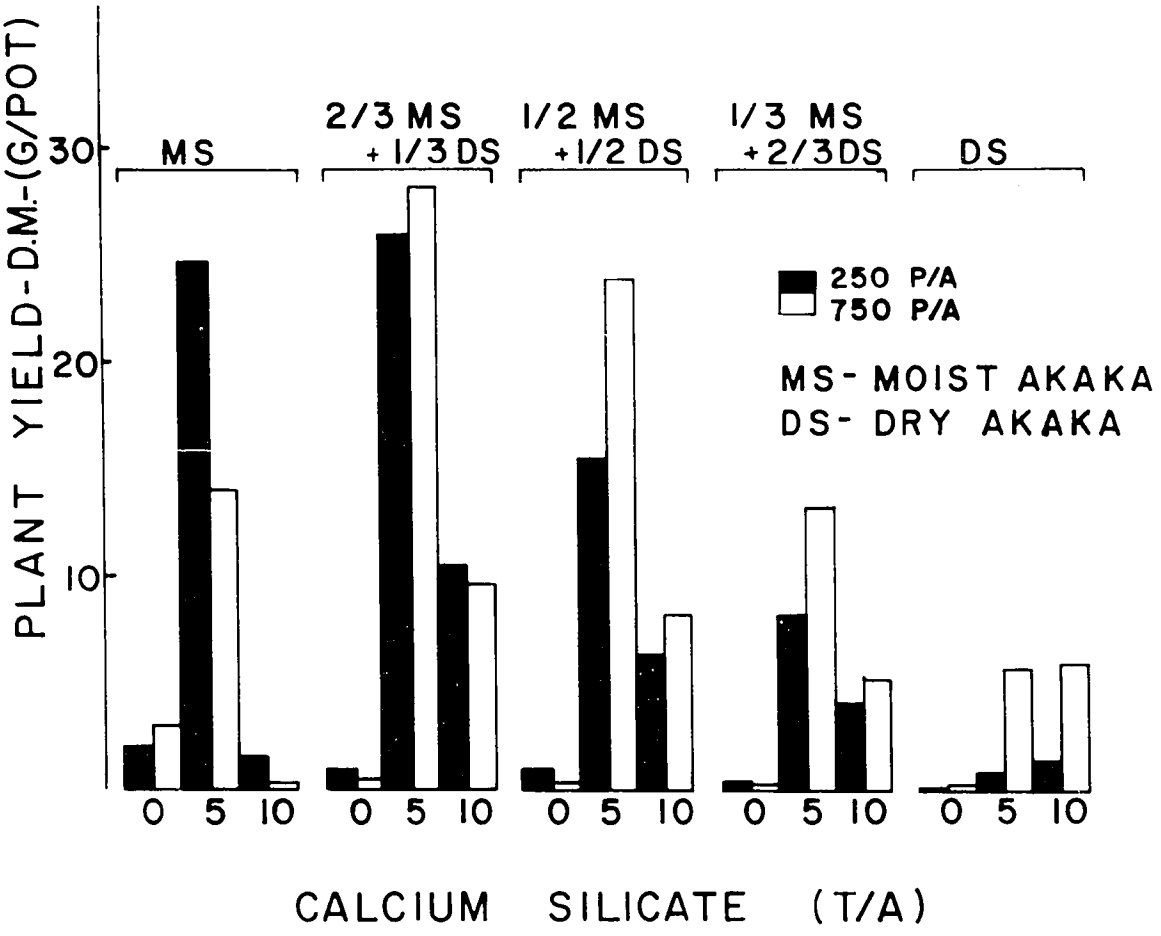

FIGURE 23. INTERACTION OF DIFFERENT COMBINATIONS OF AKAKA MOIST AND AKAKA DRY SUBSOIL x VARYING RATES OF $CaSiO_3$ x TWO LEVELS OF PHOSPHORUS

Table 8 gives the variance analysis on the dry matter plant yields. This experiment also features main effects and interactions significant at the 1 per cent level. The mean differences of the main effects are recorded below.

	Moist Soil	2/3 Moist + 1/3 Dry	1/2 Moist + 1/2 Dry	1/3 Moist + 2/3 Dry	Dry Soil
Sudan grass yields (g dry matter/pot)	7.58	12.71	9.25	5.29	2.48

D (5% level) = 2.58

CALCIUM SILICATE (TONS/A)

	0	5	10
Sudan grass yields (g dry matter/pot)	0.94	16.14	5.31

D (5% level) = 2.20

PHOSPHORUS (LB/A)

	250	750
Sudan grass yields (g dry matter/pot)	6.92	8.00

D (5% level) = 1.84

It is interesting to note that upon the admixture of a limited quantity of dry soil into the moist Akaka, highly significant increased yields resulted. On the other hand, as the ratio of dry soil to moist soil increases, the yield progressively declines. From a study of these yield data, even though it

TABLE 8.

SUMMARY OF VARIANCE ANALYSIS DATA ON SUDAN GRASS YIELDS (DRY MATTER) IN A THREE FACTORIAL EXPERIMENT WITH FIVE COMBINATIONS OF MOIST AND DRY AKAKA SUBSOIL (MOIST, 2/3 MOIST + 1/3 DRY, 1/2 MOIST + 1/2 DRY, 1/3 MOIST + 2/3 DRY, DRY) x THREE LEVELS OF CALCIUM SILICATE (0, 5 AND 10 T/A) x TWO LEVELS OF PHOSPHORUS (250 and 750 LB/A)

Variates	D.F.	Calculated "F" Values	Table "F" Values 5%	1%
Replicates	2	2.4	3.16	4.99
Soil (S)	4	210.4**	2.53	3.66
Calcium Silicate (C)	2	1423.98**	3.16	4.99
Phosphate (P)	1	21.39**	4.10	7.10
S x C	8	123.62**	2.10	2.83
S x P	4	28.69**	2.53	3.66
C x P	2	6.71**	3.16	4.99
S x C x P	8	21.39**	2.10	2.83
	58			
TOTAL	89			

might appear that 2/3 moist + 1/3 dry gives the best response, yet a reference to Experiment 3 would reveal that with moist soils the most favorable rate of calcium silicate under these experimental conditions was 2.5 tons per acre. On the other hand, however, it is always possible that even at 2.5 tons per acre of calcium silicate, a combination of moist and dry soils (2/3 + 1/3) may have given a better response over the moist soil. In the absence of more data this must remain speculative.

In this experiment, again one finds the depression of yield at 10 tons per acre of silicate while the performance without calcium silicate is very poor.

Once more there is also the situation of an inability to show significant mean differences in the P variable, even though the variance analysis indicates the existence of such differences. With regard to the phosphate variable it is noted once again (See Figure 23) that the drier members of the soil series responded consistently to the higher level of P. Plates 8 and 9 show the response of sudan grass to the various interactions.

Plant and Soil Analysis

Once more with reference to extractable P (Table 9) and probably more so with regard to exchangeable Ca (Table 10), a dramatic depression in extractability occurs with an increase in the ratio of dry to moist soil.

Exchangeable Al (Table 11) again is hardly affected by the variation in the dry soil to moist soil ratio, though the characteristic upswing in exchangeable

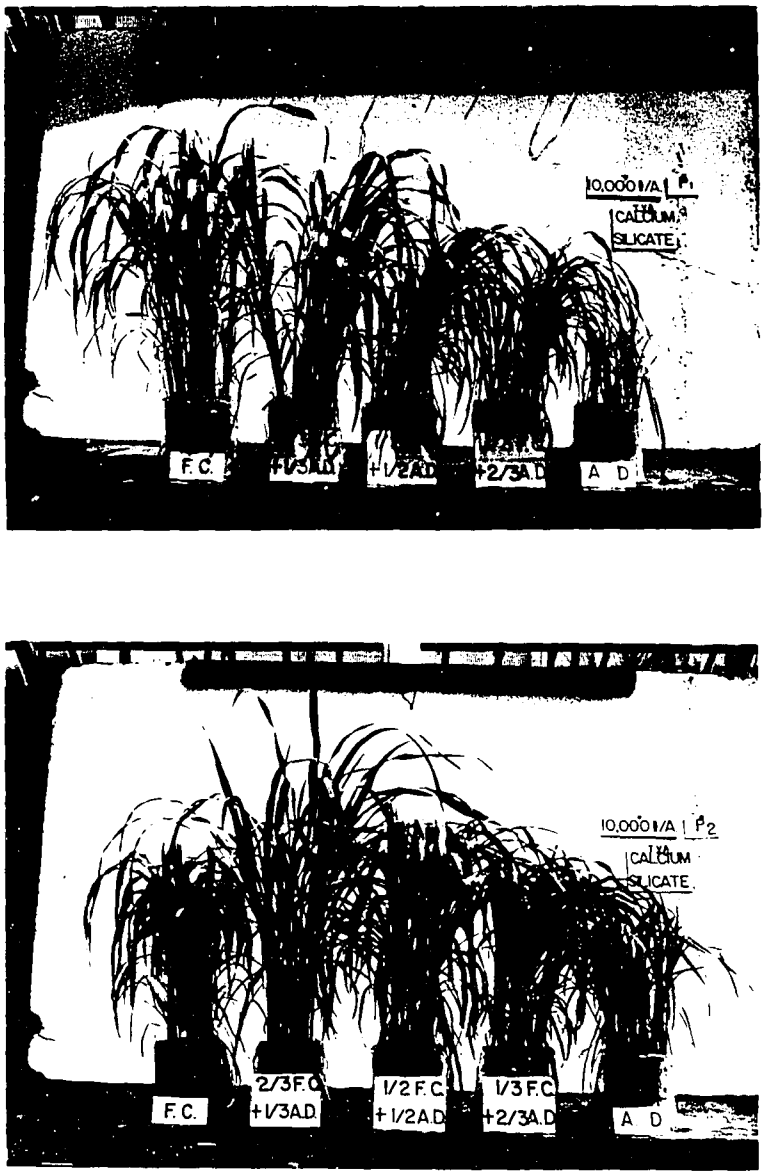

PLATE 8. RESPONSE OF SUDAN GRASS TO DIFFERENT COMBINATIONS OF MOIST AKAKA (F.C.) AND DRY AKAKA (A.D.) SUBSOIL TREATED WITH 5 T/A $CaSiO_3$ AND P AT 250 (P_1) AND 750 (P_2) LB/A

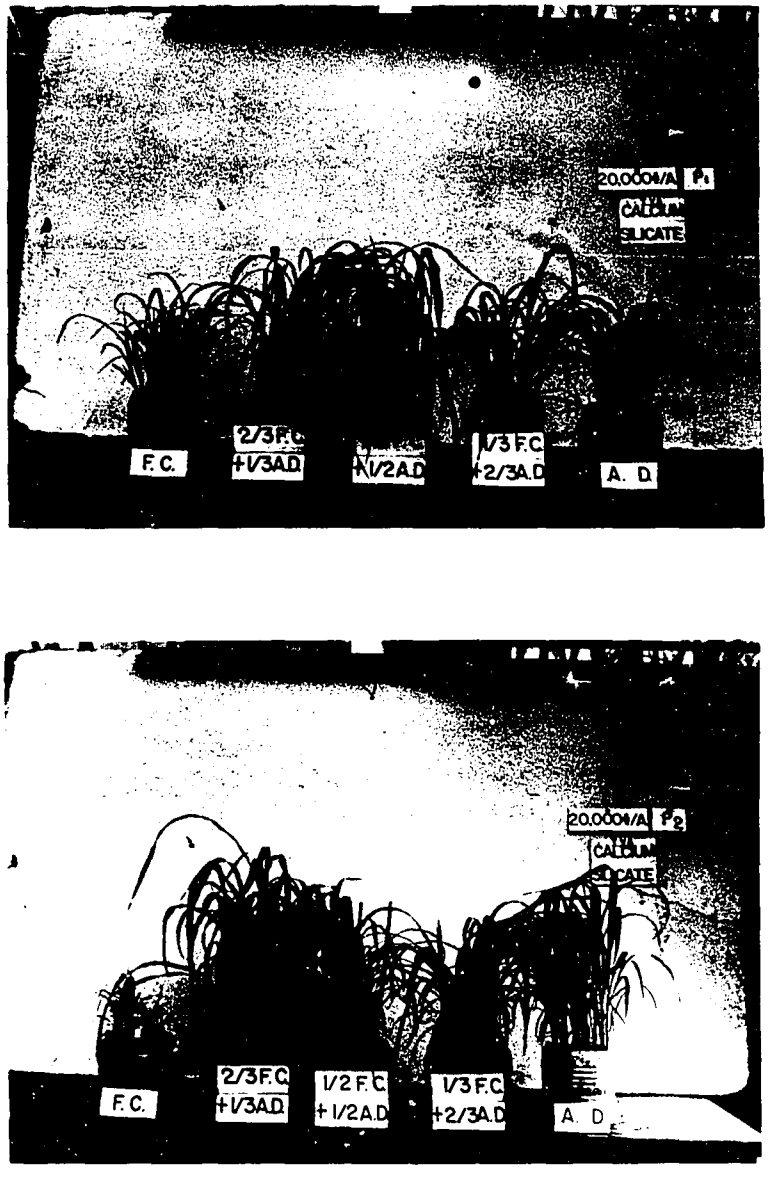

PLATE 9. RESPONSE OF SUDAN GRASS TO DIFFERENT COMBINATIONS OF MOIST AKAKA (F.C.) AND DRY AKAKA (A.D.) SUBSOIL TREATED WITH 10 T/A $CaSiO_3$ AND P AT 250 (P_1) and 750 (P_2) LB/A

TABLE 9.

SUDAN GRASS DRY MATTER YIELD, PLANT P COMPOSITION AND EXTRACTABLE SOIL P, AS INFLUENCED BY THE VARYING SOIL COMBINATIONS AND LEVELS OF CALCIUM SILICATE

Calcium Silicate (tons/A)	Plant Yield (g/pot)			Plant P (ppm)			Soil P (ppm)		
	0	5	10	0	5	10	0	5	10
Moist Soil	2.54	19.33	0.88	2030	2341	1251	317	271	452
2/3 Moist + 1/3 Dry	0.75	27.46	9.93	1921	1659	2360	88	96	135
1/2 Moist + 1/2 Dry	0.67	19.75	7.32	1647	1834	2379	92	99	118
1/3 Moist + 2/3 Dry	0.47	10.74	4.68	1507	1888	2368	63	69	89
Dry Soil	0.26	3.40	3.77	1530	1412	1518	48	50	53

TABLE 10.

SUDAN GRASS DRY MATTER YIELD, PLANT Ca COMPOSITION AND EXCHANGEABLE SOIL Ca, AS INFLUENCED BY THE VARYING SOIL COMBINATIONS AND LEVELS OF CALCIUM SILICATE

Calcium Silicate (tons/A)	Plant Yield (g/pot)			Plant Ca (%)			Soil Ca (%)		
	0	5	10	0	5	10	0	5	10
Moist Soil	2.54	19.33	0.88	0.32	1.19	1.47	0.04	1.01	2.07
2/3 Moist + 1/3 Dry	0.75	27.46	9.93	0.33	1.04	1.07	0.04	0.54	0.99
1/2 Moist + 1/2 Dry	0.67	19.75	7.32	0.33	1.16	1.03	0.04	0.43	0.82
1/3 Moist + 2/3 Dry	0.47	10.74	4.68	0.30	0.88	0.94	0.04	0.42	0.74
Dry Soil	0.26	3.40	3.77	--	0.98	1.08	0.02	0.30	0.54

TABLE 11.

SUDAN GRASS DRY MATTER YIELD, PLANT Al COMPOSITION AND EXCHANGEABLE SOIL Al, AS INFLUENCED BY THE VARYING SOIL COMBINATIONS AND LEVELS OF CALCIUM SILICATE

Calcium Silicate (tons/A)	Plant Yield (g/pot)			Plant Al (ppm)			Soil Al (ppm)		
	0	5	10	0	5	10	0	5	10
Moist Soil	2.54	19.33	0.88	166	132	126	833	386	593
2/3 Moist + 1/3 Dry	0.75	27.46	9.93	140	148	150	811	386	358
1/2 Moist + 1/2 Dry	0.67	19.75	7.32	158	171	117	829	427	365
1/3 Moist + 2/3 Dry	0.47	10.74	4.68	109	150	142	805	452	383
Dry Soil	0.26	3.40	3.77	265	145	118	861	466	355

Al, with 10 tons per acre of calcium silicate on moist soil is again evident.

The extractability of Mg, K and Mn (Table 12, 13, 14) do not appear to be influenced to any great degree with the variation in dry to moist soil ratios.

The plant composition correlates even less with plant yield, in this experiment as compared to the earlier experiments discussed.

Plant Al as in the instance of the two previous experiments remains unaffected by treatment.

Plant P is very low in the completely dry soil, but varies within narrow ranges in the wet soil as well as in the other soil combinations.

Plant Ca drops slightly but progressively with increase in the ratio of dry to moist soil. What is more interesting is the change in relationship between the plant Ca levels and the soil Ca levels with increase in the ratio of dry to moist soil.

Plant Mg drops slightly with an increase in the dry to moist soil ratio, while plant K is not affected to any great extent.

Plant Mn drops with liming but is not affected very much by the varying ratio of dry to moist soil.

The trend with plant Zn (Table 15) is interesting. As in Experiment 3 at the level of 10 tons per acre of calcium silicate, there is a steep increase in plant Zn in the moister end of the soil series. As the ratio of dry to moist soil increased, plant Zn gets depressed with increasing calcium silicate. The high plant zinc at 10 tons per acre of calcium silicate as in Experiment 3 probably

TABLE 12.

SUDAN GRASS DRY MATTER YIELD, PLANT Mg COMPOSITION AND EXCHANGEABLE SOIL Mg, AS INFLUENCED BY THE VARYING SOIL COMBINATIONS AND LEVELS OF CALCIUM SILICATE

Calcium Silicate (tons/A)	Plant Yield (g/pot)			Plant Mg (%)			Soil Mg (%)		
	0	5	10	0	5	10	0	5	10
Moist Soil	2.54	19.33	0.88	0.29	0.46	0.26	0.02	0.03	0.03
2/3 Moist + 1/3 Dry	0.75	27.46	9.93	0.41	0.42	0.30	0.01	0.01	0.02
1/2 Moist + 1/2 Dry	0.67	19.75	7.32	0.48	0.39	0.39	0.01	0.01	0.01
1/3 Moist + 2/3 Dry	0.47	10.74	4.68	0.31	0.30	0.38	0.01	0.01	0.01
Dry Soil	0.26	3.40	3.77	--	0.37	0.38	0.02	0.02	0.01

TABLE 13.

SUDAN GRASS DRY MATTER YIELD, PLANT K COMPOSITION AND EXCHANGEABLE SOIL K, AS INFLUENCED BY THE VARYING SOIL COMBINATIONS AND LEVELS OF CALCIUM SILICATE

Calcium Silicate (tons/A)	Plant Yield (g/pot)			Plant K (%)			Soil K (ppm)		
	0	5	10	0	5	10	0	5	10
Moist Soil	2.54	19.33	0.88	2.82	2.52	2.15	1177	1709	1720
2/3 Moist + 1/3 Dry	0.75	27.46	9.93	2.78	2.11	3.46	1052	119	895
1/2 Moist + 1/2 Dry	0.67	19.75	7.32	2.99	2.91	3.02	929	113	642
1/3 Moist + 2/3 Dry	0.47	10.74	4.68	3.02	3.28	2.91	800	283	772
Dry Soil	0.26	3.40	3.77	1.21	2.13	2.01	598	424	474

TABLE 14.

SUDAN GRASS DRY MATTER YIELD, PLANT Mn COMPOSITION AND SOIL Mn (EXCHANGEABLE AND REDUCIBLE), AS INFLUENCED BY THE VARYING SOIL COMBINATIONS AND LEVELS OF CALCIUM SILICATE

Calcium Silicate (tons/A)	Plant Yield (g/pot)			Plant Mn			Soil Mn					
							0		5		10	
	0	5	10	0	5	10	Ex.	Red.	Ex.	Red.	Ex.	Red.
Moist Soil	2.54	19.33	0.88	70	49	32	3.13	2.59	1.16	2.20	1.99	1.83
2/3 Moist + 1/3 Dry	0.75	27.46	9.93	94	46	56	1.31	2.34	0.56	2.09	0.78	2.66
1/2 Moist + 1/2 Dry	0.67	19.75	7.32	96	54	47	1.18	2.36	0.73	2.18	0.69	1.96
1/3 Moist + 2/3 Dry	0.47	10.74	4.68	79	50	49	0.93	2.75	0.60	2.42	0.45	2.64
Dry Soil	0.26	3.40	3.77	--	48	46	0.94	1.53	0.77	1.82	0.49	3.23

TABLE 15.

SUDAN GRASS DRY MATTER YIELD, PLANT Zn AND PLANT Si COMPOSITION AS INFLUENCED BY THE VARYING SOIL COMBINATIONS AND LEVELS OF CALCIUM SILICATE

Calcium Silicate (tons/A)	Plant Yield (g/pot)			Plant Zn (ppm)			Plant Si (%)		
	0	5	10	0	5	10	0	5	10
Moist Soil	2.54	19.33	0.88	54	20	71	1.10	3.35	1.60
2/3 Moist + 1/3 Dry	0.75	27.46	9.93	83	16	41	1.88	2.46	2.59
1/2 Moist + 1/2 Dry	0.67	19.75	7.32	73	26	22	2.12	2.51	1.90
1/3 Moist + 2/3 Dry	0.47	10.74	4.68	52	52	43	0.92	1.84	1.77
Dry Soil	0.26	3.40	3.77	--	82	61	1.49	1.92	1.66

involves the formation of a soluble zincate ion at higher pH values, as speculated by Camp (1945). The pH values (post harvest) of this soil series from wet to dry ranged from 7.7 to 6.5 This steep increase in Zn concentration at the higher levels of $CaSiO_3$ could also be associated with unthrifty plant growth as observed by Kanehiro (1964).

Plant Si (Table 15) in the moist soil again characteristically drops with 10 tons per acre of calcium silicate. This was observed in Experiment 3 as well. In the rest of the soil series, however, plant Si does not follow any particular trend.

Discussion

In the previous experiments, the moist soil invariably gave rise to better plant growth than the dehydrated soil. In this experiment, however, one finds that the moist soil containing one-third of its volume of dry soil, proving to be significantly superior to the completely moist soil. This is despite greater extractability of soil P and Ca in the moist soil. This reversal of trends, could very well have been due to one or both of two possible effects, consequent on a mixing of 2/3 moist and 1/3 dry soil. One of these effects could have been a lowering of pH from 7.2 to 6.9 in the treatment with calcium silicate at 5 tons per acre. The other factor could very well have been the result of an improvement in the soil physical conditions of the moist soil conferred by better soil aeration. Be it either one or both effects that could

have effected a yield increase, the data show that these beneficial effects, if any, do not persist as the ratio of dry to moist soil increases any furhter. In fact, the progressively decreased yields thereafter follow the general trend observed with dry Akaka in the earlier experiments.

THE RATOON CROP

The ratoon crops of the experiments followed similar trends to those of the plant crop. Treatments which failed to produce a good plant crop, did not ratoon at all. For instance in Experiments 3, 4, and 5, the number of treatments that failed to ratoon were 10, 20, and 26, respectively, out of a total of 90 in each experiment. For these reasons a detailed discussion of the ratoon crop was not undertaken. However, the Tables F, G, and H of the Appendix show the dry matter yields as well as the plant composition of the ratoon crop in respect to Experiments 3, 4, and 5, respectively. Also a summary of the variance analysis for all three experiments is given in Table 16 and the results would seem to be almost identical with those of the plant crop.

The ratoon crop did, however, produce two features worthy of note:

(1) A greater response of sudan grass to the higher level of P in the moist Akaka.

(2) The observation of what appeared to be very characteristic symptoms of Ca deficiency in the unlimed soils as well as in the olivine-treated soils (See Plate 10).

TABLE 16.

SUMMARY OF VARIANCE ANALYSIS DATA OF SUDAN GRASS DRY MATTER YIELDS IN THE RATOON CROP OF EXPERIMENTS 3, 4, AND 5

Variates	Exp. 3		Exp. 4		Exp. 5
	I	II	I	II	
Replicates					
Soil/Soil Combinations(S)	**	**	**	**	**
Soil Amendments (C)	**	**	**	*	**
Phosphate (P)	**	**	**	**	**
S x C	**	**	**	--	*
S x P	*	*	*	--	--
C x P	--	**	--	**	**
S x C x P	**	*	--	--	**

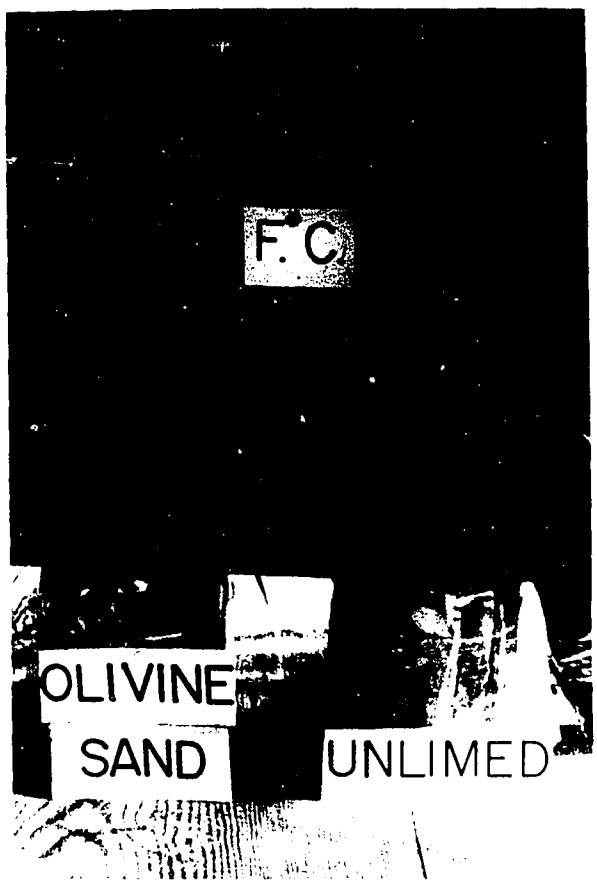

PLATE 10. SYMPTOMS SIMULATING Ca DEFICIENCY IN THE RATOON CROP OF SUDAN GRASS

CORRELATION ANALYSIS

There is a marked absence of correlations between soil and plant analysis versus plant yields.

In the case of the moist and 50% moist soils, this situation resulted no doubt from the fact that the 2.5 ton rate of lime proved to be most effective. The pattern of the yield curve thus tended to be highly parabolic. Besides with certain of the elements investigated, there was also evidence of dilution effects, effected by high plant yields. In these same treatments, the soil analysis evinced a corresponding draining effect. All of these phenomena thus obliterated any definite trends of plant yields in relation to plant and soil analysis.

With the dry Akaka on the other hand, the yield curve stayed more or less constant, but at a low level after the first increment of lime. Thus, here too, the soil and plant analysis data failed to show any trend in relation to plant yield.

In the above circumstances, correlation statistics with respect to plant yield are not reported here. However, certain trends in soil Ca, P, and Al consequent on the liming of these soils are shown in Tables 17, 18, and 19 in respect of Experiments 3, 4, and 5, respectively.

These tables reveal the very consistently negative correlations of soil Al versus both soil Ca and soil P and also with increasing rates of lime. Soil Ca and soil P on the other hand are positively correlated and also show very

TABLE 17.

CORRELATION COEFFICIENTS CALCULATED WITHIN SOIL ANALYSIS (EXPERIMENT 3)

Factor a vs. Factor b	Akaka Moist		50% Moist		Akaka Dry	
	r	Significance	r	Significance	r	Significance
In Soils						
Soil Ca vs. Soil Al	-.244	NS	-.525	NS	-.912	**
Soil Ca vs. Soil P	+.335	NS	+.192	NS	+.197	NS
Soil Al vs. Soil P	-.239	NS	-.340	NS	-.301	NS
Soil Ca vs. $CaSiO_3$ rates	+.987	**	+.996*	**	+.996	**
Soil Al vs. $CaSiO_3$ rates	-.237	NS	-.488	NS	-.892	**
Soil P vs. $CaSiO_3$ rates	+.309	NS	+.368	NS	+.173	NS

NS Not Significant
* Significant at 5% level
** Significant at 1% level

TABLE 18.

CORRELATION COEFFICIENTS CALCULATED WITHIN SOIL ANALYSIS (EXPERIMENT 4)

Factor a vs. Factor b	Akaka Moist		50% Moist		Akaka Dry	
	r	Significance	r	Significance	r	Significance
In Soils						
Soil Ca vs. Soil Al	-.697	NS	-.697	NS	-.866	**
Soil Ca vs. Soil P	+.619	NS	+.425	NS	+.682	NS
Soil Al vs. Soil P	-.593	NS	-.756	*	-.842	**
Soil Ca vs. Coral Rock rates	+.985	**	+.995	**	+.997	**
Soil Al vs. Coral Rock rates	-.644	NS	-.791	*	-.760	*
Soil P vs. Coral Rock rates	+.614	NS	+.426	NS	+.709	*

NS Not Significant
* Significant at 5% level
** Significant at 1% level

TABLE 19.

CORRELATION COEFFICIENTS CALCULATED WITHIN SOIL ANALYSIS (EXPERIMENT 5)

Factor a vs. Factor b	2/3 Moist + 1/3 Dry r	Significance	1/2 Moist + 1/2 Dry r	Significance	1/3 Moist + 2/3 Dry r	Significance
In Soils						
Soil Ca vs. Soil Al	-.839	*	-.871	*	-.913	**
Soil Ca vs. Soil P	+.302	NS	+.215	NS	+.321	NS
Soil Al vs. Soil P	-.522	NS	-.483	NS	-.434	NS
Soil Ca vs. $CaSiO_3$ rates	+.997	**	+.999	**	-.997	**
Soil Al vs. $CaSiO_3$ rates	-.840	*	-.880	*	-.896	*
Soil P vs. $CaSiO_3$ rates	+.356	NS	+.253	NS	+.322	NS

NS Not Significant
** Significant at 5% level
* Significant at 1% level

positive correlations with increasing rates of lime applications.

In Experiment 5, the correlation coefficients have been calculated only for the intermediate members of the soil series, since experiment 3 has similar statistics for the moist and the dry soils.

SUMMARY AND CONCLUSIONS

Some of the changes with dehydration, in the physical, chemical and mineralogical properties of Akaka subsoil were studied. The moist Akaka as well as soil dehydrated to 50 per cent of its initial moisture and completely dry Akaka were subjected to treatment with three soil amendments at rates varying from 0, 2.5, 5 and 10 tons per acre. In addition, the moist and the dry Akaka were physically mixed in three different properties, to evaluate the bearing of such physical admixtures on plant growth on these soils. In addition to an initial study on dehydration, four discrete experiments were carried out to determine the soil-plant inter-relationships, with respect to the above treatments. In these soil-plant studies, phosphorus at 250 and 750 lb/A was also a variable. In two of the experiments, a micro-nutrient supplement was also used as a variable in conjunction with the highest level of soil amendment used. The three soil amendments used were calcium silicate (TVA "Mix 398" electric phosphorus furnace slag), Coral rock and Olivine sand, all of 100 mesh fineness. The experimental designs were factorial and laid out in randomized block design. Sudan grass (sweet Sudan premium) was the indicator crop and treatment responses were evaluated on a basis of plant yield, plant composition and soil analysis. Sudan grass was grown in one gallon pots, after the soil had being incubated for four weeks with the soil

amendments and thereafter treated with NPK and micro-nutrients (in the relevant treatments) prior to the sowing of seed.

The progressive dehydration of soils showed a tremendous drop in the CEC of the soils even after only 25 per cent of the moisture had been lost. Dehydration was also accompanied by a progressive decline in extractable P. Exchangeable Al did not show any particular trend. The soil pH also declined slightly. Mineralogical changes based on X-ray diffraction and DTA analysis, showed an increase in the concentration of gibbsite as a function of dehydration.

Studies on plant-soil inter-relationships showed the following trends:

(1) With one exception there was a distinct depression of plant yields with dehydration of soils. Soil analysis revealed that this could have been the result of very low extractability, in general, of plant nutrients, in the dehydrated soils as opposed to the moist soils.

(2) Akaka subsoil (moist) admixed with 1/3 of its volume with Akaka dry and treated with 5 tons per acre of calcium silicate, increased sudan grass yields very significantly over the moist Akaka soil. This might well have been as a result of an improvement in the physical status of the Akaka moist soil. Any further increase in the ratio of dry to moist soils caused yield depressions in sudan grass.

(3) As to the performance of the 3 soil amendments, sudan grass responded best to calcium silicate. Of the other two, responses to Coral rock was intermediate, while under the conditions of this investigation, olivine

sand failed to prove itself as a soil amendment.

(4) The best yield responses with sudan grass was obtained at 2.5 tons per acre of soil amendment on moist Akaka, both in the case of calcium silicate and coral rock. This rate of application brought the soil pH to around 6.8 to 7.0. So as a corallary, one might say that so long as other factors are not limiting, a soil pH of about 6.8 produces the best plant response on these soils.

(5) Soil amendment rates of 5 and 10 tons per acre drastically reduced yields in the case of coral rock while with calcium silicate, the 10 ton rate depressed yields more than the 5 ton rate. It is appreciated that while this is true under greenhouse conditions (in a closed system pot culture), these results would not hold true under field conditions. With the free draining soil properties and the heavy precipitation associated with the Hilo coast, it is improbable that 10 ton applications of these amendments would cause any decrease in plant yields. However, what could probably be translated to field conditions from these findings would be to aim at a pH of not more than 6.8, with adequate nutrition.

(6) The depression in plant yields with high levels of soil amendment, was shown to be largely due to a severe Mn deficiency in the instance of coral rock. With calcium silicate on the other hand, the severe yield depression at 10 tons per acre was probably the result of unavailability of phosphorus.

LITERATURE CITED

Addoms, Ruth. 1927. Toxicity as evidenced by changes in the protoplasmic structures of root hairs of wheat. Amer. Jour. Bot. 14:147-156.

Akhromeiko, A. I. 1934. Influence of silicic acid upon the utilization by plants of P_2O_5 from various sources. Z. P. Dungung Bocken K. 34A:340-359. (From Minor Elements Vol. 1)

Albrecht, W. A. 1941. Plants and exchangeable calcium of the soil. Amer. Jour. Bot. 28:394-402.

Anderson, I. and H. J. Evans. 1956. Effect of Manganese and certain other metal cations on isocitric dehydrogenase and malic enzyme activities in Phaeseolus vulgaris. Plant Phys. 31:22-28.

Arnon, D. J. and C. M. Johnson. 1942. Influence of hydrogen ion concentration on the growth of higher plants under controlled conditions. Plant Phys. 17:525-539.

Ayres, A. 1934. Phosphate fixation in Hawaiian soils. 11. Haw. Planter's Record. 38:131-145.

Ayres, A. and H. H. Hagihara. 1955. Available phosphorus in Hawaiian soil profiles. Hawaiian Planter's Record. 54:81-89.

Black, C. A. 1957. Soil and Plant Relations. Wiley, N. Y.

Bromfield, S. M. 1959. The effect of the siliceous compound of decomposing rice hulls on the solubility of phosphate. Austr. Jour. Agr. Res. 10(3):353-363.

Brown, J. C. and R. S. Holmes. 1956. Iron supply and interacting factors related to lime induced chlorosis. Soil Sci. 82:507-509.

Camp, A. F. 1945. Zinc as a nutrient in plant growth. Soil Sci. 60:157-163.

Chenery, E. M. 1948. Thioglycollic acid as an inhibitor for iron in the colorimetric determination of aluminum by means of aluminon. The Analyst 73:501-502.

_____. 1955. A preliminary study of aluminum and the tea bush. Plant and Soil. 6(2):174-200.

Chernov, V. A. and N. I. Belyaneva. 1946. (The nature of soil acidity). Pedology 593-603. (R.e.)

Chu, Ada C. and G. D. Sherman. 1952. Differential fixation of phosphate by typical soils of the Hawaiian Great Soil Groups. Univ. of Hawaii Agr. Expt. Sta. Tech. Bull. 16.

Clements, H. F. 1958. Recent developments in the crop logging of Sugarcane Phosphorus and Calcium. Univ. of Hawaii Agr. Expt. Sta. Progress Notes 114.

_____. 1961. The coral stone-phosphate experiments on the Hilo and Hamakua coasts. Repts Haw. Sugar Technologists. 20th Ann. Meeting.

_____. 1962. Factors determining the response of sugarcane to calcium carbonate in Hydrol Humic Latosols. Proc. 11th Congress I.S.S.C.T.

Cline, M. G. et al. 1955. Soil Survey of the Territory of Hawaii. U.S.D.A. Soil Survey Seires 1939. No. 25.

Cole, C. V., S. R. Olsen, and C. O. Scott. 1953. The nature of phosphate sorption by calcium carbonate. Soil Sci. Soc. Amer. Proc. 17:352-356.

Coleman, N., J. Throp and M. Jackson. 1960. Phosphate sorption reactions that involve exchangeable aluminum. Soil Sci. 190:1-7.

Coleman, N. T., E. J. Kamprath and S. B. Weed. 1958. Liming. Adv. in Agron. 10:475-522.

Coleman, R. 1944. The mechanism of phosphate fixation by montmorillonitic and kaolinitic clays. Soil Sci. Soc. Amer. Proc. 9:72-78.

Davies, E. B. 1956. Factors affecting molybdenum availability in soils. Soil Sci. 81:209-221.

Dean, L. A. and E. J. Rubins. 1947. Anion exchange in soils: 1. Exchangeable phosphorus and the anion exchange capacity. Soil Sci. 63:377-387.

Dewan, M. L. and A. S. Hunter. 1949. Absorption of phosphorus by soybeans and sudan grass. 11. Effect of silicates. Soil Sci. 63:479-482.

Engels, O. 1936. (The influence of liming on the solubility of phosphoric acid in acid soils). Ztschr. Pflanz. Dung. 43:350-356. (G)

Epstein, E. 1960. Calcium -lithium competition in absorption by plant roots. Nature 185:705-706.

_____. 1961. The essential role of calcium in selective cation transport by plant cells. Plant Phys. 36:437-444.

Evans, H. and R. B. Cate (Jr.). 1962. Studies in the improvement of problem soils in British Guiana. World Crops 14:370.

Forsee, W. T. 1954. Conditions affecting the availability of residual and applied manganese in the organic soils of the Florida Everglades. Soil Sci. Soc. Amer. Proc. 18:475-478.

Fried, M. and M. Peech. 1946. The comparative effect of lime and gypsum upon plant growth on acid soils. Jour. Amer. Soc. Agron. 38:614-623.

Fried, M. and R. E. Shapiro. 1961. Soil-plant relationships in ion uptake. Ann. Rev. Plant Phys. 12:91-112.

Fujimoto, C. K. and G. D. Sherman, 1946. The effect of drying, heating and wetting on the level of exchangeable manganese in Hawaiian soils. Soil Sci. Soc. Amer. Proc. 10:107-118.

Gericke, S. 1951. (Relationships between the growth factors lime and phosphorus). Z. Acker-U. Pfbau. 93:141-178. (G)

Ghani, M. O. and S. A. Aleem. 1942. Effect of liming on the transformation of phosphorus in acid soils. Indian Jour. Agr. Sci. 12:873-882.

Gilbert, A. 1952. Copper in Nutrition. Advances in Agron. 4:147-178.

Hagen, C. E. and H. T. Hopkins. 1955. Ionic species in orthophosphate absorption by barley roots. Plant Phys. 30:193-199.

Hall, A. D. and Morrison. 1955. On the function of silicon in the nutrition of cereals. Proc. Royal Soc. Ser. B. 77, 455.

Hartwell, B. L. and F. R. Pember. 1918. The presence of aluminum as a reason for the difference in the effect of so-called acid soil on barley and rye. Soil Sci. 6:259-279.

_____. 1920. The effect of dicalcium silicate on an acid soil. Soil Sci. 10:57-60.

Hemwall, J. B. 1957. The fixation of phosphorus by soils. Adv. in Agron. 9:95-112.

Ikawa, H. 1956. The role soluble silicate on the fixation and release of phosphorus of tropical soils. M. S. Thesis, Univ. of Hawaii.

Jackson, M. L. 1962. Soil Chemical Analysis. Prentice Hall.

Jackson, R. K. and J. G. Brown. 1956. The determination of zinc in plant material without the use of organic extractant. Proc. Amer. Soc. Hort. Sci. 68:1-5.

Jacobson, L., J. H. Raymond, D. P. Moon and M. Schaedle. 1961. Influence of calcium on selectivity of ion absorption process. Plant Phys. 36:58.

Kanehiro, Y. 1964. Status and availability of zinc in Hawaiian soils. Ph.D. Thesis. Univ. of Hawaii.

_____ and Annie T. Chang. 1956. Cation exchange properties of the Hawaiian Great Soil Groups. Univ. of Hawaii Agr. Expt. Sta. Bull. 31.

King, D. L. 1961. Phosphorus fixation in soils containing amorphous and crystalline aluminum and iron compounds. M. S. Thesis. Univ. of Hawaii.

Leow, O. 1903. The physiological role of mineral nutrients in plants. U.S.D.A. Bur. Plant Indus. Bull. 45.

Magistad, O. C. 1925. The aluminum content of the soil solution and its relation to soil reaction and plant growth. Soil Sci. 20:181-225.

Matsusaka, Y. and G. D. Sherman. 1950. Titration curves and buffering capacities of Hawaiian soils. Haw. Agr. Expt. Sta. Tech. Bull. 11.

Mattson, S. 1931. The laws of soil colloidal behavior. Soil Sci. 32:343-365.

McAuliffe, C. and N. T. Coleman, 1955. Hydrogen ion catalysis by acid clays and exchange resins. Soil Sci. Soc. Amer. Proc. 19:156-160.

McLean, F. T. and B. E. Gilbert. 1926. The relative aluminum tolerance of crop plants. Soil Sci. 24(3):163-174.

_____. 1928. Aluminum Toxicity, Plant Phys. 3:293-302.

Mehlich, A. 1957. Aluminum, iron and pH in relation to lime-induced manganese deficiency. Soil Sci. Soc. Amer. Proc. 21:625-630.

_____ and W. E. Colewell. 1943. Influence of nature of soil colloids and degree of base saturation on growth and nutrient uptake by cotton and soybeans. Soil Sci. Soc. Amer. Proc. 8:179-184.

Meyer, B. S., D. B. Anderson, and R. H. Bohning. 1960. Introduction to plant physiology - Van Nostrand.

Miller, E. C. 1938. Plant Physiology. McGraw Hill, N. Y.

Mitscherlich, E. A. 1947. Experiments on the fixation of phosphoric acid by applications of calcium carbonate. Ztschr. Phlanz. Dung. 39:1-9. (G)

Monteith, N. H. 1961. The comparative effects of calcium carbonate and calcium silicate on the yields of sudan grass grown in a Ferruginous Latosol and Hydrol Humic Latosol. M. S. Thesis. Univ. of Hawaii.

_____ and G. D. Sherman. 1963. The comparative effects of calcium carbonate and of calcium silicate on the yield of sudan grass grown in a Ferruginous Latosol and a Hydrol Humic Latosol. Univ. of Hawaii Agr. Expt. Sta. Tech. Bull. 53.

Moomaw, J. C., M. T. Nakamura, and G. D. Sherman. 1959. Aluminum in some Hawaiian plants. Pacific Sci. 335:341.

Mulder, E. G. and F. C. Gerretsen. 1952. Soil Manganese in relation to plant growth. Adv. in Agron. 4:222-278. Acad. Press. N. Y.

Paver, H. and C. E. Marshall. 1934. The role of aluminum in the reactions of the clays. Jour. Soc. Chem. Ind. Index of Chem. and Ind. XII:750-760.

Pierre, W. H. and G. M. Browning. 1935. The temporary injurious effects of excessive liming of acid soils and its relation to the phosphate nutrition of plants. Jour. Amer. Soc. Agron. 27:742-759.

Pierre, W. H. and A. D. Stuart. 1933. Soluble aluminum studies. IV. The effects of phosphorus in reducing the deterimental effects of soil acidity on plant growth. Soil Sci. 36:211-227.

Piper, C. S. 1944. Soil and Plant Analysis. Interscience Publ. Inc.

Rana, S. K. 1964. Ph.D. Thesis. Univ. of Hawaii. Effects of dehydration and heavy liming on plant nutrition in the amorphous and crystalline tropical soils of Hawaii.

Reddy, G. G. 1964. Ph.D. Thesis. Univ. of Hawaii. Influence of associated anion on the effects of calcium on nutrient uptake by sudan grass on two tropical soils.

Richardson, H. L. 1951. Soil acidity and liming with tropical crops. World Crops. 3:339-340.

Rixon, A. J. 1962. Effects of heavy applications of lime to soil derived from volcanic ash on the Humid Hilo and Hamakua coast, Island of Hawaii. Ph.D. Thesis. Univ. of Hawaii.

Rogers, L. H. and C. H. Wu. 1948. Zinc uptake by oats as influenced by application of lime and phosphate. Jour. Amer. Soc. Agron. 40:563-566.

Russel, E. W. 1961. Soil conditions and plant growth. Wiley, N. Y.

Russel, R. S., E. W. Russel, P. G. Marais and W. N. M. Foster. 1950. Factors affecting the availability to plants of soil phosphates. Proc. Peaceful Uses of Atomic Energy. 12:103-108.

Scarseth, G. D. 1935. The mechanism of phosphate retention by natural alumino-silicate colloids. Jour. Amer. Soc. Agron. 27:596-616.

_____ and J. W. Tidmore. 1934. Fixation of phosphate by clay soils. Jour. Amer. Soc. Agron. 26:152-162.

Scheidt, A. W. 1917. A comparison of calcium silicate, carbonate and hydrate as fertilizer materials with experimental data. Electric smelting and aluminum company. Sewaren. N. J.

Schmehl, W. R., M. Peech and R. Bradfield. 1950. Cause of poor growth of plants on acid soils and beneficial effects of liming. 1. Evaluation of factors responsible for acid soil injury. Soil Sci. 70:393-410.

Sherman, G. D. 1957. Formation of gibbsite aggregates in latosols developed on volcanic ash. Science 125:3260.

_____. 1958. Gibbsite rich soils of the Hawaiian Islands. Haw. Agr. Expt. Sta. Bull. 116.

_____, J. S. McHargue and W. S. Hodgkin. 1942. Determination of active manganese in soil. Soil Sci. 54:253-257.

Sherman, G. D., A. C. Chu and C. M. Sakamoto. 1954. The influence of application of soluble silicates on phosphorus availability in certain Hawaiian soils. Proc. Acad. Sci. 30th Ann. Meeting. Honolulu.

Suehisa, R. H. 1961. Effects of silicates on phosphorus availability to sudan grass grown on Hawaiian soils. M. S. Thesis. Univ. of Hawaii.

Tamura, T., M. L. Jackson and G. D. Sherman. 1953. Structural and energy relationships in formation of iron and aluminum oxides, hydroxides and silicates. Science 117:381-383.

Taranovskaya, V. G. 1941. The effectiveness of lime and silicate applications on red loam. Chemisation Socialistic Agr. (USSR) 10(4):37-42. (From Minor Elements, Vol. 1)

Taylor, A. W. 1960. The agronomic value of silica. Literature Survey. Report No. 693. Tennessee Valley Authority, Div. of Chem. Dev. Fundamental Res. Br. Wilson Dam. Alabama.

Thompson, L. M. 1957. Soils and Soil Fertility. (2nd Ed.) McGraw-Hill.

Toth, S. J. 1939. The stimulating effects of silicates on plant yields in relation to anion displacement. Soil Sci. 47:122-139.

Trenel, M. and F. Alten. 1934. The physiological importance of the mineral soil acidity whereon consists the toxic action of aluminum. Angew. Chem. 47:813-820.

Truog, E. 1938. Phosphate fixation. Soil Sci. 38:263-271.

_____. 1953. Liming and the availability of phosphates. "Soil and fertilizer phosphorus in crop nutrition." pp. 281-297. Edited by W. H. Pierre and A. G. Norman. Acad. Press Inc. N. Y.

Vlamis, J. 1953. Acid soil infertility as related to soil solution and soil phase effects. Soil Sci. 75:383-393.

Willis, L. G. 1931. The effect of liming soils on the availability of manganese and iron. Jour. Amer. Soc. Agron. 23:1050-1051.

Woodruff, C. M. 1947. Determination of the exchangeable hydrogen and lime requirement of the soil by means of the glass electrode and a buffered solution. Soil Sci. Soc. Amer. Proc. 12:141-142.

Wright, K. E. 1943. Effects of fertilizer and lime in reducing aluminum toxicity of acid soils. Plant Phys. 12:173-181.

Younge, O. R. and J. C. Moomaw. 1960. Revegetation of stripmined bauxite lands in Hawaii. Econ. Bot. 14:316-330.

APPENDIX TABL

SUDAN GRASS (PLANT CROP) DRY MATTER YIELDS (AVG. 3 REPS), PLANT COMPOSITION
3 LIMING MATERIALS (CORAL ROCK, CALCIUM SILICATE, OLIVINE SAND) x THREE
DEHYDRATION (MOIST AND DRY) x 2 LE

Soil Amendments	Soil	P lb/A	Soil pH	D.M. Yield g/pot	Ca (%) Plant	Ca (%) Soil	Mg (%) Plant	Mg (%) Soil	P (ppn Plant
Coral Rock tons/A									
0	M.S.	250	4.73	3.22	0.26	0.08	0.50	0.04	1520
		750	4.20	3.91	0.50	0.04	0.38	0.03	2440
	D.S.	250	4.50	0.15	--	0.02	--	0.01	1606
		750	4.70	0.26	--	0.02	--	0.01	1480
5	M.S.	250	7.24	1.29	1.29	1.26	0.32	0.04	2600
		750	7.16	0.60	1.50	1.35	0.61	0.06	3320
	D.S.	250	6.20	0.70	1.20	0.32	0.79	0.01	1200
		750	6.20	4.82	1.39	0.32	0.49	0.01	1457
10	M.S.	250	7.50	1.44	1.35	1.91	0.58	0.03	1820
		750	7.41	0.69	1.40	2.12	0.67	0.03	2330
	D.S.	250	6.76	1.01	2.01	0.57	0.21	0.01	1418
		750	6.71	4.50	1.35	0.53	0.38	0.01	1617
Calcium Silicate TVA									
0	M.S.	250	4.71	2.07	0.30	0.04	0.32	0.02	1530
		750	4.20	3.00	0.33	0.04	0.26	0.01	2530
	D.S.	250	4.83	0.17	--	0.02	--	0.02	1626
		750	4.93	0.35	--	0.02	--	0.02	1434
5	M.S.	250	7.04	24.66	1.06	0.99	0.42	0.04	1533
		750	6.90	13.99	1.31	1.02	0.49	0.02	3149
	D.S.	250	5.94	0.94	0.96	0.30	0.28	0.01	1403
		750	5.97	5.86	0.96	0.29	0.45	0.02	1420
10	M.S.	250	7.70	1.53	1.11	2.03	0.20	0.03	1510
		750	7.58	0.22	1.82	2.11	0.31	0.03	991
	D.S.	250	6.50	1.47	1.08	0.51	0.32	0.01	1472
		750	6.46	6.06	1.08	0.56	0.43	0.01	1564
Olivine Sand									
0	M.S.	250	4.50	7.22	0.35	0.04	0.43	0.02	1601
		750	4.41	2.02	0.35	0.04	0.31	0.03	2631
	D.S.	250	4.82	--	--	0.02	--	0.01	--
		750	4.86	0.04	--	0.02	--	0.01	1449
5	M.S.	250	5.57	0.81	0.33	0.04	0.84	0.22	3528
		750	5.16	0.95	0.30	0.04	0.82	0.27	4850
	D.S.	250	5.42	--	--	0.02	--	0.07	--
		750	5.37	0.01	--	0.02	--	0.08	--
10	M.S.	250	5.70	0.22	0.56	0.04	1.02	0.30	2912
		750	5.53	0.36	0.39	0.04	0.92	0.35	4539
	D.S.	250	5.43	0.12	--	0.02	--	0.10	1601
		750	5.51	0.02	--	0.01	--	0.08	--

M.S. = Akaka Moist
D.S. = Akaka Dry

ENDIX TABLE A.

OMPOSITION AND SOIL ANALYSIS. DATA FROM A 4 FACTORIAL EXPERIMENT WITH
D) x THREE RATES OF APPLICATION (0, 5 AND 10 TONS/A) x 2 DEGREES OF SOIL
DRY) x 2 LEVELS OF P (250 AND 750 LB P/A)

	P (ppm)		Al (ppm)		K		Mn (ppm)			Zn	Si
	Plant	Soil	Plant	Soil	Plant (%)	Soil (ppm)	Plant	Soil Ex.	Red.	ppm Plant	% Plant
4	1520	156	124	996	3.01	1472	64	2.89	2.89	46	0.52
3	2440	346	145	622	3.22	881	94	7.54	3.77	123	1.56
1	1606	38	363	906	--	602	--	1.06	1.76	--	0.37
1	1480	72	181	651	--	594	--	0.88	1.76	--	0.42
4	2600	119	116	548	4.09	1642	7	0.66	1.65	91	0.32
5	3320	516	252	270	4.21	1775	22	0.96	2.89	133	1.57
1	1200	110	201	549	2.12	420	39	0.41	1.53	51	2.74
1	1457	180	169	446	2.81	428	43	0.47	1.76	98	1.13
3	1820	320	123	452	3.56	1771	8	0.92	1.83	16	0.17
3	2330	1061	119	272	3.95	1668	22	0.78	2.51	133	0.44
1	1418	99	168	428	1.71	563	45	0.29	1.18	135	2.05
1	1617	228	140	305	2.81	385	39	0.38	1.32	86	0.99
2	1530	152	102	1044	2.69	1668	63	2.20	3.14	55	0.96
1	2530	481	230	622	2.95	918	76	4.06	2.03	53	1.24
2	1626	33	429	933	1.64	618	--	0.76	1.53	--	1.70
2	1434	63	99	788	0.78	674	--	1.12	1.53	--	1.28
4	1533	112	122	478	1.94	261	43	1.16	2.07	17	3.48
2	3149	429	141	294	3.10	228	54	1.16	2.33	22	3.22
1	1403	30	144	510	1.59	626	50	0.71	1.76	122	2.14
2	1420	69	146	422	2.66	324	45	0.82	1.88	42	1.69
3	1510	163	185	683	2.17	2016	36	2.14	1.83	14	1.45
3	991	741	124	503	2.13	2160	28	1.83	1.83	127	1.74
1	1472	24	105	393	1.53	626	45	0.53	2.94	81	1.86
1	1564	81	130	316	2.50	414	46	0.44	3.51	40	1.45
2	1601	139	173	979	2.88	1669	52	2.45	3.36	66	1.31
3	2631	467	121	655	2.77	722	86	7.83	2.90	46	1.19
1	--	24	--	797	--	491	--	0.76	1.65	--	--
1	1449	24	145	705	--	626	--	1.18	2.00	--	2.08
2	3528	36	126	804	1.98	1648	90	2.82	3.14	50	1.76
7	4850	24	87	377	2.56	1543	98	5.95	3.48	47	3.15
7	--	06	--	735	--	633	--	1.00	1.41	--	--
8	--	20	--	597	--	570	--	1.23	1.88	--	--
30	2912	43	106	710	--	1751	81	1.68	3.36	216	3.51
35	4539	78	190	338	--	923	83	5.66	4.47	50	3.47
10	1601	18	454	698	1.55	633	98	0.65	2.12	--	4.80
08	--	26	--	575	--	633	--	1.00	1.65	--	--

APPENDIX TABLE B.

SUDAN GRASS (RATOON CROP) DRY MATTER YIELDS AND PLANT

Soil Amendments	Soil	P lb/A	D.M. Yield g/pot	Ca %	M %
Coral Rock tons/A					
0	M.S.	250	2.20	0.33	0.
		750	5.49	0.36	0.
	D.S.	250	--	--	--
		750	--	--	--
5	M.S.	250	0.72	1.29	0.
		750	0.29	--	--
	D.S.	250	0.28	--	--
		750	3.39	1.21	0.
10	M.S.	250	1.08	1.39	0.
		750	1.11	1.32	0.
	D.S.	250	0.37	--	--
		750	4.41	1.22	0.
Calcium Silicate TVA - tons/A					
0	M.S.	250	1.93	0.28	0
		750	6.52	0.26	0
	D.S.	250	--	--	-
		750	--	--	-
5	M.S.	250	12.80	1.37	0
		750	14.60	1.52	0
	D.S.	250	0.56	1.30	0
		750	5.62	1.06	0
10	M.S.	250	0.71	0.99	0
		750	--	--	-
	D.S.	250	0.78	1.96	-
		750	0.66	1.06	0
Olivine Sand tons/A					
0	M.S.	250	6.49	0.48	0
		750	4.05	0.36	0
	D.S.	250	--	--	-
		750	--	--	-
5	M.S.	250	1.23	0.30	0
		750	4.80	0.33	0
	D.S.	250	--	--	-
		750	--	--	-
10	M.S.	250	0.09	--	-
		750	0.71	0.30	0
	D.S.	250	--	--	-
		750	--	--	-

M.S. = Akaka Moist
D.S. = Akaka Dry

IX TABLE B.

S AND PLANT COMPOSITION -- EXPERIMENT 2

Ca %	Mg %	P ppm	Al ppm	K %	Mn ppm	Zn ppm	Si %
).33	0.31	1540	152	3.26	85	62	1.04
).36	0.31	2532	192	3.76	106	54	1.18
--	--	--	--	--	--	--	--
--	---	--	--	--	--	--	--
1.29	0.33	3279	140	4.36	10	29	0.63
--	--	5241	370	4.50	16	--	--
--	--	1007	254	2.40	85	--	--
1.21	0.30	1327	118	2.70	54	25	0.60
1.39	0.41	2440	167	3.72	12	22	0.60
1.32	0.41	3919	140	4.11	13	20	0.56
--	--	937	198	2.32	65	--	0.98
1.22	0.40	1235	123	2.68	42	25	0.90
0.28	0.43	2288	112	3.37	83	60	1.12
0.26	0.40	2539	135	3.57	94	61	1.29
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
1.37	0.40	1434	82	1.74	55	16	5.39
1.52	0.42	2639	104	1.79	68	15	5.64
1.30	0.45	1434	118	--	85	39	2.14
1.06	0.38	1281	106	2.83	63	29	1.92
0.99	0.33	1754	107	3.10	45	24	1.33
--	--	--	--	--	--	--	--
1.96	--	714	109	--	81	35	2.54
1.06	0.35	1250	120	2.79	58	24	1.57
0.48	0.37	1327	128	2.91	68	49	1.01
0.36	0.35	2860	160	3.74	114	58	1.31
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
0.30	0.67	3023	83	3.00	101	44	2.43
0.33	0.98	3744	296	3.20	119	66	4.06
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	3056	253	3.10	65	--	2.96
0.30	0.78	5490	109	3.02	97	37	4.09
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--

APPENDIX TABLE C

SUDAN GRASS (PLANT CROP) DRY MATTER YIELDS (AVG. OF 3 REPS), PLANT COMPO
WITH 5 CALCIUM SILICATE TREATMENTS (0, 2.5, 5, 10 AND 10 TONS/A + MICRO
(MOIST, 50% MOIST, DRY) x 2 LEVELS

Calcium Silicate TVA tons/A	Soil	P lb/A	Soil pH	D.M. Yield g/pot	Ca % Plant	Ca % Soil	Mg % Plant	Mg % Soil	P Plant
0	M.S.	250	4.71	2.07	0.30	0.04	0.32	0.02	1530
		750	4.20	3.00	0.33	0.04	0.26	0.01	2530
	50%	250	4.63	2.58	0.32	0.06	0.44	0.01	1320
		750	4.52	0.75	0.26	0.05	0.42	0.01	1555
	D.S.	250	4.82	0.17	--	0.02	--	0.02	1626
		750	4.92	0.35	--	0.02	--	0.02	1434
2.5	M.S.	250	6.66	30.64	1.22	0.49	0.55	0.02	1281
		750	6.47	32.61	1.18	0.68	0.44	0.03	2402
	50%	250	6.26	9.07	1.01	0.42	0.47	0.02	2005
		750	6.25	22.68	1.02	0.40	0.53	0.01	2273
	D.S.	250	5.45	0.66	0.92	0.17	0.41	0.01	955
		750	5.41	1.88	0.71	0.17	0.56	0.01	2105
5	M.S.	250	7.04	24.66	1.06	0.99	0.42	0.04	1533
		750	6.90	13.99	1.31	1.02	0.49	0.02	3149
	50%	250	6.68	6.14	1.06	0.83	0.56	0.02	2375
		750	6.74	13.28	1.13	0.76	0.55	0.02	2928
	D.S.	250	5.94	0.94	0.96	0.30	0.28	0.01	1403
		750	5.97	5.86	0.96	0.29	0.45	0.02	1420
10	M.S.	250	7.70	1.53	1.11	2.03	0.20	0.03	1510
		750	7.58	0.22	1.82	2.11	0.31	0.03	991
	50%	250	7.32	1.45	1.19	1.56	0.50	0.02	1159
		750	7.23	1.19	1.19	1.58	0.52	0.02	1144
	D.S.	250	6.50	1.47	1.08	0.51	0.32	0.01	1472
		750	6.46	6.06	1.08	0.56	0.43	0.01	1564
10+ Micro-nutrients	M.S.	250	7.77	1.34	1.16	2.28	0.19	0.03	1357
		750	7.59	1.62	0.99	2.36	0.20	0.03	2150
	50%	250	7.34	1.69	1.11	1.45	0.20	0.02	1403
		750	7.23	2.10	1.19	1.54	0.16	0.02	1510
	D.S.	250	6.51	1.06	1.25	0.59	0.27	0.01	115
		750	6.45	5.40	0.94	0.59	0.31	0.01	155

M.S. = Akaka Moist
50% = Akaka dehydrated to 50% of its initial moisture.
D.S. = Akaka Dry

)IX TABLE C.

ANT COMPOSITION AND SOIL ANALYSIS. DATA FROM A 3 FACTORIAL EXPERIMENT
'A + MICRO-NUTRIENT SUPPLEMENT) x 3 DEGREES OF SOIL DEHYDRATION
2 LEVELS OF P (250 AND 750 LB P/A)

	P		Al		K			Mn		Zn	Si
	ppm		ppm		%	ppm		ppm		ppm	%
1	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Ex.	Red.	Plant	Plant
)2	1530	152	102	1044	2.69	1668	63	2.20	3.14	55	0.96
)1	2530	481	230	622	2.95	918	76	4.06	2.03	53	1.24
)1	1320	77	138	976	2.73	1098	59	0.25	2.26	86	1.09
)1	1555	271	162	789	2.87	1376	69	1.42	2.85	138	2.25
)2	1626	33	429	933	1.64	618	--	0.76	1.53	--	1.70
)2	1434	63	99	788	0.78	674	--	1.12	1.53	--	1.28
)2	1281	87	122	432	1.80	183	34	1.14	3.86	20	2.64
)3	2402	291	152	333	1.80	202	49	1.13	3.26	18	3.27
)2	2005	61	150	566	3.12	154	55	0.91	2.50	49	2.81
)1	2273	189	168	402	2.42	143	42	0.85	2.75	33	2.21
)1	955	12	106	629	--	611	68	0.82	1.88	139	3.76
)1	2105	50	160	540	2.75	578	65	0.88	2.23	90	1.94
.04	1533	112	122	478	1.94	261	43	1.16	2.07	17	3.48
.02	3149	429	141	294	3.10	228	54	1.16	2.33	22	3.22
.02	2375	90	155	471	3.59	870	68	0.71	2.35	49	3.18
.02	2928	244	153	302	3.66	151	60	0.61	2.65	31	2.91
.01	1403	30	144	510	1.59	626	50	0.71	1.76	122	2.14
.02	1420	69	146	422	2.66	324	45	0.82	1.88	41	1.69
.03	1510	163	127	683	2.17	2016	36	2.14	1.83	14	1.45
.03	991	741	124	503	2.13	2160	28	1.83	1.83	127	1.74
.02	1159	147	109	550	2.04	1571	41	1.13	2.76	26	1.47
.02	1144	364	109	429	1.36	1606	26	0.75	3.01	131	1.74
.01	1472	24	105	393	1.53	626	45	0.53	2.94	81	1.86
.01	1564	81	130	316	2.50	414	46	0.44	3.51	40	1.45
.03	1357	208	68	752	2.05	2196	46	2.98	5.64	118	1.80
.03	2150	746	96	533	2.75	2226	37	3.05	5.79	108	1.38
.02	1403	114	127	504	2.25	1425	59	1.68	5.64	103	1.85
.02	1510	347	126	378	2.05	1113	38	1.94	5.59	119	1.47
.01	1151	48	132	393	1.89	689	79	0.65	9.76	139	2.93
.01	1556	69	139	329	2.69	531	51	0.53	13.88	77	1.02

APPENDIX TABLE D.

SUDAN GRASS (PLANT CROP) DRY MATTER YIELDS (AVG. OF 3 REPS), PLANT COMPOSI
WITH 5 CORAL ROCK TREATMENTS (0, 2.5, 5, 10 AND 10 TONS/A + MICRO-NUTRIE
50% MOIST, DRY) x 2 LEVELS OF P (250 A

Coral Rock tons/A	Soil	P lb/A	Soil pH	D.M. Yield g/pot	Ca %		Mg %		P ppm	
					Plant	Soil	Plant	Soil	Plant	S
0	M.S.	250	4.73	3.22	0.26	0.08	0.50	0.04	1520	1
		750	4.20	3.91	0.50	0.04	0.38	0.03	2440	3
	50%	250	4.57	1.13	0.30	0.02	0.40	0.02	1251	
		750	4.59	0.93	0.30	0.03	0.56	0.02	1477	1
	D.S.	250	4.50	0.15	--	0.02	--	0.01	1606	
		750	4.70	0.26	--	0.02	--	0.01	1480	
2.5	M.S.	250	6.78	5.06	1.24	0.67	0.44	0.02	2684	
		750	6.60	2.32	1.26	0.70	0.65	0.02	2791	1
	50%	250	6.48	5.50	1.13	0.49	0.25	0.02	2082	
		750	6.49	17.06	1.22	0.43	0.66	0.02	2265	1
	D.S.	250	5.81	1.23	1.06	0.18	0.58	0.01	1205	
		750	5.85	6.41	1.05	0.17	0.35	0.01	1510	
5	M.S.	250	7.24	1.29	1.29	1.26	0.32	0.04	2600	
		750	7.16	0.58	1.50	1.35	0.61	0.06	3320	5
	50%	250	6.94	0.99	1.29	0.90	0.37	0.03	2227	
		750	6.86	0.85	1.49	0.85	0.40	0.02	3671	1
	D.S.	250	6.20	0.70	1.20	0.32	0.79	0.01	1200	
		750	6.20	4.82	1.39	0.32	0.49	0.01	1457	
10	M.S.	250	7.50	1.44	1.35	1.91	0.58	0.03	1820	
		750	7.41	0.69	1.40	2.12	0.67	0.03	2330	1
	50%	250	7.40	1.43	1.24	1.53	0.37	0.03	2237	
		750	7.35	1.74	1.25	1.51	0.46	0.03	3417	
	D.S.	250	6.76	1.01	2.01	0.57	0.21	0.01	1418	
		750	6.71	4.50	1.35	0.53	0.38	0.01	1617	
10+ Micro-nutrients	M.S.	250	7.47	15.81	1.16	1.85	0.62	0.04	1830	
		750	7.51	4.67	1.35	1.80	0.83	0.03	2760	
	50%	250	7.31	3.62	1.23	1.61	0.73	0.02	1784	
		750	7.34	6.87	1.22	1.56	0.66	0.02	2684	
	D.S.	250	6.82	1.07	1.68	0.60	0.41	0.01	1083	
		750	6.75	5.18	1.31	0.61	0.43	0.01	1792	

M. S. = Akaka Moist
50% = Akaka dehydrated to 50% of the initial soil moisture.
D. S. = Akaka Dry

ENDIX TABLE D.

PLANT COMPOSITION AND SOIL ANALYSIS. DATA FROM A 3 FACTORIAL EXPERIMENT
· MICRO-NUTRIENT SUPPLEMENT) x 3 DEGREES OF SOIL DEHYDRATION (MOIST,
'ELS OF P (250 AND 750 LB P/A)

	P		Al		K			Mn		Zn	Si
	ppm		ppm		%	ppm		ppm		ppm	%
oil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Ex.	Red.	Plant	Plant
.04	1520	156	124	996	3.01	1472	64	2.89	2.89	46	0.52
.03	2440	346	145	622	3.22	881	94	7.54	3.77	123	1.56
.02	1251	13	160	1014	2.64	1267	66	0.88	2.51	120	0.93
.02	1477	122	110	789	2.72	1343	64	1.81	3.10	119	1.21
.01	1606	38	363	906	--	602	--	1.06	1.76	--	0.37
.01	1480	72	181	651	--	594	--	0.88	1.76	--	0.42
.02	2684	53	164	608	3.99	441	23	0.60	2.98	51	0.92
.02	2791	188	153	346	3.99	648	14	0.56	2.26	81	0.80
.02	2082	53	256	736	2.83	611	36	1.03	2.07	87	0.99
.02	2265	149	177	403	2.83	134	22	0.44	1.76	20	0.58
.01	1205	18	144	702	3.41	389	52	0.63	1.25	65	0.59
.01	1510	59	249	586	3.45	363	52	0.50	1.51	46	0.67
.04	2600	119	116	548	4.09	1642	07	0.66	1.65	91	0.32
.06	3320	516	252	270	4.21	1775	22	0.96	2.89	133	1.57
.03	2227	103	183	611	2.02	1130	18	0.50	2.01	119	0.91
.02	3671	270	195	378	3.88	1047	17	0.49	1.70	39	0.90
.01	1200	110	201	549	2.12	420	39	0.41	1.53	51	2.74
.01	1457	180	169	446	2.81	428	43	0.47	1.76	98	1.13
.03	1820	320	123	452	3.56	1771	8	0.92	1.83	16	0.17
.03	2330	1061	119	272	3.95	1668	22	0.78	2.51	133	0.44
.03	2237	62	230	415	3.94	753	18	0.61	2.43	81	1.62
.03	3417	270	381	267	3.44	903	13	0.47	0.71	42	0.57
.01	1418	99	168	428	1.71	563	45	0.29	0.18	135	2.05
.01	1617	228	140	305	2.81	385	39	0.38	1.32	80	0.99
.04	1830	58	200	320	3.06	180	71	1.33	8.53	48	0.77
.03	2760	384	252	224	3.65	269	93	1.20	7.46	77	0.80
.02	1784	68	291	400	3.74	918	90	2.07	5.35	79	0.42
.02	2684	183	184	282	3.32	285	97	1.18	4.70	85	0.66
0.01	1083	21	205	392	2.25	515	54	0.59	4.23	73	0.55
0.01	1792	63	220	309	3.14	309	50	0.53	5.17	50	0.62

APPENDIX TABLE E

SUDAN GRASS (PLANT CROP) DRY MATTER YIELDS, (AVG. OF 3 REPS), PLANT COMPOSITI
WITH 5 COMBINATIONS OF MOIST AND DRY SOILS (MOIST, 2/3 MOIST + 1/3 DRY, 1/2
OF CALCIUM SILICATE (0, 5 AND 10 TONS/

Soils	Calcium Silicate TVA tons/A	P lb/A	Soil pH	D.M. Yield g/pot	Ca % Plant	Ca % Soil	Mg % Plant	Mg % Soil	P ppm Plant	P ppm So
M.S.	0	250	4.71	2.07	0.30	0.04	0.32	0.02	1530	15
		750	4.20	3.00	0.33	0.04	0.26	0.01	2530	48
	5	250	7.04	24.66	1.06	0.99	0.42	0.04	1533	11
		750	6.90	13.99	1.11	1.02	0.49	0.02	3149	42
	10	250	7.70	1.53	1.11	2.03	0.20	0.03	1510	16
		750	7.58	0.22	1.32	2.11	0.31	0.03	991	7
2/3 M.S. + 1/3 D.S.	0	250	4.37	1.02	0.33	0.04	0.41	0.01	1495	
		750	4.12	0.48	--	0.04	--	0.01	2346	1
	5	250	6.48	26.04	0.99	0.54	0.42	0.01	1357	
		750	6.43	28.88	1.09	0.54	0.42	0.01	1960	1
	10	250	7.03	10.22	1.08	1.03	0.31	0.02	2150	
		750	6.98	9.63	1.06	0.94	0.29	0.01	2570	2
1/2 M.S. + 1/2 D.S.	0	250	4.44	1.07	0.33	0.04	0.48	0.01	1464	
		750	4.39	0.27	--	0.03	--	0.01	1830	1
	5	250	6.36	15.45	1.23	0.42	0.40	0.01	1640	
		750	6.41	24.05	1.09	0.44	0.38	0.01	2028	1
	10	250	6.85	6.29	1.04	0.85	0.35	0.01	1998	
		750	6.73	8.35	1.02	0.79	0.43	0.01	2760	
1/3 M.S. + 2/3 D.S.	0	250	4.48	0.57	0.30	0.03	0.31	0.01	1245	
		750	4.41	0.37	--	0.04	--	0.01	1769	
	5	250	6.16	8.20	0.84	0.44	0.29	0.01	1579	
		750	6.22	13.27	0.91	0.41	0.31	0.01	2196	
	10	250	6.65	4.15	0.96	0.73	0.32	0.01	1937	
		750	6.58	5.20	0.92	0.75	0.44	0.01	2799	1
D.S.	0	250	4.82	0.17	--	0.02	--	0.02	1626	
		750	4.92	0.35	--	0.02	--	0.02	1434	
	5	250	5.94	0.94	0.96	0.30	0.28	0.01	1403	
		750	5.97	5.86	0.99	0.29	0.45	0.02	1420	
	10	250	6.50	1.47	1.08	0.51	0.32	0.01	1472	
		750	6.46	6.06	1.08	0.56	0.43	0.01	1564	

M.S. = Akaka Moist
D.S. = Akaka Dry

APPENDIX TABLE E.

), PLANT COMPOSITION AND SOIL ANALYSIS. DATA FROM A 3 FACTORIAL EXPERIMENT
IOIST + 1/3 DRY, 1/2 MOIST + 1/2 DRY, 1/3 MOIST + 2/3 DRY, AND DRY), x 3 LEVELS
E (0, 5 AND 10 TONS/A) x 2 LEVELS OF P (250 AND 750 LB P/A)

g	P		Al		K			Mn		Zn	Si
%	ppm		ppm		%	ppm		ppm		ppm	%
Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Ex.	Red.	Plant	Plant
0.02	1530	152	102	1044	2.69	1472	63	2.20	3.14	55	0.96
0.01	2530	481	230	622	2.95	881	76	4.06	2.03	53	1.24
0.04	1533	112	122	478	1.94	1642	43	1.16	2.07	17	3.48
0.02	3149	429	141	294	3.10	1775	54	1.16	2.33	22	3.22
0.03	1510	163	127	683	2.17	1771	36	2.14	1.83	14	1.45
0.03	991	741	124	503	2.13	1668	28	1.83	1.83	127	1.74
0.01	1495	67	152	892	2.56	1033	77	0.99	2.34	83	1.50
0.01	2346	108	127	729	3.00	1070	110	1.62	2.34	--	2.26
0.01	1357	42	146	452	2.17	111	45	0.49	2.14	18	2.54
0.01	1960	150	149	320	2.04	126	46	0.63	2.04	14	2.38
0.02	2150	69	145	432	3.60	681	61	0.90	2.52	20	3.18
0.01	2570	200	154	284	3.31	1109	51	0.66	2.80	61	2.00
0.01	1464	50	193	908	3.18	898	100	0.71	2.04	73	1.59
0.01	1830	134	122	750	2.79	960	92	1.65	2.67	--	2.64
0.01	1640	80	182	479	3.22	131	58	0.82	2.38	32	2.99
0.01	2028	117	160	374	2.60	95	50	0.64	1.98	20	2.03
0.01	1998	65	92	420	2.98	703	47	0.74	2.09	20	1.84
0.01	2760	171	142	310	3.06	580	46	0.64	1.83	24	1.95
0.01	1245	31	145	867	--	791	86	0.87	2.53	52	0.92
0.01	1769	95	73	743	3.02	808	72	0.99	2.96	--	--
0.01	1579	50	141	513	3.22	455	52	0.56	2.96	54	1.80
0.01	2196	87	158	390	3.33	110	48	0.63	1.88	50	1.87
0.01	1937	51	127	410	2.81	736	49	0.47	2.27	55	1.66
0.01	2799	126	157	356	3.01	808	49	0.42	3.00	30	1.87
0.02	1626	33	429	933	1.64	602	--	0.76	1.53	--	1.70
0.02	1434	63	99	788	0.78	594	--	1.12	1.53	--	1.28
0.01	1403	30	144	510	1.59	420	50	0.71	1.76	122	2.14
0.02	1420	69	146	422	2.66	428	45	0.82	1.88	42	1.69
0.01	1472	24	105	393	1.53	563	45	0.53	2.94	81	1.86
0.01	1564	81	130	316	2.50	385	46	0.44	3.51	40	1.45

APPENDIX TABLE F.

SUDAN GRASS (RATOON CROP) DRY MATTER YIELDS AND PLANT

Calcium Silicate TVA tons/A	Soil	P lb/A	D.M. Yield g/pot	Ca %	Mg %
0	M.S.	250	1.93	0.26	0.4
		750	6.52	0.26	0.4
	50%	250	2.33	0.38	0.3
		750	0.42	0.42	0.3
	D.S.	250	--	--	--
		750	--	--	--
2.5	M.S.	250	14.24	1.35	0.2
		750	16.99	1.37	0.4
	50%	250	10.69	1.09	0.3
		750	15.66	1.60	0.4
	D.S.	250	0.16	--	--
		750	0.67	1.09	0.3
5	M.S.	250	12.50	1.37	0.4
		750	14.60	1.52	0.4
	50%	250	4.32	1.16	0.3
		750	14.60	1.36	0.3
	D.S.	250	0.56	1.30	0.
		750	5.63	1.06	0.
10	M.S.	250	0.71	0.99	0.
		750	--	--	--
	50%	250	0.12	--	--
		750	0.10	--	--
	D.S.	250	0.78	1.96	--
		750	6.66	1.06	0.
10 + Micro-nutrients	M.S.	250	0.20	--	--
		750	0.03	--	--
	50%	250	0.13	--	--
		750	0.04	--	--
	D.S.	250	0.38	1.44	0
		750	4.21	1.14	0

M.S. = Akaka Moist
50% = Akaka dehydrated to 50% of initial moisture.
D.S. = Akaka Dry

X TABLE F.

)S AND PLANT COMPOSITION -- EXPERIMENT 3

a %	Mg %	P ppm	Al ppm	K %	Mn ppm	Zn ppm	Si %
.26	0.43	2288	112	3.37	83	60	1.12
.26	0.40	2539	135	3.59	94	61	1.29
.38	0.31	1403	339	2.95	86	90	0.93
.42	0.37	1063	115	--	91	70	0.70
-	--	--	--	--	--	--	--
-	--	--	--	--	--	--	--
.35	0.29	1487	82	1.53	56	22	3.56
.37	0.43	2333	93	1.43	78	23	3.25
..09	0.35	1296	91	2.56	47	28	2.98
..60	0.40	1906	101	1.61	70	21	3.06
--	--	1987	237	3.88	--	--	2.66
1.09	0.34	1640	107	3.68	68	48	1.29
1.37	0.40	1434	82	1.74	55	16	5.39
1.52	0.42	2639	104	1.79	68	15	5.64
1.16	0.28	1937	87	3.80	67	41	3.37
1.36	0.70	1823	91	2.06	70	31	3.81
1.30	0.45	1434	118	--	85	39	2.14
1.06	0.38	1281	106	2.83	63	29	1.92
0.99	0.33	1754	107	3.10	45	24	1.33
--	--	--	--	--	--	--	--
--	--	712	198	2.58	44	--	1.87
--	--	763	182	1.94	65	--	2.60
1.96	--	714	109	--	81	35	2.54
1.06	0.35	1250	120	2.79	58	24	1.57
--	--	1114	171	1.29	--	--	0.84
--	--	915	198	1.29	--	--	1.53
--	--	1296	248	1.45	--	--	1.75
--	--	1830	330	1.94	--	--	1.60
1.44	0.88	999	156	--	171	135	2.05
1.14	0.57	1434	99	2.25	89	80	1.89

APPENDIX TABLE G

SUDAN GRASS (RATOON CROP) DRY MATTER YIELDS AND PLAN

Coral Rock tons/A	Soil	P lb/A	D.M. Yield g/pot	Ca %	Mg %
0	M.S.	250	2.20	0.33	0.31
		750	5.49	0.36	0.31
	50%	250	0.79	0.33	0.27
		750	--	--	--
	D.S.	250	--	--	--
		750	--	--	--
2.5	M.S.	250	12.45	1.21	0.4
		750	8.42	1.36	0.5
	50%	250	5.31	1.16	0.4
		750	13.80	1.45	0.5
	D.S.	250	1.30	1.08	0.3
		750	3.39	1.04	0.3
5	M.S.	250	0.72	1.29	0.3
		750	0.29	--	--
	50%	250	2.66	1.12	0.2
		750	4.68	1.24	0.3
	D.S.	250	0.28	--	--
		750	3.39	1.21	0.3
10	M.S.	250	1.08	1.39	0.4
		750	1.11	1.32	0.4
	50%	250	1.33	1.27	0.2
		750	3.48	1.29	0.3
	D.S.	250	0.37	--	--
		750	4.41	1.22	0.4
10 + Micro-nutrients	M.S.	250	12.80	1.44	0.3
		750	18.07	1.21	0.3
	50%	250	3.32	1.19	0.3
		750	12.50	1.27	0.3
	D.S.	250	0.75	2.02	0.3
		750	4.79	1.21	0.3

M.S. = Akaka Moist
50% = Akaka dehydrated to 50% of the initial moisture.
D.S. = Akaka Dry

APPENDIX TABLE G

ATTER YIELDS AND PLANT COMPOSITION -- EXPERIMENT 4

Ca %	Mg %	P ppm	Al ppm	K %	Mn ppm	Zn ppm	Si %
0.33	0.31	1540	152	3.26	85	62	1.04
0.36	0.31	2532	192	3.76	106	54	1.18
0.33	0.27	2555	244	3.97	111	121	0.84
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
1.21	0.44	2006	122	2.83	15	26	0.76
1.36	0.52	3660	134	3.53	23	32	0.87
1.16	0.44	1625	221	3.48	32	52	0.63
1.45	0.50	1922	119	1.73	31	22	0.94
1.08	0.38	1792	149	3.78	62	76	0.71
1.04	0.31	1647	186	3.35	77	39	0.87
1.29	0.33	3279	140	4.36	10	29	0.63
--	--	5241	370	4.50	16	--	--
1.12	0.27	1845	144	3.68	15	34	0.51
1.24	0.31	3523	131	4.24	17	58	0.53
--	--	1007	254	2.40	85	--	--
1.21	0.30	1327	118	2.70	54	25	0.60
1.39	0.41	2440	167	3.72	12	22	0.60
1.32	0.41	3919	140	4.11	13	20	0.56
1.27	0.26	1952	139	3.95	14	69	0.46
1.29	0.33	3355	170	4.09	10	30	0.62
--	--	937	198	2.32	65	--	0.98
1.22	0.40	1235	123	2.68	42	25	0.90
1.44	0.38	1449	121	1.98	96	41	1.04
1.21	0.30	2333	112	2.50	67	34	0.77
1.19	0.27	1464	170	3.26	138	87	0.74
1.27	0.33	2059	126	2.91	89	56	0.91
2.02	0.39	1121	157	2.45	171	148	0.89
1.21	0.26	1563	157	3.08	82	58	0.74

ire.

APPENDIX TABLE H.

SUDAN GRASS (RATOON CROP) DRY MATTER YIELDS A

Soils	Calcium Silicate TVA tons/A	P lb/A	D.M. Yield g/pot	Ca %
M.S.	0	250	1.93	0.26
		750	6.52	0.26
	5	250	12.80	1.37
		750	14.60	1.52
	10	250	0.71	0.99
		750	--	--
2/3 M.S. + 1/3 D.S.	0	250	0.15	--
		750	--	--
	5	250	14.10	1.32
		750	16.86	1.49
	10	250	8.23	1.11
		750	10.18	1.22
1/2 M.S. + 1/2 D.S.	0	250	0.09	--
		750	--	--
	5	250	10.76	1.09
		750	16.24	1.39
	10	250	4.93	1.26
		750	2.82	1.24
1/3 M.S. + 2/3 D.S.	0	250	--	--
		750	--	--
	5	250	5.35	1.09
		750	14.20	1.14
	10	250	2.59	1.19
		750	1.03	1.25
D.S.	0	250	--	--
		750	--	--
	5	250	0.56	1.30
		750	5.62	1.06
	10	250	0.78	1.96
		750	6.66	1.06

M.S. = Akaka Moist
D.S. = Akaka Dry

)IX TABLE H.

ΓER YIELDS AND PLANT COMPOSITION -- EXPERIMENT 5

Ca %	Mg %	P ppm	Al ppm	K %	Mn ppm	Zn ppm	Si %
0.26	0.43	2288	112	3.37	83	60	1.12
0.26	0.40	2539	135	3.59	94	61	1.29
1.37	0.40	1434	82	1.74	55	16	5.39
1.52	0.42	2639	104	1.79	68	15	5.64
0.99	0.33	1754	107	3.10	45	24	1.33
--	--	--	--	--	--	--	--
--	--	999	260	3.88	131	--	--
--	--	--	--	--	--	--	--
1.32	0.85	1189	117	1.71	67	17	3.80
1.49	0.88	1655	115	1.49	79	16	3.23
1.11	0.36	1647	121	2.77	75	16	4.20
1.22	0.37	2494	109	3.43	58	14	3.00
--	--	2598	215	2.97	--	--	1.67
--	--	--	--	--	--	--	--
1.09	0.94	1135	108	2.60	68	22	3.41
1.39	0.96	1723	87	1.55	72	17	3.30
1.26	0.68	1510	96	2.85	72	21	3.00
1.24	0.59	2303	98	3.55	70	19	3.23
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
1.09	0.67	1388	112	2.31	88	37	2.73
1.14	0.58	1403	116	1.50	57	25	2.41
1.19	0.46	1350	112	2.11	59	34	2.07
1.25	0.73	2257	96	2.29	54	24	2.20
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
1.30	0.45	1434	118	--	85	29	2.14
1.06	0.38	1281	106	2.83	63	28	1.92
1.96	--	714	109	--	81	35	2.54
1.06	0.35	1250	120	2.79	58	24	1.57