EFFECTS OF CALCIUM SILICATE ON YIELD AND NUTRIENT UPTAKE AND MECHANISM OF SILICON TRANSPORT IN PLANTS

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ABSTRACT

The effect of calcium silicate on yield and nutrient uptake by plants and the mechanism of Si uptake were studied in a series of three experiments. First, response to Si was measured on 22 plant species grown on two soils with four levels of calcium silicate in a greenhouse; second, corn was grown in the field to determine the magnitude of response to residual Si with variable P and pH levels; and third, five plant species were grown in culture solutions at varying transpiration rates to study the mechanism of Si uptake.

Response to calcium silicate differed with species and the same species grown on different soils had variable amounts of Si and P depending on the Si contents of the soils. In general the 2.2 T Si/ha application produced maximum yields in both soils and in some species it produced yields comparable to those with 8.8 T Si/ha at lower cost. Silicon concentrations in different plant groups were in the following order: grains $\geq$ grasses $\geq$ vegetables and fruits $\geq$ legumes except for those of the two Desmodiums in which concentrations were similar to those of grasses. Plant Ca concentrations generally increased whereas Mg, Mn, Al and Fe concentrations generally decreased when calcium silicate was applied. Silicon concentration was greatest in papaya and pineapple leaves and in sugarcane sheaths and was lowest in stems.

Hawaiian Cement Corporation (HCC) and Tennessee Valley Authority (TVA) calcium silicates generally produced higher yields than Technical grade (TG) calcium silicate, especially at low rates and in the third and fourth harvests. Plant Si concentrations in both HCC and TG calcium silicate were generally higher than in the TVA material indicating greater

Si availability in these two materials.

Ear corn yields in the field were significantly increased by P applications but were not significantly affected by residual Si or pH. Highest stover yields were obtained at pH 5.5 suggesting increased Si solubility at this pH may have increased stover yields by increasing mechanical strength and P availability. The application of 280 kg P/ha with Si produced yields nearly equal (98%) to those of 1120 kg P/ha without Si suggesting that comparable yields at lower cost may be obtained with the combination of high Si and low P, than with high P alone. Corn leaf Si values of 0.5 to 0.6% at silking appeared adequate for corn growth. Silicon taken up by the plant is more closely related to soil Si extracted with water than with sulphuric acid. Multiple regression analysis with yield and leaf nutrients indicated that Si, P and Fe are especially important for stover production while P, Ca, K, Al and Fe are important for ear production.

A statistically significant increase in the amount of water transpired per gram of dry weight with decreasing relative humidity was found in all species except *D. intortum* in solution cultures, but no significant increase in Si transport was obtained with increasing transpiration in any species. This suggests that transport of Si in plants is not related to transpiration. In continuous dark, plants accumulated Si in the roots and only sugarcane translocated large amounts of Si to the tops suggesting that metabolic energy is required for Si transport. Additional evidence of active Si transport was provided by the transpiration stream concentration factor (TSCF) values which were above or below one. Silicon concentrations in xylem exudates of

D. intortum, corn and sugarcane were greater than those of external solutions suggesting Si movement by active transport rather than by mass flow. In tomato and alfalfa Si concentrations were lower in exudates than in external solutions suggesting a selectivity mechanism in the root. These experiments demonstrated that both Si and P transport require metabolic energy.

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INTRODUCTION

In the past decades many attempts have been made to demonstrate the essentiality of Si for plant growth. Silicon is found in varying amounts in different plants and appreciable amounts are present in members of the Graminae. Silicon does have beneficial effects on the growth of several Graminacious species, particularly rice and sugarcane.

In Hawaii, Maxwell in 1898 (quoted from Moir, 1936) found that high rainfall areas are low in silicon and speculated that this might affect sugarcane yield. McGeorge (1924) reported that Si affected P assimilation in sugarcane and several years later Sherman, et al. (1955) verified the conclusion of McGeorge (1924). Further research by Monteith and Sherman (1963) and Suehisa, et al. (1963) suggested that yield increases in Sudan grass from Si applications were due to increased availability of soil P. Several other investigators interested in the effects of Si on sugarcane and rice nutrition have also suggested that interactions of Si with P, Al, Mn and Fe are responsible for the observed yield responses following Si applications. At times the response is great. For example, Fox, et al. (1967) reported a pol yield increase of 5.4 tons/acre with the application of 2 tons of TVA slag/acre.

The work on silicon nutrition in Hawaii has generally included only sugarcane, Sudan grass and papaya. Therefore this study was initiated to investigate the effects of calcium silicate (which was produced locally in a relatively pure form from coral limestone and silica sand) on the growth and uptake of several plant species on two Hawaiian soils. This study was designed to provide information on a range of species which may benefit from calcium silicate applications. Corn was used in a field experiment to evaluate yield response to calcium silicate, under variable P and pH.

Several views regarding the mechanism of Si uptake have been expressed by different investigators. Some conclude that Si is taken up passively in the transpiration stream, whereas others argue uptake is at the expense of respiratory energy. Therefore several species were utilized in experiments designed to study the mechanism of Si uptake.

The main objectives of the study can be summarized as follows:

1. To investigate the effects of calcium silicate on the growth and nutrient uptake of several plant species (grasses, grains, legumes, vegetables and fruits) on two Hawaiian soils.
2. To investigate the effects of three different calcium silicate materials on growth and nutrient uptake of Kikuyu grass and lettuce on the above soils.
3. To investigate the residual effects of silicon, phosphorus and pH on yield and nutrient uptake of field corn.
4. To study the mechanism of Si uptake in several plant species.

REVIEW OF LITERATURE

Effect of Silicon on Growth and Yield of Plants

Increased plant growth due to silicate applications have been reported by several investigators (Hall and Morrison, 1906; Barnett, 1924; Raleigh, 1939; Lipman, 1938; Brenchly, et al.,1927; Toth, 1939). Rice and sugarcane have given large responses to silicate applications, while yields of barley, oats, wheat and rye were also increased when the plants were grown in the presence of silicon (Vlamis J. and Williams, 1967).

No beneficial effects were obtained when various soluble silicates were applied together with phosphate to a Low Humic Latosol and a Humic Ferruginous Latosol, whereas Sudan grass yields were significantly increased when soluble silicates were applied to a Humic Latosol (Suehisa, et al., 1963). Monteith and Sherman (1963) showed both $CaCO_3$ and $CaSiO_3$ increased yields of Sudan grass in a Hydrol Humic Latosol when the pH was below 6.8, above this pH yields were depressed. However, in a Humic Ferruginous Latosol, lime did not increase yield but depressed it at high pH values while high rates of silicate continued to increase yield. These increases were believed to have been due to improved P nutrition and decreased aluminum toxicity.

An experiment conducted at Kilauea Sugar Plantation in 1962 involving phosphate, coral stone and sodium metasilicate showed no response to phosphate or coral stone but a gain in sugar for sodium silicate (Clements, 1965). Yield increases in sugarcane from calcium silicate applications were also reported in areas where freckling was usually most severe (Clements, 1965). Ayres (1966) obtained increased sugarcane yield in pot tests from purified $CaSiO_3$ and Electric furnace slag. No gain in cane yield was obtained from slag addition to a Si-deficient soil which was irrigated with water containing 50 ppm SiO_2. Ali (1966) concluded that silicate applications increased cane yields twofold in a pot test when no phosphorus was applied. Field cane yields were increased by both silicate and phosphate applications in Kapaa soil (Teranishi, 1968). The increases were attributed largely to improved P nutrition.

Wooley (1957) reported that Si did not significantly increase yield or Si concentration of tomato regardless of treatment. He concluded that Si, if essential to tomato, would be required in concentrations less than 0.2 μg atoms per gram plant dry matter. Gaussmann (1962) found that growth and yield of oats and beans increased in sand cultures due to colloidal Si application which improved moisture holding capacity of the medium.

Williams and Vlamis (1957a) have obtained characteristic toxicity symptoms on barley grown in standard Hoagland's solution containing 0.5 ppm Mn. Addition of 10 ppm Si to the culture solution prevented the toxicity symptoms and increased yield threefold. They concluded that Si caused the Mn to be more evenly distributed in the leaves. Vlamis and Williams (1967), conducted additional studies with barley, oats, wheat, rye, rice and ryegrass in culture solutions with the Mn content ranging from 0 to 5 ppm. Toxocity symptoms appeared at high Mn levels and addition of Si prevented the appearance of these symptoms. In all species the concentration of Mn decreased as a result of dilution by increased growth when Si was added.

Silicon supply did not influence the growth of tomato, radish, green onion and Chinese cabbage, whereas it greatly influenced the growth of rice (Okuda and Takahashi, 1964). The same authors reported both roots and shoots of rice were longer and grain yield was greater in the presence of silicon. Thus Si applied to acid soils as $CaSiO_3$ directly or indirectly influences the growth and yield of certain plants, especially rice and sugarcane.

Effect of Soil Silicon on Plant Uptake

The concentration and form of Si in soils is important in plant uptake. Several investigators (Iler, 1955; Jones and Handreck, 1965; McKeague and Cline, 1963) have reported that Si in the soil solution exists as non-polar monosilicic acid, $Si(OH)_4$.

The levels of soluble Si in soils of the same pH are influenced by the kind, amount, and crystallinity of free sesquioxides. Germer and Storks (1939) reported that the formation of hydrated aluminum oxide around silicious particles depressed the solubility of Si in soils. Likewise (Jones and Handreck, 1963, 1965b) showed the addition of Fe_2O_3 and Al_2O_3 depressed the concentration of monosilicic acid in soil solution and also was found to decrease the monosilicic acid concentration more than did Fe_2O_3. Jones and Handreck (1965b), who grew oat plants on various soils and soil oxide mixtures showed that Si concentrations in plant dry matter was directly proportional to monosilicic acid concentrations in soil solution.

Cheong (1967) found a highly significant correlation (γ = 0.989**) between extractable soil Si and pH when the mean figures for great soil groups were considered, however, when soil groups were considered individually, only the low humic latosols showed a significant correlation (γ = 0.871) between these variables. A significant correlation (γ = 0.893) was also obtained between total Si content of sugarcane sheaths and soil silicon extracted by 0.5N ammonium acetate pH 4.8, which implies that plant uptake of Si is governed by Si concentration in the soil.

Calcium silicate slag increased sugar yields 12 ton/ha in a field where phosphate extractable soil silicon and trichloroacetic acid (TCA) extractable silicon of sugarcane leaf sheaths were about 20 ppm. Leaf sheath silicon (TCA extractable) was highly correlated with log water extractable soil silicon (r = 0.97**) (Fox, et al., 1967).

Highly significant increases in sugarcane yields were obtained in both field and pot tests with application of calcium silicate to an Aluminous Humic Ferruginous Latosol. Silicon uptake was increased with the application of slag but there was no significant change in the uptake of other nutrients except Ca and P (Ayers, 1966). The author also found a highly significant inverse relationship between extractable soil Si and gain in sugar from slag applications. Most of these gains were obtained on Aluminous Humic Ferruginous Latosols. Therefore the author concluded that there is a level of available extractable soil Si below which satisfactory growth of sugarcane will not be obtained, regardless of macro and micro nutrients to which it has access.

Acquaye and Tinsley (1964) observed that the solubility of Si approaches zero in the presence of Al at pH 5.0, and in the presence of Fe at pH 4.0. The pH required for precipitation of Si in the presence of Fe and Al was decreased from 4 to 2 by phosphate. They also observed that calcium caused Si to remain insoluble in alkaline media with both Fe and Al, while Na caused it to redissolve with Al.

The concentration of $Si(OH)_4$ remaining in solution after an equilibration period, increased with the acidity of the soil suspension. With most soils the final monosilicic acid concentration in more acid suspensions exceeded the level added, indicating a net release of $Si(OH)_4$ (Beckwith and Reeve, 1963). The authors suggested that much of the monosilicic acid dissolving from soils is derived from adsorbing surfaces rather than from amorphous or crystalline silicate mineral structures. The amount of Si extracted from the soils studied varied with pH. Release was minimum at pH 7-9 and increased continuously as pH decreased.

Ayers (1966) found that liming a soil decreased Si uptake by sugarcane, this may be due to the increased pH. Grosse-Brauckmann (1953, 1956) also reported that liming a soil decreased Si uptake of oats, rye grass, red clover, barley, sugarcane and rice, whereas Jones and Handreck (1965b) found that the concentration of SiO_2 in oats increased from 1.68 to 2.77% when soil pH was lowered from 6.8 to 5.6.

The uptake of Si by plants increased with increasing soil water content (Baba, et al., 1956; Sreenivasan, 1936a; Williams and Shapter, 1955). This effect was shown in rice in which the concentration of SiO_2 in the leaf blades increased from 7.68 to 9.97% when soil water was increased from 50% of the "moisture holding capacity" to complete saturation (Baba, et al., 1956).

The amount of Si present in a plant (as percent of dry wt.) increased in direct proportion to the amount of silicic acid dissolved in the soil solution or culture medium for rye and sunflower

(Whittenbeger, 1945), for oats (Jones and Handreck, 1965), and for rice (Tanaka and Park, 1966). The uptake of Si in plants was also found to be related to the content of iron and Aluminum Oxides in the soil. Thus the leaf sheaths of sugarcane grown on gravelly soils contained about 5% SiO_2 whereas those grown on Humic Ferruginous Latosols contained about 1% SiO_2 (Halais and Parish, 1963).

The above review suggests that Si in soil solution is controlled by pH, the amount and kind of oxides and moisture content of the soil. The uptake and concentration of Si in a plant is proportional to the amount of dissolved silica in the soil solution and to the moisture content of soils.

Effect of Silicon on Phosphorus and Other Nutrients

Several investigators (Hall and Morrison, 1906; Schollenberger, 1922; Gile and Smith, 1925; Toth, 1939; Dewan and Hunter, 1949; Noda and Saito, 1952; Taylor, 1960) have suggested that the increased yield following $CaSiO_3$ application was due to improved P nutrition as a result of anion exchange with soil P. Yields, total P harvested in plants and soil P taken up by plants were increased significantly more by $CaSiO_3$ than by slag or limestone (Hunter, 1965). (The author concludes that Si present in large amounts increased the availability of soil P by anion exchange and stated that there is no evidence of silicate substituting for P within the plant.)

Calcium and magnesium silicates increased yield of barley and rye grass through displacement of P from soil (Toth, 1939). The main effect of silicate was to increase the availability of soil P and had nothing to do with P metabolism in the plant (Fisher, 1929). The same author showed that the Si/P ratio increased with Si application, but concluded that the contribution of silicon to increased yield was less when P was present than when P was absent. Raleigh (1953), working on a wide range of soils, reported that increased uptake of P with sodium and potassium silicate applications occurred only on soils where P levels were too low for normal crop growth.

Phosphorus utilization was improved when colloidal Si was used as an amendment with P applications (Noda and Saito, 1952). Akhromeiko (1934) reported that phosphate diffusion increased when in the form of a SiO_2 - P_2O_5 complex at the soil solution - root interface. Fox, et al. (1967) concluded that silicate response did not entirely result from improved P nutrition because, in a situation where Si greatly increased sugarcane production, a fourfold increase of applied P had little effect on yield.

The effect of silicon supply (50 ppm SiO_2) on growth of rice, P uptake and translocation were examined by Okuda and Takahashi (1964) with four levels of P (0, 2, 10, 50 ppm). The influence of silicon on P uptake by rice differed with P supply. At 10 and 50 ppm P the silicon supply decreased the concentration and uptake of P. An experiment utilizing radioactive P indicated that added silicon increased the translocation rate of absorbed P to the rice grain (Okuda and Takahashi, 1964). This may have resulted from Si decreasing the iron content of rice and thus increasing the P/Fe ratio in the plant.

Sherman, et al. (1955) and Monteith and Sherman (1963) concluded that the yield increases of Sudan grass resulting from silicate slag and coral stone applications were due to a reduction in soluble Al and in the case of slag, to an increase in the amount of available soil P. Clements (1965) reported a decrease in P concentration in cane following the application of TVA slag to a Humic Ferruginous Latosol, and attributed this to the dilution effect associated with increased growth. Teranishi (1968) found that at low P levels, low rates of applied Si increased sheath P while high rates of applied Si caused decreased sheath P and P uptake.

De Datta, et al. (1962) reported that in wheat dry matter and P uptake increased, whether silicate was applied alone or with P, whereas with rice, only the silicate treatment was effective in increasing dry matter. Additions of silicate increased uptake of soil P from soils with high P fixing capacity and resulted in greater uptake of fertilizer P from soils with low P fixing capacity. The dry matter yield of Sudan grass was three times greater when phosphorus was applied with soluble silicon than when phosphorus was applied alone to Helemano soil (Suehisa, et al., 1963). The less soluble phosphate fertilizer produced greater yield increases than did the more soluble phosphate fertilizer when they were applied together with silicon.

Brenchly (1927) reported that the effect of silicate application on the growth of barley was high in the P deficient solution and that the P content of the plant was decreased by silicate application. He speculated that silicate increased the efficiency of utilization of absorbed P in barley. Silicate had no significant effect upon yield or P concentration of soybeans, but P concentration was greater in Sudan grass grown on soils treated with magnesium and sodium silicates than in Sudan grass grown on the check soil (Dewan and Hunter, 1949).

Calcium silicate had no significant effect on the levels of sheath Zn, K, Mo, S, Al and Cu, but significantly increased the Si and calcium concentration of sugarcane sheaths (Clements, 1965). The author also reported that levels of P, Mg, Mn, B, N and tissue moisture were significantly reduced by $CaSiO_3$ applications. He concluded that the increased sheath Si and decreased sheath B and Mn were largely responsible for the yield increases following $CaSiO_3$ applications.

Okuda and Takahashi (1964) showed that the silicon supply alleviated Fe and Mn toxicity in rice by decreasing uptake of Fe and Mn. They demonstrated that Fe^{++} and Mn^{++} were readily oxidized by rice roots, which causes these ions to become insoluble and precipitate on the surface of roots. Since this effect was found to be greater in plants supplied with silicon, they concluded that silicon promoted the oxidation power of rice roots with the resulting deposition of Fe and Mn oxides on the root surface. This effect depended on silicon within the rice plants rather than in the external solution.

Barley plants grown in nutrient culture developed necrotic spots on their leaves. The necrosis increased when the Mn concentration was increased and decreased when the Mn concentration was lowered. When silicon was added, the symptoms disappeared (Williams and Vlamis, 1957). By using Mn^{54} they found that silicon affected the micro distribution of Mn in barley leaves. Vlamis and Williams (1967) showed that barley, rice, rye and rye grass exhibited the brown spotting in the absence of silicon but not in the presence of silicon. The authors concluded that the greater plant growth in the presence of silicon lowered the Mn concentration in the tissue.

Application of 50 ppm Si to rice accelerated flowering by one week over the zero Si treatment (Tanaka and Park, 1966). The same authors found that in green leaves, the content of N, P, Fe and Mn decreased with an increase in Si level. Rhodes, et al., 1956, reported decreased Mn uptake by avocado seedlings with silicate application. The decrease was attributed to increased soil pH and not Si uptake. Ayers (1966) also reported decreased Mn uptake by cane following slag application and explained it by the decreased solubility of Mn in soils resulting from the increased soil pH. The same authors also found that larger amounts of N and K were taken up where slag was applied, than when it was omitted. Slag also increased Ca and Mg contents of the crop.

Moisture content of heads, leaf blades, leaf sheaths and roots of rice decreased with maturity and the rate of decrease was accelerated by SiO_2 application. Silicate also decreased N and P_2O_5 concentration in every part of the plant, although the total amount of N absorbed was increased (Utagawa, et al., 1963).

The Distribution of Si in Plants

The distribution of Si in plants differs with species. In plants which accumulate little Si, such as tomato, radish, green onion and Chinese cabbage, the Si content of roots was equal to or greater than shoots (Okuda and Takahashi, 1964). In *Trifolium incarnatum* the Si concentration in roots was about 6 to 7 times higher than that in tops (Handreck and Jones, 1967a). In plants which accumulate much Si, such as rice and oats, most of the Si was found in the tops (leaf blades, leaf sheaths, stems and nodes). This distribution was clearly shown in rice (Okuda and Takahashi, 1964; Tanaka and Park, 1966; Yoshida, et al., 1962) as well as in oats (Jones and Handreck, 1965).

Much of the silicon absorbed by rice was found in the epidermis of the leaf blade and the husk. In leaf blades the density of silicified cells was highest at the tip and decreased towards the base (Yoshida, et al., 1962). These authors suggested that silicon distribution within rice tissues was closely related to transpiration. They demonstrated the low mobility of Si within rice and concluded that reutilization of Si once it is deposited in rice tissue is unlikely. The Si content in rice was found to vary with age. Mature plants and older leaves have a higher Si content than do young plants and leaves (Tanaka and Park, 1966).

Fox, et al. (1969) reported that both total and soluble Si were higher in sugarcane leaf sheaths than in leaf blades while total Si was much higher in leaf sheaths and blades than in internodal tissue. Soluble Si was most concentrated in the least mature tissues, whereas total Si was highest in recently matured tissue.

Solid silica in mature oat plants is in the form of opal (Jones, et al., 1963). Glumes have the highest Si content followed in decreasing order by the nodes, lemma, leaf blades, leaf sheath, root and seeds, showing that the tops generally contain more Si than roots. Handreck and Jones (1968) reported that the concentration of Si in dry matter of oats was highest in the palea, lemma, glumes, awn and leaves. Among the leaves, the flag leaf had the highest Si content, both in terms of concentration in the dry matter and amount per leaf. The distribution of silica along a leaf followed a hyperbolic curve, the concentration being highest at the apex and lowest at the base of the blade. They concluded that water and monosilicic acid move in the transpiration stream and that Si is deposited in greater quantities in actively transpiring regions of the plant.

Mechanism of Silicon Uptake

Several views regarding the mechanism of Si uptake have been expressed by different investigators. Some conclude that Si is taken up passively in the transpiration stream, whereas others argue that Si is taken up actively with the utilization of respiratory energy and another group suggests it is taken up both passively and actively.

Graminacious species generally accumulate more silicon than leguminous species (Russel, 1961; Jones and Handreck, 1965). Yoshida, et al. (1962) concluded that Si uptake in rice was passive since silicic acid is constantly absorbed by rice roots along with water and accumulates as silica in the aerial parts, as water is lost by transpiration. On the other hand, Kono and Takahashi (1958) reported that rice plants absorbed Si rapidly regardless of transpiration. Similarly, when transpiration was reduced from 106 ml to 32 ml/plant, the uptake of Si by rice was reduced from 1.9 to 1.8 mg/plant (Okuda and Takahashi, 1964), which suggests, in contrast to Yoshida, et al. (1962), that in rice at least, Si uptake is not passive.

When rice was grown under natural light, transpiration was 32 ml/plant and in the dark, 7.5 ml/plant in 4 hours, but there was no difference in the amount of Si absorbed (1.46 mg and 1.45 mg/plant). However, in 8 hours the amount of Si absorbed was slightly higher in light (6.16 mg/plant) than in dark (5.19 mg/plant), but the results were not statistically significant (Tanaka and Park, 1966). These authors also found about the same amount of Si in the growing young leaves irrespective of light treatments. In old leaves the Si content in the blade was higher than that in the sheath, and Si content was lower in the light than in the dark. In the dark, the amount of Si going to the younger leaves was greater than that going to the older leaves. It was concluded that Si uptake and the amount of Si going into young leaves were not influenced by transpiration.

Experiments were conducted using radioactive Si^{31} and P^{32} in rice and wheat (Mitsui and Takatoh, 1963). More Si^{31} was absorbed by Si deficient plants than by Si sufficient plants in both rice and wheat. Almost all of the Si^{31} absorbed by rice was translocated into shoots, while most of the P^{32} remained in the roots, therefore they concluded that translocation of Si from roots to shoots in rice may be regulated by the rate of transpiration.

The silicon concentration of cell sap of rice was several hundred times higher than that of the external solution (Okuda and Takahashi, 1964). Shone (1964) concluded that the initial entry of silicic acid into the free space of excised barley roots appears to conform to the passive diffusion of a non-polar solute. However, Barber and Shone (1966) could not explain the movement of silicic acid across the root into the transpiration stream by passive diffusion or mass flow of water.

Uptake of Si and P by rice was compared using metabolic inhibitors related to P uptake (Okuda and Takahashi, 1960; Mitsui and Takatoh, 1963). Sodium malonate and phloridzin inhibited P uptake but did not inhibit Si uptake, whereas sodium floride inhibited both Si and P uptake.

Iodoacetate, 2-4 dinitrophenol and sodium cyanide depressed the rate of translocation of silicon but not of P (Mitsui and Takatoh, 1963). Silicon uptake was inhibited more severely by 2-4 dinitrophenol than P uptake, whereas sodium cyanide inhibited Si uptake as severely as P and K uptake (Okuda and Takahashi, 1964). The authors concluded that energy from aerobic respiration is required for the uptake of Si by rice, but did not take into account the effect of inhibitors on transpiration.

Barber and Shone (1966) reported that inhibitors affected both transpiration and uptake of Si while temperature affected the uptake of Si but not transpiration in the 48-hour period. Thus they concluded that absorption of Si by roots was affected by metabolic energy arising from respiration.

Jones and Handreck (1965) concluded that the amount of Si in a plant can be calculated if the concentration of silicic acid in the soil solution and the amount of water transpired are known. Their calculated values agreed closely with the amounts found by actual analysis, leading the authors to conclude that the uptake of silicic acid was passive in oats. They suggested that it is likely that Si uptake by other graminacious species is also passive. However, they mentioned that leguminous species containing relatively low amounts of Si must have some mechanism for excluding Si at the root surface.

In tomatoes when transpiration was reduced from 150 ml/plant to 63.5 ml/plant, the Si uptake was reduced from 1.1 mg to 0.4 mg/plant, suggesting that Si may enter the tomato plants in the transpiration stream (Okuda and Takahashi, 1964). The same authors also reported that Si concentration in the bleeding sap of tomatoes was lower than that of the external solution, indicating less Si movement into the plant.

In Trifolium incarnatum the transpiration stream concentration factor, TSCF (which is the ratio of the concentration of Si in the transpiration stream to that in the external solution) ranged from 0.052 to 0.073 (Handreck and Jones, 1967) while in rice it greatly exceeded unity (Okuda and Takahashi, 1964). This suggests that in rice Si accumulation in tops exceeds that expected by passive uptake in the transpiration stream. Thus both passive and active mechanisms may be involved in Si uptake or active mechanisms may be the sole means of Si uptake.

Investigations with rice by Okuda and Takahashi (1964) and Tanaka and Park (1966) supports that idea that silicic acid is absorbed independently of the rate of H_2O absorption and that metabolic energy is involved. This is contrary to the report of Yoshida, et al. (1962) that Si is taken into the plant with the transpiration stream. Okuda and Takahashi (1964) and Tanaka and Park (1966) also found that rice plants previously grown at low levels of Si had a greater capacity to absorb silicic acid than plants grown at high Si levels. Tanaka and Park (1966) concluded that the transpiration rate was greater in light than in dark and there was no significant difference in the amount of silicic acid absorbed under the two conditions.

EFFECTS OF CALCIUM SILICATE APPLICATION ON YIELD AND NUTRIENT UPTAKE BY SEVERAL PLANT SPECIES ON TWO SOILS

A series of studies was conducted to evaluate effects of calcium silicate. Initial effects on yield and nutrient uptake of 22 plant species were measured in a pot study conducted on two soils, Kapaa and Paaloa. Residual effects were measured on some of the species which were replanted or allowed to regrow. Nutrient distribution in three species, papaya, pineapple and sugarcane, was also determined. In addition, responses to three silicate materials were evaluated with lettuce and Kikuyu grass on the two soils mentioned previously. The results and discussion in this section are arranged in the order described above.

Materials and Methods

Description of Soils

Surface soils representing two great soil groups belonging to the Humoxic Trophohumult (Humic Latosol) and Typic Gibbsihumux (Humic Ferruginous Latosol) were used in this study. These soils differ in physical, chemical and mineralogical properties and are described by Cline, et al. (1955). A brief description of these two soils follows.

Paaloa Soil

Paaloa soil is a Humoxic Trophohumult collected from Helemano, Oahu. This soil is formed from basalt weathered in place under an annual rainfall of 70-100 inches at elevations ranging from 500-1300 feet above sea level. The clay minerals present in this soil are kaolin, illite, iron oxides and gibbsite. Cation saturation is low and the buffering capacity moderately high.

Kapaa Soil

Kapaa soil is a Typic Gibbsihumux collected from the Kauai Branch Station. The characteristics of this soil are the presence of crystalline alumina as gibbsite and a concentration of resistant heavy minerals (concretions of Fe and Ti oxides) in the upper part of the soil profile. This soil is low in bases and silica and has a low bulk density (about 1.5). Its pH is low (4.8) and oxides are the dominant minerals, therefore its phosphate fixing capacity is high.

Experimental Procedure

Plant species used in this experiment are listed in Table 1. One-gallon cans, lined with polyethylene bags with a hole at the bottom for drainage were used for all plant species except papaya and sugarcane for which five-gallon cans were used. The one and five gallon cans were filled with 2 kg and 5 kg (oven dry basis) soil, respectively. Soil pH was adjusted to 6.0 ± .2 by adding appropriate amounts of $CaCO_3$ or S. The blanket application of fertilizer material and the Si treatments are shown in Tables 2 and 3, respectively. A randomized complete block design with 22 plant species, 4 Si treatments, 2 soils and 2 replications was used.

Planting and Maintenance

Most species were planted by seed 1/4 to 1 inch below the soil surface. Mimosa and Desmodium seeds were scarified with concentrated H_2SO_4 to facilitate early germination. Pineapples were started from crowns which were dried for 2 weeks, trimmed to relatively uniform weight, then soaked in water for 2 days and planted. Sugarcane was

TABLE 1. SPECIES NAMES, NUMBER OF PLANTS PER POT AND AGE AT HARVEST FOR PLANTS IN THE SPECIES EXPERIMENT

Common Name	Botanical Name	Variety	No. of Plants Per Pot	Age at Harvest
				(days)
Legumes				
Big Trefoil	Lotus pedunculatus	--	5	72
Intortum	Desmodium intortum	4331 (HAES)*	5	71
Kaimi clover	Desmodium canum	5335 (HAES)*	8	94
Alfalfa	Medicago sativa	Sonora	5	72
Sensitive plant	Mimosa pudica	--	6	88
Grasses				
Kikuyu grass	Pennisetum clandestinum	--	4	42
Bermuda grass	Cynodon dactylon	--	4	42
Sudan grass	Sorghum sudanense	--	5	42
Guinea grass	Panicum maximum	Trichoglume	3	42
Sugarcane	Saccharum officinarum	H 50 - 7209	2	128
Grains				
Sorghum	Sorghum vulgare	--	10	29
Corn	Zea mays	H-38	3	42
Oats	Avena sativa	Nortex 107	20	42
Rice	Oryza sativa	Colusa (Kauai)	20	42
Barley	Hordeum vulgare	Daytona	20	45
Al-tolerent wheat	Triticum aestivum	Atlas 66	20	46
Al-sensitive wheat	Triticum aestivum	Thatcher	20	46
Vegetables & Fruits				
Tomato	Lycopersicon esculentum	Healani	10	37
Lettuce	Lactuca sativa	Manoa	8	28
Cabbage	Brassica oleracea capitata	--	5	32
Pineapple	Ananas comosus	Smooth Cayenne	1	420
Papaya	Carica papaya	--	3	84

*Hawaii Agricultural Experiment Station, Department of Agronomy and Soil Science accession number.

TABLE 2. FERTILIZER MATERIALS AND RATES OF APPLICATION USED IN SPECIES EXPERIMENT

Element	Rate of Element ppm	Source
N	200	Urea
P	500	H_3PO_4
K	200	KCl
Ca	10	$CaCO_3$
Mg	100	$MgSO_4 \cdot 7H_2O$
Zn	50	$ZnSO_4 \cdot 7H_2O$
B	2	H_3BO_4
Mo	1	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$
Mn	25	$MnSO_4 \cdot H_2O$

TABLE 3. SILICON TREATMENTS USED IN SPECIES EXPERIMENT

Element	T Si/ha	Source
	0	
	0.56	Calcium Silicate prepared by Hawaiian Cement Corp. (HCC)
Si	2.2	
	8.8	

planted from one-eye seed cuttings which were pretreated with 0.0125% PMA (Phenyl Mercuric Acetate). One-eye cuttings were also used for Kikuyu grass and Bermuda grass. The pots were watered twice daily with rain water and the leachate, collected in a can below, was returned to the pots in subsequent waterings. One week after germination the pots were thinned to a constant number of plants for each species. Plants were sprayed with insecticide and iron chelate every week. A blanket application of N and K were applied every two weeks for pineapple and sugarcane and also for the ratoon crops of several species.

Harvest

The majority of species were harvested after 4 to 6 weeks growth except pineapple, sugarcane, papaya and the legumes (Table 1). Successive harvests of at least one species from each group were taken to study the residual effects of silicon. Immediately after harvest, plant tops were washed in 0.01% detergent solution, rinsed in distilled water and then ovendried at 70°C. Sugarcane was divided into leaves and sheaths 3, 4, 5, 6 from the two primary stalks in each pot and the remaining plant material was chopped, mixed and each sampled for moisture and total analysis. Pineapple was divided into stem, leaves, peduncle, fruit and crown. Papaya was separated into petiole, stem and leaves. In sugarcane, pineapple and papaya a sample of fresh tissue was used for soluble Si determination.

Plant Analyses

Ground ovendried plant samples were analyzed for Si, P, Ca, Mg, K, Mn, Al and Fe. Detailed methods of extraction and analysis are presented in Appendix A.

Soluble Silicon

Soluble silicon in fresh plant material was extracted immediately after harvest with trichloro-aceticacid (Fox, et al., 1967). Silicon was determined by the silico-molybdate method described by Kilmer (1965).

Total Silicon

Total silicon was determined by fusion of ashed samples with lithium tetraborate (Suhr and Ingamells, 1966) and color was developed by the silico-molybdate blue method of Kilmer (1965).

Wet Ashing

One gram of the ground plant material was digested in a 2:1 nitric acid-perchloric acid mixture. This digest was used for the determination of P, Ca, Mg, K, Mn, Al and Fe.

Phosphorus

Phosphorus was determined in the lithium tetraborate digest and the nitric-perchloric acid digest by the vanadate-molybdate yellow method of Barton (1948).

Calcium, Magnesium and Potassium

Plant Ca and Mg in the nitric-perchloric digest was determined with a Perkin-Elmer atomic absorption spectrophotometer. Lanthanum, 0.3%, was added to a diluted aliquot from the nitric-perchloric digest to eliminate interferences from aluminum, phosphate and sulphate ions. The original solution was used for K analysis on the Beckman Du flame photometer.

Manganese, Aluminum and Iron

Plant Mn, Al and Fe were determined directly on a portion of the nitric-perchloric digest solution with a Perkin-Elmer atomic adsorption spectrophotometer.

Results and Discussion

Initial Effects of Calcium Silicate

Several investigators have reported yield responses from calcium silicate applications for rice in Japan and for sugarcane in Hawaii. A pot study was conducted to determine whether other species also responded to calcium silicate applications. The study included 22 plant species, four Si levels and two soils, a Humoxic Tropohumult (Paaloa soil) and a Typic Gibbsihumox (Kapaa soil). Soil pH control was attempted by adding $CaCO_3$ or sulpher as required in all treatments. Control was successful in the Kapaa soil. However in the Paaloa, the desired pH (±0.5 units) was achieved in the first three Si treatments only. In the 8.8 T Si treatment final soil pH was about 0.7 pH unit higher than for the other treatments. The effect of P was minimized by supplying the equivalent of 1120 kg P/ha to all treatments (mixed throughout the soil). The effects of Ca were also minimized by supplying Ca at a rate that was considered adequate even at the lowest Ca level (570 ppm Ca) which was the 0 Si treatment. A Ca differential was present in both soils due to variable calcium silicate applications, but the minimum amount of Ca supplied was considered adequate for most crops.

Kapaa Soil

Yield: All 22 species grown on Kapaa soil had higher yields when Si was applied than when no Si was applied (Table 4). The yield increases of 10 species were statistically significant at the 1, 5 and

TABLE 4. INFLUENCE OF CALCIUM SILICATE APPLICATIONS ON DRY MATTER YIELD OF PLANTS GROWN ON KAPAA SOIL

Species	Dry matter yield T Si/ha				Percent of maximum yield T Si/ha			
	0	0.56	2.2	8.8	0	0.56	2.2	8.8
	(g/pot)				(%)			
Legumes								
Big trefoil	4.15	5.05	7.55	5.80	55	66	100	77
Intortum**	11.20b	14.70c	15.20c	8.90a#	74	97	100	59
Kaimi clover*	5.60a	6.30a	9.30c	7.00b	60	68	100	75
Alfalfa	6.65	8.70	11.40	12.10	55	72	94	100
Mimosa	7.10	8.30	11.10	10.30	64	75	100	93
Grasses								
Kikuyu grass*	4.45a	8.35ab	12.45b	5.85a	36	67	100	47
Bermuda grass*	4.30a	14.50c	14.80c	10.30b	29	95	100	69
Sudan grass	18.60	20.10	21.05	27.15	67	74	78	100
Guinea grass	15.70	16.30	16.60	21.60	73	75	77	100
Sugarcane†	213.00	259.00	218.00	268.00	79	96	81	100
Grains								
Sorghum*	2.60a	5.70b	4.90b	3.00a	46	100	86	53
Corn†	3.20	3.25	4.75	5.15	62	63	92	100
Oats	6.80	7.00	7.90	7.60	86	89	100	96
Rice†	6.25	7.45	9.05	11.30	55	66	80	100
Barley	5.70	6.30	6.80	6.50	84	93	100	96
Al-tolerant wheat	3.80	5.80	7.00	7.80	49	74	90	100
Al-sensitive wheat	3.60	3.40	4.50	5.15	70	66	87	100
Vegetables & Fruits								
Tomato†	6.60	7.80	8.25	9.50	69	82	87	100
Lettuce**	0.74b	0.82c	1.05d	0.58a	70	78	100	55
Cabbage	3.38	3.76	4.33	3.42	78	87	100	79
Pineapple*	149.00b	116.00a	139.00b	158.00b	94	73	88	100
Papaya	10.50	20.90	13.80	12.60	50	100	66	60

*Significant at 1% level.
**Significant at 5% level.
†Significant at 10% level.
#Means not followed by the same letter are significantly different from each other at the 5% level.

10% levels. Maximum yields were obtained with different Si rates in various species. There were 10, 10, and 2 species which had maximum yields at 8.8, 2.2 and 0.56 T Si/ha, respectively. Of the 10 species with maximum yields at the 8.8 T Si level, seven had yields at the 2.2 T Si level which were 85% or more of the maximum. Thus in 17 of the 22 species 2.2 T Si/ha produced yields which were 85% or more of the maximum. Therefore 2.2 T Si/ha should produce comparable or higher yields at lower cost than 8.8 T Si/ha.

All legume yields were 90% or more of maximum at the 2.2 T Si level which appears adequate. Yield increases were statistically significant only in D. intortum and D. canum at the 0.56 and 2.2 T Si levels respectively while 8.8 T Si significantly decreased yields in both species. Yields of all other legumes except alfalfa were depressed by 8.8 T Si/ha.

Kikuyu grass and Bermuda grass yields were only about one-third of maximum without silicate application but maximum yields were obtained with 2.2 T Si/ha. These yield increases were statistically significant for the 2.2 T Si level, but the 8.8 T Si level produced significantly lower yields in both species. Yields of Sudan grass, Guinea grass and sugarcane were 67 to 79% of maximum without Si application.

Calcium silicate applications significantly increased yields of sorghum at the 0.56 T Si level and of corn and rice at the 8.8 T Si level. The yields of these species increased by 40 to 60% with the application of calcium silicate. Yields of Al-sensitive and Al-tolerent wheat at the zero silicon treatment were 70 and 49% of maximum indicating that a greater response was obtained by Al-tolerent wheat. Since pH was maintained at 6.0 ± .2, the Al levels even at the zero Si treatment were not high enough to cause a reduction in yield in the Al-sensitive wheat. The greater response by the Al-tolerent variety may be due to some other factor. Yield in the zero Si treatment for oats and barley was 86 and 84%, respectively, of maximum yield. Thus suggesting that these species have a low Si requirement or are very efficient extractors of soil Si.

Yields of lettuce and tomato were significantly increased by Si application whereas yield of pineapple was significantly decreased by the 0.56 T Si treatment. At the zero silicate treatment lettuce and tomato had about 70% of maximum yield while pineapple had 94% of maximum yield indicating that response to silicate by pineapple in this soil respectively is very low. Yields of papaya and cabbage increased by 50 and 22%, respectively, at the 0.56 T Si and 2.2 T Si levels, respectively. Higher Si levels caused lower yields in these species.

Silicon and Phosphorus

The concentration of silicon varied with species and ranged from 0.008% in trefoil to 0.766% in rice without the application of calcium silicate. When calcium silicate was applied, the range in Si was from 0.024% in cabbage to 3.31% in rice (Table 5). Calcium-silicate applications significantly increased Si concentration in all species. Plant Si in legumes ranged from 0.01 to 0.06% for Big trefoil and *D. canum*, respectively, in the zero Si treatment, and increased with Si application in all legumes. The increase in Si concentration at maximum yield from that at zero Si ranged from 0.13 to 1.16% for mimosa and *D. intortum*, respectively (Table 5). Silicon concentrations in legumes are generally low but it is interesting to note that Si concentrations

TABLE 5. INFLUENCE OF CALCIUM SILICATE APPLICATIONS ON Si AND P CONCENTRATIONS IN PLANTS GROWN ON KAPAA SOIL

Species	Si in tops T Si/ha				P in tops T Si/ha			
	0	0.56	2.2	8.8	0	0.56	2.2	8.8
	(%)				(%)			
Legumes								
Big trefoil	0.01	0.02	0.02	0.04	0.27	0.31	0.31	0.30
Intortum	0.04	0.10	0.50	1.20	0.28	0.30	0.33	0.36
Kaimi clover	0.06	0.17	0.62	1.30	0.28	0.27	0.26	0.25
Alfalfa	0.01	0.02	0.02	0.03	0.25	0.25	0.25	0.23
Mimosa	0.02	0.03	0.04	0.06	0.25	0.23	0.19	0.25
Grasses								
Kikuyu grass	0.05	0.17	0.46	0.73	0.20	0.18	0.22	0.21
Bermuda grass	0.16	0.42	1.34	1.77	0.15	0.16	0.17	0.14
Sudan grass	0.08	0.30	1.07	1.65	0.12	0.10	0.10	0.10
Guinea grass	0.14	0.49	1.69	2.76	0.20	0.26	0.18	0.12
Sugarcane	0.16	0.34	0.98	1.77	0.10	0.11	0.11	0.12
Grains								
Sorghum	0.11	0.28	0.98	1.69	0.10	0.11	0.12	0.13
Corn	0.09	0.28	1.01	1.47	0.16	0.17	0.18	0.15
Oats	0.20	0.69	1.98	3.07	0.42	0.44	0.46	0.52
Rice	0.77	1.91	2.95	3.31	0.17	0.17	0.16	0.16
Barley	0.16	0.41	1.56	2.85	0.21	0.22	0.23	0.25
Al-tolerant wheat	0.24	0.60	1.90	2.99	0.13	0.19	0.22	0.20
Al-sensitive wheat	0.18	0.60	1.74	3.03	0.19	0.21	0.19	0.19
Vegetables & Fruits								
Tomato	0.03	0.04	0.06	0.07	0.17	0.19	0.21	0.22
Lettuce	0.01	0.02	0.03	0.04	0.29	0.25	0.32	0.32
Cabbage	0.01	0.01	0.01	0.02	0.31	0.32	0.34	0.35
Pineapple	0.05	0.08	0.12	0.23	0.14	0.14	0.13	0.11
Papaya	0.02	0.03	0.10	0.10	0.19	0.21	0.28	0.29

in the two tropical legumes, D. intortum and D. canum, are similar to those in graminacious species. The largest yield responses to Si applications were produced by alfalfa and Big trefoil which had the lowest Si concentrations in the zero Si treatment.

Phosphorus concentrations in all legumes varied from 0.25 to 0.28% without Si application. In D. canum, alfalfa and mimosa concentrations of plant P decreased with applied Si while yields were increased by silicate applications. This suggests that the internal P requirements of these species were reduced by the application of calcium silicate. Big trefoil and D. intortum had higher plant P concentrations and yields with the application of Si than without, suggesting a species difference in P utilization among the legumes.

Grasses generally were richer in Si than legumes. Plant Si ranged from 0.05 to 0.16% for Kikuyu grass and sugarcane, respectively, in the zero Si treatment. Apparently sugarcane is an efficient extractor of native Si from soils. The increases in Si concentrations at maximum yield from that at zero Si ranged from 1.17 to 1.56% for Bermuda grass and Sudan grass, respectively (Table 5). Yields of Sudan grass, Guinea grass and sugarcane increased with increasing plant Si, but Bermuda grass and Kikuyu grass yields were significantly reduced at the highest Si concentrations.

Phosphorus concentrations in grasses were lower than those in legumes when silicate was applied. Phosphorus concentrations increased in Bermuda grass, Kikuyu grass and sugarcane, but decreased in Sudan grass and Guinea grass. Bermuda grass had the highest percentage yield increase even through the relative rates of increase in Si and P were lower than those in other grass species.

Grain crops generally had the highest plant Si concentrations of the species tested. Plant Si ranged from 0.09 to 0.77% for corn and rice, respectively at the zero Si treatment. Increase in Si concentration at maximum yield from that at zero Si ranged from 0.17 to 3.14% for sorghum and Al-sensitive wheat.

At maximum yield, P concentration increased in oats, barley, sorghum, and Al-tolerent wheat, but decreased in corn, Al-sensitive wheat and rice. Responses at maximum yield over the zero Si treatment were 105 and 43% for Al-tolerent and Al-sensitive wheat, respectively, possibly because of the large increase (53%) in P at maximum yield in Al-tolerent wheat.

Silicon concentrations in vegetable and fruit crops ranged from 0.01% in cabbage to 0.05% in pineapple when no Si was applied. The increase in Si concentration at maximum yield from that at zero Si ranged from 0.01 to 0.18 for cabbage and pineapple, respectively (Table 5). Plant P concentrations increased at maximum yield in papaya, cabbage, lettuce and tomato and decreased in pineapple. The large yield responses in papaya, tomato, lettuce and cabbage may be due to increased Si and P with the higher Si application.

Thus in this soil the yield increases following calcium silicate applications ranged from 6% in pineapple to 244% in Bermuda grass. Silicon concentrations in all species were higher at maximum yield than at zero Si, but in only 13 of the 22 species were P concentrations highest at maximum yield. The yield increases in general followed the increase in Si content with applications of Si up to the 2.2 T/ha Si level while the highest Si level frequently reduced dry matter yields.

Calcium, Magnesium and Potassium

Effects of $CaSiO_3$ on Ca, Mg and K were different in the various species. Plant Ca concentration increased in 17 of the 22 species with silicate applications and only Kikuyu grass, Bermuda grass, Sudan grass, sorghum and corn had lower Ca levels with than without Si (Table 6). The changes in Ca concentration were not statistically significant except in Bermuda grass and corn in which Ca decreased significantly. The Ca supplied in the zero Si treatment appeared to be adequate for normal growth according to ranges suggested by Chapman (1966).

Concentration of plant Mg was reduced by silicate applications in 15 of the 22 species, and increased in the remaining seven species. These changes were statistically significant in Bermuda grass, Sudan grass and sugarcane where Mg concentrations were depressed and also in Al-sensitive wheat, where Mg concentration was increased. Magnesium levels in many cases appeared to be adequate for normal plant growth (Chapman, 1966).

Potassium concentration was significantly decreased by Si application in *D. intortum*, alfalfa, mimosa, Kikuyu grass and Sudan grass, but was significantly increased by Si application in corn and Al-sensitive wheat. The remaining species did not show a regular pattern of K concentration with silicate application. Potassium levels in many cases appeared to be adequate for normal plant growth (Chapman, 1966).

TABLE 6. INFLUENCE OF CALCIUM SILICATE APPLICATIONS ON Ca, Mg AND K CONCENTRATIONS IN PLANTS GROWN ON KAPAA SOIL

Species	Ca in tops T Si/ha				Mg in tops T Si/ha				K in tops T Si/ha			
	0	0.56	2.2	8.8	0	0.56	2.2	8.8	0	0.56	2.2	8.8
		(%)				(%)				(%)		
Legumes												
Big trefoil	2.61	2.68	2.50	2.82	0.23	0.19	0.19	0.20	2.78	2.44	2.85	3.05
Intortum	2.81	2.72	2.76	2.87	0.15	0.14	0.14	0.15	3.15	2.77	2.25	2.37
Kaimi clover	2.13	2.33	1.80	2.24	0.10	0.11	0.10	0.11	2.41	2.63	2.39	2.65
Alfalfa	2.76	2.79	2.54	3.25	0.13	0.14	0.15	0.15	3.15	2.58	2.06	1.40
Mimosa	2.54	2.60	2.34	2.61	0.18	0.19	0.18	0.18	3.37	3.05	2.91	2.47
Grasses												
Kikuyu grass	1.44	1.36	1.03	1.35	0.29	0.30	0.26	0.30	6.60	6.18	4.97	3.81
Bermuda grass	2.07	1.79	1.41	1.02	0.24	0.23	0.20	0.14	6.96	6.28	7.18	8.06
Sudan grass	1.96	1.79	1.80	1.89	0.30	0.29	0.29	0.26	7.36	5.89	5.31	4.53
Guinea grass	1.12	1.66	1.53	1.53	0.26	0.19	0.19	0.19	4.08	2.71	2.75	2.39
Sugarcane	0.57	0.61	0.49	0.52	0.35	0.34	0.32	0.26	1.63	1.61	1.46	1.75
Grains												
Sorghum	1.30	1.09	1.04	0.85	0.17	0.17	0.18	0.13	2.57	2.03	2.34	3.69
Corn	1.29	1.01	0.76	0.94	0.18	0.16	0.17	0.15	2.08	2.08	2.35	3.46
Oats	1.27	1.27	1.32	1.31	0.20	0.20	0.21	0.18	3.13	3.18	3.27	2.61
Rice	0.81	0.82	0.58	0.69	0.23	0.21	0.20	0.16	2.41	2.82	2.05	1.60
Barley	1.12	1.30	1.17	1.22	0.78	0.92	0.95	0.93	2.12	3.09	2.74	2.59
Al-tolerant wheat	0.75	0.92	0.95	0.93	0.11	0.15	0.15	0.12	2.92	3.26	2.80	2.38
Al-sensitive wheat	1.07	0.81	0.91	1.09	0.11	0.24	0.22	0.22	2.27	2.43	2.92	2.74
Vegetables & Fruits												
Tomato	4.16	4.39	4.14	4.44	0.76	0.73	0.73	0.65	3.04	2.60	3.13	2.87
Lettuce	3.13	3.16	3.10	3.53	0.37	0.33	0.39	0.35	–	–	–	–
Cabbage	6.15	6.06	5.96	6.28	0.53	0.56	0.62	0.44	2.87	2.97	2.99	2.89
Pineapple	0.94	0.92	0.91	0.97	0.18	0.18	0.17	0.14	0.76	1.06	1.13	1.08
Papaya	1.27	1.50	2.65	2.44	0.55	0.55	1.19	0.96	3.01	2.74	2.62	2.40

Earlier studies have included only sugarcane in Hawaii. Clements (1965) found that calcium silicate applications increased Ca and decreased Mg concentration and had no significant effect on potassium. Ayres (1966) reported that both Ca and Mg were increased with slag application. The present findings for sugarcane agree with the results of Clements (1965) and in addition show that considerable variation exists among species.

Manganese, Aluminum and Iron

Many investigators have attributed increased yields from calcium silicate applications to reduction of Mn, Al and Fe levels in soil and plants. In the present study silicate applications appeared to have little effect on Mn concentration in most species (Table 7). This may have been due to the constant pH of 6.0 maintained in all Si treatments which kept the solubility of Mn, Al and Fe low. Any increase or decrease in Mn, Al or Fe was presumably the result of silicate *per se*. Manganese concentrations generally decreased with silicate applications in a few leguminous and graminacious species while in the grain crops there was a slight tendency for Mn to increase with silicate application, especially with the 8.8 T Si/ha treatment. Manganese levels in plants seemed to be within the tolerance range. Concentrations of Al decreased with Si applications in all species tested, but the decrease was statistically significant only in barley. In all species tested, Fe concentrations were reduced by calcium silicate applications and this reduction was statistically significant at the highest Si level in sorghum, corn, rice and barley. The concentration of Fe in the zero silicate treatment appeared high even though a constant pH was maintained

TABLE 7. INFLUENCE OF CALCIUM SILICATE APPLICATIONS ON Mn, Al AND Fe CONCENTRATIONS IN PLANTS GROWN ON KAPAA SOIL

Species	Mn in tops T Si/ha				Al in tops T Si/ha				Fe in tops T Si/ha			
	0	0.56	2.2	8.8	0	0.56	2.2	8.8	0	0.56	2.2	8.8
	(ppm)				(ppm)				(ppm)			
Legumes												
Big trefoil	29	24	17	16	108	127	131	63	404	321	322	221
Intortum	30	14	16	17	46	44	50	47	181	178	184	180
Kaimi clover	37	11	17	11	189	189	161	117	495	413	397	330
Alfalfa	21	15	12	19	63	49	44	39	215	175	157	150
Mimosa	21	20	14	13	177	155	152	114	367	354	281	221
Grasses												
Kikuyu grass	28	9	8	8	50	49	44	42	217	198	167	118
Bermuda grass	7	12	10	21	34	34	28	21	127	123	113	105
Sudan grass	6	8	7	19	28	32	43	34	86	96	79	78
Guinea grass	22	20	27	12	91	82	75	66	201	165	160	138
Sugarcane	15	13	13	10	139	106	110	88	446	286	279	222
Grains												
Sorghum	10	11	13	13	122	87	78	77	370	176	152	187
Corn	10	12	8	20	131	106	94	82	278	222	193	166
Oats	29	28	27	34	50	59	49	47	139	129	117	125
Rice	26	27	31	43	78	69	43	71	220	217	161	149
Barley	29	34	27	68	65	55	56	38	221	198	178	165
Al-tolerant wheat	8	17	21	37	50	63	41	45	204	267	211	170
Al-sensitive wheat	11	12	13	15	56	61	58	54	289	180	147	145
Vegetables & Fruits												
Tomato	21	29	19	34	104	96	90	47	251	243	234	185
Lettuce	-	-	-	-	-	-	-	-	-	-	-	-
Cabbage	28	21	15	17	28	18	19	21	128	128	134	191
Pineapple	84	115	119	83	73	96	67	62	-	-	-	-
Papaya	21	19	20	19	99	72	87	73	313	254	214	188

(Table 7). Addition of calcium silicate resulted in low Fe levels in the plant due to the reduction of soil Fe activity by silicate.

Paaloa Soil

Yield: In Paaloa soil higher yields were obtained in 19 of the 22 species when calcium silicate was applied (up to 2.2 T Si/ha) than when no silicate was applied (Table 8). Soil pH control was achieved in the first three Si treatments, but not in the 8.8 T Si treatment. Tomato yields increased significantly when the treatment was 2.2 T Si/ha whereas no significant yield difference were obtained by any other species at this Si level. Significant yield decreases at the 8.8 T Si/ha treatment were obtained in four species and a significant yield increase at this Si level occurred only in Al-sensitive wheat. In general, 8.8 T Si/ha reduced yields even though soil pH was only 6.0. This suggests that high Si *per se* or Ca may reduce yield. Yields of 14 species in this soil were 80% of the maximum or more without Si application indicating a lower yield response to silicate applications in this soil than in the Kapaa soil. A possible explanation for this is that Paaloa soil had slightly higher available Si and lower pH than Kapaa soil.

Among the legumes, only alfalfa and *D. canum* responded to the 2.2 T Si/ha treatment and their yields increased by 41 and 16%, respectively. Yields of trefoil, *D. intortum* and mimosa did not respond to silicate applications. The 8.8 T Si/ha treatment caused depressed yields in all legumes.

Grasses generally did not respond to silicate applications with the exception of Guinea grass and sugarcane whose yields increased about

TABLE 8. INFLUENCE OF CALCIUM SILICATE APPLICATIONS ON DRY MATTER YIELD OF PLANTS GROWN ON PAALOA SOIL

Species	Dry matter yield T Si/ha				Percent of maximum yield T Si/ha			
	0	0.56	2.2	8.8	0	0.56	2.2	8.8
	(g/pot)				(%)			
Legumes								
Trefoil	7.50	7.00	6.50	1.60	100	93	87	21
Intortum*	13.50b	12.00b	12.60b	10.40a#	100	89	93	77
Kaimi clover	9.60	10.30	11.40	9.60	84	90	100	84
Alfalfa	4.70	5.10	8.00	7.00	59	64	100	88
Mimosa**	17.40b	18.00b	18.40b	7.60a	95	98	100	41
Grasses								
Kikuyu grass	14.68	15.46	15.28	11.42	95	100	99	74
Bermuda grass*	11.35b	11.02b	10.72b	5.41a	100	97	94	48
Sudan grass	8.22	7.65	8.78	7.30	94	87	100	83
Guinea grass	17.40	20.60	22.90	18.80	76	90	100	82
Sugarcane	326.00	412.00	432.00	454.00	72	91	95	100
Grains								
Sorghum	5.19	5.50	6.18	5.60	84	89	100	91
Corn	5.48	5.78	5.45	4.23	95	100	94	73
Oats	9.84	10.73	10.66	10.46	92	100	99	97
Rice	9.14	9.15	8.81	6.39	99	100	96	70
Barley	7.92	8.59	11.06	10.30	72	78	100	93
Al-tolerant wheat	8.30	9.00	9.05	8.00	92	99	100	88
Al-sensitive wheat*	5.60a	6.47a	6.43a	8.26b	68	78	78	100
Vegetables & Fruits								
Tomato**	7.84b	8.89b	11.00c	7.81a	71	81	100	71
Lettuce	0.97	1.20	1.90	2.32	42	52	82	100
Cabbage	3.86	4.44	4.69	4.08	82	95	100	87
Pineapple	152.00	174.00	160.00	190.00	80	92	84	100
Papaya	21.60	28.00	33.80	40.90	53	68	83	100

*Significant at 1% level.
**Significant at 5% level.
#Means not followed by the same letter are significantly different from each other at the 5% level.

25% with application of 2.2 T Si/ha. The 8.8 T Si/ha treatment caused reduced yields in all grasses except sugarcane possibly because sugarcane is more tolerant to high Si applications than other grasses.

Corn, oats, rice and Al-tolerant wheat produced 90% or more of maximum yield without Si application whereas sorghum and barley yields increased 16 and 28%, respectively with application of 2.2 T Si/ha. Yields of Al-sensitive wheat increased by 10% with the application of 2.2 T Si/ha whereas yields of Al-tolerant wheat did not respond to Si applications. This may have been caused by high Al activity associated with some peculiar property of the roots of Al-sensitive wheat. The 8.8 T Si/ha treatment increased yields in Al-sensitive wheat, but decreased yields in the Al-tolerant wheat.

Among the vegetable and fruit crops, lettuce and papaya yields increased by 58 and 47%, respectively with Si applications, whereas tomato, pineapple and cabbage yields increased by only 29, 18 and 20%, respectively with Si applications. Tomato yields were significantly reduced by the 8.8 T Si/ha level.

In general, crops on Kapaa soil responded better to silicate applications than those on Paaloa soil. This may be attributed to higher native Si and lower pH in the Paaloa soil.

Silicon and Phosphorus

In the absence of applied Si, Si concentration in legumes generally ranged from 0.02 to 0.03% with the exception of the two *Desmodiums* which had levels similar to those of grasses (0.08-0.1%). Plant Si increased with Si applications in all legumes and the increase in Si concentration at maximum yield from that in the zero Si treatment ranged from 0.02 to 0.64% for alfalfa and *D. canum*, respectively (Table 9). Phosphorus concentrations of all legumes increased with calcium silicate applications and P concentrations in the zero Si treatment ranged from 0.17 to 0.25% for *D. intortum* and big trefoil, respectively. The yields of big trefoil and *D. intortum* were reduced as a result of Si applications even though concentrations of Si and P increased. The largest yield increase among legumes in this soil (70%) was produced by alfalfa with the 2.2 T Si/ha treatment, and Si and P concentrations increased in this treatment to 0.34 and 0.25%, respectively. Silicon concentration in alfalfa, which produced the largest yield increase among legumes in both soils, increased with Si applications in both soils; however, P concentration increased with Si application only in the Paaloa soil.

Silicon concentrations in grasses were higher than those in legumes except the *Desmodiums*. In the absence of applied Si, Si concentrations ranged from 0.08 to 0.10% for sugarcane and Kikuyu grass, respectively. Plant Si increased with Si applications in all grasses and the increase in Si concentration at maximum yield from that in the zero Si treatment ranged from 0.28 to 1.31% for Kikuyu grass and Guinea grass, respectively (Table 9). Yields of Bermuda grass were significantly reduced by Si applications even though Si and P concentrations increased, suggesting that other factors may have reduced yield. Phosphorus concentrations increased with Si applications in all grasses except Sudan grass and sugarcane. The yield increase for sugarcane was the largest among the grasses (33%) at 2.2 T Si/ha and Si concentration was increased to 0.28% while P concentration decreased to 0.17%. This suggests a reduction of

TABLE 9. INFLUENCE OF CALCIUM SILICATE APPLICATIONS ON Si AND P CONCENTRATIONS IN PLANTS GROWN ON PAALOA SOIL

Species	Si in tops T Si/ha				P in tops T Si/ha			
	0	0.56	2.2	8.8	0	0.56	2.2	8.8
	(%)				(%)			
Legumes								
Big trefoil	0.03	0.04	0.05	0.05	0.25	0.28	0.28	0.29
Intortum	0.08	0.28	0.63	0.75	0.17	0.19	0.19	0.29
Kaimi clover	0.11	0.38	0.75	0.86	0.23	0.26	0.27	0.28
Alfalfa	0.02	0.02	0.03	0.02	0.22	0.23	0.25	0.25
Mimosa	0.02	0.04	0.06	0.04	0.22	0.24	0.25	0.28
Grasses								
Kikuyu grass	0.10	0.39	0.64	0.68	0.22	0.23	0.25	0.25
Bermuda grass	0.12	0.60	1.17	1.54	0.23	0.24	0.25	0.28
Sudan grass	0.12	0.46	1.16	1.27	0.21	0.18	0.17	0.16
Guinea grass	0.12	0.42	1.43	2.92	0.19	0.24	0.23	0.17
Sugarcane	0.08	0.26	0.28	2.33	0.18	0.19	0.17	0.16
Grains								
Sorghum	0.12	0.39	0.59	0.89	0.19	0.20	0.20	0.20
Corn	0.08	0.49	0.84	0.85	0.18	0.16	0.12	0.16
Oats	0.16	0.85	1.57	1.72	0.52	0.54	0.58	0.66
Rice	0.36	1.49	2.57	2.16	0.38	0.38	0.32	0.31
Barley	0.21	1.00	1.95	3.08	0.28	0.31	0.31	0.32
Al-tolerant wheat	0.29	1.19	2.73	2.31	0.28	0.29	0.32	0.34
Al-sensitive wheat	0.16	1.08	2.51	2.59	0.32	0.33	0.32	0.33
Vegetables & Fruits								
Tomato	0.03	0.07	0.07	0.07	0.20	0.22	0.25	0.35
Lettuce	0.04	0.04	0.05	0.14	0.31	0.37	0.42	0.46
Cabbage	0.06	0.07	0.07	0.06	0.36	0.38	0.42	0.45
Pineapple	0.06	0.11	0.14	0.34	0.15	0.12	0.13	0.11
Papaya	0.03	0.04	0.06	0.08	0.32	0.33	0.36	0.37

internal P by Si application.

In the grain crops plant Si concentrations in the zero Si treatment ranged from 0.08 to 0.36% for corn and rice, respectively. The increase in plant Si concentration at maximum yield from that in the zero treatment ranged from 1.13 to 2.35% for rice and Al-sensitive wheat, respectively. Concentrations of P increased with silicate application in all grain crops except corn and rice in which they decreased.

In the vegetable and fruit crops Si concentrations increased with increasing Si applications and ranged from 0.03 to 0.06% in the zero Si treatment. Plant Si and P concentrations in lettuce were 0.02 and 0.11% higher, respectively at maximum yield (2.2 T Si/ha) than without Si application. Therefore the yield increase of 139% may be due to improved P nutrition with silicate application. Both P concentration and P uptake increased with increasing Si applications in all species in this group except pineapple, even though uniform P (1120 kg P/ha) was applied in all treatments. In general the yield increases may be attributed to increased availability of soil P and increased P uptake resulting from silicate application.

Plants of the same species absorb different amounts of Si when grown in different soils (Jones and Handreck, 1965). In the present study 14 of the 22 species absorbed more Si when grown in the zero Si treatment on the Paaloa soil than on the Kapaa soil. This is possibly because Paaloa soil had more available native Si (0.54 ppm) than the Kapaa soil (0.42 ppm) and also a lower pH which resulted in increased Si availability (Table 10).

The relationships between yield, Si and P levels are discussed for a few species selected from each group in the Paaloa soil. A "low Si"

TABLE 10. SILICON, PHOSPHORUS AND pH ANALYSES OF KAPAA AND PAALOA SOILS

Element	Kapaa soil	Paaloa soil
Si (1:10 water extractable	4.8	5.3
ppm Si in solution)	0.42	0.54
Si (modified Truog, ppm Si)	21	15
P (modified Truog ppm P)	9	126
Soil pH (1:25)		

legume (alfalfa) is compared with a "high Si" legume (*D. canum*) in Fig. 1. Their yield and plant P responses to Si application are similar, but their responses in plant Si are very different. Plant Si increased only slightly with Si applications in alfalfa while it increased markedly in *D. canum* to levels that are comparable to those found in grasses. Alfalfa which has a high Ca requirement, accumulated the highest Ca concentration of the legumes tested. Calcium concentration in *D. canum* was variable, but the absolute values were about one-half those for alfalfa. The reduction in Al concentration as a result of Si applications was greater in *D. canum* than in alfalfa. Although both sugarcane and Guinea grass responded to the 2.2 T Si/ha application, only sugarcane yield increased at the 8.8 T Si/ha level (Table 8). Guinea grass showed a marked increase in plant Si at all levels of applied Si and also a larger increase in P concentration with Si applications than sugarcane (Table 9).

The response patterns for the two varieties of wheat are compared in Fig. 2. The Al-sensitive wheat differed from the Al-tolerant variety in that its yields increased with 8.8 T Si/ha, while those of the Al-tolerant variety decreased. Plant Si increased more with Si application in the Al-sensitive variety than in the Al-tolerant variety and plant P was higher in the Al-tolerant than in the Al-sensitive variety. The Al-tolerant variety generally had lower Al levels than the Al-sensitive variety, but the decrease in Al with Si application was greater in the Al-sensitive variety. The response patterns for these plants on Kapaa soil differed in that the yield response of the Al-tolerant variety was larger than that of the Al-sensitive variety. This may be due to the

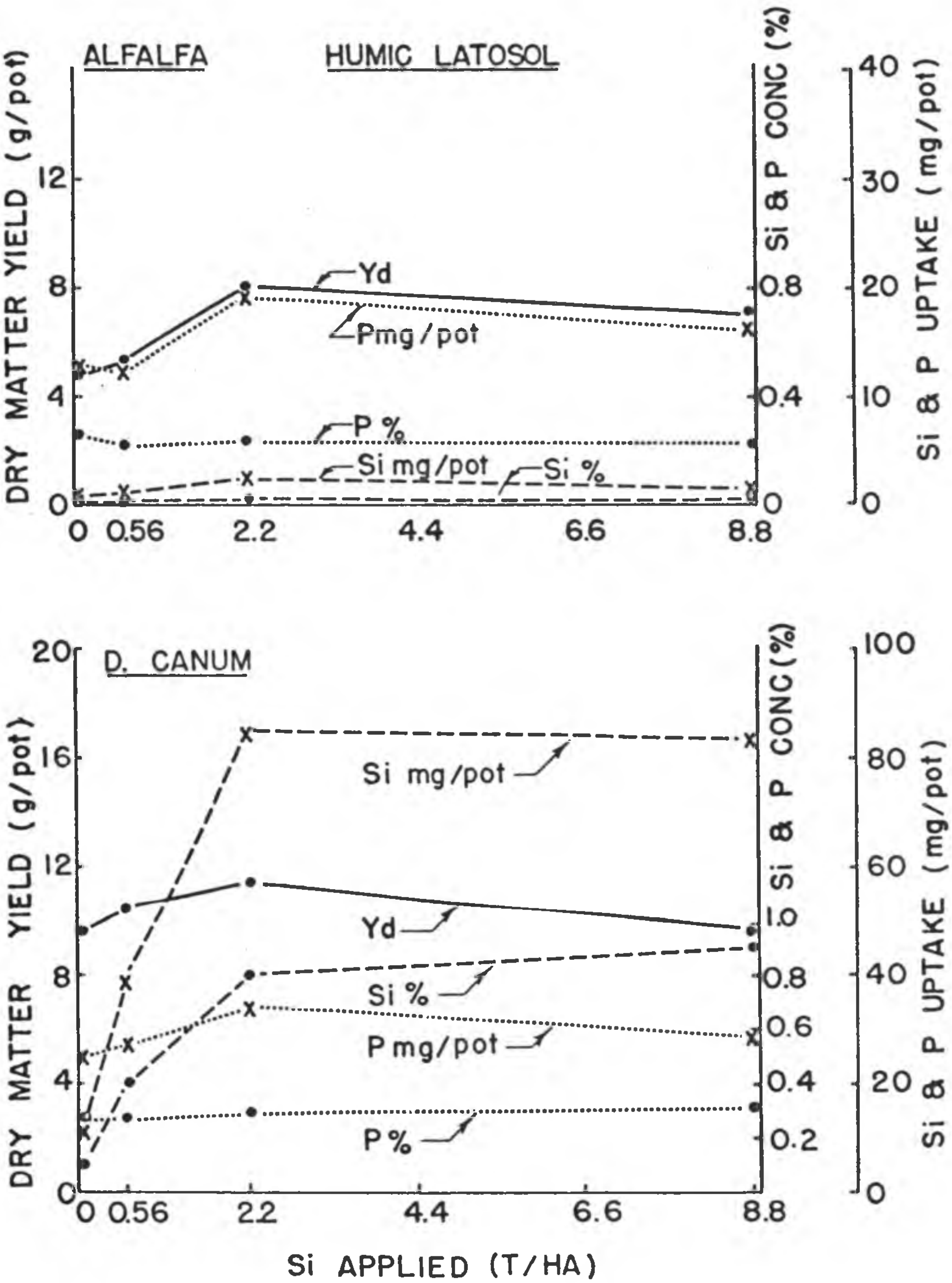

FIGURE 1. RESPONSE OF ALFALFA AND D. CANUM TO CALCIUM SILICATE APPLICATIONS

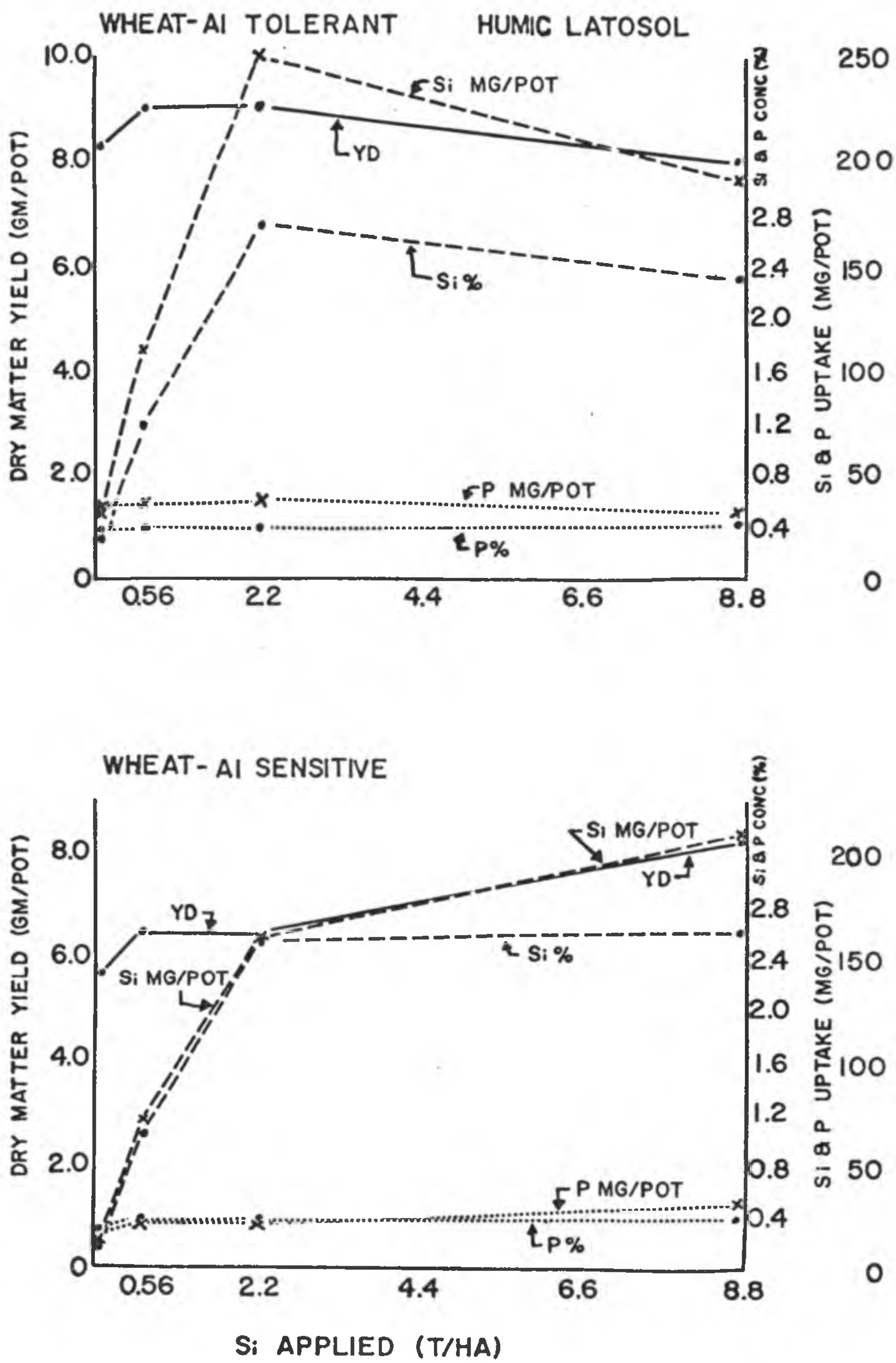

FIGURE 2. RESPONSE OF WHEAT TO CALCIUM SILICATE APPLICATIONS

constant pH 6.0 maintained in the Kapaa soil which greatly reduced Al activity and allowed factors other than Al sensitivity to influence yield.

The yield increase in lettuce was linear with increasing Si applications, while plant Si changed very little (Fig. 3). Plant P, on the other hand, increased markedly with increasing Si applications. However, it is possible that both the pH and Si differentials between 2.2 and 8.8 T Si/ha may have increased P availability and thus increased plant P and yield. In Kapaa soil, yields of these two plants increased to the 2.2 T Si/ha level and P concentration increased 30 and 13% for tomato and lettuce, respectively. There was no pH differential in this soil and equal P was supplied to all treatments, therefore increases in P concentration and yield may be attributed to silicate applications. These examples show quite clearly that almost any combination of yield, Si and P response can be found among the various crops and that effects of pH, P and Ca on response to silicate applications cannot be ignored.

Calcium, Magnesium and Potassium

The effects of calcium silicate on Ca concentration were considered only in the first three Si levels because of the pH differential in the 8.8 T Si treatment mentioned earlier. All species generally showed increasing Ca with increasing silicate application up to 2.2 T Si. This increase was significant only in Sudan grass, oats, Al-tolerant wheat, tomato, lettuce and cabbage. The calcium concentrations in the grass and grain crops at the zero Si treatment were in the deficiency range, and Ca concentrations generally increased with Si applications in all species (Table 11).

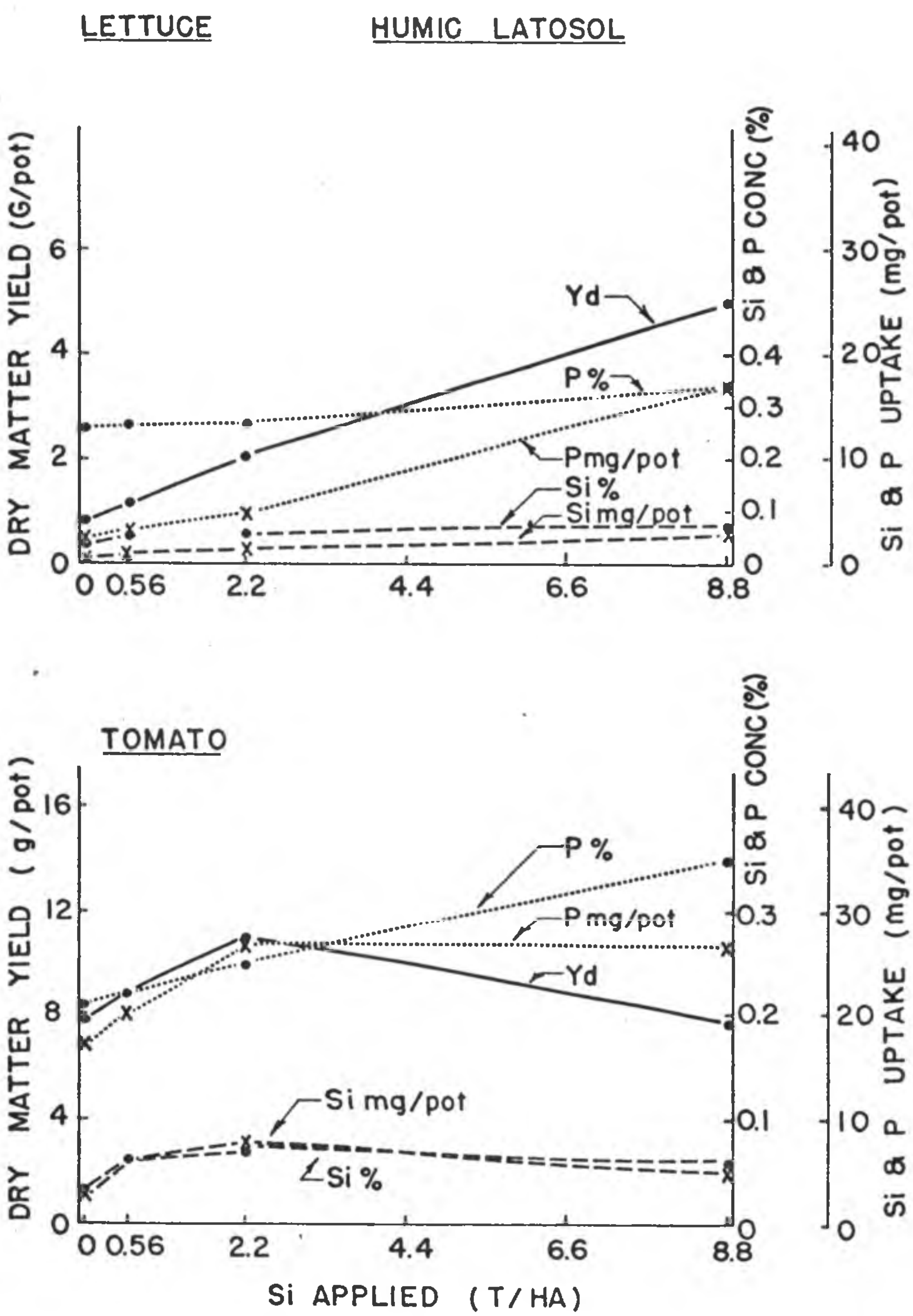

FIGURE 3. RESPONSE OF LETTUCE AND TOMATOES TO CALCIUM SILICATE APPLICATIONS

TABLE 11. INFLUENCE OF CALCIUM SILICATE APPLICATIONS ON Ca, Mg AND K CONCENTRATIONS IN PLANTS GROWN ON PAALOA SOIL

Species	Ca in tops				Mg in tops				K in tops			
	T Si/ha				T Si/ha				T Si/ha			
	0	0.56	2.2	8.8	0	0.56	2.2	8.8	0	0.56	2.2	8.8
	(%)				(%)				(%)			
Legumes												
Big trefoil	1.35	1.55	1.71	2.17	0.40	0.32	0.30	0.18	2.04	2.00	2.11	1.73
Intortum	1.17	1.37	1.80	2.16	0.25	0.24	0.22	0.25	3.16	2.80	2.74	2.95
Kaimi clover	0.97	1.18	1.37	1.22	0.15	0.16	0.15	0.15	2.45	2.62	2.37	2.06
Alfalfa	1.99	2.35	2.49	2.51	0.30	0.29	0.24	0.17	3.28	3.37	3.15	2.90
Mimosa	1.18	1.23	1.40	2.13	0.21	0.20	0.21	0.24	1.91	2.32	2.37	2.14
Grasses												
Kikuyu grass	0.26	0.25	0.29	0.46	0.22	0.21	0.22	0.26	2.97	2.95	2.87	3.36
Bermuda grass	0.29	0.28	0.31	0.35	0.16	0.15	0.12	0.09	3.17	3.52	3.44	3.19
Sudan grass	0.57	0.70	0.83	1.18	0.26	0.28	0.25	0.22	2.75	2.99	2.83	2.88
Guinea grass	0.77	0.79	0.82	0.90	0.26	0.25	0.23	0.21	3.04	3.26	2.94	2.95
Sugarcane	0.30	0.28	0.29	0.33	0.22	0.19	0.21	0.19	1.94	1.67	1.50	1.48
Grains												
Sorghum	0.65	0.73	0.77	0.99	0.31	0.31	0.30	0.24	3.45	3.57	3.09	3.12
Corn	0.29	0.31	0.35	0.63	0.23	0.22	0.20	0.23	2.96	3.09	2.42	2.98
Oats	0.48	0.53	0.58	0.77	0.25	0.24	0.21	0.22	3.00	2.90	3.12	3.17
Rice	0.33	0.29	0.37	0.66	0.26	0.27	0.26	0.30	3.57	3.17	2.95	3.13
Barley	0.38	0.44	0.49	0.70	0.24	0.25	0.22	0.24	3.51	3.09	2.82	2.63
Al-tolerant wheat	0.32	0.34	0.41	0.57	0.15	0.14	0.13	0.12	3.02	3.09	3.36	3.02
Al-sensitive wheat	0.32	0.37	0.45	0.61	0.15	0.14	0.12	0.11	2.50	2.85	2.86	2.64
Vegetables & Fruits												
Tomato	1.21	1.77	2.47	3.45	0.34	0.35	0.35	0.36	2.69	2.91	2.62	2.92
Lettuce	1.91	3.92	4.75	4.15	0.31	0.35	0.31	0.63	1.02	1.05	0.98	1.14
Cabbage	2.48	3.22	3.76	4.40	0.43	0.42	0.38	0.32	3.29	3.26	3.29	3.63
Pineapple	0.52	0.50	0.69	1.08	0.18	0.14	0.16	0.15	2.70	2.09	2.35	1.96
Papaya	0.68	0.67	0.62	0.63	1.76	2.05	2.28	2.11	1.60	1.89	2.18	2.86

Ayres (1966) reported that silicate application increased plant Ca which agrees with the present results. Calcium levels were generally lower in plants grown on Paaloa soil than on Kapaa soil. This may be due to the low pH of the Paaloa soil.

The concentration of Magnesium was reduced by silicate applications in all plant species studied except D. canum, Mimosa, Kikuyu grass, tomato and papaya (Table 11). In general Mg levels are within the sufficiency levels for many species as reported by Chapman (1966).

Increasing silicate applications decreased K concentrations in 13 species and increased K concentrations in all other species (Table 11). Ayres (1966) reported a large increase in K uptake with silicate applications whereas Clements (1965) found silicate had no significant effect on sheath K levels of sugarcane. Potassium levels for a number of species are generally in the sufficiency range reported by Chapman (1966).

Manganese, Aluminum and Iron

The concentration of Mn was reduced by the 2.2 T Si/ha application in all species and in a majority of these species the reduction was statistically significant (Table 12). This reduction can be attributed to Si since pH was constant in the 0 to 2.2 T Si treatments.

The concentration of Al decreased with application of 2.2 T Si/ha calcium silicate in most species and the reduction in D. canum, Mimosa, rice and barley were significant (Table 12). Increased Si concentrations appear largely responsible for the reduction of Al since pH was held constant through the 2.2 T Si treatment.

TABLE 12. INFLUENCE OF CALCIUM SILICATE APPLICATIONS ON Mn, Al AND Fe CONCENTRATIONS IN PLANTS GROWN ON PAALOA SOIL

Species	Mn in tops				Al in tops				Fe in tops			
	T Si/ha				T Si/ha				T Si/ha			
	0	0.56	2.2	8.8	0	0.56	2.2	8.8	0	0.56	2.2	8.8
	(ppm)				(ppm)				(ppm)			
Legumes												
Big trefoil	193	113	69	43	210	232	157	135	489	398	340	188
Intortum	177	141	47	19	110	104	118	50	255	190	172	143
Kaimi clover	125	118	63	12	109	92	64	35	223	210	190	132
Alfalfa	115	108	55	16	99	60	61	52	218	195	177	151
Mimosa	134	98	118	82	92	89	70	22	391	271	192	63
Grasses												
Kikuyu grass	81	53	19	18	47	37	35	18	182	143	118	105
Bermuda grass	71	78	19	10	64	35	23	17	178	125	109	63
Sudan grass	66	35	21	10	140	48	39	28	220	126	100	84
Guinea grass	116	92	34	7	94	70	67	40	148	123	98	43
Sugarcane	231	158	150	74	137	125	134	131	221	256	211	219
Grains												
Sorghum	61	38	26	11	47	42	32	31	338	145	130	67
Corn	41	25	12	7	36	30	27	24	127	83	86	75
Oats	148	134	69	24	178	132	120	88	316	205	198	153
Rice	386	237	130	31	182	115	112	78	353	309	198	196
Barley	102	79	30	27	167	143	103	92	289	306	240	195
Al-tolerant wheat	120	110	57	10	77	72	61	54	180	150	174	144
Al-sensitive wheat	54	70	38	18	123	120	93	71	255	206	190	163
Vegetables & Fruits												
Tomato	74	64	23	6	97	91	58	49	216	205	166	148
Lettuce	-	-	-	-	-	-	-	-	-	-	-	-
Cabbage	19	5	5	3	125	60	89	51	225	209	141	129
Pineapple	231	158	150	74	137	125	134	131	221	256	211	219
Papaya	137	97	93	13	92	65	71	58	284	219	191	160

Iron concentrations in all species were reduced by the application of silicate and in 13 of the 22 species these reductions were significant at high Si levels (Table 12).

Silicon Status of Plants

Total Si values in Table 13 are based on the results of the preceding pot studies with two soils and are presented as a tentative guide of Si nutrition of these species. Low values are Si concentrations of plants in the zero Si treatment and adequate values are Si concentrations associated with maximum yields. High values are Si concentrations of plants having depressed yields in the highest Si treatment. Comparison with the established adequate values for sugarcane, >0.7% Si (Clements, 1965; Fox, et al., 1967) shows that the suggested adequate values are above this. However, the low values are considerably lower than that reported by Fox, et al. (1967) and may be the result of growing conditions in the pots.

Residual Effects of Calcium Silicate

A few species in each group were allowed to grow in the same pots for 2, 3 or 4 crops. The plants were either replanted or allowed to regrow after the first harvest. In all species except sorghum the time between each harvest was the same.

Kapaa Soil

Yield: Yields of big trefoil and the two *Desmodiums* decreased with successive harvests in all treatments. At the end of the last harvest the yields of these crops were only 50% of the first harvest, whereas alfalfa yields in the second harvest were 20% higher

TABLE 13. TISSUE ANALYSIS VALUES FOR DETERMINING SILICON STATUS OF PLANTS*

Species	Low	Adequate	High
	(%)	(%)	(%)
Legumes			
Big trefoil	0.01	0.02-0.03	>0.05
Intortum	0.04	0.08-0.60	0.70-1.20
Kaimi clover	0.06-0.11	0.38-0.75	---
Alfalfa	0.01	0.02-0.30	---
Mimosa	0.02	0.03-0.06	---
Grasses			
Kikuyu grass	0.05	0.10-0.60	0.70
Bermuda grass	0.09	0.11-1.34	1.77
Sudan grass	0.08-0.13	1.08-1.65	---
Guinea grass	0.12-0.14	1.43-2.75	---
Sugarcane (Sheaths 3,4,5,6)	0.07-0.16	1.32-2.88	---
Grains			
Sorghum	0.11	0.27-0.59	0.98-1.69
Corn	0.08-0.09	0.49-1.47	---
Oats	0.16-0.20	0.84-1.98	3.08
Rice	0.36-0.77	1.49-3.31	---
Barley	0.16-0.21	0.41-1.95	2.85
Al-tolerant wheat	0.24-0.29	1.19-2.99	---
Al-sensitive wheat	0.16-0.18	1.08-3.03	---
Vegetables & Fruits			
Tomato	0.03	0.06-0.07	---
Lettuce	0.01-0.02	0.03-0.05	---
Cabbage	0.008	0.01-0.07	---
Pineapple (D-leaf white tissue)	0.10-0.16	0.30-0.60	---
Papaya (blades)	0.03-0.05	0.08-0.21	0.30

*Values based on whole plant samples except where otherwise indicated.

than those of the first harvest (Table 14). The cumulative yields of these legumes increased with increasing Si applications up to 2.2 T Si/ha but yields of big trefoil and the Desmodiums decreased whereas alfalfa yields increased at the 8.8 T Si level. The 2.2 T Si/ha level produced maximum yields in each of the successive harvests of trefoil and the Desmodiums indicating a continued availability of residual Si. Maximum yield for alfalfa was at the 8.8 T Si/ha level for both harvests. This is because of the high Ca supply at this Si level which favored the growth of alfalfa with a high Ca requirement. Yields of Kikuyu grass, Bermuda grass and Guinea grass were highest in the second harvest. This may be due to poor establishment in the first harvest and crop-induced deficiencies of certain elements in the third or fourth harvests. Maximum yields were generally obtained at the 2.2 T Si/ha level with few exceptions. Maximum or 90% of maximum yield in Kikuyu grass was obtained at the 2.2 T Si level in the first and second harvests but in harvests 3 and 4 yields were 87% or more of maximum in all plus Si treatments. Maximum yield of Guinea grass was attained with 8.8 T Si/ha in the first harvest and with 2.2 T Si/ha in the three subsequent harvests. Cumulative yields of these three grasses increased with silicate applications up to the 2.2 T Si/ha level and yields were depressed at the 8.8 T Si treatment. Sorghum yields were highest in the second harvest at the 2.2 T Si treatment and decreased as residual Si increased above this.

Maximum yields of lettuce were attained at 2.2 T Si/ha in the first and second harvests and at 8.8 T Si/ha in the third and fourth harvests. The marked reduction (50%) in yield in the fourth harvest

TABLE 14. RESIDUAL EFFECTS OF CALCIUM SILICATE APPLICATIONS ON DRY MATTER YIELD OF PLANTS GROWN ON KAPAA SOIL

Species	Harvest	Dry Matter Yield T Si/ha 0	0.56	2.2	8.8	% of Maximum Yield T Si/ha 0	0.56	2.2	8.8
		(g/pot)				(%)			
Big trefoil	1	4.15	5.05	7.55	5.80	55	66	100	77
	2	3.80	4.20	5.00	4.80	76	84	100	96
	3	2.45	3.05	3.45	2.10	71	88	100	75
	Total	10.40	12.30	16.00	12.70				
Intortum	1	11.20	14.70	15.20	8.90	74	97	100	59
	2	8.10	8.60	9.70	7.50	84	89	100	77
	3	3.25	3.45	3.75	2.80	87	92	100	75
	4	4.70	5.40	5.50	2.85	85	98	100	52
	Total	27.25	32.15	34.15	22.05				
Kaimi clover	1	5.60	6.30	9.30	7.00	60	68	100	75
	2	2.90	4.10	4.15	4.50	64	91	92	100
	Total	8.50	10.40	13.45	11.50				
Alfalfa	1	6.65	8.70	11.40	12.10	55	72	94	100
	2	9.90	10.65	13.30	14.40	69	74	92	100
	Total	16.55	19.35	24.70	26.50				
Kikuyu grass	1	4.45	8.35	12.45	5.85	36	67	100	47
	2	10.30	15.40	17.00	17.50	59	88	97	100
	3	9.30	11.80	12.30	12.25	76	96	100	99
	4	9.45	11.15	11.50	12.85	74	87	89	100
	Total	33.50	46.70	53.25	48.45				
Bermuda grass	1	4.30	14.50	14.80	10.30	29	95	100	69
	2	6.30	12.95	14.95	12.25	42	87	100	82
	3	7.50	9.80	10.90	9.90	69	90	100	91
	Total	18.10	37.25	40.65	32.45				
Guinea grass	1	15.70	16.30	16.60	21.60	73	75	77	100
	2	16.40	19.10	23.50	22.70	70	81	100	97
	3	14.90	16.50	17.70	15.40	84	93	100	87
	4	12.65	10.50	14.45	10.40	88	73	100	72
	Total	59.65	62.40	72.25	70.10				
Sorghum	1	2.60	5.70	4.90	3.00	46	100	86	83
	2	7.40	15.00	11.50	8.15	49	100	77	54
	3	12.90	13.90	10.35	7.45	93	100	74	54
	Total	22.90	34.60	26.75	18.60				
Lettuce	1	0.74	0.82	1.05	0.58	70	78	100	55
	2	0.55	0.83	1.00	0.60	55	83	100	60
	3	0.50	0.80	1.05	1.50	33	53	70	100
	4	0.20	0.40	0.48	0.68	29	59	71	100
	Total	1.99	2.85	3.58	3.36				

may be due to crop-induced deficiencies at all Si levels.

In general the 2.2 T Si/ha rate appears to allow near maximum yields in all species tested for as many as four successive crops.

Silicon and Phosphorus

Silicon concentrations in big trefoil and alfalfa increased in successive harvests whereas P concentrations were lower in both species in the second harvest (Table 15). Alfalfa yields were higher in the second harvest than in the first. Plant Si in *D. intortum* was relatively high in the first and second harvests but was relatively low in the third and fourth harvests. In addition, yields were greatly reduced in the last two harvests while plant P concentration increased, possibly due to the reduced yields. In *D. canum* both Si and P were lower in the second harvest than the first. Plant Si and P concentrations in Kikuyu grass generally increased in successive harvests at all except the 8.8 T Si treatment where P concentration was reduced. The response of plant Si and P in Kikuyu grass does not correspond to the response in yields which were highest in harvest two and greatly reduced in harvests three and four. Silicon concentrations in Bermuda grass and Guinea grass were high in the first and second harvests but low in the third and fourth harvests in which low yields were also produced. Phosphorus concentrations remained nearly unchanged in successive harvests in Bermuda grass but in Guinea grass they increased to the third harvest and decreased in the fourth harvest and Si and P concentrations of sorghum were highest in the second harvest. Concentrations of Si in lettuce increased with successive harvests. Since both lettuce yields and P concentrations were higher with residual

TABLE 15. RESIDUAL EFFECTS OF CALCIUM SILICATE APPLICATIONS ON Si AND P CONCENTRATIONS IN PLANTS GROWN ON KAPAA SOIL

Species	Harvest	Si in tops T Si/ha 0	0.56	2.2	8.8	P in tops T P/ha 0	0.56	2.2	8.8
		(%)				(%)			
Big trefoil	1	0.01	0.02	0.02	0.04	0.27	0.31	0.31	0.30
	2	0.01	0.02	0.04	0.04	0.28	0.28	0.30	0.29
	3	0.02	0.03	0.05	0.09	0.31	0.38	0.38	0.36
Intortum	1	0.04	0.10	0.50	1.20	0.28	0.29	0.30	0.33
	2	0.11	0.47	0.62	1.04	0.28	0.32	0.32	0.31
	3	0.04	0.11	0.45	0.60	0.32	0.34	0.33	0.34
	4	0.01	0.05	0.18	0.54	0.33	0.34	0.35	0.37
Kaimi clover	1	0.06	0.17	0.63	1.30	0.28	0.27	0.26	0.26
	2	0.07	0.14	0.58	1.22	0.17	0.27	0.30	0.29
Alfalfa	1	0.02	0.02	0.02	0.03	0.25	0.25	0.25	0.23
	2	0.01	0.02	0.03	0.04	0.29	0.20	0.19	0.17
Kikuyu grass	1	0.05	0.17	0.46	0.73	0.17	0.18	0.22	0.22
	2	0.06	0.29	0.74	0.90	0.18	0.19	0.19	0.20
	3	0.06	0.21	0.62	1.19	0.19	0.22	0.22	0.19
	4	0.09	0.20	0.67	1.25	0.19	0.22	0.20	0.18
Bermuda grass	1	0.16	0.42	1.34	1.77	0.15	0.16	0.17	0.14
	2	0.24	0.45	1.49	2.28	0.26	0.16	0.19	0.14
	3	0.22	0.38	1.09	2.15	0.18	0.18	0.16	0.18
Guinea grass	1	0.14	0.49	1.69	2.76	0.20	0.26	0.18	0.12
	2	0.21	0.53	1.11	3.12	0.16	0.20	0.20	0.20
	3	0.21	0.40	0.91	2.95	0.26	0.29	0.28	0.27
	4	0.15	0.27	0.50	2.41	0.20	0.25	0.20	0.22
Sorghum	1	0.11	0.28	0.98	1.69	0.10	0.11	0.12	0.13
	2	0.10	0.34	1.10	1.89	0.15	0.24	0.20	0.21
	3	0.12	0.23	0.88	1.44	0.11	0.27	0.24	0.25
Lettuce	1	0.01	0.02	0.03	0.04	0.29	0.25	0.32	0.32
	2	0.03	0.04	0.05	0.06	0.21	0.31	0.32	0.27
	3	0.04	0.04	0.06	0.08	0.23	0.27	0.26	0.28
	4	0.06	0.08	0.09	0.67	0.13	0.27	0.38	0.52

Si than without, the yield response to Si applications may be due to the increased availability of P.

Calcium, Magnesium and Potassium

Calcium contents in legumes generally decreased with subsequent harvests except in *D. intortum* in which Ca was highest in the second harvest and lower in the other harvests (Appendix Table 1). Calcium levels seem to be adequate for normal plant growth. In Kikuyu grass and Bermuda grass Ca contents decreased with increasing Si applications and with successive harvests. Calcium concentrations in Guinea grass increased with successive harvests while it decreased in Kikuyu grass and Bermuda grass. Calcium levels in sorghum and lettuce appear to be adequate for normal plant growth. In all legumes and grasses except sorghum Mg concentrations were highest in the second harvest and decreased in the third and fourth harvests (Appendix Table 1). Magnesium concentrations in sorghum increased with successive harvest. In general, mg levels are within sufficiency levels reported in the literature. Potassium contents showed no consistent trend with successive harvests and were generally above 1.90% which appears to be adequate for the species grown. Calcium and Mg levels in lettuce decreased in the second harvest, then increased with each successive harvest.

Manganese and Aluminum

There was no consistent trend in Mn concentrations with successive harvests. Low Mn values in this soil may be due to low Mn availability at pH 6.0. Aluminum concentrations were higher in successive harvests with the exception of the third harvest of big trefoil and the second harvest of alfalfa (Appendix Table 3).

Paaloa Soil

Yield: Yield responses were negative in all harvests of big trefoil and in the first harvest of *D. intortum* (Table 16). The 2.2 T Si/ha treatment produced maximum yields of *D. intortum* in the second, third and fourth harvests. Yields of *D. canum* in the second harvest were about 50% of first harvest yields whereas yields of alfalfa were higher in the second harvest. A similar response was also observed with these species in the Kapaa soil. Yields of Kikuyu grass and Bermuda grass were highest in the third harvest whereas Guinea grass yields were highest in the second harvest. The 0.56 T Si/ha level produced maximum yields of Kikuyu grass in the first harvest, but the 8.8 T Si/ha level produced maximum yields in successive harvests. Bermuda grass yields decreased in the first two harvests and then increased by 60 to 275% in the third harvest. Guinea grass and sorghum yields were highest in the second harvest possibly because a good root system was not established until the second crop. Lettuce yields increased with increasing Si applications at all harvests. When yields of all harvests are combined, big trefoil yields responded negatively to silicate applications whereas the *Desmodiums* and alfalfa produced maximum yields with 2.2 T Si/ha. Kikuyu grass, Guinea grass, sorghum and lettuce all produced highest yields with 8.8 T Si/ha. These data suggest the 2.2 T Si/ha level is sufficient for several crops of legumes in this soil while grasses and lettuce require the 8.8 T Si/ha level. This is in agreement with the earlier conclusion that this soil was low in Ca and thus crops benefitted from the high Ca in the high Si treatment.

TABLE 16. RESIDUAL EFFECTS OF CALCIUM SILICATE APPLICATIONS ON DRY MATTER YIELD OF PLANTS GROWN ON PAALOA SOIL

Species	Harvest	Dry Matter Yield				% of Maximum Yield			
		T Si/ha				T Si/ha			
		0	0.56	2.2	8.8	0	0.56	2.2	8.8
		(g/pot)				(%)			
Big trefoil	1	7.50	7.00	6.50	1.60	100	93	87	21
	2	8.60	6.70	6.90	7.00	100	78	80	81
	3	5.60	4.50	4.40	3.50	100	80	79	63
	Total	21.70	18.20	17.80	12.10				
Intortum	1	13.50	12.00	12.60	10.40	100	89	93	77
	2	12.25	11.20	13.10	6.75	94	85	100	52
	3	5.30	2.90	5.80	3.60	91	50	100	62
	4	4.32	4.60	6.30	4.90	69	73	100	78
	Total	35.37	30.70	37.80	25.65				
Kaimi clover	1	9.60	10.30	11.40	9.60	84	90	100	84
	2	4.60	5.90	6.10	5.00	75	97	100	82
	Total	14.20	16.20	17.50	14.60				
Alfalfa	1	4.70	5.10	8.00	7.00	59	64	100	88
	2	8.00	9.50	13.30	13.40	60	71	99	100
	Total	12.70	14.60	21.30	20.40				
Kikuyu grass	1	14.68	15.46	15.28	11.42	95	100	99	74
	2	15.10	15.20	17.30	18.50	82	82	94	100
	3	20.50	16.10	22.10	22.80	90	70	97	100
	4	13.98	14.35	15.44	18.30	76	78	84	100
	Total	64.26	61.11	70.12	71.02				
Bermuda grass	1	11.35	11.02	10.72	5.41	100	97	94	48
	2	13.95	13.94	11.40	13.90	100	99	82	99
	3	19.10	21.40	22.20	20.30	86	96	100	91
	Total	44.40	46.36	44.32	39.61				
Guinea grass	1	17.40	20.60	22.90	18.80	76	90	100	82
	2	27.20	29.50	26.90	31.10	87	95	86	100
	3	17.00	17.10	19.10	22.00	77	78	87	100
	4	14.48	15.23	16.70	17.30	84	88	96	100
	Total	76.08	82.43	85.60	89.20				
Sorghum	1	5.19	5.50	6.18	5.60	84	89	100	91
	2	33.90	36.00	35.95	36.30	93	99	99	100
	3	19.35	21.13	22.58	26.28	74	80	86	100
	Total	58.44	62.63	64.71	68.18				
Lettuce	1	0.97	1.20	1.90	2.32	42	52	82	100
	2	1.70	1.90	2.20	2.05	77	86	100	93
	3	0.28	0.67	1.43	1.60	18	42	89	100
	4	0.65	1.15	2.05	4.35	15	26	47	100
	Total	3.60	4.92	7.58	10.32				

Silicon and Phosphorus

Silicon and P concentrations in legumes generally increased with increasing Si applications and also with successive harvests (Table 17). Although Si and P concentrations increased with Si application in big trefoil yields decreased suggesting that some factor other than Si and P were responsible for this decrease. Alfalfa yields increased with increasing plant Si and P in both harvests. Phosphorus concentrations in all three grasses increased with successive harvests, but Si concentrations in the 0.56 and 2.2 T Si treatments decreased. Increasing Si applications increased plant Si and P in lettuce in all four harvests and the concentrations varied with harvests. Increased yields with Si applications may be due to increased P availability.

Calcium, Magnesium and Potassium

Calcium concentrations increased with increasing Si applications in legumes and also increased with successive harvests except in alfalfa in which they decreased in the second harvest (Appendix Table 2). Calcium levels in grasses and sorghum were generally low in the first harvest which may account for low yields in this harvest. Calcium concentrations in lettuce followed the patterns reported for legumes. Concentrations of Mg in most species generally decreased with Si applications and with successive harvests. These Mg levels seemed to be adequate for plant growth. No consistent trends in K concentration within Si applications or harvests were evident (Appendix Table 2).

Manganese and Aluminum

Plant Mn contents generally decreased with increasing Si applications and increased slightly in successive harvests of the

TABLE 17. RESIDUAL EFFECTS OF CALCIUM SILICATE APPLICATIONS ON Si AND P CONCENTRATIONS IN PLANTS GROWN ON PAALOA SOIL

Species	Harvest	Si in tops				P in tops			
		T Si/ha				T Si/ha			
		0	0.56	2.2	8.8	0	0.56	2.2	8.8
		(%)				(%)			
Big trefoil	1	0.03	0.04	0.05	0.05	0.25	0.28	0.28	0.29
	2	0.05	0.06	0.09	0.07	0.41	0.42	0.40	0.40
	3	0.07	0.12	0.13	0.11	0.37	0.39	0.37	0.36
Intortum	1	0.08	0.28	0.63	0.75	0.17	0.19	0.19	0.29
	2	0.10	0.30	0.70	0.74	0.33	0.33	0.34	0.38
	3	0.09	0.25	0.79	1.12	0.33	0.36	0.37	0.40
	4	0.12	0.26	0.58	1.04	0.28	0.31	0.33	0.33
Kaimi clover	1	0.11	0.38	0.75	0.86	0.23	0.26	0.27	0.28
	2	0.15	0.42	1.81	2.37	0.29	0.30	0.32	0.34
Alfalfa	1	0.02	0.02	0.03	0.02	0.22	0.23	0.25	0.28
	2	0.04	0.03	0.05	0.04	0.33	0.30	0.29	0.31
Kikuyu grass	1	0.10	0.39	0.64	0.68	0.22	0.23	0.25	0.25
	2	0.09	0.31	0.86	1.32	0.27	0.30	0.26	0.26
	3	0.07	0.19	0.60	1.29	0.25	0.27	0.28	0.28
	4	0.09	0.18	0.46	1.06	0.33	0.34	0.35	0.33
Bermuda grass	1	0.12	0.60	1.17	1.53	0.23	0.24	0.25	0.28
	2	0.09	0.37	1.49	2.34	0.27	0.25	0.26	0.24
	3	0.08	0.28	0.88	2.49	0.24	0.25	0.25	0.24
Guinea grass	1	0.12	0.42	1.43	2.92	0.19	0.24	0.23	0.17
	2	0.11	0.31	0.95	2.22	0.27	0.29	0.28	0.24
	3	0.14	0.25	0.66	3.42	0.33	0.33	0.35	0.34
	4	0.13	0.17	0.37	2.42	0.44	0.41	0.41	0.37
Sorghum	1	0.12	0.39	0.59	0.89	0.19	0.20	0.20	0.20
	2	0.09	0.26	0.72	1.96	0.22	0.23	0.22	0.21
	3	0.12	0.22	0.72	2.68	0.30	0.28	0.26	0.23
Lettuce	1	0.04	0.04	0.05	0.14	0.31	0.37	0.42	0.46
	2	0.02	0.03	0.06	0.04	0.39	0.44	0.50	0.42
	3	0.01	0.03	0.04	0.05	0.10	0.22	0.37	0.41
	4	0.04	0.05	0.06	0.07	0.26	0.27	0.27	0.34

Desmodiums, Bermuda grass and Guinea grass. Aluminum concentrations also decreased with additions of calcium silicate but tended to increase with successive harvests (Appendix Table 3).

Distribution of Silicon, Phosphorus and Other Nutrients in Papaya, Sugarcane and Pineapple

It has long been recognized that Si concentrations vary widely among plant parts. It has been reported that grains (husks, etc., included) contain a higher concentration of Si than vegetative parts (Coppenet, et al., 1947; Jones, et al., 1964; Russel, 1961). In the present study plant tops were divided into several parts and analyzed for Si, P, Ca, Mg, K, Mn, Al and Fe. The separation and age of the crop differed among species, but were the same for the same species in the two soils. Papaya tops were separated into leaf blades, petioles, and stem whereas sugarcane was divided into leaf blades, leaf sheaths, and stalk. Pineapple was harvested at early fruiting and was separated into the crown, fruit, peduncle, leaves and stem. Some pineapple plants did not fruit so values reported are averages of the two or three plants that did fruit.

Kapaa soil

Papaya: Leaves accumulated the highest amounts of Si while lowest Si concentrations were found in the stems (Table 18). The high Si concentration in the leaves where transpiration is highest suggests that Si distribution is related to transpiration. Concentrations of Si varied from 0.032 to 0.344% for leaves, 0.018 to 0.045% for petioles, and 0.009 to 0.015% for stems. Concentrations of P, Ca, Mg, Mn and Al were all high in leaves while K and Fe were high in the stem.

TABLE 18. DISTRIBUTION OF NUTRIENTS IN PAPAYA GROWN ON KAPAA SOIL

	Treatments (T Si/ha)	Si	P	Ca	Mg	K	Mn	Al	Fe
		(%)					(ppm)		
Leaf Blade	0	0.03	0.42	1.84	2.14	2.67	44	98	186
	0.56	0.08	0.43	4.57	2.03	2.40	40	64	126
	2.2	0.26	0.46	4.39	1.62	2.71	31	71	119
	8.8	0.34	0.51	3.43	0.62	2.23	34	27	94
Petiole	0	0.02	-	-	-	-	-	-	-
	0.56	0.03	-	-	-	-	-	-	-
	2.2	0.04	-	-	-	-	-	-	-
	8.8	0.05	-	-	-	-	-	-	-
Stem	0	0.01	0.34	1.83	1.72	2.99	15	30	442
	0.56	0.01	0.35	2.26	0.91	2.72	14	32	380
	2.2	0.01	0.37	2.15	0.95	2.64	11	28	301
	8.8	0.02	0.42	3.89	0.64	2.60	10	12	281

Concentrations of Si and Ca increased with increasing Si applications in all parts whereas Mg, Mn, Al and Fe concentrations generally decreased with additions of calcium silicate.

Sugarcane: Total Si concentrations were higher in sugarcane leaf sheaths than in blades or stalks, which is in agreement with Fox, et al. (1969). In all tissues Si concentrations increased with increasing Si applications (Table 19). Phosphorus and Ca contents of blades were higher than those of stalks or sheaths and there was little change in Ca concentrations with increasing applications of calcium silicate. Magnesium and K concentrations were highest in sheaths and only Mg decreased consistently with silicate treatment in all tissues. The stalk accumulated high Fe and Al concentrations which decreased with increasing silicate applications. Manganese concentrations also decreased with increasing Si applications in all plant parts.

Pineapple: The highest Si concentrations were found in pineapple leaves followed in decreasing order by fruit, peduncle, crown and stem (Table 20). Leaves had the lowest concentrations of phosphorus. Increasing Si applications increased Si concentrations but decreased P concentrations in leaves, stem, fruit, peduncle and crown, suggesting an antagonistic relationship between Si and P. Stems had the maximum concentration of Ca while the peduncle had the lowest. Fruit had the highest Mg and Mn levels generally were reduced by the 8.8 T Si/ha treatment. Potassium appears to be equally distributed in all plant parts except the stem where it is about one-third of the levels in other tissues. Aluminum was high in the leaves and fruit and was low in the crown, peduncle and stem.

TABLE 19. DISTRIBUTION OF NUTRIENTS IN SUGARCANE GROWN ON KAPAA SOIL

	Treatments (T Si/ha)	Si	P (%)	Ca	Mg	K	Mn	Al (ppm)	Fe
Blades	0	0.15	0.17	0.75	0.28	1.59	14	72	156
	0.56	0.37	0.17	0.72	0.26	1.31	12	74	160
	2.2	1.00	0.18	0.70	0.21	1.28	12	80	155
	8.8	1.70	0.18	0.63	0.12	1.43	10	74	154
Sheaths (3,4,5 & 6)	0	0.16	0.06	0.54	0.42	2.04	24	67	178
	0.56	0.28	0.07	0.55	0.36	1.88	11	22	98
	2.2	1.32	0.08	0.47	0.33	1.95	14	49	206
	8.8	2.88	0.05	0.55	0.27	2.05	9	37	125
Stalk and Remaining Leaves	0	0.16	0.10	0.57	0.35	1.63	15	138	446
	0.56	0.34	0.11	0.61	0.34	1.61	13	106	286
	2.2	0.98	0.11	0.49	0.32	1.46	13	110	279
	8.8	1.77	0.12	0.52	0.26	1.75	10	88	222

TABLE 20. DISTRIBUTION OF NUTRIENTS IN PINEAPPLE GROWN ON KAPAA SOIL

	Treatments (T Si/ha)	Si	P (%)	Ca	Mg	K	Mn	Al (ppm)	Fe
Crown	0	0.03	0.20	0.75	0.18	1.21	64	8	-
	0.56	0.05	0.21	0.80	0.18	1.10	55	7	-
	2.2	0.10	0.21	0.77	0.16	1.18	46	13	-
	8.8	0.13	0.19	0.81	0.17	1.26	42	15	-
Fruit	0	0.04	0.20	1.09	0.26	0.84	134	77	-
	0.56	0.07	0.20	1.03	0.25	1.10	165	82	-
	2.2	0.12	0.19	1.09	0.25	1.19	164	58	-
	8.8	0.18	0.18	1.29	0.25	1.10	127	60	-
Peduncle	0	0.04	0.16	0.36	0.13	1.33	31	23	-
	0.56	0.04	0.16	0.31	0.12	1.32	31	8	-
	2.2	0.09	0.16	0.36	0.13	1.18	42	21	-
	8.8	0.16	0.11	0.38	0.11	1.09	31	9	-
Leaves	0	0.05	0.12	0.80	0.16	0.79	87	85	150
	0.56	0.08	0.13	0.76	0.18	1.14	124	104	141
	2.2	0.14	0.11	0.77	0.16	1.21	126	78	82
	8.8	0.26	0.09	0.84	0.14	1.19	99	75	79
Stem	0	0.01	0.21	1.99	0.12	0.40	34	11	51
	0.56	0.02	0.23	2.25	0.13	0.48	58	27	80
	2.2	0.03	0.20	1.84	0.12	0.47	53	29	67
	8.8	0.10	0.14	1.74	0.08	0.36	25	18	52

Paaloa Soil

Papaya: Concentrations of Si were higher in leaves than in petioles or stems (Table 21). Concentrations of P were slightly higher in leaves than in stems or petioles. Calcium concentrations were slightly higher in petioles than leaves, but concentrations in both leaves and petioles were higher than in stems. Concentrations of Mg, Mn, Al and Fe were all higher in leaves than in petioles or stems whereas K appeared to be slightly higher in stems. Plant Mn, Al and Fe concentrations decreased with increasing Si applications. These distribution patterns were similar to those of papaya grown on the Kapaa soil, but Mn levels were considerably higher in the Paaloa soil.

Sugarcane: There was more Si and potassium in sheaths than in blades or stalks (Table 22). Concentrations of Ca and P were highest in the blades and Ca concentrations increased with increasing Si applications. High concentrations of Mn and Fe were found in the stalk plus remaining leaves whereas blades had high aluminum. Concentrations of all three elements, Mn, Al, Fe, decreased with increasing Si applications. These patterns were generally similar to those on the Kapaa soil, but again Paaloa soil had higher Mn concentrations.

Pineapple: Concentrations of Si in leaves were higher than those in fruit, peduncle, crown or stem (Table 23). Phosphorus concentrations decreased with increasing Si applications and generally P was uniformly distributed in all plant parts except leaves in which P concentration was low. This indicates that P distribution is not related to water loss. Calcium content were high in stems followed by the fruit, peduncle and leaves. Concentrations of Mg, K and Mn were all highest

TABLE 21. DISTRIBUTION OF NUTRIENTS IN PAPAYA GROWN ON PAALOA SOIL

	Treatments (T Si/ha)	Si	P	Ca	Mg	K	Mn	Al	Fe
		(%)					(ppm)		
Leaf blade	0	0.05	0.29	2.72	0.37	2.89	122	78	377
	0.56	0.11	0.31	3.25	0.39	3.96	214	74	260
	2.2	0.21	0.29	3.91	0.38	4.16	63	51	210
	8.8	0.23	0.32	4.24	0.35	3.71	21	42	150
Petiole	0	0.02	0.21	2.81	0.36	2.62	116	38	108
	0.56	0.03	0.25	3.39	0.36	2.96	133	32	117
	2.2	0.04	0.23	4.11	0.30	2.64	43	24	90
	8.8	0.04	0.24	4.78	0.23	3.39	16	27	110
Stem	0	0.02	0.21	1.24	0.27	2.49	63	30	135
	0.56	0.02	0.25	1.41	0.28	3.29	65	29	145
	2.2	0.03	0.22	2.06	0.26	3.86	26	19	119
	8.8	0.03	0.25	2.73	0.24	4.43	16	24	93

TABLE 22. DISTRIBUTION OF NUTRIENTS IN SUGARCANE GROWN ON PAALOA SOIL

	Treatments (T Si/ha)	Si	P (%)	Ca	Mg	K	Mn	Al (ppm)	Fe
Blade	0	0.05	0.20	0.35	0.17	1.69	75	108	126
	0.56	0.25	0.21	0.38	0.16	1.85	64	78	136
	2.2	0.31	0.21	0.38	0.18	1.73	72	68	169
	8.8	1.53	0.22	0.46	0.16	1.30	17	53	182
Sheath	0	0.07	0.10	0.21	0.16	2.19	99	22	50
	0.56	0.28	0.11	0.21	0.14	2.44	85	21	43
	2.2	0.30	0.10	0.20	0.15	2.55	81	17	45
	8.8	2.80	0.10	0.26	0.15	2.16	9	16	23
Sheath and Remaining Leaves	0	0.08	0.18	0.30	0.22	1.94	137	92	284
	0.56	0.26	0.19	0.28	0.19	1.67	97	65	219
	2.2	0.28	0.17	0.29	0.21	1.50	93	71	191
	8.8	2.33	0.17	0.33	0.19	1.74	13	58	160

TABLE 23. DISTRIBUTION OF NUTRIENTS IN PINEAPPLE GROWN ON PAALOA SOIL

	Treatments (T Si/ha)	Si (%)	P	Ca	Mg	K	Mn (ppm)	Al	Fe
Crown	0	0.02	0.20	-	-	-	-	-	-
	0.56	0.03	0.20	-	-	-	-	-	-
	2.2	0.05	0.20	-	-	-	-	-	-
	8.8	0.18	0.22	-	-	-	-	-	-
Fruit	0	0.03	0.21	0.91	0.25	2.78	419	94	242
	0.56	0.05	0.20	0.66	0.19	2.81	186	64	203
	2.2	0.09	0.19	0.98	0.25	3.06	224	62	178
	8.8	0.21	0.18	0.98	0.16	2.40	68	51	190
Peduncle	0	0.03	0.20	0.31	0.31	1.69	107	35	127
	0.56	0.03	0.13	0.27	0.13	2.10	74	34	96
	2.2	0.06	0.16	0.41	0.16	2.19	60	57	96
	8.8	0.24	0.10	0.46	0.08	2.15	20	59	78
Leaves	0	0.06	0.12	0.30	0.15	2.33	204	143	255
	0.56	0.12	0.12	0.38	0.14	2.06	179	162	315
	2.2	0.19	0.12	0.54	0.15	2.40	165	175	252
	8.8	0.42	0.09	0.80	0.17	1.98	90	176	265
Stem	0	0.01	0.29	0.87	0.13	1.81	45	32	125
	0.56	0.02	0.24	1.14	0.12	1.26	42	37	128
	2.2	0.03	0.22	1.26	0.10	1.43	17	34	116
	8.8	0.16	0.14	1.65	0.07	0.99	6	42	127

in the fruit, whereas Al and Fe were highest in leaves. Generally Mn, Al and Fe levels decreased with increasing Si applications.

In general leaves accumulated more Si than other parts analyzed in all species except sugarcane where Si accumulation was highest in sheaths. Thus Si distribution in papaya and pineapple may be related to transpiration. Phosphorus concentrations in general were low in leaves and were equally distributed among other plant parts, suggesting that distribution of P is not related to transpiration.

Comparative Effects of Three Calcium Silicate Materials on Yield and Nutrient Content of Kikuyu Grass and Lettuce

The comparative effects of Tennessee Valley Authority (TVA), Hawaiian Cement Corporation (HCC) and Technical Grade (TG) calcium silicates on growth and nutrient uptake were studied in pots with Kapaa and Paaloa soils using Kikuyu grass and lettuce. The residual effects of these materials were evaluated by growing four successive crops of Kikuyu grass and lettuce. A randomized complete block design with 2 plant species, 5 Si treatments, 2 soils, 3 silicate materials and 2 replicates was used. The silicon treatments are shown in Table 24. Other procedures were the same as those described previously for the species experiment.

Kapaa Soil

Kikuyu grass: Kikuyu grass yields increased with applications of all three silicate materials. Maximum yields for TVA and HCC $CaSiO_3$ were produced at the 2 T material/A Si level and for TG $CaSiO_3$ at the 4 T material level in the first harvest, although the 2 T level produced 94% of maximum yield (Fig. 4 and Appendix Table 4). Low yields in the first harvest may be due to poor establishment of plants whereas low

TABLE 24. RATES AND SOURCES OF CALCIUM SILICATE MATERIALS

T Calcium Silicate Material/A	Sources
0	Tennessee Valley Authority $CaSiO_3$
2	Hawaiian Cement Corporation $CaSiO_3$
4	Technical Grade $CaSiO_3$
8	
16	

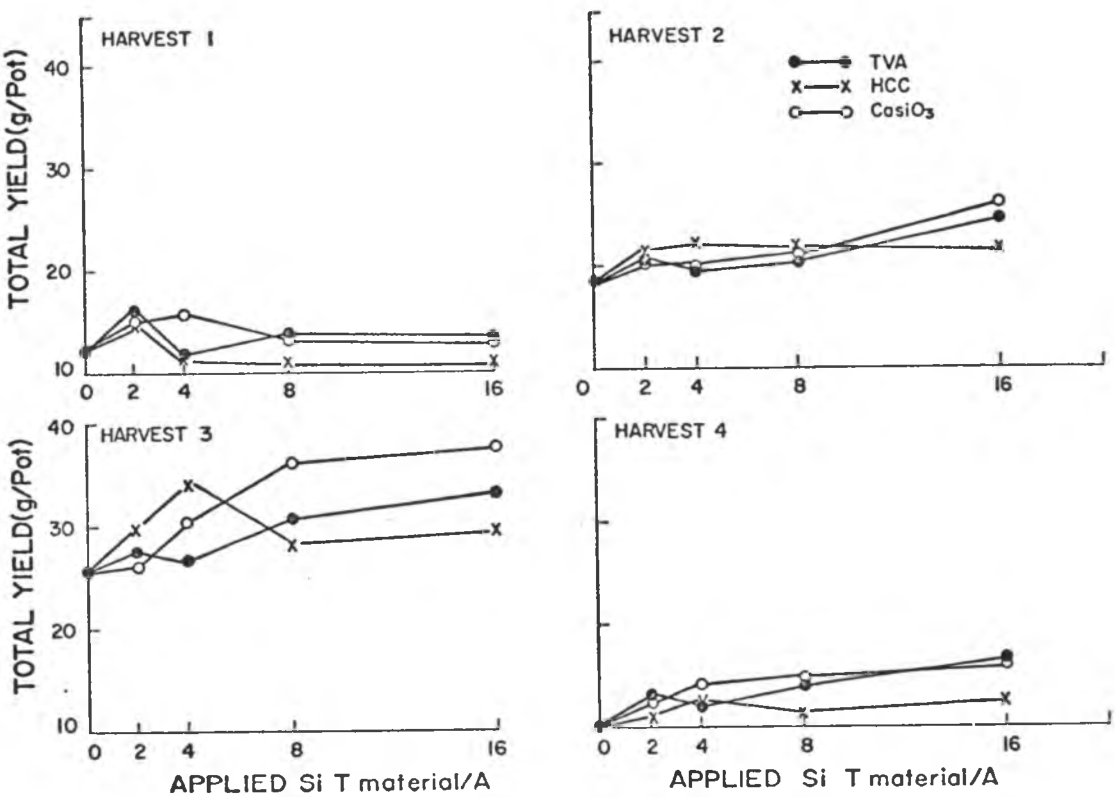

FIGURE 4. INITIAL AND RESIDUAL EFFECTS OF HCC, TVA AND TG $CaSiO_3$ ON THE YIELD OF KIKUYU GRASS GROWN ON KAPAA SOIL

yields in the last harvest may be due to low levels of certain micronutrients resulting from continued extraction by plants. Residual Si continued to produce yield responses in the second and third harvests with all materials but maximum yields in TVA and TG $CaSiO_3$ were at the 16 T material/A application. In contrast, maximum yields for HCC $CaSiO_3$ were obtained at the 4 T material/A level in the second and third harvests, but maximum yield was considerably higher in the third harvest. This implies that low levels of residual TVA and TG silicate were less effective in increasing yields than HCC $CaSiO_3$, but high levels of these two materials produced higher yields than HCC $CaSiO_3$. The HCC $CaSiO_3$ can produce sustained yield increases at low rate of application and thus at low cost.

Plant Si concentration increased significantly with increased Si applications. Silicon concentrations ranged from 0.06 to 0.77% with TVA, 0.06 to 1.03% with HCC and 0.06 to 1.09% with TG $CaSiO_3$ (Appendix Table 5). The availability of silicate is apparently higher in HCC and TG than in TVA $CaSiO_3$. Average plant Si values for TVA $CaSiO_3$ were significantly lower than those for HCC and TG $CaSiO_3$ in all four harvests. In general yields did not follow plant Si concentration directly.

Phosphorus concentrations showed relatively little change with applications of $CaSiO_3$ and in the four harvests it ranged from 0.18 to 0.32% with TVA, 0.18 to 0.33% with HCC and 0.18 to 0.31% with TG $CaSiO_3$ (Appendix Table 5). High P concentrations in the fourth harvest may have been caused by low yields in this harvest. Plant P concentration was significantly higher in TG $CaSiO_3$ than in the other materials, but yields did not follow the same pattern.

Calcium concentration of Kikuyu grass increased with increasing Si applications. In the second and third harvests Ca concentrations in TG $CaSiO_3$ were significantly lower than those of the TVA and HCC materials (Appendix Table 6). Calcium levels generally increased in successive harvests and only in the third and fourth harvests were they within the adequate range (1.04 - 1.75%) reported for grasses by Chapman (1966). Calcium concentrations ranged from 0.37 to 1.68% for TVA, 0.37 to 1.74% for HCC and 0.37 to 1.68% for TG $CaSiO_3$ (all four harvests included). The Si materials had no effect on plant Mg concentration except in the first harvest where Mg concentration decreased with increasing Si applications. Concentrations of K with all three materials were within critical levels described for grasses in the literature and were generally unaffected by treatment.

Concentrations of Mn decreased with increasing Si applications in all materials and the decreases were statistically significant in harvests two, three and four. Plant Mn concentrations were significantly lower in HCC and TVA calcium silicate than in the TG calcium silicate. This may have been caused by the lower pH of the TG $CaSiO_3$ (4.75 - 5.95) which was significantly lower than the pH of HCC or TVA materials (4.75 - 6.45) (Appendix Table 8).

Lettuce: Yields of lettuce increased with applications of all three silicate materials. Maximum yields in the first harvest were produced at the 8 T material/A for TVA and HCC $CaSiO_3$ and at the 16 T material level for TG $CaSiO_3$ (Fig. 5). Yields with silicate applications were 80% or more higher than yields with zero Si indicating that larger

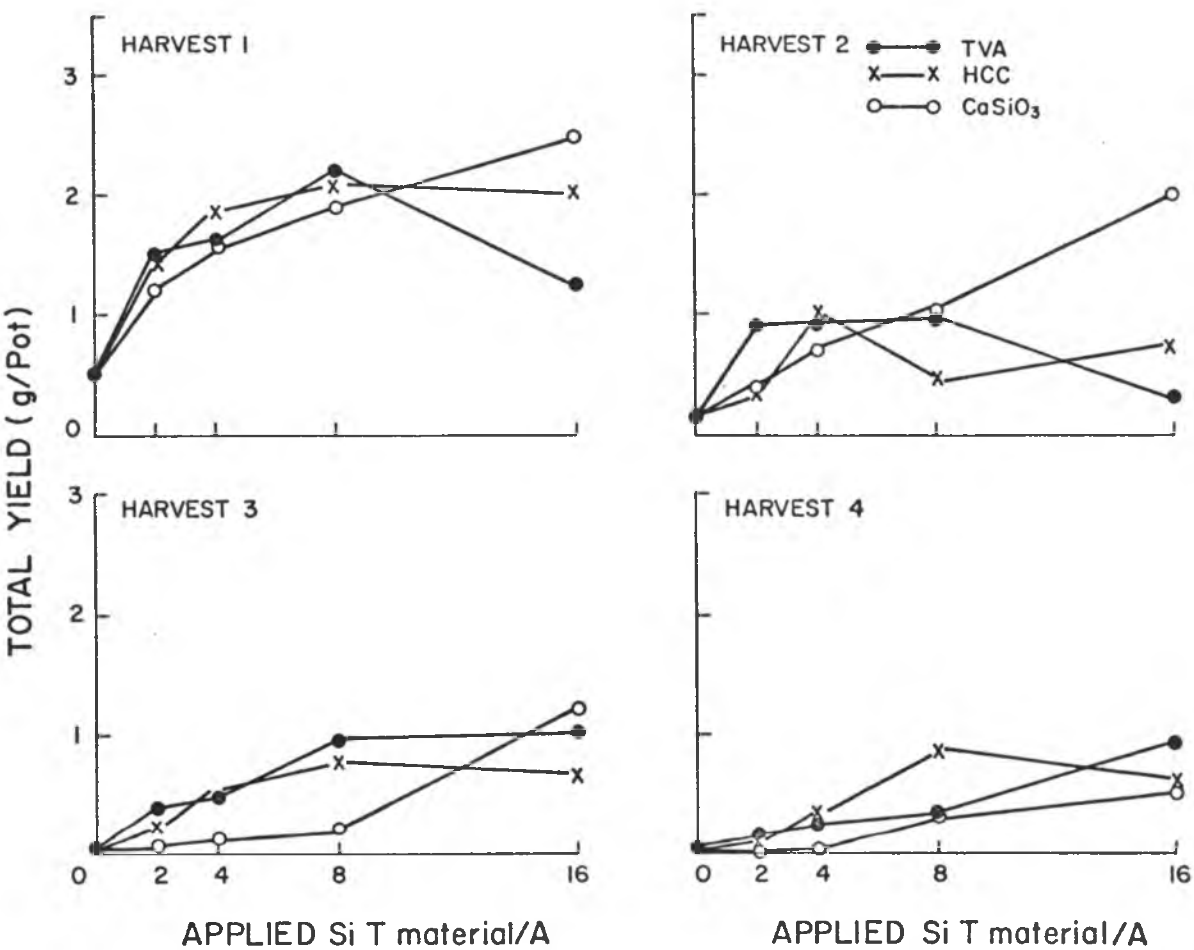

FIGURE 5. INITIAL AND RESIDUAL EFFECTS OF HCC, TVA AND TG $CaSiO_3$ ON THE YIELD OF LETTUCE GROWN ON KAPAA SOIL

responses to silicate applications were obtained with lettuce than with Kikuyu grass. Reduced yields with HCC and TVA $CaSiO_3$ at the 16 T material/A treatment may be due to reduced availability of micro-nutrients. Yields decreased with successive harvests possibly because of reduced Si availability and reduced supplies of certain micro-nutrients (Appendix Table 10). Maximum yields in each harvest were produced by TG $CaSiO_3$ in all harvests except the fourth, in which TG $CaSiO_3$ yields were reduced markedly at all levels.

Plant Si concentrations increased with increasing Si applications up to 8 T material/A and decreased in the 16 T material/A treatment probably due to dilution in the larger plants produced. Average Si values for TG and HCC $CaSiO_3$ were significantly higher than those for TVA $CaSiO_3$ in the first harvest which implies greater Si availability in both HCC and TG $CaSiO_3$ (Appendix Table 11). Plant P concentrations were highest in the first harvest which in combination with Si may be responsible for the large yields for all these materials in this harvest. Phosphorus levels in all harvests were at or below 0.56% reported to be sufficient for lettuce by Chapman (1966) in spite of the fact that 1000 lbs/A had been applied to all treatments.

Calcium concentration increased significantly with increasing Si applications in the first harvest (Appendix Table 12). Calcium concentrations were significantly lower in TG $CaSiO_3$ than in TVA or HCC $CaSiO_3$. There was generally no effect of treatment or harvest on Mg concentration.

Lettuce in HCC $CaSiO_3$ had significantly lower Mn concentrations than that in the TVA and TG material in the first harvest and there was a general decrease in Mn with increasing Si application in all materials (Appendix Table 13). Manganese levels were generally high with low Si applications and increased with successive harvests as pH decreased. Thus increasing Mn concentrations may account for decreasing lettuce yields with successive harvests. In contrast Kikuyu grass did not have high Mn concentrations in this soil possibly because it has relatively low Mn uptake.

Paaloa Soil

Kikuyu grass: Yields generally decreased with increasing rates of all silicate materials in the first harvest and may be due to the greater availability of native Si in this soil (Fig. 6). Residual Si produced positive yield responses in the second, third and fourth harvests with all three silicate materials, but HCC and TVA generally produced higher yields than TG $CaSiO_3$. Average yields of TG $CaSiO_3$ in the fourth harvest were significantly lower than those of the HCC or TVA materials. The yield responses in this soil were generally lower than those in the Kapaa soil.

Plant Si concentrations increased significantly with increasing Si application in the first and second harvests (Appendix Table 5). The average plant Si concentration of plants in TG $CaSiO_3$ in the first harvest was significantly higher than that of plants in the TVA or HCC materials, implying that Si availability was greater in TG $CaSiO_3$. However, yield did not follow the pattern of Si concentrations. Increasing silicate applications resulted in increased plant P concentrations in all harvests except the fourth in which it decreased (Appendix Table 5).

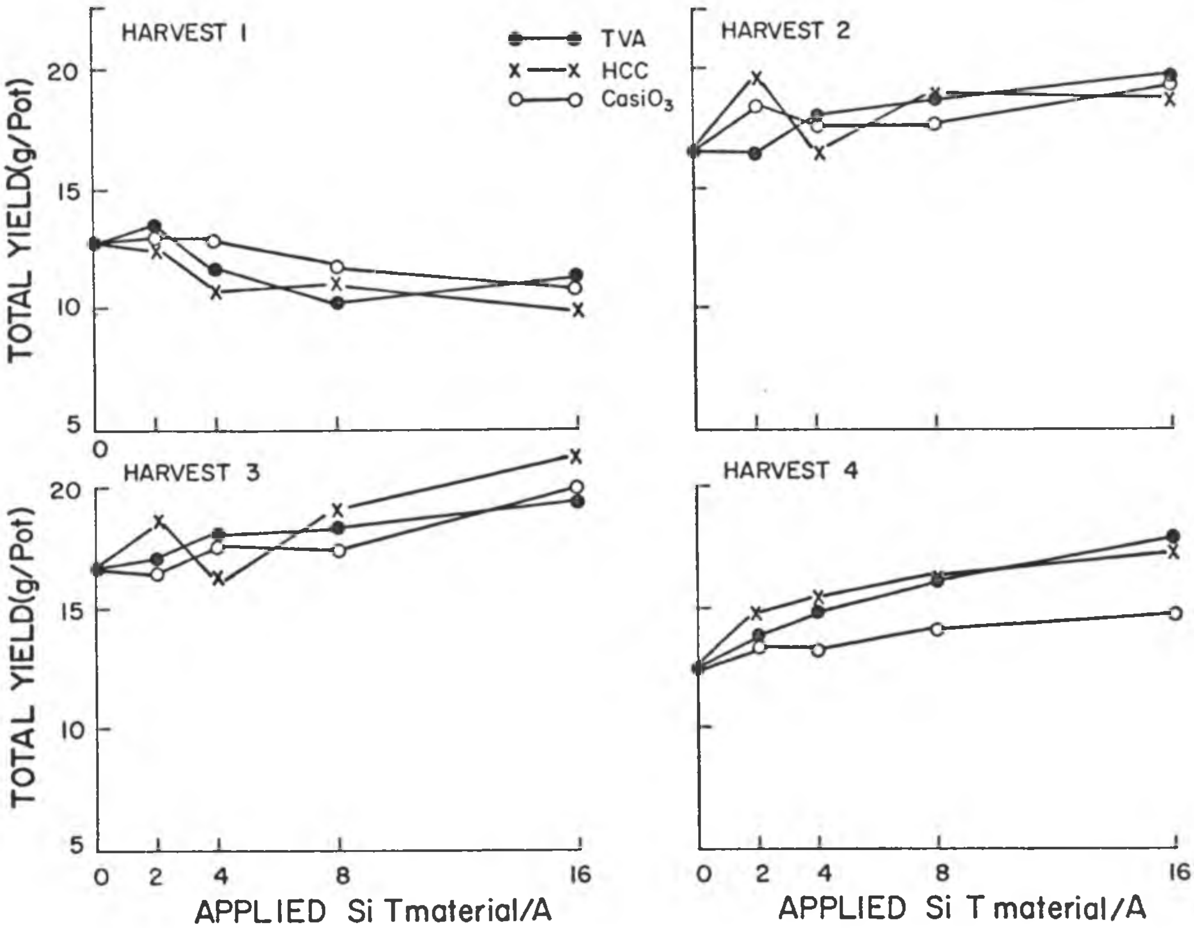

FIGURE 6. INITIAL AND RESIDUAL EFFECTS OF HCC, TVA AND TG $CaSiO_3$ ON THE YIELD OF KIKUYU GRASS GROWN ON PAALOA SOIL

Calcium concentrations increased with increasing Si application in all materials, but the average plant Ca concentration of TG $CaSiO_3$ in the first harvest was significantly lower than that of the HCC or TVA material. Magnesium concentrations generally decreased with Si treatments, but appeared to be unaffected by the silicate materials (Appendix Table 7). All K levels were above the deficiency level of 2.0% reported for grasses by Chapman (1966). The TG $CaSiO_3$ had significantly higher Mn concentration in the first and the fourth harvests than either the TVA and HCC materials. Plant Mn concentrations generally decreased with increasing Si applications (Appendix Table 8).

Lettuce: Yields of lettuce increased with applications of all three materials and highest yields were obtained with 8 T material/A application of HCC material in the first harvest (Fig. 7). Average yields for TG $CaSiO_3$ were significantly lower than those of TVA and HCC $CaSiO_3$ in harvests 1, 3 and 4, and the yield response patterns for HCC and TVA materials were generally similar. Residual Si from all materials continued to produce yield responses in the third harvest and from TVA and HCC materials in the fourth harvest.

Concentrations of Si were low at high Si rates possibly due to dilution in larger plants and did not follow yield patterns. Plant P concentrations generally increased with Si applications with a few exceptions and may have influenced yield (Appendix Table 11). Calcium concentrations increased with increasing Si applications of all three materials and the average plant Ca concentration for TG $CaSiO_3$ in harvests 2, 3 and 4 were significantly lower than those for TVA and HCC materials. Plant Mg concentrations showed no clear relationship with

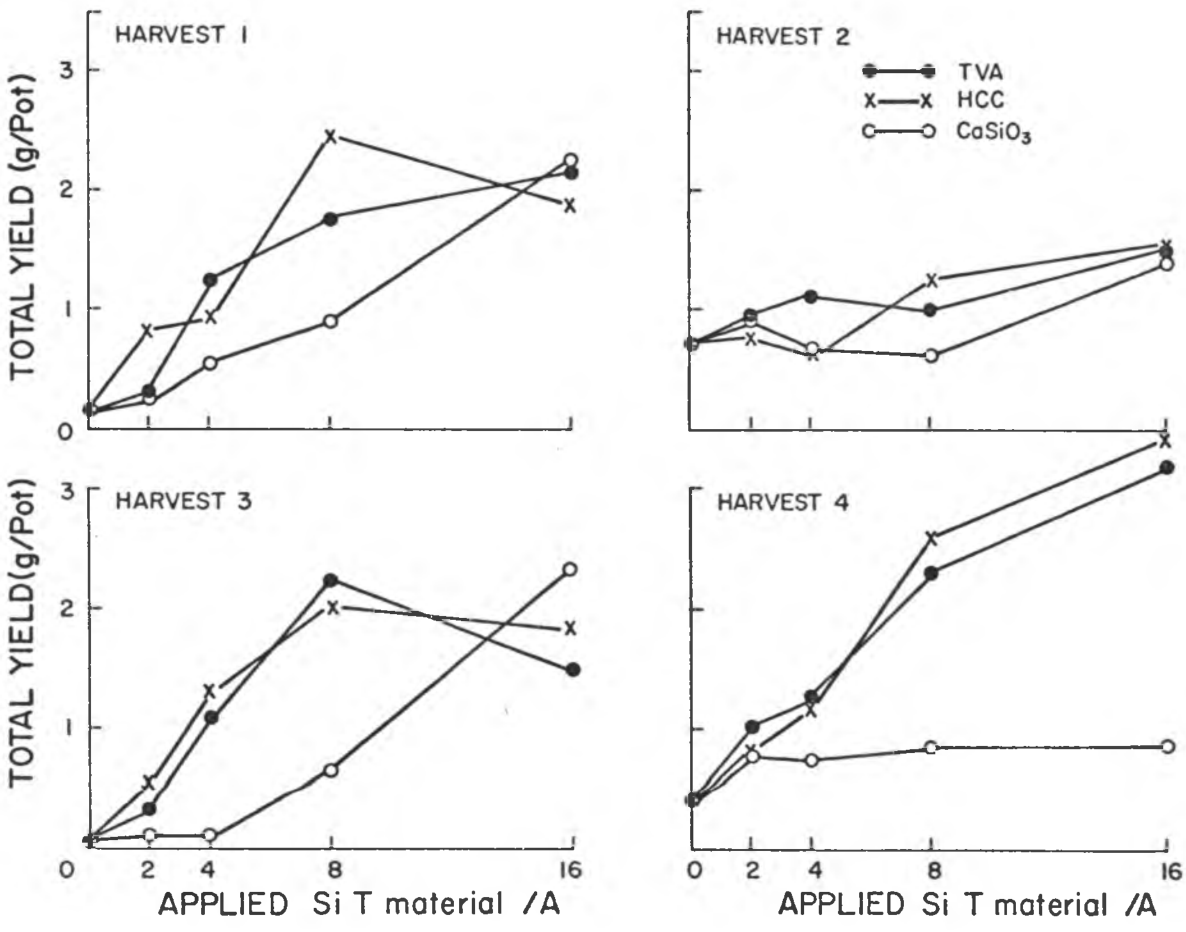

FIGURE 7. INITIAL AND RESIDUAL EFFECTS OF HCC, TVA AND TG $CaSiO_3$ ON THE YIELD OF LETTUCE GROWN ON PAALOA SOIL

silicate materials (Appendix Table 12). Manganese levels were generally high for plants grown in this soil and decreased with Si application (Appendix Table 13). Average Mn concentrations for TG $CaSiO_3$ in harvests 2, 3 and 4 were significantly higher than those for TVA or HCC, which may be due to low pH values obtained with TG $CaSiO_3$ (Appendix Table 14).

Conclusions

Yields of 22 species on Kapaa soil and 19 species on Paaloa soil were higher with applications of calcium silicate than without. In 10 of the 22 species yield increases were statistically significant on Kapaa soil whereas the yield increase of only one species was significant on Paaloa soil. Yields at 2.2 T Si/ha were 85% or more of maximum in 17 of the 22 species on Kapaa soil and indicates this rate should produce yields at lower cost than 8.8 T Si/ha. In both soils yields of many species decreased at the 8.8 T Si/ha level and in some species the decrease was statistically significant. Thus high calcium silicate levels may be toxic to some species.

Yield increases from calcium silicate applications were generally greater on Kapaa than on Paaloa soil. Although water and modified Truog extractable Si in both soils were lower than critical levels set by Fox, et al. (1967), Si availability was apparently higher in the Paaloa than in the Kapaa soil. Plant Si levels in the zero Si treatment of the Paaloa soil were generally higher because of the low pH in this soil. Extractable soil P was much higher in the Paaloa (126 ppm) than in Kapaa soil (9 ppm) where it was below the critical level set for P. These combinations of Si and P availability may have accounted for the differential responses obtained on these two soils.

Calcium silicate applications significantly increased Si concentrations in all species, but Si concentrations varied in the different groups and decreased in the following order: Grains $\geq$ Grasses $\geq$ Vegetables and Fruits $\geq$ Legumes, except the two Desmodiums which were similar to grasses. Although P concentrations increased with Si applications in 13 and 14 species on Kapaa and Paaloa soils, respectively, significantly higher yields were obtained only on Kapaa soil. Calcium concentrations in plants grown on both soils generally increased whereas Mg concentrations decreased with few exceptions with applications of calcium silicate. Plant Mn, Al and Fe concentrations were reduced by applications of calcium silicate in both soils.

Calcium silicate exhibited continued availability of Si for as many as four successive crops in which 2.2 T Si/ha produced near maximum yields in all species tested. Silicon and P concentrations generally increased with successive harvests except in a few species. Plant Ca levels decreased with successive harvests in Kapaa soil but increased in Paaloa soil. Concentrations of Mn and Al increased slightly with successive harvests in both soils possibly because residual Si was not sufficiently soluble to reduce Mn and Al activity.

Silicon distribution in papaya, sugarcane and pineapple was studied and it appeared that leaves accumulated the highest amounts of Si in papaya and pineapple while sugarcane sheaths had maximum Si concentrations. In pineapple and papaya Si distribution may be related to transpiration. Plant P concentrations were generally lower in leaves suggesting that P distribution is not related to transpiration.

Of the three silicate materials studied, TVA and HCC $CaSiO_3$ produced maximum Kikuyu grass yields in the first harvest with 2 T material/A whereas TG $CaSiO_3$ produced maximum yield with 4 T material/A in Kapaa soil. In subsequent harvests maximum yields were obtained with 16 T Si/A of TVA and TG $CaSiO_3$ while only 4 T material/A were needed for HCC $CaSiO_3$. However HCC maximum yields were lower than those of TVA or TG and in addition, high rates of HCC depressed Kikuyu grass yields on Kapaa soil. Lettuce yields did not show the same depression with HCC $CaSiO_3$ on this soil and the yield responses were generally larger than those of Kikuyu grass. These materials did not produce significant Kikuyu grass yield responses in the first harvest in Paaloa soil, but in successive harvests, higher yields were obtained with HCC and TVA $CaSiO_3$ than with TG $CaSiO_3$. Maximum yields were obtained with the 16 T treatment of all materials. Lettuce yields were increased by all three silicate materials in all harvests on Paaloa soil, but effects were greater for HCC and TVA $CaSiO_3$ than the TG material. Maximum yields were produced with 8 or 16 T levels of all materials. Plant Si levels were generally higher in HCC and TG $CaSiO_3$ than TVA $CaSiO_3$ indicating greater Si solubility of these two materials. Concentrations of Mn were significantly reduced by both HCC and TVA materials while they remained slightly higher with TG $CaSiO_3$.

II. THE RESIDUAL EFFECTS OF SILICON, PHOSPHORUS AND SOIL pH ON YIELD AND NUTRIENT UPTAKE OF CORN UNDER FIELD CONDITIONS

Responses of several species to silicate applications were studied in pot experiments and corn was selected for a field study to determine the magnitude of response to Si applications with variable P and pH levels. The experiment used was installed in November 1966 by D. Y. Teranishi at the Kauai Branch Station and sugarcane was grown for nine months and harvested. A ratoon crop of sugarcane was harvested at ten months (June 17, 1968) by A. J. Rosenau. The corn was planted on August 14, 1968 and thus reflected the residual effects of Si, P and pH.

Materials and Methods

Plan of Experiment

Three replicates of a 3 x 3 x 3 factorial experiment with Si, P and pH variables were laid out in a split-plot design. The three pH treatments (pH 5.5, 6.0, 6.5) were the whole plots and Si (0, 833, 1666 kg Si/ha) and P (112, 280 and 1120 kg P/ha) treatment combinations were the subplots. A blanket application of N, K, Mg, Zn, B and Mo was applied at the installation of the experiment in 1966.

Supplementary treatments were included in this experiment at pH 6.0 to study the effects of increasing Si (0, 833, 1666 kg Si/ha) at zero P and at pH 5.0 to study the effects of increasing P (112, 280 and 1120 kg P/ha) with 833 kg Si/ha. A control plot without Si or P application was also included. These plots were adjacent to the main factorial experiment and were not included in the analysis of variance of the split-plot experiment.

Cultural Practices

The whole plots were 18.3 x 27.4 meters and the subplots were 6.1 x 9.1 meters. The pH of every plot was determined after the ratoon crop of sugarcane. Based on these values, titration curves were used to calculate the amounts of calcium carbonate or elemental sulphur required to readjust the pH to the original values (5.5, 6.0 and 6.5). Soil samples from the 1120 kg P plots were used to determine the additional P required for normal growth of plants in this treatment. The adsorption isotherm method of Fox and Kamprath (1970) was used to determine the amount of P required to maintain 0.1 ppm P in solution. On the basis of values from the 1120 kg P/ha treatment P was applied as treble superphosphate at the rate of 1/4, 1/8 and all of the total P required (59, 149 and 596 kg P/ha) to the 112, 280 and 1120 kg P/ha treatments, respectively. For sake of simplicity and continuity the original P rates are referred to throughout this dissertation. A blanket application of 560 kg/ha of a 1:1 KCl:Urea mixture was made prior to planting and 112 kg N/ha as Urea was applied in September 1968.

The field was tilled with a disc harrow to mix the soil and fertilizer. Corn variety WP x H & C grown on Lalamilo farm (Hawaii was planted on August 14, 1968. Eleven rows each 30" apart were planted in each plot. Corn was thinned to 242 plants per plot or 17,570 plants per acre in September 1968. Since there was adequate rainfall the field was not irrigated. Monthly rainfall during the five month period of the experiment is presented in Table 25. Weeds were controlled with herbicides.

TABLE 25. RAINFALL DISTRIBUTION DURING THE GROWING PERIOD OF THE CORN CROP ON KAUAI

Month	Rainfall (cm)
August (14-31)	5.23
September	14.25
October	25.47
November	39.63
December (1-10)	33.08
Total	117.66

Plant Sampling

Three whole plants were taken from each treatment at the one month stage and replicates composited. At the silking stage, October 1968, the first leaf blade below and opposite the topmost ear was sampled. The samples were dried at 70°C, weighed for moisture determination, ground and stored for analysis.

Harvest

The matured corn was harvested after five months (December 10, 1968). Five feet from each end of the plot and the two outside rows on each side of the plot were discarded to remove border effects and the seven inner rows were harvested. Plants were cut at ground level and weighed. A subsample of 14 stalks per plot was taken for moisture determination and chemical analysis. Ears were separated from the stover in this subsample to obtain an estimate of grain yield. Samples were dried at 70°C, weighed, and ground to less than 20 mesh in a wiley mill.

Plant Analyses

Ground, oven-dried plant samples were analyzed for Si, P, Ca, K, Al and N. Methods of extraction and analysis were the same as those described for the pot experiments. The detailed method for total nitrogen is presented in Appendix A.

Soil Analysis

Soil pH, extractable Si and P were determined on the soil samples collected after the corn was harvested. The complete methods of extraction and analysis are given in Appendix A.

Results and Discussion

Corn plants were analyzed at three different stages of maturity for residual effects of Si, P and pH on yield and composition. The results will be discussed separately for (a) one month-old corn plants in which the replicates were composited and samples analyzed for Si, P, Ca and Al; (b) leaves at the silking stage which were analyzed for Si, P, Ca, K, N, Fe and Al; and (c) ear and stover yields of the final harvest at which time Si, P, Ca, and Al were determined again.

One Month Old Corn

Total dry matter yields at one month increased with increasing applications of Si and P (Fig. 8) and decreased with increasing pH (Appendix Table 15). Yield increases from 1666 kg Si/ha application are greater at 112 and 280 kg P/ha (49 and 54%, respectively) than at 1120 kg P/ha (11%) although the absolute yield increases are similar. There is relatively little difference between the 833 and 1666 kg/ha Si rates (4 to 17%) at all P levels, therefore 833 kg Si/ha may be considered adequate for corn growth at this stage. There seems to be an interaction between Si, P and pH in which the pH (5.5), 1666 kg Si/ha, and 1120 kg P/ha treatment produced maximum yield (Appendix Table 15), possibly because more Si was available at pH 5.5 and this in combination with P produced a high yield of dry matter.

Plant Silicon

Plant Si concentration increased with increased Si treatment and decreased with increased pH (Appendix Table 16). Silicon concentrations in the zero Si treatment were doubled by the application of 1120 kg P/ha, possibly because added P released native soil Si as

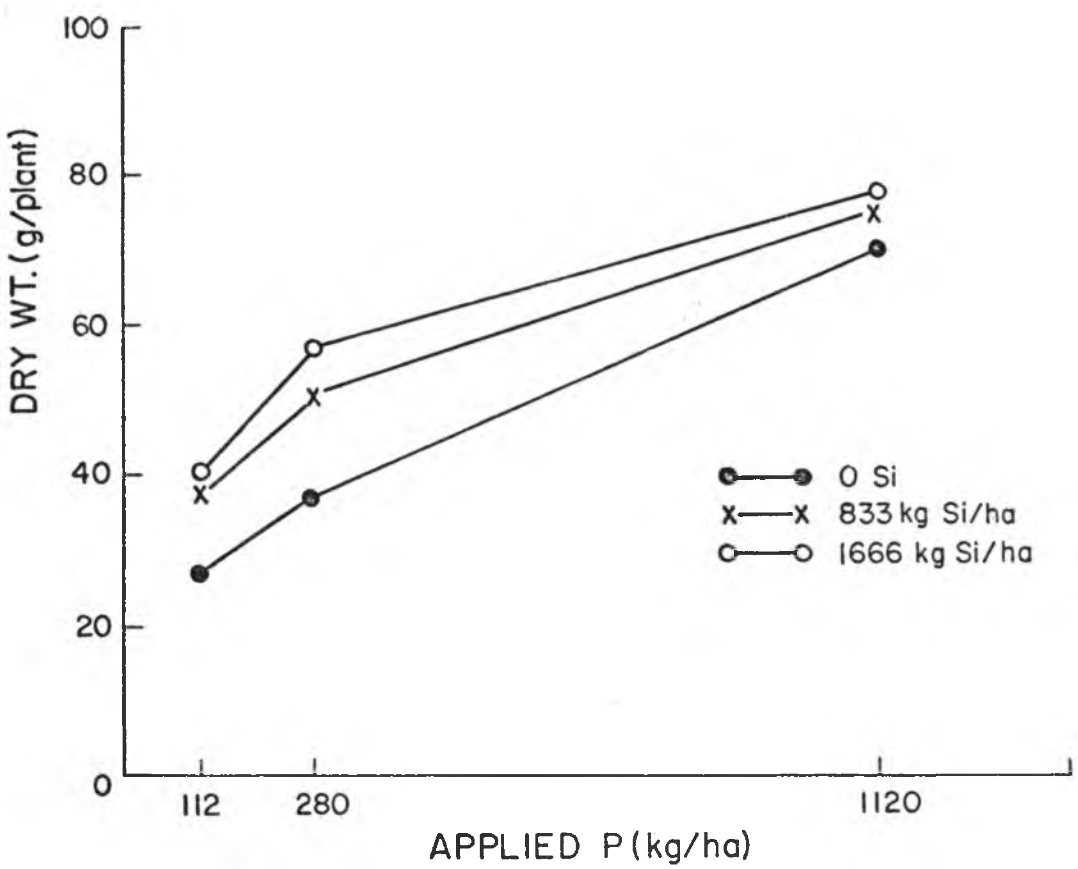

FIGURE 8. INFLUENCE OF RESIDUAL Si AND P ON CORN DRY WEIGHT (ONE-MONTH OLD CORN)

reported by Roy (1970). Addition of P had relatively little effect on plant Si concentrations in the 833 and 1666 kg Si/ha treatments. Yield increased with increasing plant Si concentration when P application was held constant (Fig. 9). The largest yield increase occurred at 280 kg P/ha, when Si concentration increased from 0.1% to 0.55%. Total Si uptake increased with Si applications and with additions of P (Fig. 10). Part of the increase can be attributed to increased yield with P and Si, but in addition Si concentration increased with both P and Si (Appendix Table 17), which is partly due to increased Si availability to the plant as a result of P application.

Plant Phosphorus

Generally P concentrations increased with increased pH and P applications (Appendix Table 18), while applications of Si increased plant P concentrations only at the 1120 kg P/ha and 833 kg Si/ha treatments. The uptake of P increased with increasing silicate applications and relatively little difference in uptake was found between the two Si levels (Appendix Table 19). Dry matter increased with increasing plant P concentration and the increase was greater when Si was added than when it was not (Fig. 11). Thus the internal P requirement of corn was apparently reduced by Si applications which agrees with the findings of Ali (1966), Teranishi (1968) and Rosenau (1969).

Plant Calcium and Aluminum

Plant Ca concentrations increased with increasing pH and P applications (Appendix Table 20) and was generally in a range considered adequate for corn. Plant Al concentrations decreased with increasing Si,

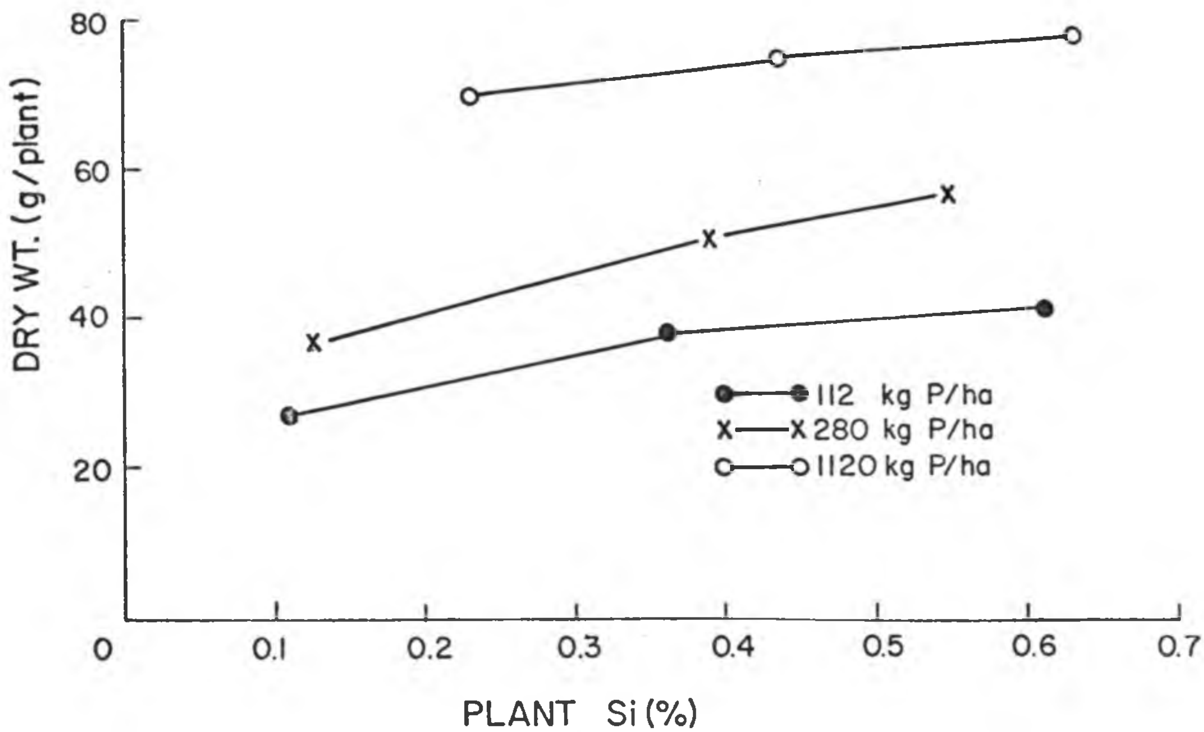

FIGURE 9. RELATIONSHIP BETWEEN WHOLE PLANT Si AND DRY WEIGHT (ONE-MONTH OLD CORN)

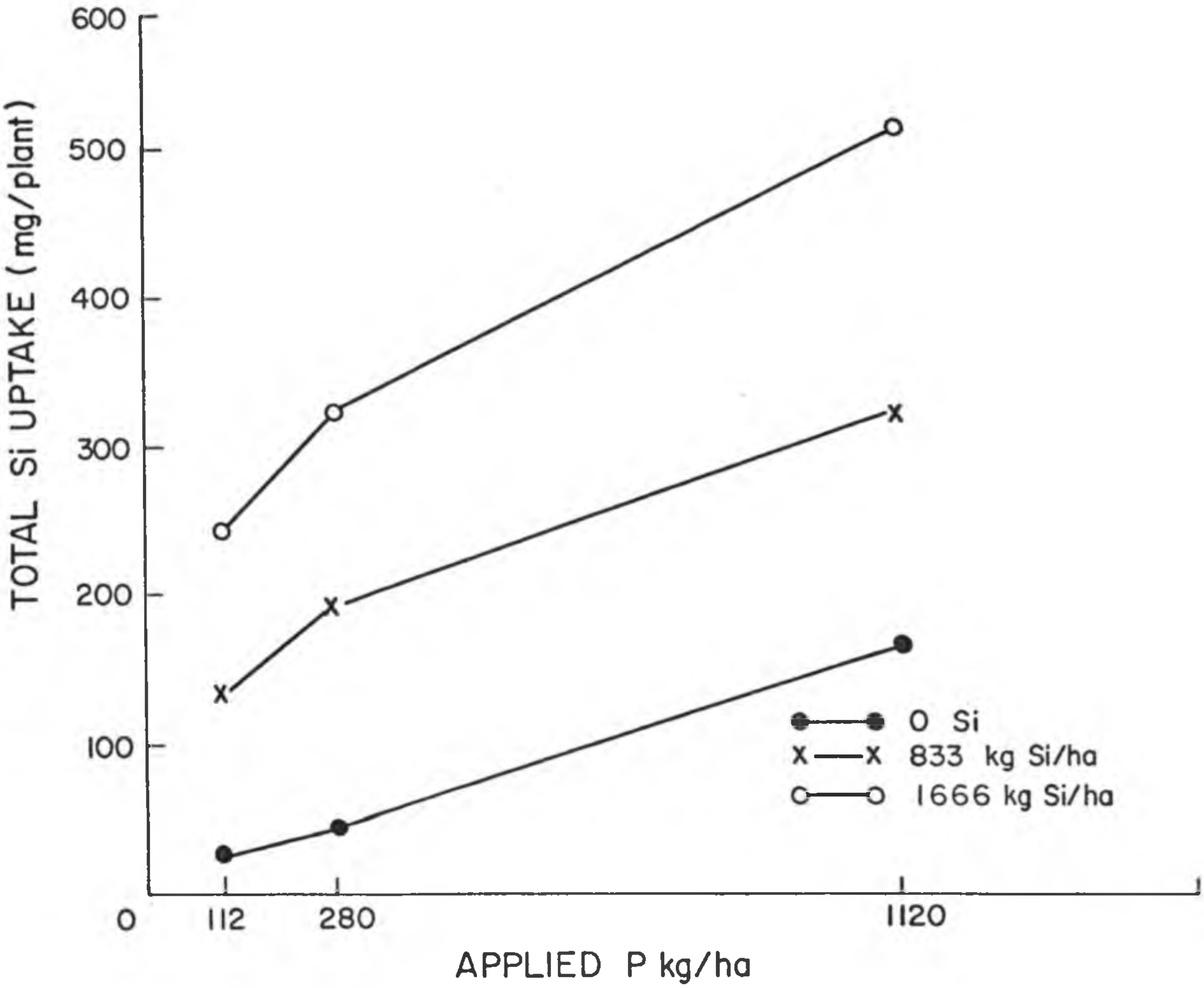

FIGURE 10. INFLUENCE OF RESIDUAL Si AND P ON Si UPTAKE
(ONE-MONTH OLD CORN)

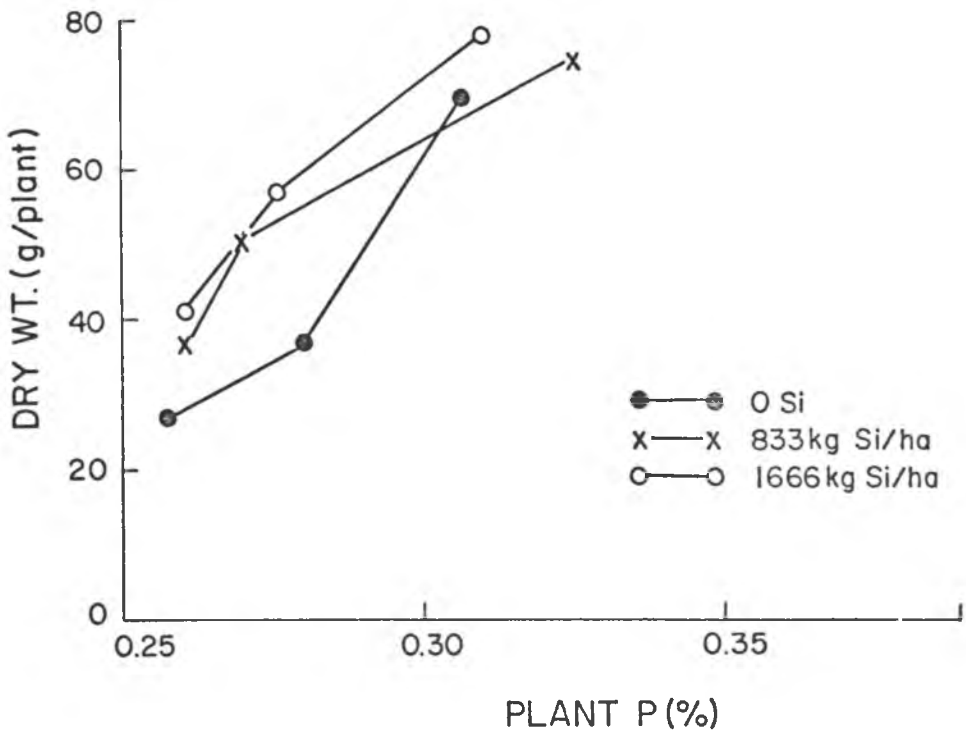

FIGURE 11. RELATIONSHIP BETWEEN WHOLE PLANT P AND DRY WEIGHT (ONE-MONTH OLD CORN)

P and pH. In addition to the decreased Al with increasing pH, there was a further reduction in plant Al with increasing Si applications which suggests a reduction in Al activity with Si (Fig. 12 and Appendix Table 21).

Leaf Nutrients at Silking

Corn leaves were sampled at the time of silking and analyzed for Si, P, Ca, K, N, Fe and Al.

Leaf Silicon

Total Si in leaves at silking was significantly affected by residual Si, P and pH. Leaf Si increased significantly with increasing Si applications and decreased significantly with increasing pH (Appendix Table 22). Increasing P applications in the zero Si treatment increased leaf Si and the largest increase at this Si treatment occurred with 1120 kg P/ha (0.18 to 0.29%) (Fig. 13). This is probably native soil Si made available by P. Phosphorus treatments had relatively little effect on leaf Si at the 833 and 1666 kg/ha Si applications. This pattern was also observed in one-month corn plants. A significant P x pH interaction was obtained and is illustrated in Fig. 14. No difference in leaf Si was found between levels of applied P at pH 6.5 because of the low availability of Si at this pH. At pH 6.0 the high P treatment increased leaf Si whereas this P effect was not observed at pH 5.5, because of higher Si availability at this pH. Increasing Si applications increased plant Si, but Si concentration was highest at pH 5.5 (Fig. 15).

Leaf Phosphorus

Leaf P concentrations were significantly increased by P treatments but were not affected by residual Si or pH (Appendix Table

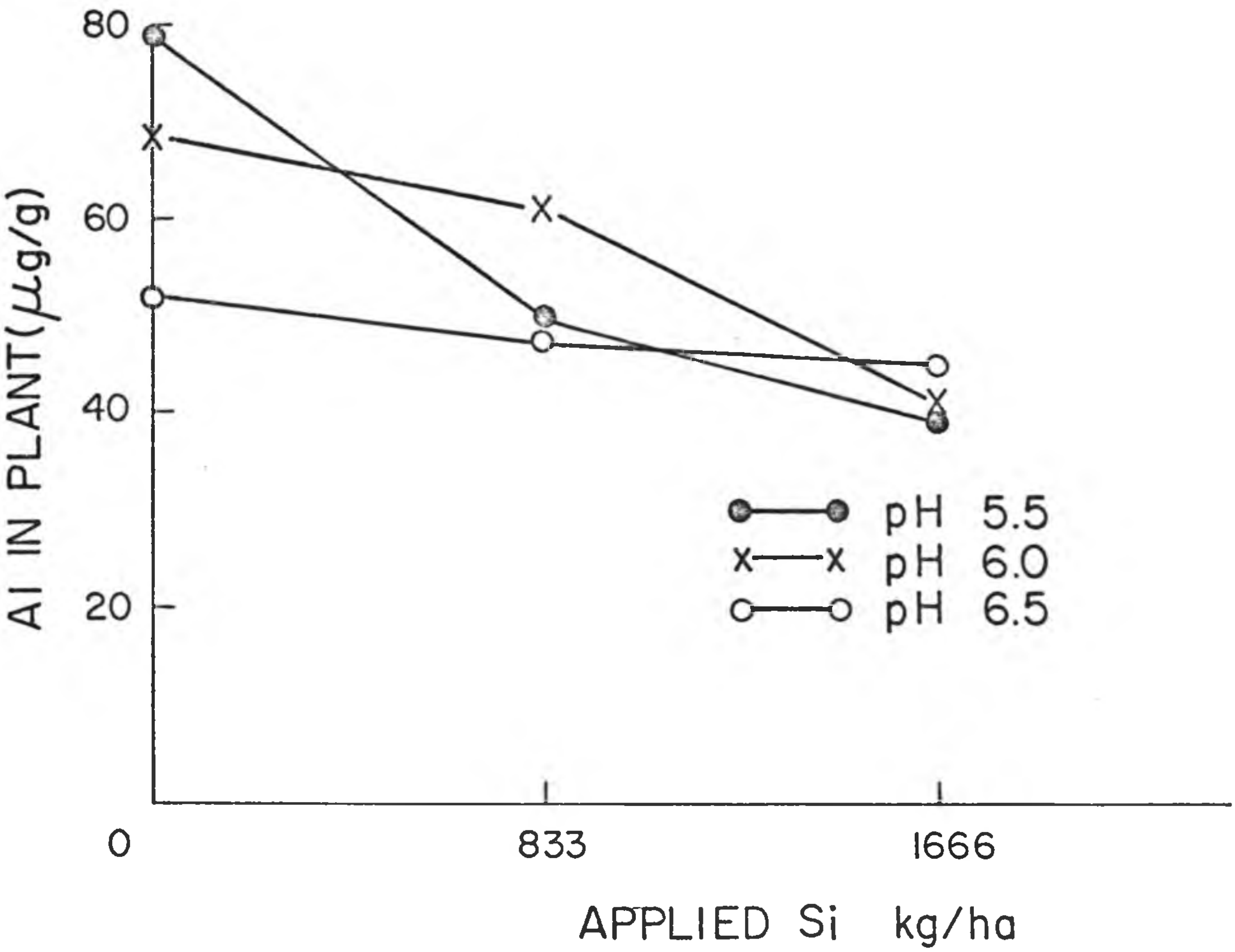

FIGURE 12. INFLUENCE OF RESIDUAL Si AND pH ON WHOLE PLANT Al (ONE-MONTH OLD CORN)

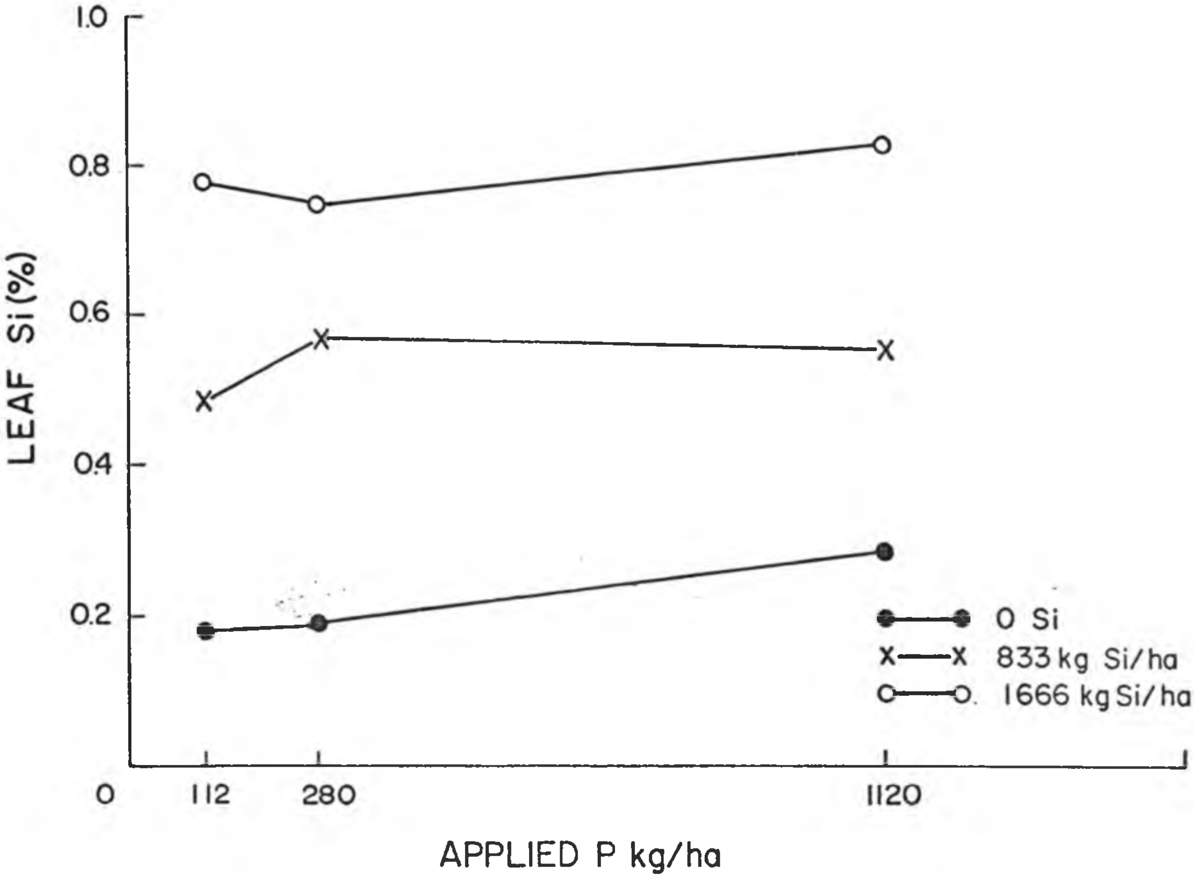

FIGURE 13. INFLUENCE OF RESIDUAL Si AND P ON LEAF Si AT SILKING

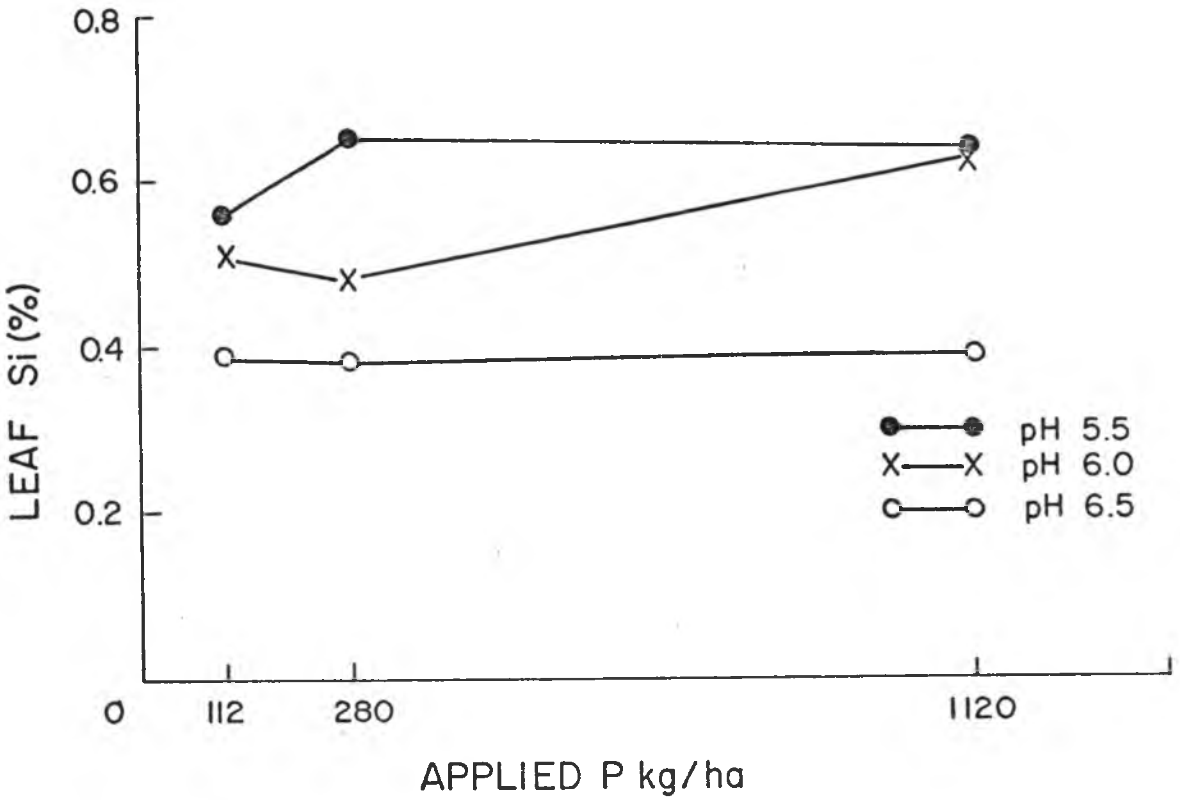

FIGURE 14. INFLUENCE OF RESIDUAL P AND pH ON LEAF Si AT SILKING

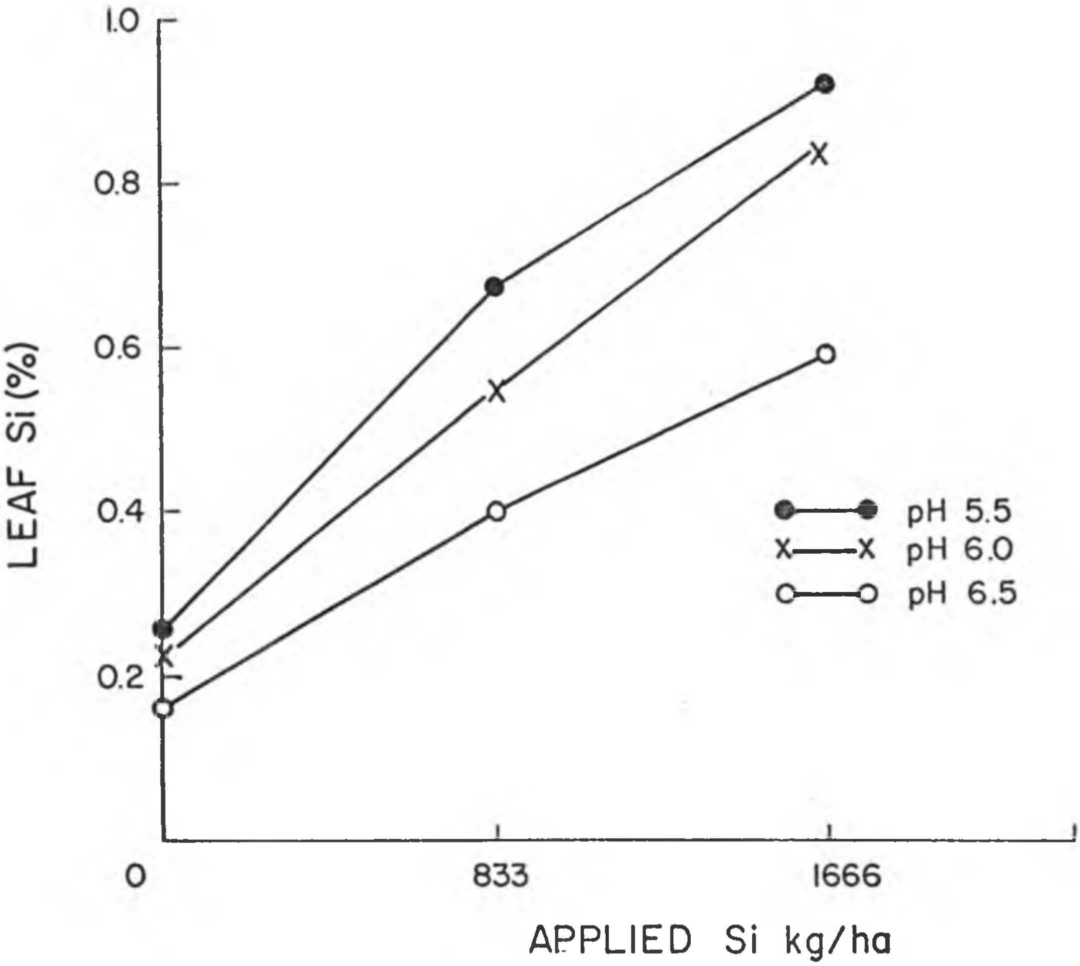

FIGURE 15. INFLUENCE OF RESIDUAL Si AND pH ON LEAF Si AT SILKING

23). Leaf P was increased by the 1120 kg P/ha treatment when pH increased from 5.5 to 6.0 or 6.5. All leaf P levels were above the sufficiency level for corn (0.25 to 0.40%) reported by Chapman (1967). This implies that P was not limiting growth of corn plants, but as will be seen in the next section, this may not be true.

Leaf Calcium

Leaf Ca increased significnatly with increasing P applications according to a Duncan's multiple range test (Appendix Table 24). Leaf Ca also increased with pH although it was not shown to be statistically significant. The range of leaf Ca (0.42 to 0.59%) was generally lower than the sufficiency levels reported for corn by Chapman (1967). A significant P x pH interaction was found for Ca as illustrated in Fig. 16. At pH 6.5 Ca increased with the 280 kg P/ha application and no further increase was obtained with the 1120 kg P/ha level. Phosphorus applications increased Ca content at both pH 5.5 and 6.0. Thus 0.55% Ca seems to be adequate for corn in this soil. At high pH additional P did not increase Ca concentration because of the high availability of Ca, but Ca response was obtained with additional P at low pH because of the relatively low supply of Ca.

Leaf Potassium

Leaf potassium concentrations were significantly affected by P applications (Appendix Table 25) and a Duncan's multiple range test indicated that the reduction in leaf K with the 1120 kg P/ha treatment was significant. This reduction in K concentration was also obtained by Rosenau (1969). This may be due to increased C.E.C. with increasing P applications (Mekaru, 1970), which may increase K retention by the soil

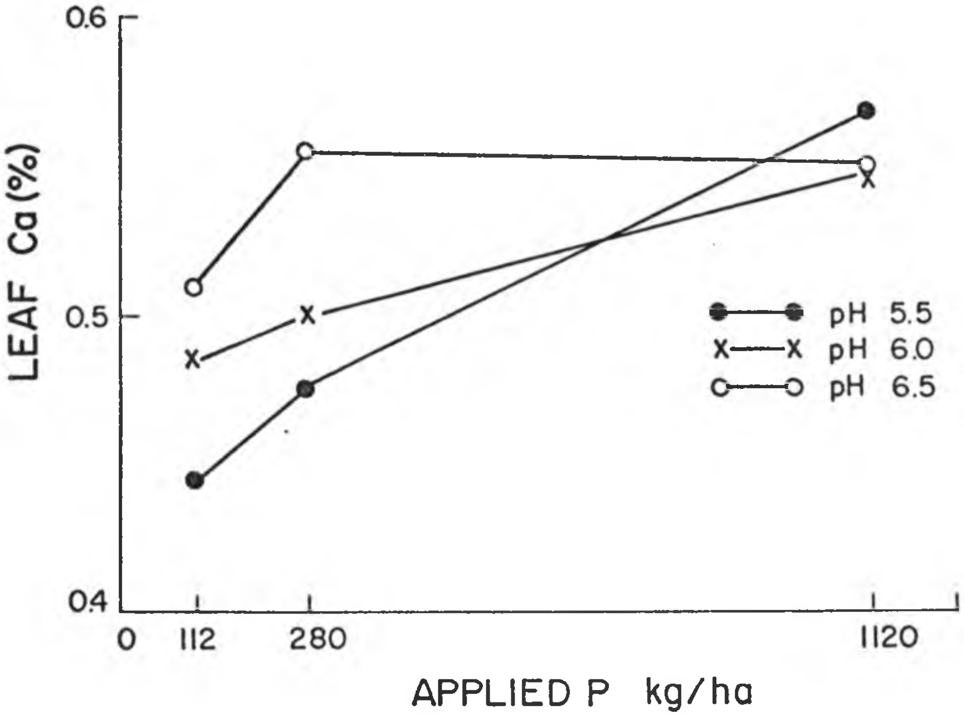

FIGURE 16. INFLUENCE OF RESIDUAL P AND pH ON LEAF CALCIUM AT SILKING

and decrease the availability of K to the plant. Furthermore, increasing Ca was applied in the superphosphate which allowed higher Ca saturation, and therefore adsorption of K by the clay. These generally low K levels were below the 1.7 to 2.25% K range reported to be adequate for corn by Chapman (1967).

Leaf Nitrogen

A significant decrease in total N was obtained with increasing silicate applications; this was probably because of a dilution effect caused by high yields with Si applications (Appendix Table 26). In general the leaves had about 2.70% N which is within the adequate range reported for corn by Chapman (1967).

Leaf Aluminum

There were no significant effects of Si, P or pH treatments on total leaf aluminum, however concentrations of aluminum decreased with increasing Si, P and pH. Concentrations in leaves ranged from 15 to 32 ppm and levels are below those reported as toxic in the literature (Appendix Table 27). Levels of Al in leaves were lower than those in one-month-old plants because of dilution effects caused by bigger plants at silking.

Leaf Iron

Silicon and P treatments significantly decreased total leaf Fe (Appendix Table 28). Silicate applications reduced leaf Fe content to a greater extent at low levels than high levels of P (Fig. 17). In addition leaf Fe decreased with increasing Si applications (Fig. 18). This indicates that Si reduced iron activity possibly by formation of insoluble iron silicates. Iron levels in the leaves are below those

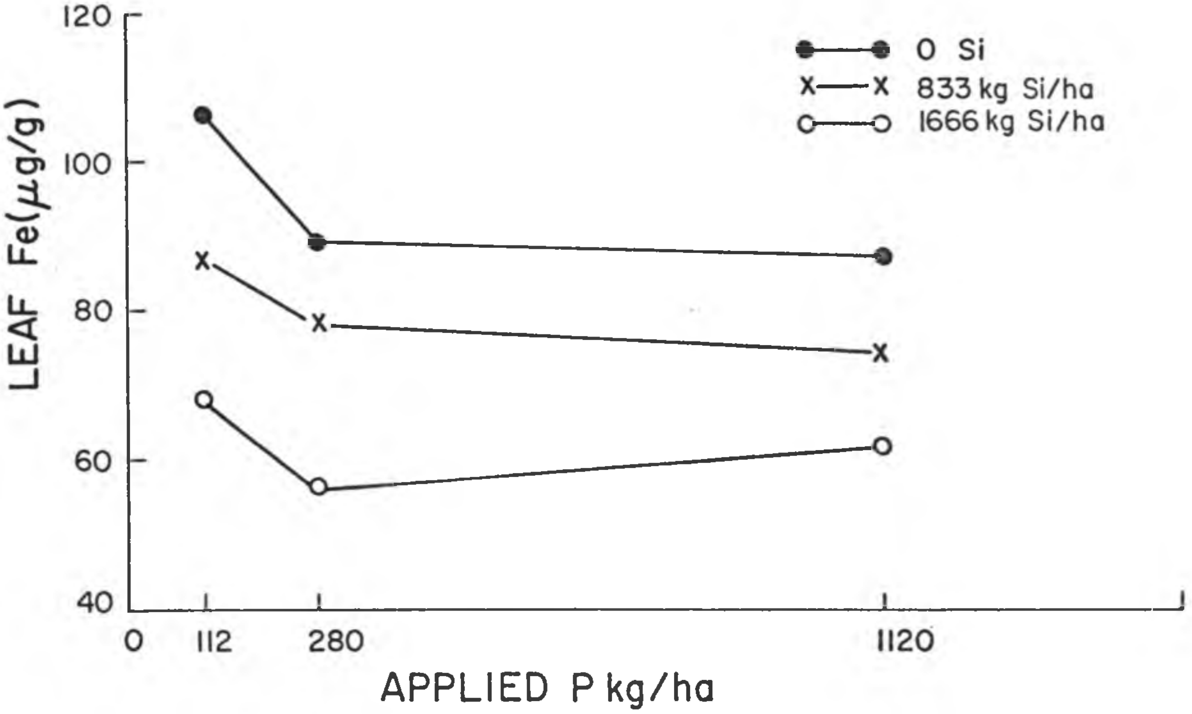

FIGURE 17. INFLUENCE OF RESIDUAL P AND Si ON LEAF Fe AT SILKING

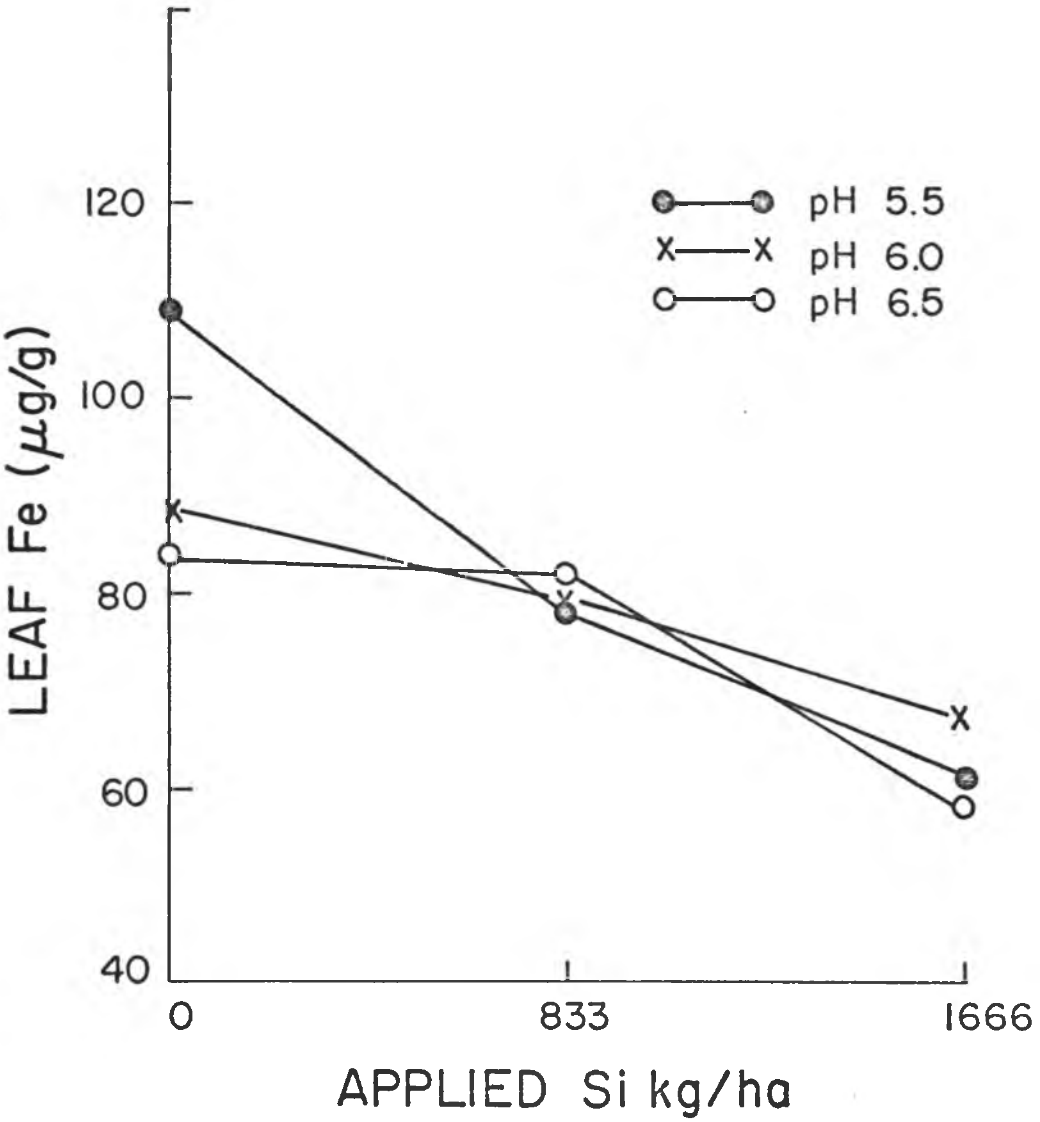

FIGURE 18. INFLUENCE OF RESIDUAL Si AND pH ON LEAF Fe AT SILKING

suggested as toxic to corn in literature.

Yields at Harvest

The yield of ear corn was significantly increased by P treatments and was not significantly affected by residual Si or pH (Table 26). The combination of low P (112 kg/ha) and high Si (1666 kg/ha) produced the lowest ear yield of any treatment combination (Fig. 19). Grain P concentration was also low in this treatment suggesting that a Si-induced P deficiency reduced grain formation. Another possible explanation for the low grain P and low yield may be that Si increased movement of P to metabolically active tissues. Thus those tissues below the ear were poorly supplied with P during ear formation and there was little P to be translocated to the developing ear. The 280 kg P/ha treatment produced slightly lower yields than the 112 kg P/ha treatment except at 1666 kg Si/ha where a marked yield increase was obtained. However, ear yield was generally higher when P was applied with Si than without. A yield increase of 1.16 T/ha was produced by 1666 kg Si/ha applied without P fertilizer in the supplementary plots (Appendix Table 29). Higher ear yields were produced at pH 6.0 than pH 5.5 or 6.5.

Residual Si and P significantly increased stover yields (Table 27) and mean yields for the plus and minus Si treatments were significantly different by Duncan's multiple range test (Appendix Table 30). Stover yields were significantly increased by the application of P. Application of 833 kg Si/ha increased stover yields at the 280 and 1120 kg P/ha levels over the 112 P level. At 112 kg P/ha, stover yield increased from 8.19 to 9.65 T/ha by the application of 1666 kg Si/ha (Fig. 19). This may be due to increased P availability brought about by high Si applications.

TABLE 26. ANALYSIS OF VARIANCE OF EAR CORN YIELDS

Source of Variation	d.f.	Mean Squares
Whole plots:		
Replications	2	7890825.23
pH	2	3688599.49
Error (a)	4	1969998.29
Sub plots:		
Si	2	695439.12
P	2	5952846.60**
Si x P	4	1129545.68
Si x pH	4	160488.12
P x pH	4	678219.16
Si x P x pH	8	1307431.40
Error (b)	48	974913.10

**Significant at 1% level.

TABLE 27. ANALYSIS OF VARIANCE OF STOVER YIELD

Source of Variation	d.f.	Mean Square
Whole plot:		
Replications	2	5279475.70
pH	2	2777468.04
Error (a)	4	2688912.24
Sub plots:		
Si	2	5448142.70*
P	2	6373293.37**
Si x P	4	968092.18
Si x pH	4	1834377.90
P x pH	4	1818230.19
Si x P x pH	8	1759847.69
Error (b)	48	1221564.79

*F test significant at 5% level.

**F test significant at 1% level.

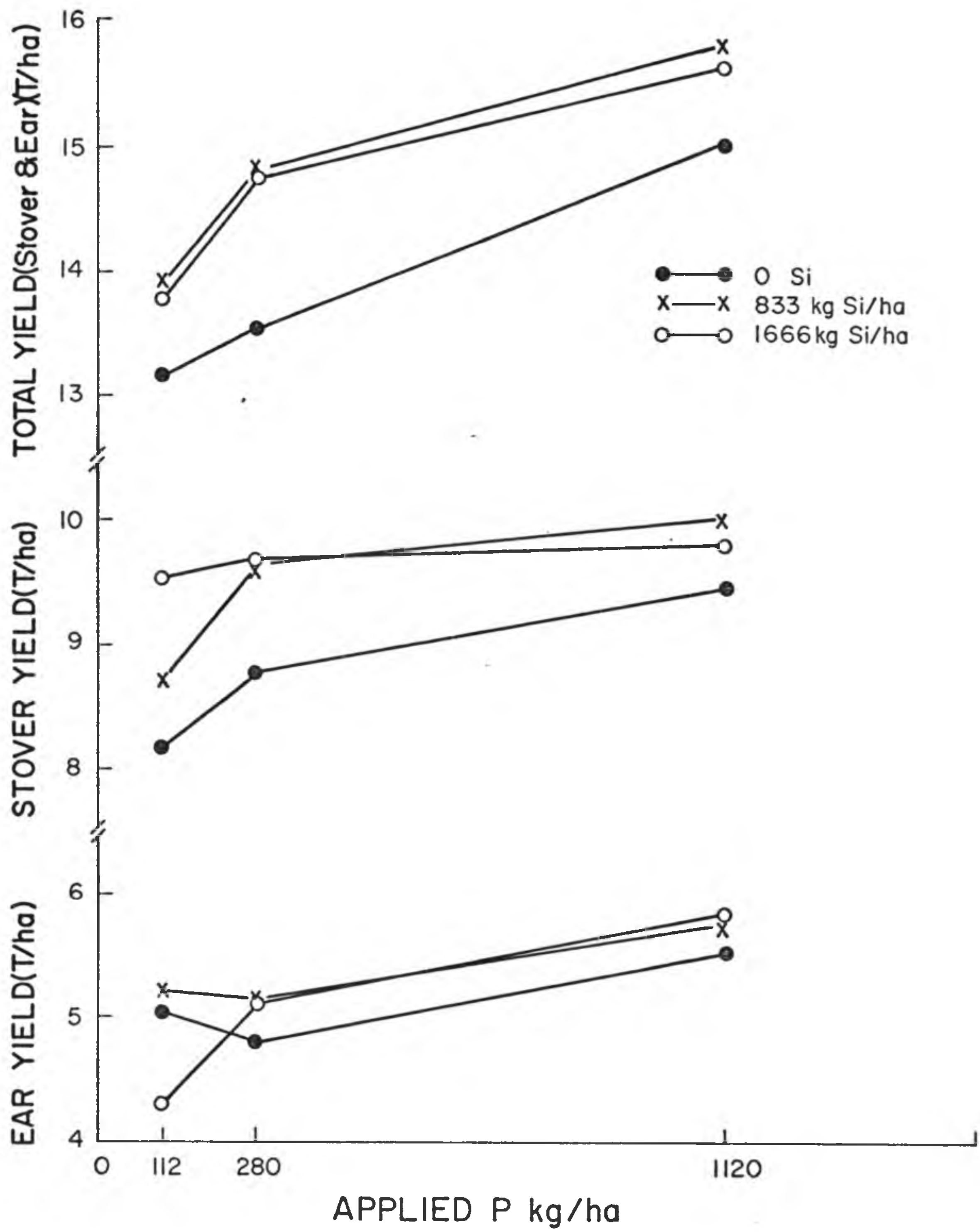

FIGURE 19. INFLUENCE OF RESIDUAL Si AND P ON EAR CORN AND STOVER YIELDS

Stover yields were generally high at pH 5.5 with its high Si availability suggesting that Si may have increased stover yields by increasing mechanical strength of the plants and increasing P availability. It should be noted that total P applied to the corn was 171, 429 and 1716 kg P/ha so yield responses to P are the combined effects of residual and newly applied P. Stover yields were also increased (1.4 to 1.9 T/ha) by Si applications in the absence of P fertilization in the supplementary plots (Appendix Table 30).

Maximum total yields (stover + ear) for each P application were produced at the 833 kg Si/ha treatment, and there was little difference in yields of the 833 and 1666 kg Si/ha levels (Appendix Table 31 and Fig. 19). The larger responses to Si application at 280 kg P/ha than at 1120 kg P/ha may indicate that responses to Si applications are partly due to increased P availability or efficiency which are less important at high P levels. Supplementary plots receiving no P fertilizer produced marked yield increases with increasing Si applications. It should be noted that 112 kg P/ha with applied Si produced higher yields than 280 kg P/ha without applied Si, but 280 kg P/ha with applied Si had yields nearly equal (98%) to those of the 1120 kg P/ha without applied Si. Thus if $CaSiO_3$ is cheaper than P fertilizer comparable yields at lower cost can be obtained with a combination of 280 kg P/ha + 833 kg Si/ha than with 1120 kg P/ha treatment. For example, if calcium silicate costs \$64/T and treble superphosphate costs \$112/T, then application of 280 kg P/ha with 833 kg Si/ha will cost \$168/ha or \$67/A less than application of 1120 kg P/ha alone.

Relationships Between Yield and Nutrient Levels at Silking

Ear yields increased with increasing leaf Si concentrations up to 0.49 to 0.6% and decreased somewhat at levels above this in the 112 and 280 kg P/ha treatments (Fig. 20). The yield decrease at 0.78% leaf Si was possibly due to a reduction in P available for grain formation. Maximum ear yield was produced with the 1666 kg Si/ha and 1120 kg P/ha treatment which had 0.83% leaf Si indicating that high ear yield can be obtained with high leaf Si provided sufficient P is available. Stover yields increased with increasing Si concentrations to about 0.8% at the 112 kg P/ha treatment. At 280 and 1120 kg P/ha stover yields increased up to 0.58% Si and remained constant or decreased as leaf Si increased above this. This pattern differs from that for ear corn yield possibly because Si is important in stover production while P is required for grain formation. Total yields (stover + ear) increased with increasing leaf Si to 0.49 to 0.58% and remained constant or decreased beyond this. It appears from these data that leaf Si values of 0.5 to 0.6% may be considered adequate for corn.

Ear yields increased with increasing leaf P and at low P concentrations, application of 833 kg Si/ha increased ear yields slightly (Fig. 21), but did not increase yield at higher P concentrations. At low levels of leaf P, high Si (1666 kg/ha) reduced ear yields markedly. Stover yields increased with increasing leaf P, but additional yield increases were obtained with Si applications even at high leaf P. This indicates that Si is required for stover yield. Total yields (stover + ear) increased with increasing leaf P, but higher yields were obtained for the same P concentration with Si application than without. Both

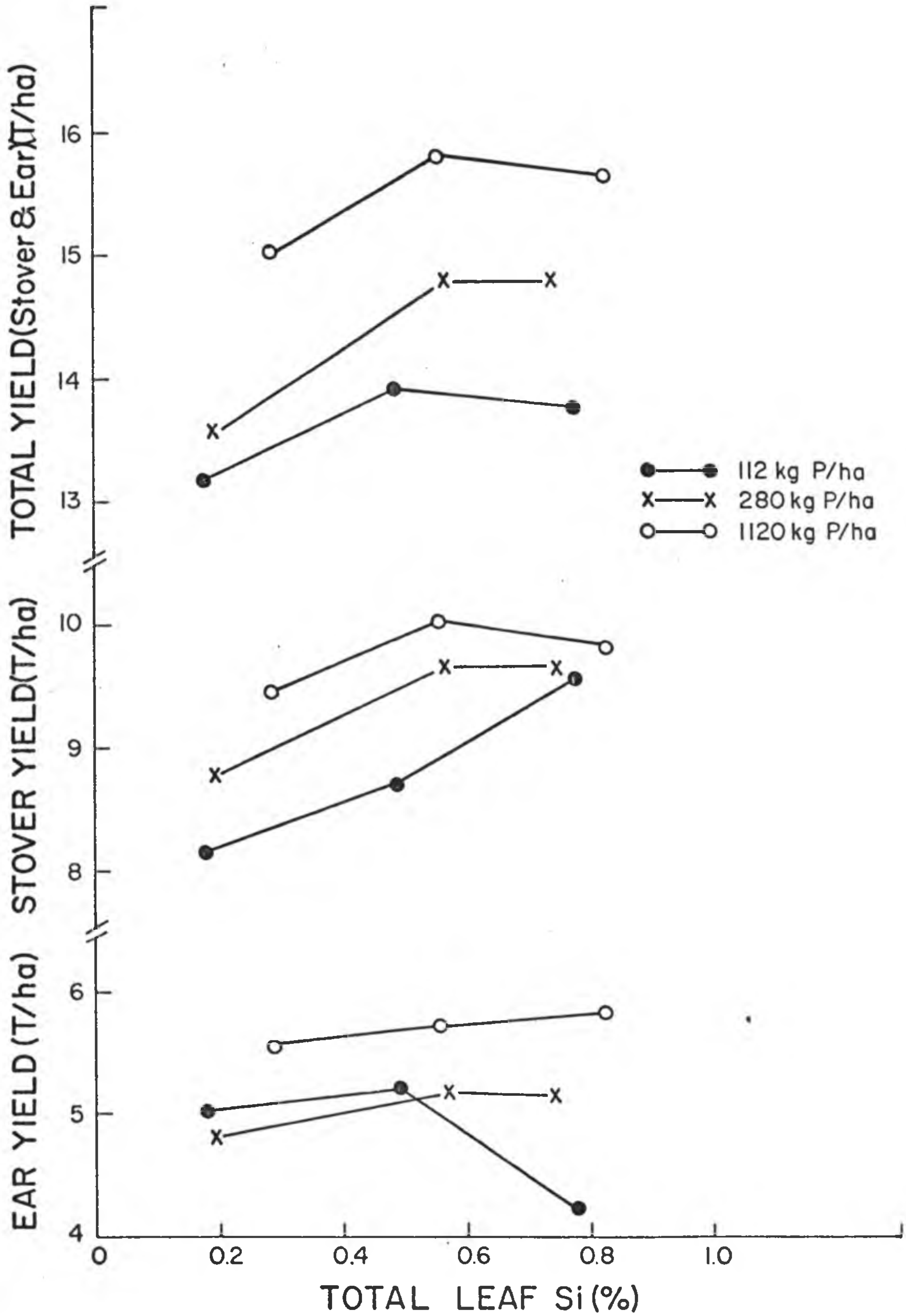

FIGURE 20. RELATIONSHIPS BETWEEN Si AT SILKING AND STOVER AND EAR YIELDS AT HARVEST

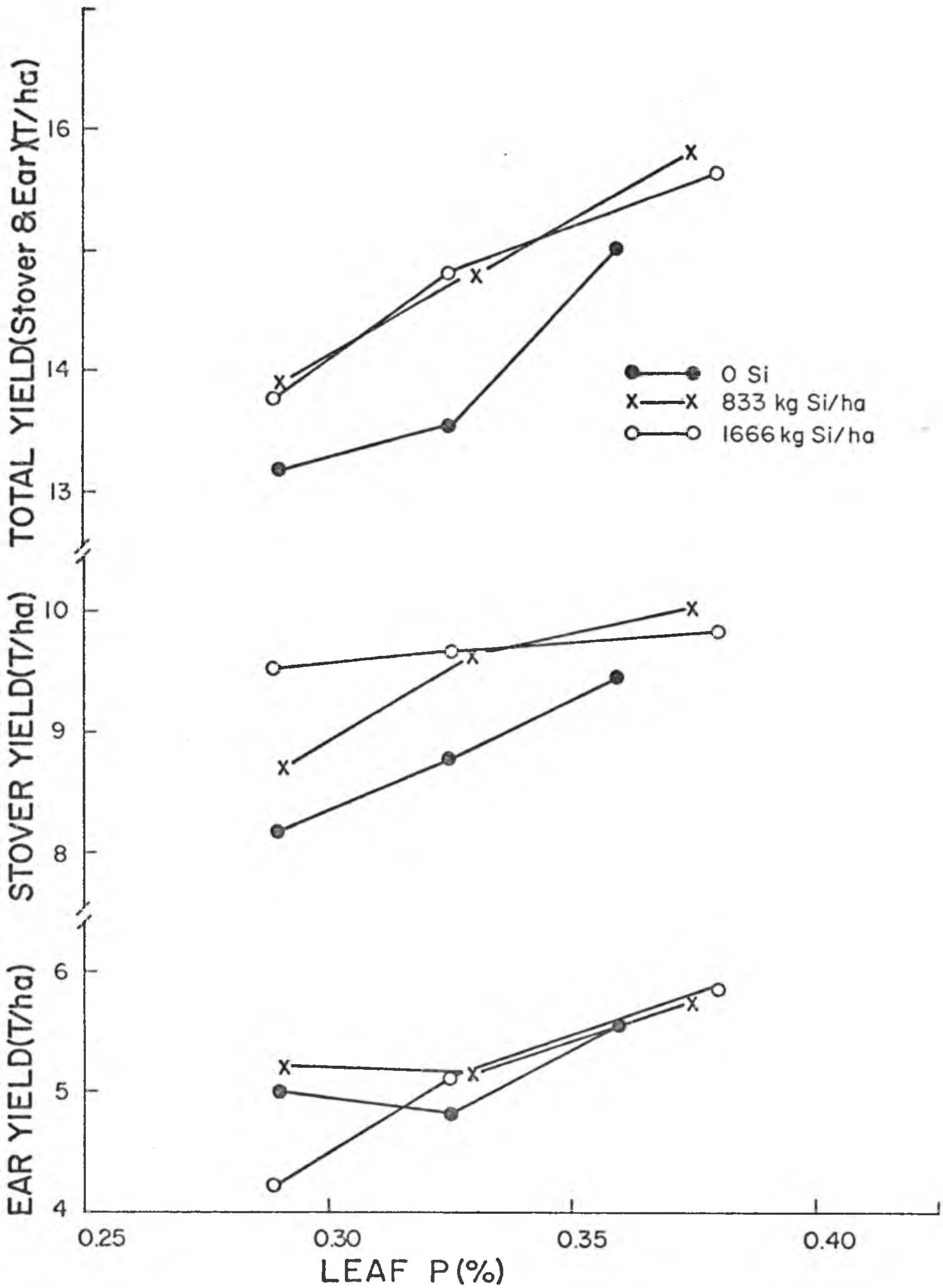

FIGURE 21. RELATIONSHIPS BETWEEN LEAF P AT SILKING AND STOVER AND EAR YIELDS AT HARVEST

stover and total yields (stover + ear) were higher at the same P concentration with than without Si application. This suggests that Si increased the efficiency of P utilization in the plant as was found by Ali (1966), Teranishi (1968) and Rosenau (1969). Leaf Ca, N, Al and Fe were all above the critical levels for corn reported in the literature. However K was below the sufficiency levels reported by Chapman (1967). Even though leaf K was significantly reduced at high P levels, yields were not reduced by low leaf K at the high P level.

Soil Analyses

Soil samples were collected from the 0 - 15 cm depth and analyzed for pH, water extractable Si, modified truog extractable Si and P.

Soil Silicon

Residual Si and pH effects on water extractable Si were highly significant and Si x P and P x pH interactions were significant. Residual Si, P and pH had highly significant effects on modified-Truog extractable Si and the Si x pH interaction was also highly significant (Table 28). Increasing pH caused a significant decrease in water extractable Si, but a significant increase in modified-Truog extractable Si (Duncan's multiple range test), (Appendix Table 32 and 33). This may be due to the fact that water extraction reflects pH effects on Si solubility while extraction with the 0.02 N acid, pH 2.2, of the modified-Truog method masks the soil pH differential, but reflects the supply of Si in the soil. Thus water extractable Si may be considered an "intensity" measurement while modified-Truog extractable Si may be considered a capacity measurement. Water extractable and modified-Truog extractable Si increased with Si applications and levels in the

TABLE 28. ANALYSIS OF VARIANCE OF WATER-EXTRACTABLE AND MODIFIED TRUOG EXTRACTABLE SOIL Si

Source of Variation	d.f.	Mean Squares	
		H_2O Extractable Si	Modified Truog Extractable Si
Whole Plots:			
Replications	2	0.071709	15.774938
pH	2	0.0398823**	15155.4038**
Error (a)	4	0.027251	543.6186
Sub Plots:			
Si	2	9.359501**	37601.9890**
P	2	0.050490	2116.6186**
Si x P	4	0.091716*	522.4619
Si x pH	4	0.040699	2103.3288**
P x pH	4	0.120905*	232.5985
Si x P x pH	8	0.029856	170.7926
Error (b)	48	0.033280	243.5175

*F test significant at 5% level.
**F test significant at 1% level.

zero Si treatment were lower than those set by Fox, et al. (1967) as deficient (0.9 and 50 ppm respectively). Water-extractable Si at both the 833 and 1666 Si levels and modified-Truog extractable Si in the 833 Si treatment were in the deficiency questionable range while the modified-Truog extractable Si in the 1666 kg Si/ha treatment was in the deficiency unlikely range.

A highly significant correlation (γ = 0.949) was found between leaf Si at silking and water-extractable soil Si (Fig. 22) which agrees with the findings of Fox, et al. (1967), Teranishi (1968) and Rosenau (1969). The simple correlation coefficients (γ) for the relationships between modified-Truog extractable Si and each of the variables, applied Si, stover Si, leaf Si, cob Si and grain Si (Table 29) were lower than for water extractable Si with these variables. This indicates that Si taken up by the plant is more closely related to soil Si extracted with water than with sulphuric acid.

Soil Phosphorus

Residual Si and pH did not have significant effects on available soil P measured by the modified-Truog procedure, but increasing P applications significantly increased available P (Appendix Table 34). Residual Si applications increased available P only at pH 6.5. Teranishi (1968) reported a large effect of applied Si on soil P, but in the ratoon cane crop (Rosenau, 1969) and the present corn crop, Si had very little effect on soil P. This agrees with the work of Raupach and Piper (1959) who found that the effect of silicate on phosphate solubility was temporary and lasted no longer than a year. Increasing pH at the high P rate increased extractable soil P, as was found by

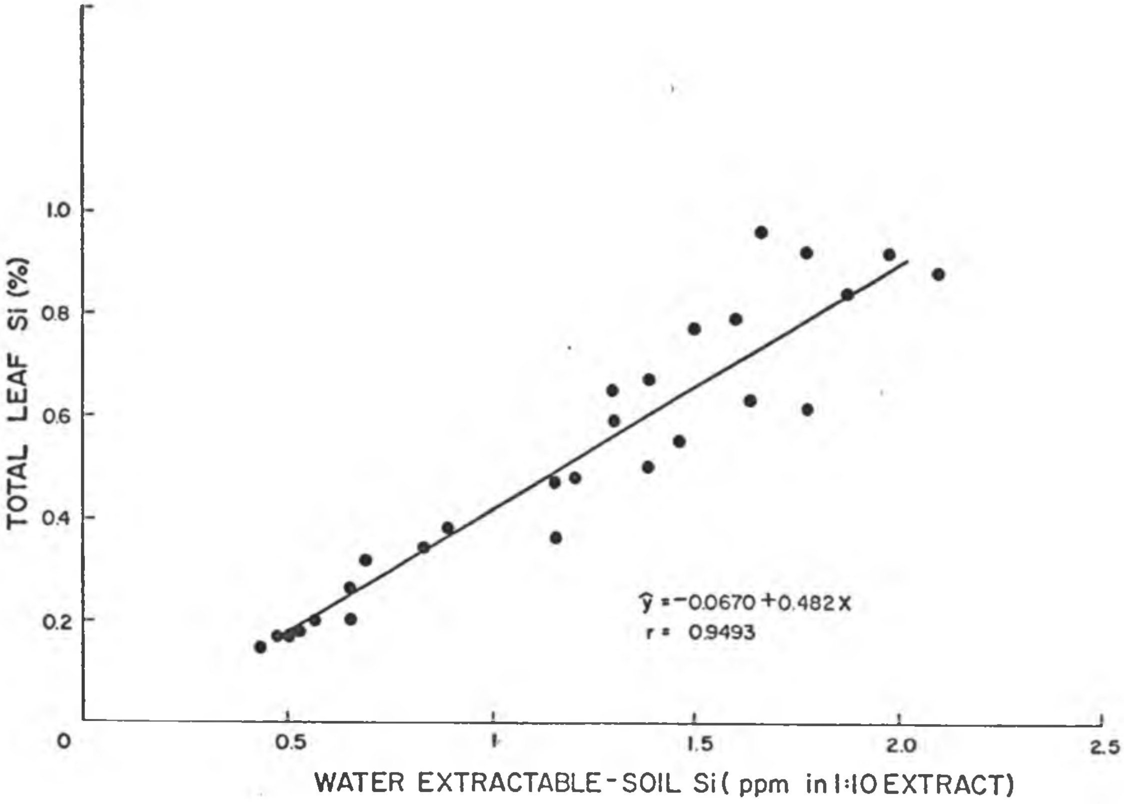

FIGURE 22. RELATIONSHIP BETWEEN WATER-EXTRACTABLE SOIL Si AND LEAF Si AT SILKING IN CORN

TABLE 29. COMPARISON OF SIMPLE CORRELATION COEFFICIENTS FOR WATER EXTRACTABLE SOIL Si AND MODIFIED TRUOG EXTRACTABLE SOIL Si WITH OTHER VARIABLES

	Treat Si	Stover Si	Leaf Si	Cob Si	Grain Si
Water Extractable Soil Si	0.905	0.869	0.892	0.790	0.326
Modified Truog Extractable Si	0.741	0.382	0.421	0.406	0.045

γ = 0.283 Significant at 1% level.

γ = 0.217 Significant at 5% level.

Rosenau (1969). Although this trend is non-significant, it is reasonable in the light of pH effects on Fe and Al solubilities and thus on P fixation.

Soil pH

Increasing application of residual Si and P had very little effect on soil pH showing that pH control was maintained efficiently. Differences in actual pH values were highly significant and average values were 5.5, 6.0 and 6.5 (Appendix Table 35).

Plant Analyses at Harvest

At harvest, plants were separated into stover and ears. Ears were further separated into cobs and grain and total Si and P were determined. In addition, Si, P, Ca and Al were determined in the stover.

Total Silicon

Grain silicon concentrations ranged from 10 to 33 (μg/g) and were not affected by P application (Appendix Table 36) while cob Si which ranged from 100 to 525 (μg/g) (Fig. 23) increased significantly with increasing Si applications. When pH increased from 5.5 to 6.5 cob Si concentrations decreased due to reduced soil Si availability at high pH (Appendix Table 37). Cob Si increased with the 280 kg P/ha application and decreased slightly with the 1120 kg P/ha application at all Si levels suggesting an antagonistic effect of P on Si, at high P levels (Fig. 23). Stover Si which ranged from 0.1 - 0.53% increased significantly with increasing Si applications and decreased with increasing pH (Appendix Table 38). Stover Si increased significantly only with the highest P treatment.

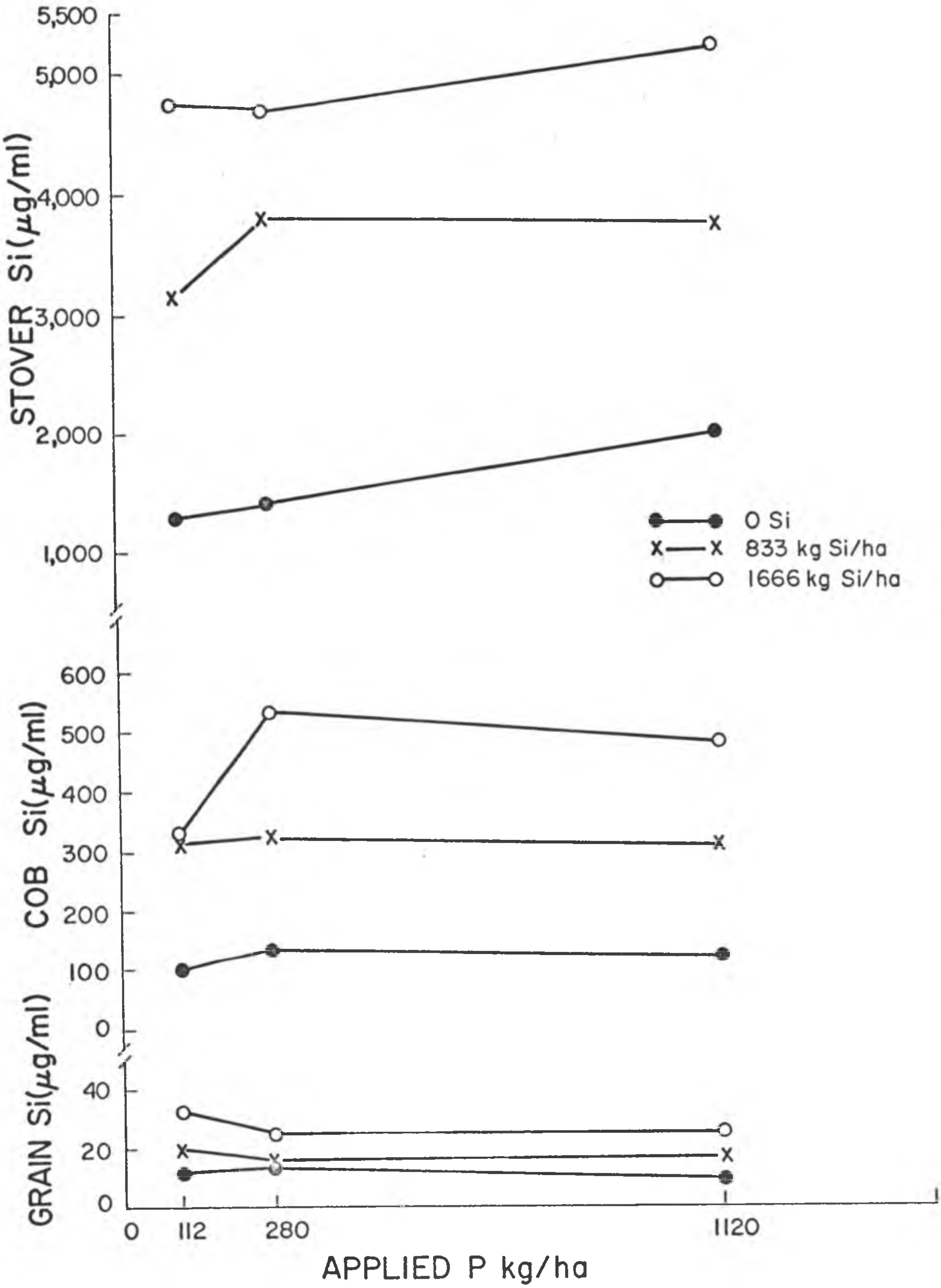

FIGURE 23. INFLUENCE OF RESIDUAL Si AND P ON GRAIN, COB AND STOVER Si AT HARVEST

Total Phosphorus

Effects of phosphorus treatments on grain P were highly significant and the Si x P interaction was significant (Table 30). Grain P increased with increasing Si application and pH although the increase was not statistically significant (Appendix Table 39). At the lowest P treatment, concentration of grain P increased with 833 kg Si/ha but decreased with the 1666 kg Si/ha treatment (Fig. 24). As mentioned previously, high Si concentration may have reduced translocation of P to the grain or promoted translocation of P to the growing corn tops earlier so that relatively little P remained in lower leaves which supply P to the ear. As was shown in Fig. 24 grain yield was also reduced by high Si in the low P treatment, but at high levels of P, yields were higher with Si than without.

Cob P generally increased with increasing pH, P and Si treatments. Cob P concentration in the highest P treatment was significantly higher than those in the two lower P levels which were not different from each other (Appendix Table 40). Cob P increased with increasing P applications except at the high Si and P level where it was lower than in the zero or 833 kg Si/ha treatments (Fig. 24). This may reflect the increased demand for P in grain development in the high Si treatment. Stover P was significantly affected by pH (5% level) and P applications (1% level), and generally increased with both pH and P application (Table 30 and Appendix Table 41).

Total Calcium

Concentrations of Ca in stover were significantly increased by P applications and pH (Table 31 and Appendix Table 42). The Ca

TABLE 30. ANALYSIS OF VARIANCE OF STOVER P, COB P AND GRAIN P AT HARVEST

Source of Variation	d.f.	Mean Squares		
		Stover P	Cob P	Grain P
Whole Plots:				
Replications	2	312717	124043	4649075
pH	2	280814*	4878	698837
Error (a)	4	32471	3248	408873
Sub Plots:				
Si	2	38573	42340	393240
P	2	1738533**	96009*	12752517**
Si x P	4	38371	31123	4968226**
Si x pH	4	25437	25939	358798
P x pH	4	68635	8704	183043
Si x P x pH	8	18534	12969	1250135
Error (b)	48	47127	23378	814095

*Significant at 5% level.

**Significant at 1% level.

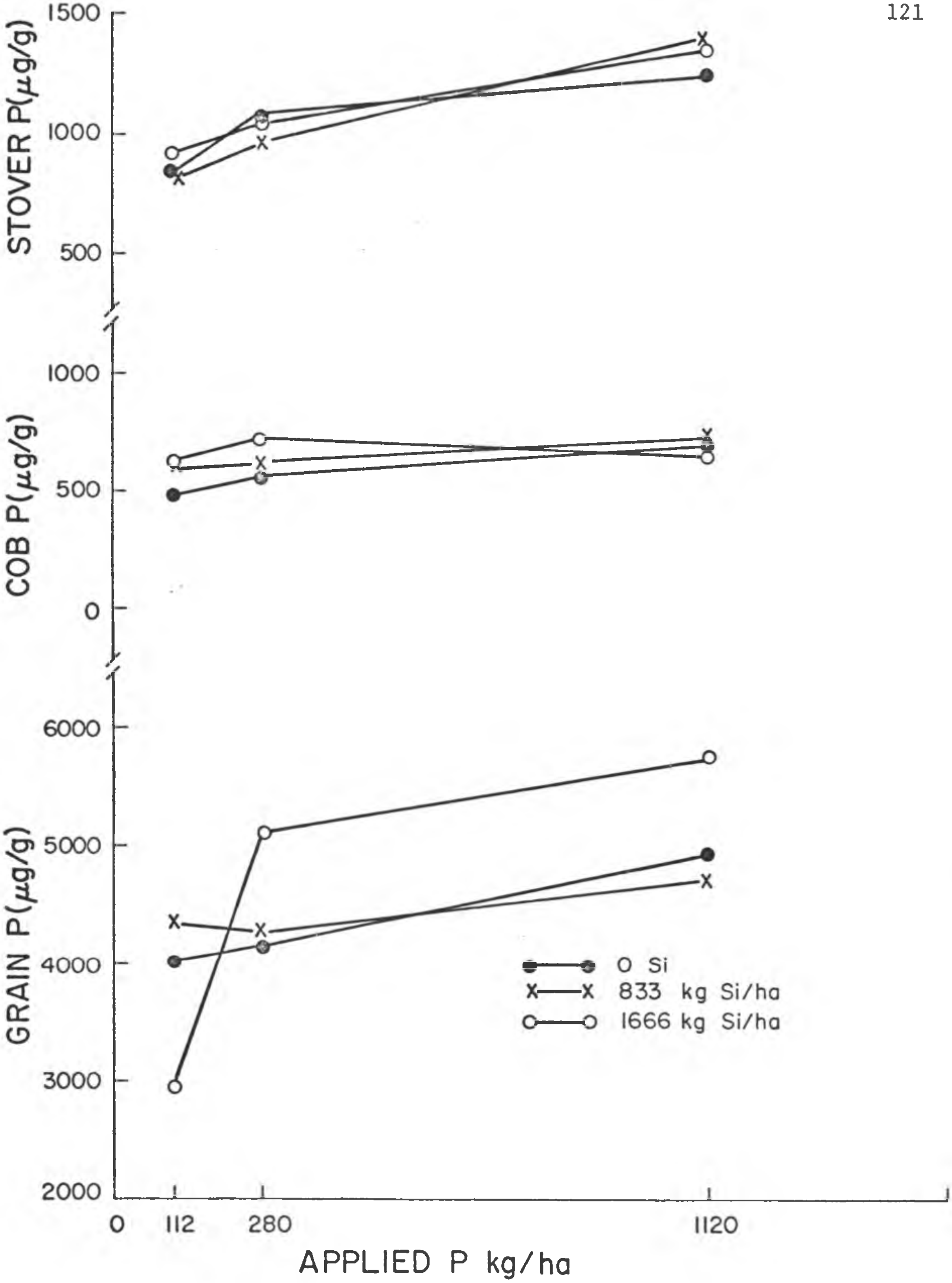

FIGURE 24. INFLUENCE OF RESIDUAL Si AND P ON GRAIN, COB AND STOVER P AT HARVEST

TABLE 31. ANALYSIS OF VARIANCE OF STOVER Ca AT HARVEST

Source of Variation	d.f.	Mean Squares
Whole plots:		
Replications	2	280000
pH	2	5101648**
Error (a)	4	118166
Sub plots:		
Silicon	2	1444
Phosphorus	2	1156425**
Si x P	4	238416
Si x pH	4	128225
P x pH	4	241115
Si x P x pH	8	120626
Error (b)	48	213926

**Significant at 1% level.

increase with P may be due to the Ca differential in the P treatments. Calcium concentrations in stover decreased with increasing Si treatments at the low P level, but increased at the high P level.

Total Aluminum

No significant effects of Si, P or pH treatments were found on stover Al, however stover Al concentration decreased with increasing Si applications (Appendix Table 43). Plant Al concentrations at harvest were higher than those in one-month samples or in leaf samples, possibly because the tissues sampled were different or stalks were contaminated with soil by heavy rains or during harvest.

Multiple Regression Analyses

Multiple regression techniques were used to study the relationships between yield parameters and soil and plant variables. Teranishi (1968) developed an equation which included Si, P and pH treatments, their interactions, their squares and 19 soil and plant analyses (25 variables) and accounted for only 59% of the yield variation. Rosenau (1969) worked with 55 variables and explained 77% of the yield variation. In the present investigation 31 variables were studied including Si, P and pH treatments, their interactions, their squares and 18 soil and plant variables which accounted for 58% of the variation in ear corn yield. When factors which contributed less than 1% to R^2 were eliminated, equation (1) containing six variables which accounted for 55% of the variation in ear corn yield was obtained ($R = 0.74$). Soil P, stover P and leaf Ca were the most important variables and accounted for 14, 21 and 13% of the yield variation, respectively (Appendix Table 44).

$$\hat{Y} = -1354 + 7.25\ (\text{soil P}) - 2.92\ (\text{stover P}) + 0.74\ (\text{leaf Ca}) + 375.66\ (\text{soil pH}) + 0.64\ (\text{leaf P}) + 518.25\ (\text{leaf K}) \quad (1)$$

Thus these three variables together accounted for 48% of the variation in ear yield. Ear corn yield was positively correlated with soil P and plant Ca and negatively correlated with stover P (Appendix Table 44). The negative correlation was probably the result of translocation of much of the stover P to the grain. Another equation which predicted stover yield on the basis of soil and plant analyses and applied nutrients was calculated and the 10 factor equation (2) below which included only factors contributing 1% or more to R^2 explained 38% of the total yield variation (R = 0.61).

$$\hat{Y} = -2771.57 + 2919.08\ (\text{H}_2\text{OSol Si}) + 16.15\ (\text{treatment P}) + 1.68\ (\text{stover Al}) - 2.78\ (\text{P x pH}) + 163.65\ (\text{pH}^2) - 15.71\ (\text{mod-Truog Si}) - 0.339\ (\text{stover Si}) + 0.229\ (\text{grain P}) + 0.921\ (\text{leaf P}) + 8.39\ (\text{leaf Fe}) \quad (2)$$

Water-soluble Si and applied P were the most important variables and accounted for 10 and 6% of the yield variation, respectively (Appendix Table 44). It should be noted that several Si and P parameters entered this equation as well as stover Al, soil pH and leaf Fe which is in contrast to the equation for ear yield which did not include Si, Fe or Al parameters. This supports the earlier statement that Si was required for stover production but not for corn ear production.

An equation which predicts total yield (stover and ears) from soil and plant analyses and applied nutrients was also calculated. Factors contributing 1% or more to R^2 make up the seven factor equation (3) below which explained 42% of the total yield variation (R = 0.65).

$$\hat{Y} = 5974 + 6.48 \text{ (soil P)} - 2.67 \text{ (stover P)} + 0.50 \text{ (leaf Ca)} + 1067 \text{ (}H_2O\text{Sol Si)} + 1.35 \text{ (leaf P)} + 10.37 \text{ (leaf Fe)} + 1.92 \text{ (stover Al)} \quad (3)$$

Here again soil P accounted for about 18% of the yield variation followed by stover P and leaf Ca which accounted for about 7 and 8% of the variation, respectively. Water soluble soil Si which accounted for about 4% of the variation in total yield in this equation had not been included in equation (1) for grain yield. This equation includes the most important parameters from the two previous equations and in addition leaf Fe and stover Al. It summarizes very concisely the relative importance of variables in total yield. The P, Si and Ca parameters are readily understandable and have been discussed earlier. The importance of leaf Fe and stover Al are interesting in that they are both positive, however, the correlation coefficients are very small and non-significant.

A multiple regression analysis was also performed with ear corn yield and leaf nutrients at silking and equation (4) was developed.

$$\hat{Y} = -2956 + 0.64 \text{ (leaf Ca)} + 775.32 \text{ (leaf K)} + 0.795 \text{ (leaf P)} + 23.62 \text{ (leaf Al)} - 6.49 \text{ (leaf Fe)} \quad (4)$$

This five-factor equation explained only 25% of the variation in ear corn yield (R = 0.50). Leaf Ca was the single factor which accounted for 12% of the ear corn yield variation (Appendix Table 45). It should be noted that leaf Al and leaf Fe are also included in this equation.

Leaf nutrients affecting stover yield are included in equation (5) below which explained 17% of the stover yield variation (R = 0.41).

$$\hat{Y} = 4940.30 + 0.1767 \text{ (leaf Si)} + 0.8215 \text{ (leaf P)} + 9.70 \text{ (leaf Fe)} \qquad (5)$$

Leaf Si accounted for 9% of the stover yield variation. Apparently for stover production Si, P and Fe are especially important and Ca, K, and Al less so, while for ear corn production Si is of little importance.

Leaf nutrients affecting total yield (stover + ears) are included in equation (6) below which explained 30% of the total yield variation (R = 0.55).

$$\hat{Y} = 2415 + 0.64 \text{ (leaf Ca)} + 1.54 \text{ (leaf P)} + 0.19 \text{ (leaf Si)} + 18.5 \text{ (leaf Fe)} + 823.44 \text{ (leaf K)} \qquad (6)$$

Leaf Ca accounted for about 12% of the variation while P and Si accounted for 6 and 3% of the yield variation, respectively. The importance of leaf Fe in yield is of interest since this is the first time this element has been determined in this experiment. Although the correlation coefficients are small and non-significant this factor is repeatedly included in the yield equations. This suggests that it must have some physiological importance in this location. The predictive ability is reduced sharply by exclusion of soil and applied parameters from equations 4, 5 and 6.

Conclusions

Ear corn yields were significantly increased by P treatments and were not significantly affected by residual Si or pH. However ear corn yields were generally higher when P was applied with Si than without. Stover yields were generally high at pH 5.5 suggesting that increased Si availability at this pH may have increased stover yields by increasing mechanical strength of plants and increasing P availability. Application of 280 kg P/ha with applied Si produced yields nearly equal (98%) to those of the 1120 kg P/ha without applied Si suggesting that comparable yields can be obtained at lower cost with combinations of low P and high Si than with high P alone. Leaf Si values of 0.5 to 0.6% at silking seem adequate for corn growth. Total corn yields (stover + ears) increased with increasing leaf P, but higher yields were obtained at the same P level with Si applications than without. This suggests that Si increased the efficiency of P utilization in the plants. A similar trend was also noted in the one-month sample. Soil Si analysis by two extraction procedures revealed that Si taken up by the plant is more closely related to soil Si extracted with water than with sulphuric acid. A multiple regression equation which included 31 variables accounted for 58% of the ear corn yield variation. Multiple regression analysis with yield and leaf nutrients revealed that Si, P and Fe are especially important for stover production while Ca, P, K, Al and Fe are important for ear production.

III. MECHANISM OF Si UPTAKE

Several views have been expressed regarding mechanisms of Si uptake by rice and sugarcane. The present study was initiated to develop information on the mechanism of Si uptake in several species. The pot experiments previously discussed here revealed that plants differed considerably in Si content and also in their Si response to Si applications. The five plant species used in the present experiment (tomato, alfalfa, *D. intortum*, corn and sugarcane) were chosen to capitalize on this natural variability. The plants were grown in "Si-free" nutrient solution containing 2 ppm P in a green house. Some plants were analyzed for Si and P before treatment to correct for Si and P carried over in cuttings or seeds.

Materials and Methods

Tomato and corn seeds were germinated on moist cotton or cheese cloth over one-fourth strength Hoagland's solution modified to supply 2 ppm P. After a few weeks, the seedlings were transferred to a plastic container fitted with a wooden frame and rubber bands. The seedlings were supported between the rubber bands. The sides of the container were covered with aluminum foil and the top covered with black plastic to prevent algae growth. The pH of the solution was maintained at 5.6 ± .2 and freshly prepared distilled water was used to minimize Si contamination. Seedlings were grown for several weeks until they had developed sufficient top and root material for use in the experiments. *D. intortum* and alfalfa plants were started from one-eye cuttings of a single clone of each species, and were planted in sponge rock and rooted in a mist chamber. After a few weeks the plants were transferred to the culture solution described above for further top and root development.

Sugarcane was started from one-eye cuttings of variety H 50 - 7209 which were treated with a 1 to 800 dilution of 10% Phenyl mercuric acetate (0.0125% PMA) and planted directly in the nutrient solution (Plate 1a).

Effects of Humidity on Transpiration and Uptake of Si and P

An experiment was set up with five plant species (tomato, alfalfa, *D. intortum*, corn and sugarcane) to investigate the effects of relative humidity on transpiration and uptake of Si and P. The plants were acclimatized in the growth chamber for two days prior to application of treatments.

Experimental Procedure

The experiment was conducted in a growth chamber under controlled light and temperature. A one-litre wide-mouthed Erlenmeyer flask fitted with a rubber stopper was used in this experiment. Aeration was performed with air which had been saturated by bubbling through water. The transpiration rate was measured by the difference in weight of plant plus flask at the beginning and end of the experiment. The set up was made air tight by sealing joints with paraffin wax after the treatments had been applied. Relative humidity was controlled by enclosing plants with wire frames which were covered for their total height with polyethylene for the high humidity treatment, covered for one-half their height for the medium humidity treatment and left uncovered for the low humidity treatment (Plate 1b). The chamber was

PLATE 1. ARRANGEMENT FOR GERMINATION OF SUGARCANE CUTTINGS IN NUTRIENT SOLUTION

PLATE 2. SUGARCANE SHIELDED WITH PLASTIC TO PRODUCE LOW, MEDIUM AND HIGH HUMIDITY CONDITIONS IN A GROWTH CHAMBER

set for 14 hours of light and 10 hours of dark with an 85°F ± 1° day temperature and a 65°F ± 1°F night temperature.

A randomized complete block design with three treatments (high, medium and low humidity) and three replications was used for each species. Five ppm P and 25 ppm Si were added as H_3PO_4 solution and sodium metasilicate, respectively in one-fourth strength Hoagland's solution and the pH of the solution was maintained at 5.6 ± .2.

Harvest and Analysis

Plants were harvested, 48 hours after application of treatments. Total weights were taken and the plants were separated into roots and shoots. In all cases roots were washed with distilled water, chopped and a portion used for soluble Si analysis. The tops were also chopped and a portion used for analysis of soluble Si. The remaining portion of roots and tops were dried at 70°C, weighed, ground and stored in plastic vials for total analysis. Ground, oven-dry samples were analyzed for total Si and P. The methods of analysis were the same as those described in Appendix A.

Effects of Light and Dark on Transpiration and Uptake of Si and P

This experiment was conducted to investigate the effects of varying periods of light and dark on transpiration and the relative rates of uptake of Si and P. Five plant species (tomato, alfalfa, *D. intortum*, corn and sugarcane) were used in this study.

Experimental Procedure

The experiment was conducted in three growth chambers providing the following conditions: 24 hours of light, 24 hours dark, and 14 hours light plus 10 hours dark. Temperature in the chambers was

80°F ± 1°F. Transpiration rates were determined from the difference in weight of sealed flasks at the beginning and end of the experiment as described previously.

A randomized complete block design with three treatments (light, dark, dark plus light) and three replications within treatments was used for each species. Five ppm P and 25 ppm Si were added as H_3PO_4 solution and sodium metasilicate, respectively, in one-fourth strength Hoagland's solution and the pH of the solution was maintained at 5.6 ± .2.

Harvest and Analysis

Harvest and analytical procedures were those described for the humidity experiment.

Effects of Si Concentrations of the Culture Solution on Si and P Concentrations in the Xylem Exudate

The experiment was conducted to investigate Si and P concentrations in exudates of different plant species (tomato, alfalfa, *D. intortum*, corn and sugarcane) grown in varying concentrations of Si under controlled conditions.

Experimental Procedure

Plants were decapitated 12 hours after treatments had been applied. The plants were cut a little above the roots and the exudate was collected at 12 and 24 hours after decapitation. After 24 hours the nutrient solution was analyzed for Si and P.

A randomized complete block design with three levels of Si (0, 5 and 25 ppm) and three replications was used for each species. Five ppm P and Si treatments were added as H_3PO_4 solution and sodium metasilicate, respectively.

Harvest and Analysis

Decapitated tops were chopped and part of the material analyzed for soluble Si and the remaining material dried at 70°C, ground and analyzed for total Si and P. Roots were chopped and analyzed for soluble Si, total Si and P. Exudates were also analyzed for Si and P. Analytical procedures were the same as those described for the first solution culture experiment.

Effect of NaCN and NaF on Uptake of Si and P and on Transpiration

This experiment was conducted with two species (tomato and corn) under controlled conditions in a growth chamber.

A. Effect of NaCN and NaF on Uptake of Si and P

A randomized complete block design with five treatments and three replications was used for each species. Seedlings of comparable size were included in a particular replicate and 3 plants were set in a one-liter plastic container fitted with a plastic lid. The treatment combinations are shown in Table 32. Phosphorus was supplied as H_3PO_4 solution and Si was added as sodium metasilicate.

TABLE 32. SILICON, PHOSPHORUS AND INHIBITOR TREATMENTS IN SOLUTION CULTURE EXPERIMENT

Si (ppm)	P (ppm)	Inhibitor (M)
50	5	0
		10^{-5} NaF
		10^{-3} NaF
		10^{-5} NaCN
		10^{-3} NaCN

B. Effect on Transpiration

Tomato and corn were used to study the effect of inhibitors (NaCN and NaF) on transpiration. The treatments are shown in Table 32 and the set up and transpiration measurements were those described for the humidity experiment.

Harvest and Analysis

Harvest and analytical procedures were those described for the humidity experiment.

Results and Discussion

Effects of Humidity on Transpiration and Uptake of Silicon and Phosphorus

Amounts of water transpired by plants were measured directly by weighing the plants and containers before and after the experiment as described earlier. This technique was checked in a dummy experiment without plants and no significant loss of water was found during 48 hours. The amount of water transpired varied with species (Fig. 25). A statistically significant increase in the amount of water lost per gram of dry weight was obtained with decreasing humidity in all species except *D. intortum*.

The order for decreasing total Si uptake (roots and shoots) was sugarcane, corn, *D. intortum*, tomato and alfalfa (Fig. 26). Total silicon uptake was not significantly affected by treatment in tomato, corn or sugarcane but decreased significantly with increasing transpiration in alfalfa. Thus suggesting that the transport of Si into the plant is not regulated by transpiration. In the case of *D. intortum*, total Si uptake increased with increasing transpiration,

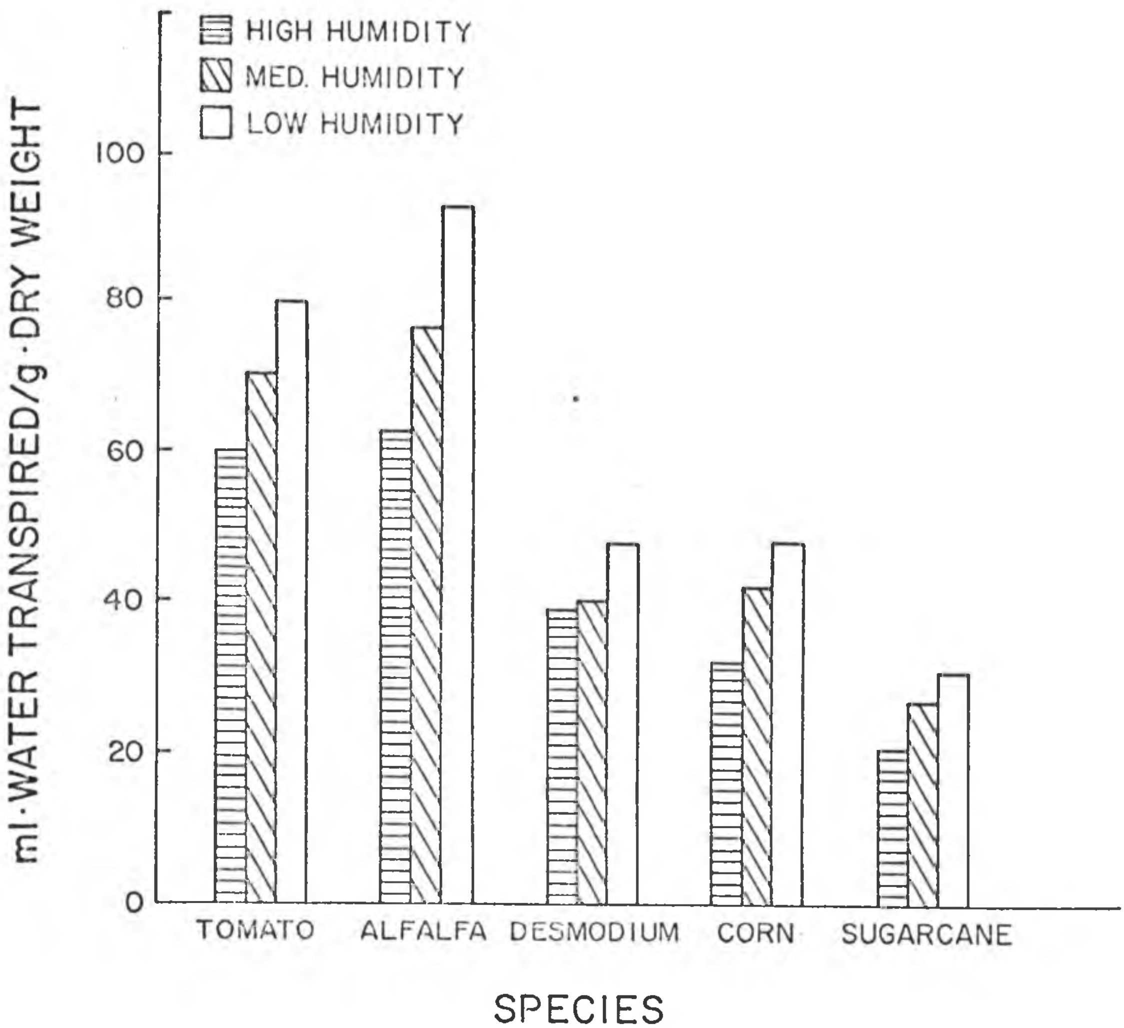

FIGURE 25. INFLUENCE OF HUMIDITY ON WATER LOST PER GRAM OF DRY WEIGHT IN PLANTS

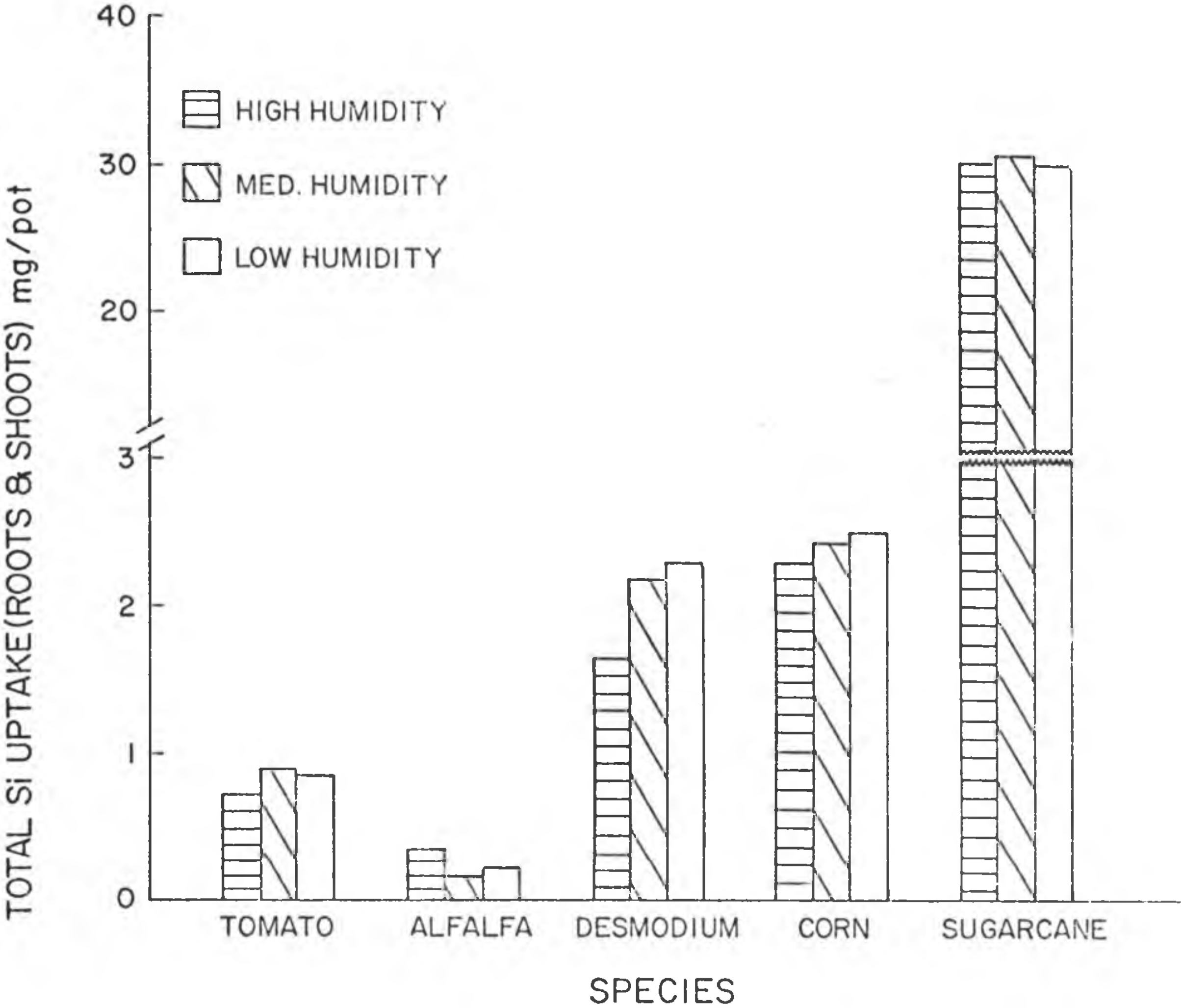

FIGURE 26. INFLUENCE OF HUMIDITY ON TOTAL Si UPTAKE IN PLANTS

but neither Si uptake nor water lost per gram of dry weight was significantly affected. Transpiration may possibly influence the uptake of silicon in this species, but this was not demonstrated beyond statistical doubt because of the high coefficient of variation (60%). The amount of water transpired per gram of dry weight appears to be inversely related to Si uptake by the tops. Sugarcane with the highest Si uptake had the lowest transpiration per gram of dry weight followed in order of increasing transpiration by corn, D. intortum, alfalfa and tomato in which Si also decreased. This suggests that high Si plants may consume less water per gram than low Si plants.

Total Si concentration in tops decreased with species in the following order: sugarcane (4500 ppm), corn (773 ppm), D. intortum (376 ppm), tomato (180 ppm) and alfalfa (158 ppm) (Fig. 27). Total Si in roots decreased with species in the following order: Desmodium (1140 - 1800 ppm), sugarcane (780 ppm), corn (638 ppm), tomato (618 ppm) and alfalfa (228 ppm). Tomato and alfalfa tops had significantly lower concentrations of total Si whereas tomato roots had a significantly higher total Si concentration as transpiration increased. Apparently movement of Si from roots to tops in these species is not by passive transport in the transpiration stream. The increased Si concentration in tomato roots with increasing transpiration may be due to mass flow into the root as transpiration is increased with low humidity. Patterns of Si distribution differed for the two legumes indicating that D. intortum roots permit diffusion of Si from the surrounding medium while alfalfa roots do not. Alfalfa may have a selectivity mechanism operative in the roots that restricts uptake of Si. The very high Si concentration in

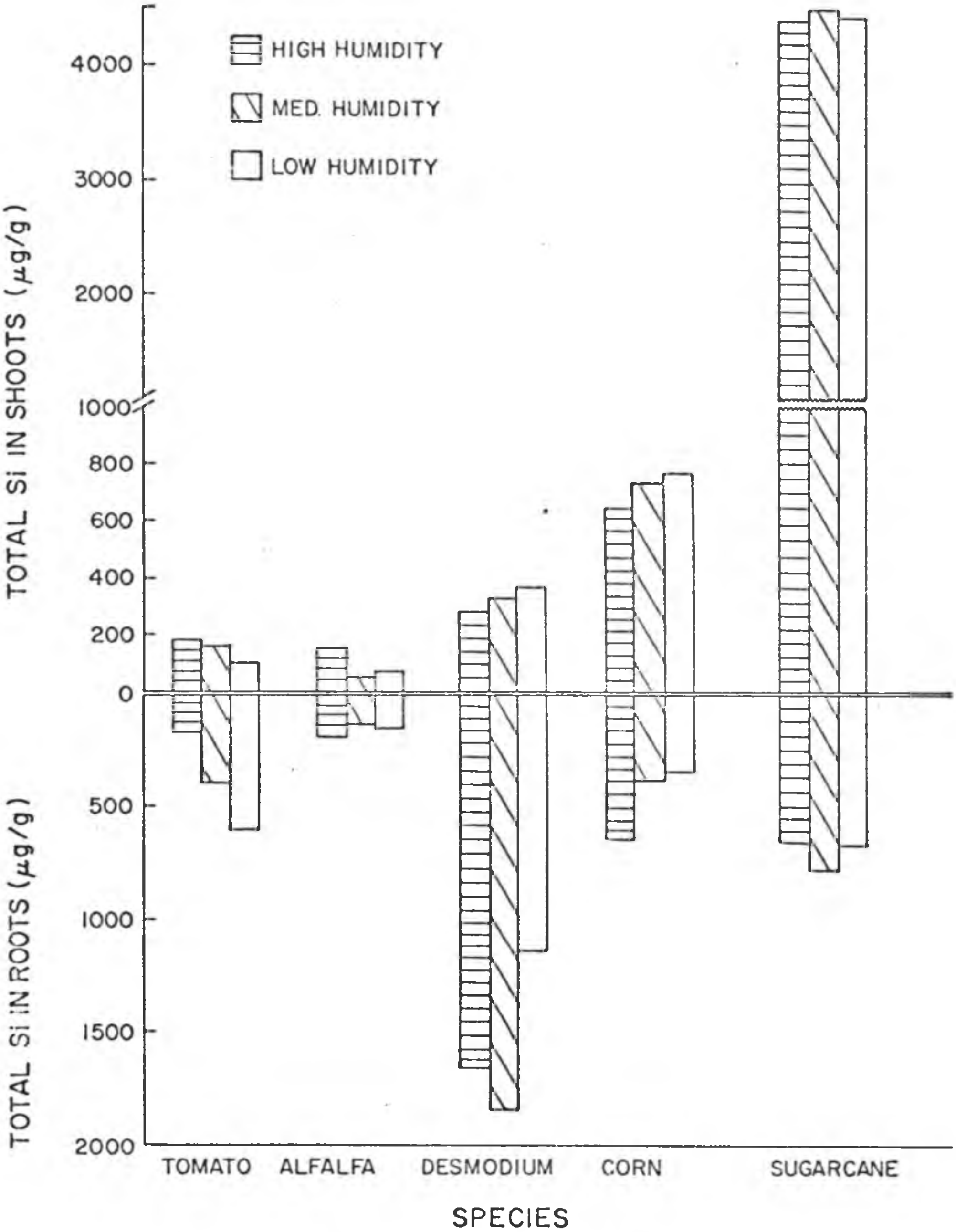

FIGURE 27. INFLUENCE OF HUMIDITY ON TOTAL Si CONCENTRATIONS IN PLANTS

D. intortum roots suggests that movement of Si from roots to tops does not take place as readily in this species as in corn and sugarcane. Both corn and sugarcane have much higher Si concentrations in tops than in roots which may imply active transport of Si.

Soluble Si in roots and shoots varied with species (Fig. 28). Soluble Si concentration of sugarcane (86 ppm) was high in the shoots followed by *D. intortum* (22 ppm), corn (18 ppm), tomato (16 ppm) and alfalfa (11 ppm). Of the two legumes, *D. intortum* accumulated more soluble Si than alfalfa in both roots and shoots. In addition soluble Si in *D. intortum* was higher in roots than tops while alfalfa had more soluble Si in tops than roots. Even though a significant difference in transpiration was observed in all species except *D. intortum*, transpiration appeared to have no significant effect on soluble Si levels in any species. This indicates that transpiration did not affect Si movement or precipitation in these species.

Theoretical uptake of Si may be calculated from the amount of water lost by the plant and concentration of Si in the culture solution (Jones and Handreck, 1965). If Si moves passively with the transpiration stream, the theoretical values should equal the actual Si uptake obtained by analysis of plant samples. In tomato, alfalfa, *D. intortum* and corn the ratios of actual:expected values (Table 33) are less than unity while in sugarcane the ratio is greater than unity. Ratios less than one suggest a possible exclusion mechanism at or in the root which prevents passive entry of Si into the plant and indicate metabolic energy is required to transport Si. Ratios greater than one indicate that Si uptake is an active process and the ratios for sugarcane is

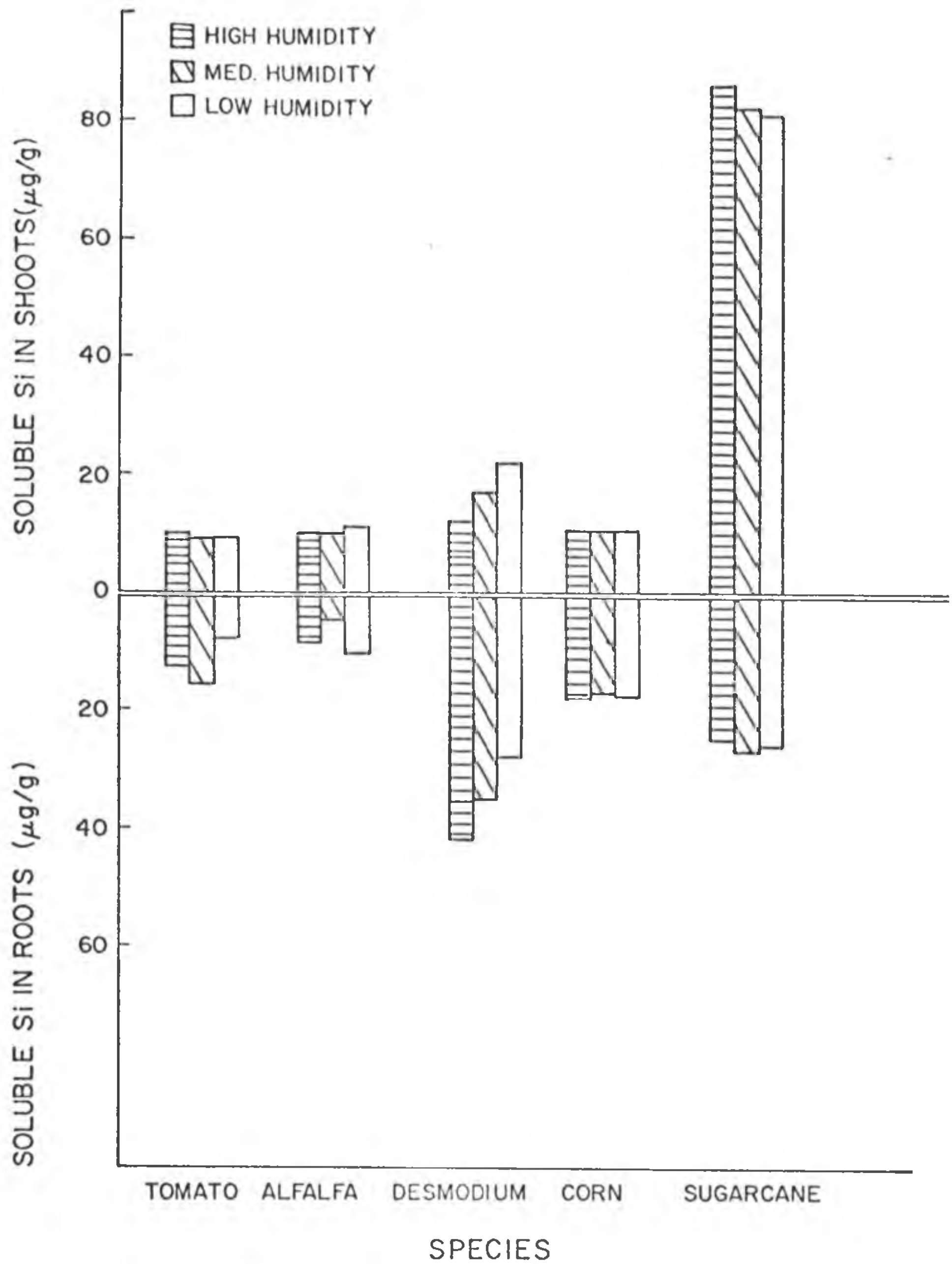

FIGURE 28. INFLUENCE OF HUMIDITY ON SOLUBLE Si IN PLANTS

TABLE 33. EFFECT OF HUMIDITY ON TRANSPIRATION AND UPTAKE OF Si AND P IN PLANTS

Species	Treatment	Total Si uptake mg/plant	Theoretical Si uptake mg/plant	Actual/Theoretical Si uptake	TSCF Si	Total P uptake mg/plant	Theoretical P uptake mg/plant	Actual/Theoretical P uptake	TSCF P
Tomato	H	0.734	4.78	0.154	0.120	3.01	0.96	3.14	2.32
	M	0.894	5.95	0.150	0.088	3.28	1.19	2.76	2.12
	L	0.856	6.41	0.134	0.048	3.48	1.28	2.72	2.20
Alfalfa	H	0.353	2.21	0.160	0.100	3.07	0.42	7.31	4.38
	M	0.147	2.64	0.056	0.028	2.99	0.53	5.64	4.02
	L	0.198	2.99	0.066	0.032	3.88	0.60	6.47	4.74
D. intortum	H	1.65	3.77	0.438	0.288	4.38	0.75	5.84	4.32
	M	2.17	4.14	0.524	0.332	4.10	0.83	4.94	3.20
	L	2.29	5.42	0.423	0.312	3.59	1.09	3.29	2.60
Corn	H	2.29	2.40	0.954	0.816	2.47	0.48	5.15	3.16
	M	2.43	3.08	0.789	0.704	1.84	0.62	2.97	1.60
	L	2.48	3.45	0.719	0.648	1.99	0.69	2.88	1.60
Sugarcane	H	30.05	3.44	8.74	8.40	11.26	0.69	16.32	13.22
	M	30.53	4.33	7.05	6.69	11.33	0.87	13.02	8.24
	L	29.98	4.42	6.78	5.73	9.81	0.88	11.15	11.12

H = High Humidity
M = Medium Humidity
L = Low Humidity

$$\text{Theoretical Si uptake (mg/plant)} = \frac{\mu g \text{ Si in Nutrient Solution x mls of } H_2O \text{ Transpired}}{1000}$$

Transpiration stream concentration factor = TSCF

$$\text{TSCF} = \frac{\text{Concentration of Si in transpiration stream}^{a}}{\text{Concentration of Si in external solution}}$$

[a] The mean concentration of Si in the transpiration stream can be calculated from the shoot Si content and the water lost by transpiration.

similar to that for rice which suggests that the active uptake mechanism postulated for rice by Okuda and Takahashi (1964) may also apply to sugarcane. However, these results are contrary to the statement of Jones and Handreck (1965), that Si uptake is passive in graminacious species.

The relative rates of entry of water and solute into the plant can be expressed as the transpiration stream concentration factor (TSCF) (Russel and Shorrocks, 1959). In tomato, alfalfa and D. intortum, the TSCF was less than one (Table 33) indicating that the rate of entry of water was greater than that of Si. In corn, on the other hand, it was nearly one with high humidity and less than one with low humidity, indicating that although Si and water may enter the plant at about the same rate in some circumstances, this was not a constant relationship. In sugarcane the TSCF was greater than one (7 to 10), denoting that the rate of entry of Si was considerably faster than that of water, thus supporting the active uptake hypothesis. Barber and Shone (1966) reported that the relative rates at which Si and water entered the shoots were largely controlled by metabolic processes in the root. They also concluded that under conditions of high humidity Si appeared to enter the tops against a concentration gradient in plants. The present results (Table 33) agree with those of Barber and Shone (1966), suggesting an active uptake of Si in the species tested.

It has been established that the entry of P into the plant is an active process and several investigators have reported that there is a close relationship between Si and P. Therefore in the present investigation P and Si uptake were compared to help clarify the mechanism of Si uptake.

The concentration of plant P varied with species (Fig. 29). The highest P concentrations were in alfalfa and sugarcane tops followed by tomato, D. intortum and corn. Humidity levels did not significantly affect P concentrations in any species except D. intortum (Table 33) in which P concentration was highest at high humidity. Phosphorus uptake was not significantly affected by treatment in any species, indicating that it is independent of transpiration and thus metabolic energy is required for uptake of P. In all species studied actual P values were higher than theoretical values calculated from P concentration in solution and amount of water transpired as described previously and in addition TSCF values for P in all species were greater than one indicating an active mechanism for P uptake. This agrees with the established mechanism for P uptake and thus demonstrates the validity of these techniques. Therefore those species which have actual:theoretical and TSCF values for Si greater than one may be considered to have an active mechanism for Si transport from roots to shoots.

Effect of Dark and Light on Transpiration and Uptake of Si and P

Varying the length of the light period was used to induce variation in energy supply as well as transpiration to gain additional understanding of the mechanism of Si uptake. Five plant species (tomato, alfalfa, D. intortum, corn and sugarcane) were used in this experiment. Transpiration rates and energy supply were varied by subjecting the plants to dark and light treatments for 48 hours under controlled conditions in growth chambers. The amount of water transpired per gram of dry weight varied with species (Fig. 30). Alfalfa and tomato

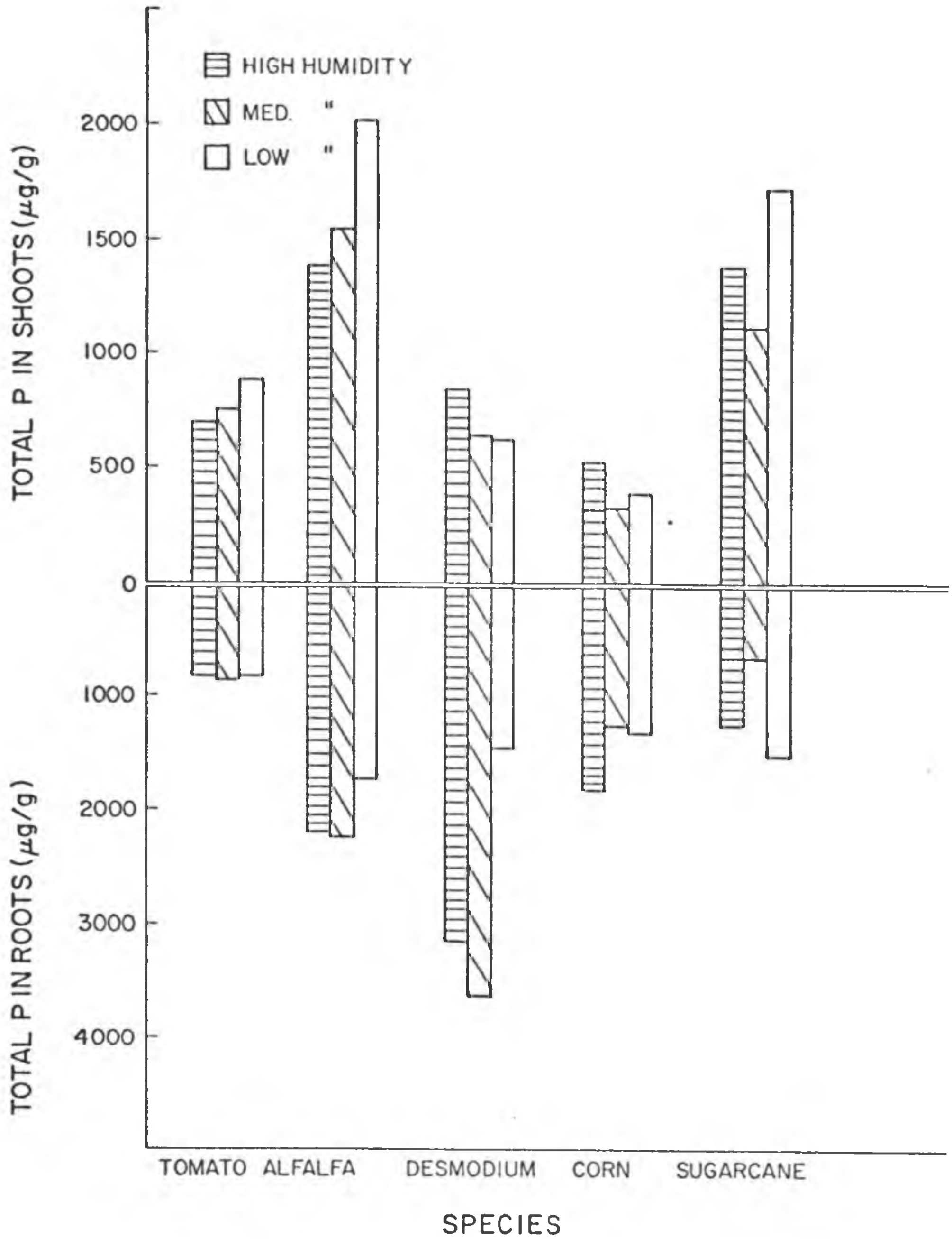

FIGURE 29. INFLUENCE OF HUMIDITY ON P CONCENTRATIONS IN PLANTS

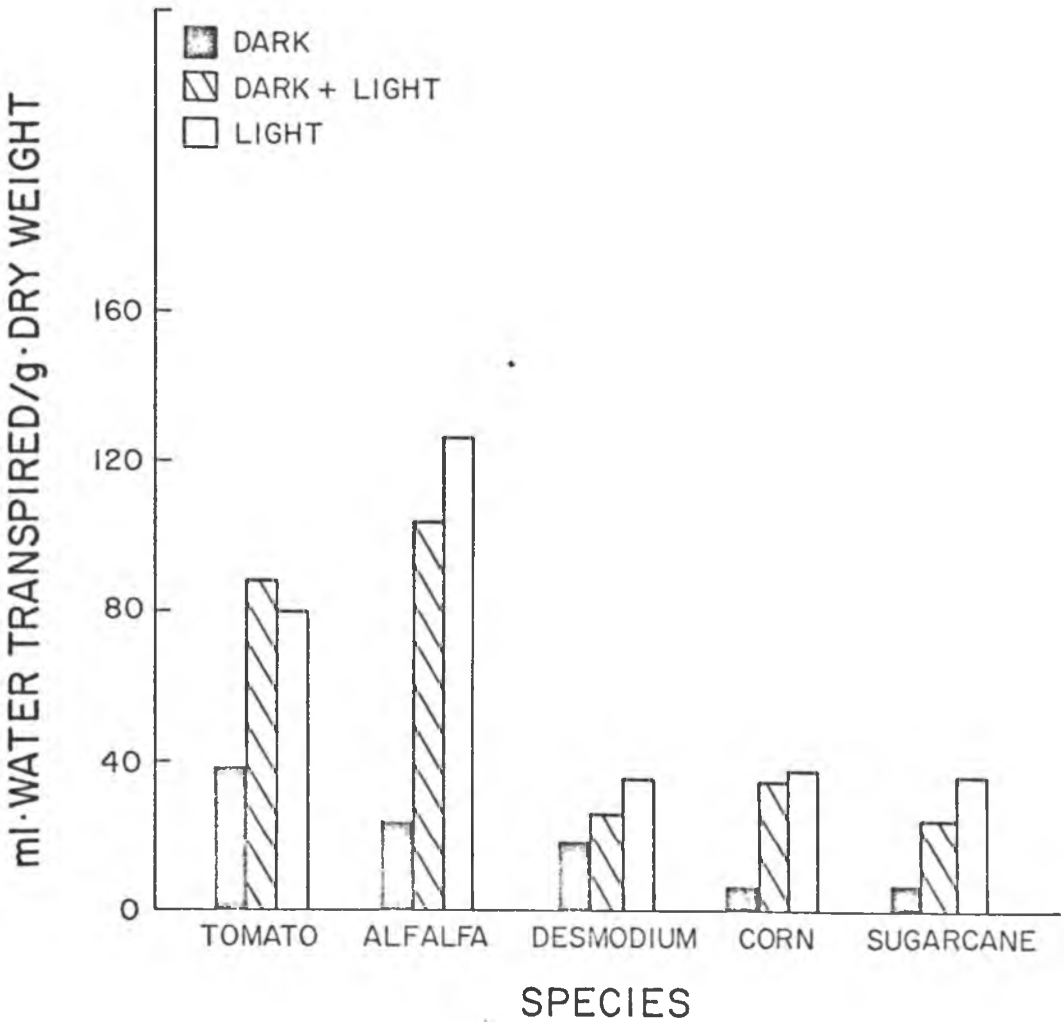

FIGURE 30. INFLUENCE OF DARK AND LIGHT TREATMENTS ON WATER LOST PER GRAM OF DRY WEIGHT IN PLANTS

lost more water (on a per gram dry weight basis) than *D. intortum*, corn or sugarcane. This difference may be attributed to species characteristics, number of leaves and relative leaf area. The increase in amounts of water transpired per gram of dry weight with increasing amount of light were highly significant in all species.

The uptake of Si was higher with light treatments in all species (Fig. 31), but only in tomato and sugarcane was Si uptake in light significantly higher than that in dark. Tanaka and Park (1966) reported that transpiration was greater in natural light than in the dark, but they found no significant difference in the amount of Si absorbed by rice in 4 and 8 hours which appear to agree with the present results.

Concentrations of total Si in roots were highest in the continuous dark treatment in all species (Fig. 32). This may be due to the fact that carbohydrates are needed for translocation of Si from roots to shoots. A greater portion of root Si was translocated into the shoots of sugarcane in the continuous dark regime than in other species, possibly because sugarcane has larger carbohydrate reserves which allowed greater Si transport. The apparent need for a carbohydrate supply in the translocation of Si may be additional evidence that metabolic energy is required and that Si transport is active. Comparison of two legumes revealed that Si absorption was higher in *D. intortum* roots in all treatments. This may indicate that *D. intortum* roots absorb Si, but do not translocate it to tops readily while alfalfa roots exclude Si.

Concentrations of soluble Si in tops were highest in sugarcane followed by corn, *D. intortum*, alfalfa and tomato (Fig. 33). Roots of

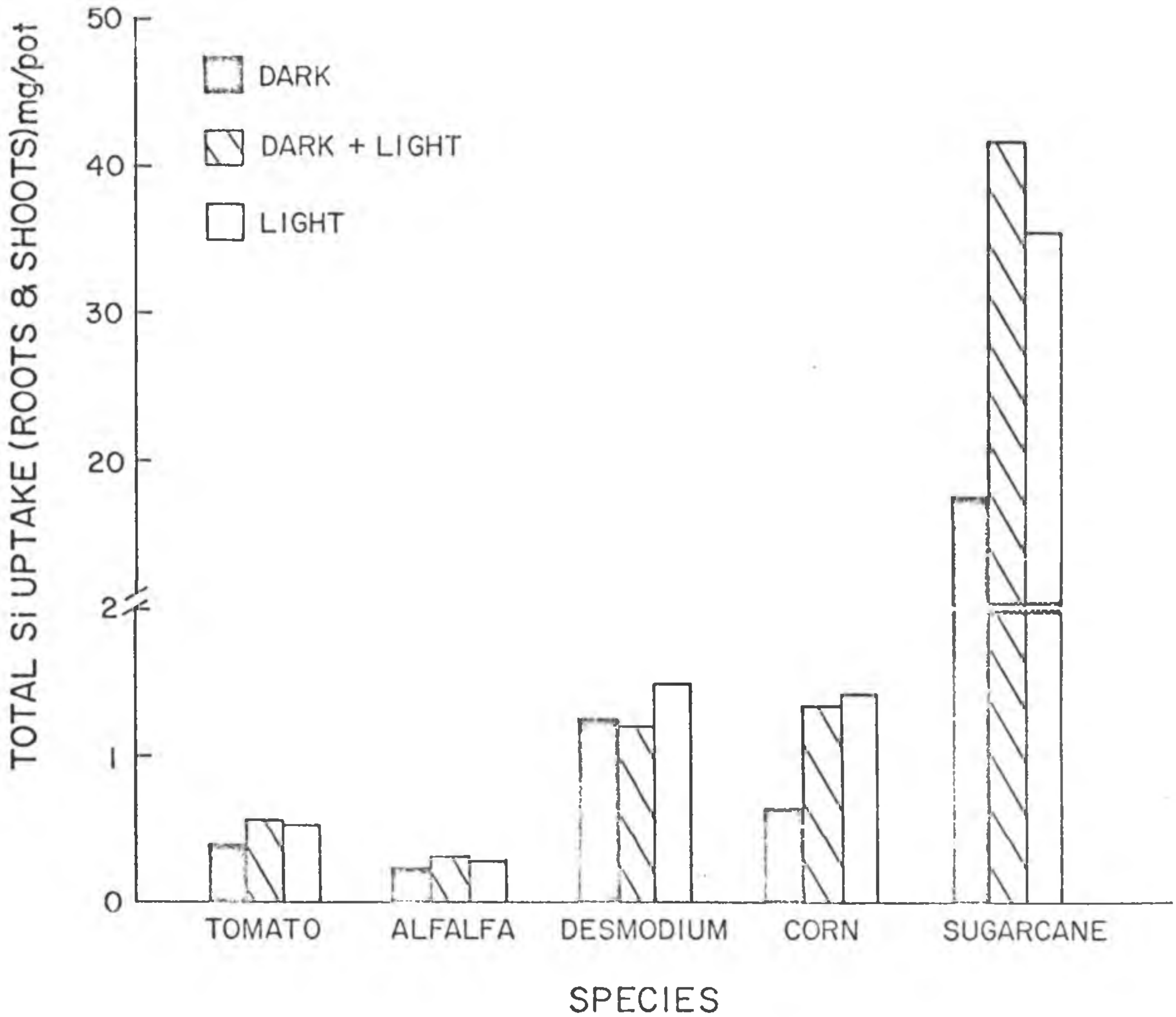

FIGURE 31. INFLUENCE OF DARK AND LIGHT TREATMENTS ON TOTAL Si UPTAKE IN PLANTS

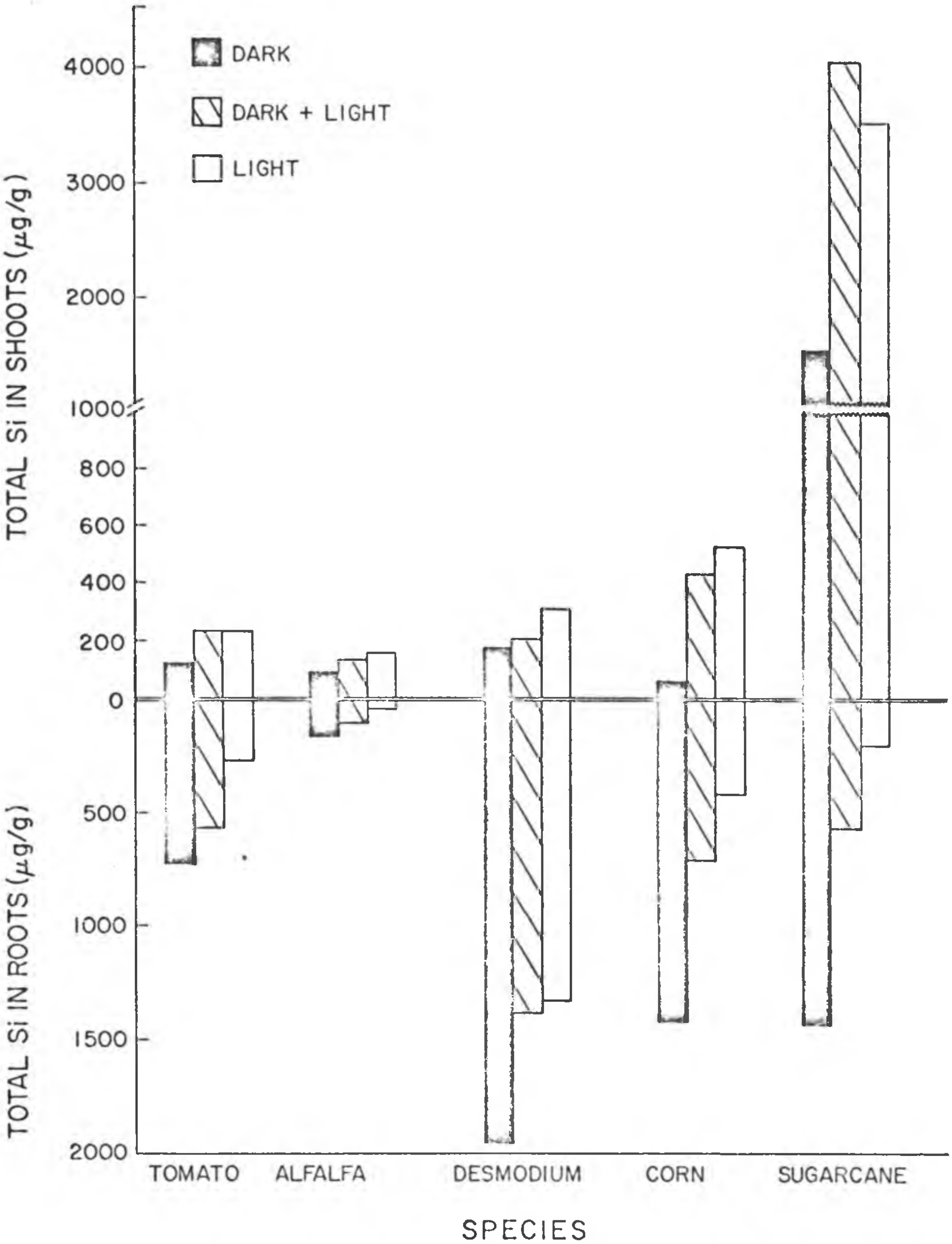

FIGURE 32. INFLUENCE OF DARK AND LIGHT TREATMENTS ON THE TOTAL Si CONCENTRATIONS IN PLANTS

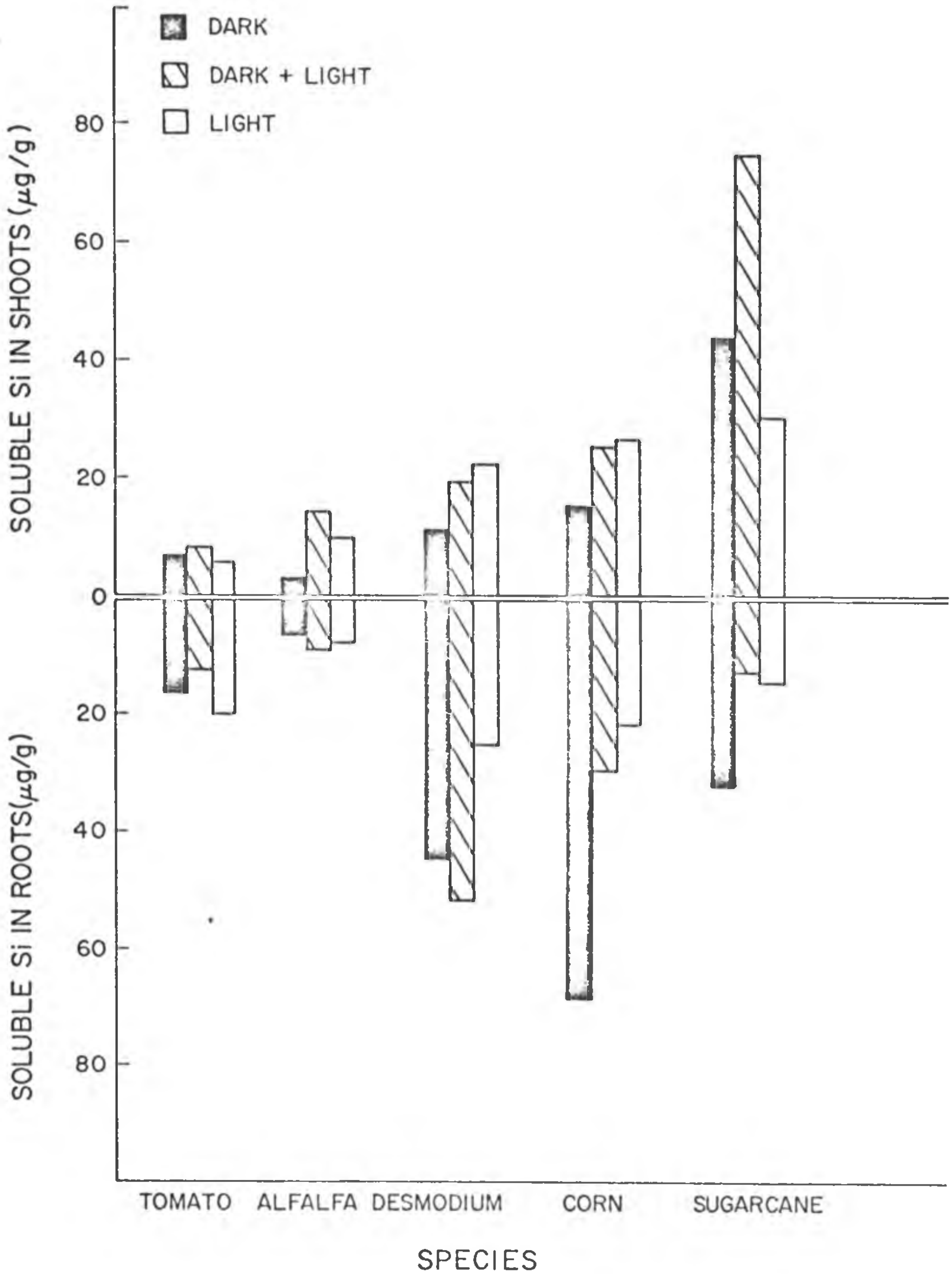

FIGURE 33. INFLUENCE OF DARK AND LIGHT TREATMENTS ON SOLUBLE Si IN PLANTS

corn and *D. intortum* contained more soluble Si than roots of other species irrespective of treatment. In sugarcane tops the highest concentration of soluble Si was found in the dark plus light treatment and the lowest in the continuous light treatment. Low concentrations in continuous light may be due to precipitation of soluble Si as water is lost by transpiration or due to greater metabolic activity in this treatment which resulted in greater precipitation of soluble silicon as suggested by Fox, et al. (1969). This is suggested by the low soluble Si and high total Si found in tops with continuous light and by the lower ratios of soluble to total Si than in the other treatments (Appendix Table 46). The high soluble Si concentration in the dark plus light regime may be due to Si entering the plant at a faster rate than the rate of Si precipitation. Thus more soluble Si is left in solution which is again evident from the higher ratio of soluble to total silicon in Appendix Table 46. In the dark regime the rate of Si precipitation and uptake in the tops appears to be low in sugarcane. *D. intortum* and corn tops had similar patterns of soluble Si concentrations under the three light regimes. There was more soluble Si in the roots of sugarcane, corn and *D. intortum* under the continuous dark regime than under the continuous light regime. Here again the two legumes behaved differently with alfalfa having low and *D. intortum* having high soluble Si in the roots. This appears to support the hypothesis that alfalfa has a mechanism for excluding Si at the root surface while Desmodium roots absorb Si.

When theoretical values for Si uptake were calculated and compared with actual plant analysis values, the actual values were lower than the

TABLE 34. EFFECT OF DARK AND LIGHT ON UPTAKE OF Si AND P IN PLANTS

Species	Treatment	Actual Si uptake mg/plant	Theoretical Si uptake mg/plant	Actual / Theoretical Si uptake	TSCF Si	Actual P uptake mg/plant	Theoretical P uptake mg/plant	Actual / Theoretical P uptake	TSCF P
1. Tomato	D	0.387	1.17	0.331	0.124	2.46	0.235	10.47	8.44
	D+L	0.542	3.18	0.170	0.104	2.98	0.635	4.69	4.26
	L	0.538	3.63	0.148	0.116	2.77	0.725	3.82	3.24
2. Alfalfa	D	0.229	0.85	0.269	0.160	1.81	0.170	10.65	9.12
	D+L	0.311	4.95	0.063	0.048	2.02	0.990	2.04	1.20
	L	0.298	5.37	0.055	0.044	1.98	1.08	1.84	0.94
3. *D. intortum*	D	1.22	1.35	0.903	0.396	4.37	0.270	13.04	14.04
	D+L	1.20	2.50	0.480	0.320	2.92	0.410	6.59	5.30
	L	1.50	2.05	0.731	0.352	2.35	0.500	5.84	3.60
4. Corn	D	0.671	0.160	4.19	0.456	1.76	0.035	50.28	53.04
	D+L	1.35	1.03	1.31	0.492	2.30	0.360	6.39	5.30
	L	1.43	1.99	0.72	0.564	1.68	0.395	4.25	4.10
5. Sugarcane	D	17.90	1.57	11.40	9.25	13.03	0.315	41.36	31.44
	D+L	42.36	5.56	7.62	7.25	13.93	1.11	12.55	11.72
	L	35.49	8.86	4.01	3.98	11.16	1.80	6.20	6.86

D = Dark

D+L = Dark plus Light
L = Light

theoretical values for tomato and the two legumes while for sugarcane actual values were higher than theoretical values (Table 34). In corn under continuous light, actual values were lower than theoretical values but they were higher in the other two treatments. The TSCF values in Table 34 were < 1 in all species except sugarcane. Thus in tomato, alfalfa, *D. intortum* and corn the rate of entry of water was greater than that of Si whereas in sugarcane the rate of entry of Si was greater than that of water. Again this suggests active Si transport to tops.

There seems to be no relationship between the amount of water lost and concentration of P (Table 34). The TSCF value and the ratio of actual:theoretical P uptake were all greater than one and were higher in the continuous dark regime. It has been established that the entry of P into the plant is an active process and the present data agree with this conclusion. The above experiments have indicated that Si appears to enter the plant against a concentration gradient and is transported actively to the plant tops.

Effect of Silicon Concentration of the Culture Solution on Si and P Concentrations in Xylem Exudate

An attempt to confirm the results of the previous studies was made by measuring Si concentration in the exudate.

Tomato, alfalfa, *D. intortum*, corn and sugarcane were grown in one-fourth strength Hoagland's solution containing 0, 5 or 25 μg Si/ml as sodium metasilicate. Phosphorus was added at the rate of 5 μg P/ml to all treatments as H_3PO_4. Treatments were applied 12 hours before decapitation and plants were decapitated just above the roots. Samples of exudate were collected at regular intervals of 2 hours in some species and at 12 and 24 hours in all species. Nutrient solutions were analyzed just before decapitation and at the end of the experiment.

Silicon concentrations in exudates were higher in *D. intortum*, corn and sugarcane than in alfalfa or tomato and it increased in all species as the concentration of Si in the nutrient solution increased (Fig. 34). Exudate from plants growing in nutrient solutions without Si contained no detectable Si. In all species except sugarcane the presence of Si in the nutrient solution was associated with a slight reduction in the quantity of exudate collected.

Bowling, et al. (1966) measured the electrical potential difference between the exuding sap of topped castor plants and the nutrient solution. They found that the concentration of ions measured in the sap was about 10 times that in the external solution and the electrical potential difference between the sap and external solution was -50 mV. From these measurements they concluded that the transport of NO_3, Cl, SO_4, H_2PO_4 and HPO_4 was an active process against the electrochemical potential gradient. In the 12 hour period of the present study Si concentrations in the xylem sap of tomato and alfalfa were lower than that in the external medium (Table 35) while *D. intortum*, corn and sugarcane, Si concentrations were higher in the xylem sap than in external solutions. Similar results were obtained in the 12-24 hour period, except total Si concentrations were higher than those in the 12 hour period for all species except *D. intortum*. Barber and Shone (1966) found that the concentration of silicic acid in the xylem sap of bean plants was greater than that in the external solution. Okuda and Takahashi (1964) also reported that Si concentration in the sap of rice

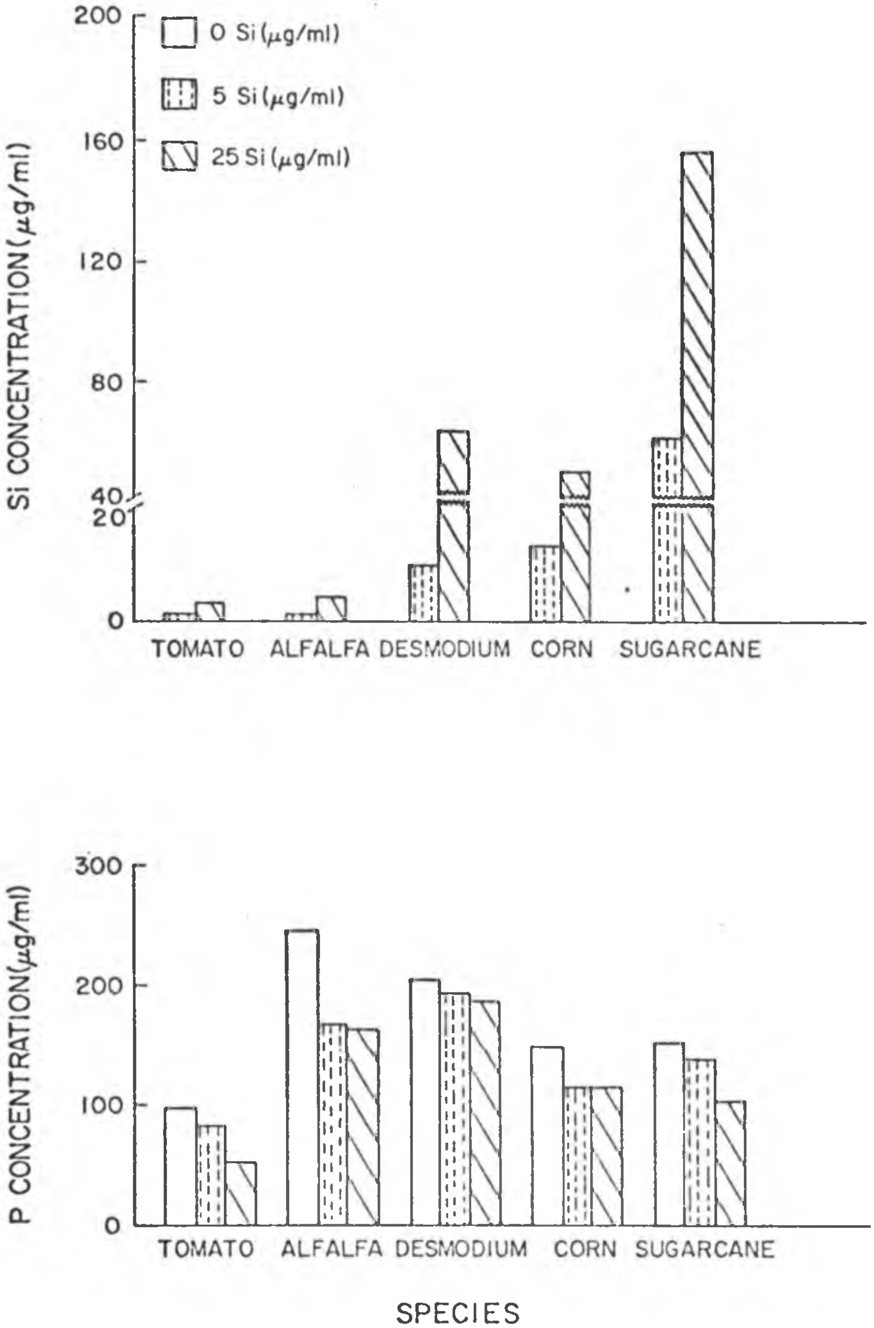

FIGURE 34. INFLUENCE OF Si CONCENTRATION OF THE CULTURE SOLUTION ON Si AND P CONCENTRATIONS IN XYLEM EXUDATES

plants was several times higher than that in the external solution whereas in tomatoes it was lower than that in the external solution, and concluded that Si is transported actively in beans, rice and tomato. In the present findings Si concentrations were either greater or lower in the xylem sap than that in the external solution suggesting active transport in the species studied.

Concentrations of P in the xylem sap decreased with increasing Si applications in all species during the 12 hour period (Fig. 35), suggesting that in the presence of Si uptake of P is reduced or that movement of P within the plant is retarded. Phosphorus concentrations in exudates of all species were higher than those in the external solutions which was similar to the findings of Bowling, et al. (1966), who concluded that the anions NO_3, Cl and H_2PO_4 are actively transported. In the present study P concentrations in the exudates of all species and Si concentrations in the exudates of D. intortum, corn and sugarcane were several times higher than Si and P concentrations in the external solutions. This suggests that Si and P are actively transported.

The TSCF values for silicon ranged from 0.1 to 16 in the first 12 hour period and 0.4 to 30 in the 12-24 hour period for the five species. In tomato and alfalfa, TSCF was less than one, indicating that water entered the plant at a faster rate than silicon. In the case of D. intortum, corn and sugarcane, TSCF values were greater than unity which suggests that the rate of movement of Si is faster than water.

The TSCF values for P which ranged from 12 to 117 indicated that in all plant species studied P entered the plant at a faster rate than water and the rate of entry was reduced with increasing Si level (Table 35). This suggests that Si and P may compete for the same sites for

TABLE 35. RELATIONSHIP BETWEEN CONCENTRATIONS OF Si AND P IN XYLEM EXUDATES AND CONCENTRATIONS IN EXTERNAL SOLUTIONS

Species	Si treatment	Total exudate in 24 hrs	TSCF			
			Si (hrs)		P (hrs)	
			12	12-24	12	12-24
	(μg/ml)	(ml)				
Tomato	0	7.8	-	-	24	18
	5	8.4	0.313	0.466	18	19
	25	6.8	0.138	0.343	13	15
Alfalfa	0	1.8	-	-	74	62
	5	1.5	0.272	0.566	42	32
	25	1.1	0.212	0.570	37	17
D. intortum	0	9.0	-	-	117	96
	5	8.2	2.39	1.49	80	63
	25	7.0	3.21	1.30	62	41
Corn	0	6.7	-	-	33	30
	5	6.2	2.92	3.65	27	26
	25	6.6	2.38	3.49	26	29
Sugarcane	0	26.3	-	-	52	31
	5	25.7	16.89	30.52	37	25
	25	27.4	7.84	10.18	23	20

entry and very high Si concentration might inhibit P uptake.

Effect of NaF and NaCN on Transpiration and Uptake of Si and P

Metabolic inhibitors NaF and NaCN were used to further evaluate the mechanism of Si uptake in tomato and corn as representatives of the dicotyledons and monocotyledons. The effect of three rates (0, 10^{-5}, 10^{-3} M) of the metabolic inhibitors NaF and NaCN on transpiration and uptake of Si and P was studied in solution culture. Inhibitors significantly reduced the rate of transpiration in both tomato and corn (Fig. 35).

The uptake of Si by roots differed in the two species and total Si uptake by roots in the control treatment was greater than that with inhibitors (Appendix Table 47). In tomato and corn Si concentration was higher in roots than in shoots. Silicon uptake in shoots was not significantly reduced by inhibitors. Barber and Shone (1966) and Okuda and Takahashi (1964) also found that metabolic inhibitors reduced transpiration of barley and rice, respectively. The same investigators reported a significant reduction in total Si concentration by inhibitors and concluded Si uptake was active.

Soluble Si concentrations of corn tops was higher than that of tomato. The soluble Si concentration in corn was significantly reduced by both levels of inhibitors and the reduction was greatest in 10^{-3} M NaCN. The ratio of soluble Si to total Si in shoots was calculated to measure the effect of inhibitors on the form of Si in plants (Appendix Table 47). In tomato, NaCN at both levels and NaF at the 10^{-5} M level appear to cause greater Si precipitation than the control whereas in corn the soluble:total Si ratio for NaF is similar to that for the

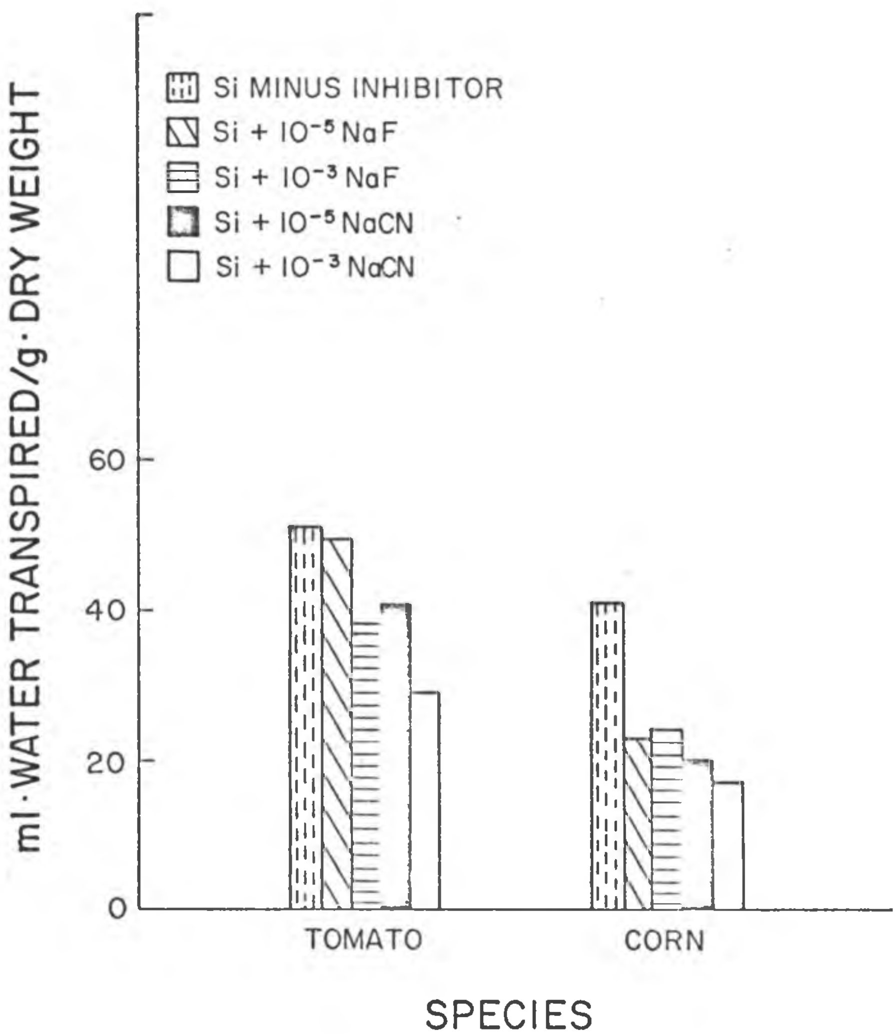

FIGURE 35. INFLUENCE OF NaF AND NaCN ON WATER LOST PER GRAM OF DRY WEIGHT IN TOMATO AND CORN

control, but is higher than the control for NaCN due to relatively more Si remaining in solution.

Since Si uptake by roots of tomato and corn was high with inhibitors, it may be concluded that translocation of Si to shoots was reduced by metabolic inhibitors and thus an active mechanism may be hypothesized for the translocation of Si to shoots. Relatively more soluble Si remained in solution in the inhibitor treatments which also suggests that metabolic energy is necessary for Si precipitation.

Conclusions

The results of all four experiments indicate that there are definite species differences in Si concentration and distribution. Although a statistically significant difference in the amount of water transpired per gram of dry weight was found in all species except *D. intortum* in the humidity study, no significant increase in Si uptake occurred with increasing transpiration in any species. This implies that entry of Si into the plant is not closely regulated by transpiration. Similar conclusions were reached for rice by Okuda and Takahashi (1964) and Tanaka and Park (1966). The rate of entry of Si in sugarcane plants was faster than that of water according to the transpiration stream concentration factor (TSCF), thus the transport of Si to the tops apparently is controlled by metabolic energy. A similar conclusion for bean plants was arrived at by Barber and Shone (1966). Water generally entered tops faster than Si according to the TSCF values for the two legumes, tomato and corn, and actual plant Si values were lower than theoretical values, suggesting that Si transport to the tops is an active process requiring metabolic energy. Patterns of Si uptake and concentrations in the two legumes were different, suggesting alfalfa may have a selectivity mechanism in roots while D. intortum is non-selective for Si in roots.

If Si transport is active then Si concentration in plant exudates should not be the same as Si concentration in the nutrient solution. In D. intortum, corn and sugarcane Si concentrations in exudates were several times higher than in the external solution. This implies that active transport produced this high Si concentration rather than movement of Si by mass flow. In tomato and alfalfa Si concentrations were lower in the exudate than in the external solution, suggesting a selectivity mechanism in the roots of these plants and also active transport of Si. Decreasing P in exudates with increasing Si in nutrient solutions indicates an antagonism between Si and P in which they may compete for the same site or carrier in the root.

Since the mechanism of P transport has been established as active (Bowling, et al., 1966), comparison of P and Si transport in the present experiments was carried out. There was no definite relationship between water transpired and P uptake in any species in either the humidity or light experiments as was found with Si. Actual plant P uptake was always higher than theoretical plant P uptake in all species supporting the concept of an active uptake mechanism for P which has already been established. Actual uptake of Si was both higher and lower than theoretical uptake, but both situations can be interpreted as indicating active transport. In all species concentrations of P in exudates were higher than those in external solutions, which is similar to the findings of Bowling, et al. (1966). Again Si concentrations in exudates were either higher or lower than those in external solutions and indicated active transport. Therefore the present series of experiments has demonstrated that both P and Si transport are by active mechanisms.

SUMMARY AND CONCLUSIONS

The influence of calcium silicate applications on the yield and nutrient uptake of 22 plant species grown on two soils was investigated in a pot test. One of the species, corn, was used in a field experiment with factorial combinations of three levels each of Si, P and pH in an attempt to isolate some of the main effects and interactions of silicate applications on growth. This was followed by a solution culture experiment with five species, including corn, in which the mechanism of Si uptake was studied.

Yields of 22 species grown on Kapaa soil and 19 species grown on Paaloa soil were higher with applications of calcium silicate than without and yield increases of 10 species on Kapaa soil and 1 species on Paaloa soil were statistically significant. The 2.2 T Si/ha treatment produced yields which were 85% or more of maximum in 17 of the 22 species on Kapaa soil, therefore may be expected to provide larger economic returns than 8.8 T Si/ha. High calcium silicate applications (8.8 T Si/ha) reduced yields in many species and thus may be toxic to some plants. Yield increases from calcium silicate applications were generally lower on Paaloa than Kapaa soil indicating greater Si availability in Paaloa soil since both soils had "deficiency" levels of Si.

Concentrations of Si were higher in monocotyledonous than in dicotyledonous plants and general plant Si levels in the different species decreased in the following order: grains $\geq$ grasses $\geq$ vegetables and fruits $\geq$ legumes except those in the two Desmodiums which were similar to those in grasses. In about half the species plant P increased with Si applications in both soils. Calcium concentrations in plants generally increased whereas plant Mg, Mn, Al and Fe concentrations generally decreased with calcium silicate applications. Calcium silicate exhibited continued availability of Si to plants for four successive crops in the pot study in which 2.2 T Si/ha produced near maximum yields in all species tested. Silicon and P concentration generally increased with increasing harvests as did plant Mn and Al in both soils.

Silicon distribution in papaya, sugarcane and pineapple was studied and it appeared that leaves accumulate the highest amounts of Si in papaya and pineapple while sugarcane sheaths have maximum Si concentrations. The lowest Si concentrations in those species were found in stems.

Evaluation of three silicate materials, Tennessee Valley Authority (TVA), Hawaiian Cement Corporation (HCC) and Technical grade (TG) calcium silicates revealed that TVA and HCC materials generally produced higher yields than TG calcium silicate, especially at low rates and in the third and fourth harvests. Plant Si concentrations were generally higher in HCC and TG $CaSiO_3$ treatments than in the TVA material indicating greater Si solubility in these two materials. Concentrations of Mn were significantly reduced by both HCC and TVA material, but they remained slightly higher with TG $CaSiO_3$.

Yields of field corn ears were significantly increased by P treatments and were not significantly affected by residual Si or pH. However, ear corn yields were generally higher when P was applied with Si than without. Stover yields were generally high at pH 5.5

suggesting that increased Si solubility at this pH may have increased stover yields by increasing P availability and mechanical strength of plants. Application of 280 kg P/ha with applied Si produced yields nearly equal (98%) to those of the 1120 kg P/ha without applied Si suggesting that comparable yields at lower cost can be obtained with combinations of low P and high Si than with high P alone. Leaf Si values of 0.5 to 0.6% at silking appear adequate for corn growth. Total corn yields (stover + ears) increased with increasing leaf P, but higher yields were obtained at the same P level with Si applications than without. This suggests that Si increased the efficiency of P utilization in the plants. Silicon taken up by the plant is more closely related to soil Si extracted with water than with sulphuric acid.

A multiple regression equation which included 31 variables accounted for 58% of the ear corn yield variation. Multiple regression analysis with yield and leaf nutrients revealed that Si, P and Fe are especially important for stover production while P, Ca, K, Al and Fe are important for ear production.

Solution culture experiments were conducted to study the mechanism of Si uptake in five species (tomato, alfalfa, *Desmodium intortum*, corn and sugarcane). Although a statistically significant difference in the amount of water transpired per gram of dry weight was found in all species, except *D. intortum*, in the Humidity experiment no significant increase in Si uptake occurred with increasing transpiration in any species. This implies that entry of Si into the plant is not closely regulated by transpiration, which is similar to the conclusions of

Okuda and Takahashi (1964) and Tanaka and Park (1966). Plants kept in continuous dark for 48 hours accumulated Si in the roots but only sugarcane translocated large amounts of Si to the tops. Apparently carbohydrate supply is important in Si transport from roots to tops so sugarcane with its high carbohydrate reserves was able to transfer Si to the tops even in complete darkness. This indicates that metabolic energy is required for Si transport in the plants. Both the transpiration stream concentration factor (TSCF) and the ratio of actual:expected Si content of plants revealed that Si is taken up by plants more slowly than water in tomato, alfalfa, D. intortum and corn and more rapidly than water in sugarcane. These relationships both indicate that Si transport to tops is an active process requiring metabolic energy. Patterns of Si uptake and concentrations differed with species. The two legumes exhibited particularly striking differences which suggest that alfalfa may have a selectivity mechanism in roots which exclude Si while D. intortum roots are non-selective in accumulation of Si.

Si concentrations in D. intortum, corn and sugarcane exudates were several times higher than those of external solutions suggesting that active transport was responsible for this high Si concentration rather than movement of Si by mass flow. In tomato and alfalfa Si concentrations were lower in the exudates than in the external solutions suggesting a selectivity mechanism in the roots of these plants and also active transport of Si to the tops. Decreasing P in exudates with increasing Si in nutrient solutions indicates an antagonism between Si and P in which they may compete for the same site or carrier in the root. Comparison of P and Si transport showed that there was no definite relationship between water transpired and P uptake in any species in either humidity or light experiments as was found with Si. Actual plant P uptake was always higher than theoretical P uptake in all species supporting the concept of an active uptake mechanism for P which has already been established. Actual uptake of Si was both higher and lower than theoretical uptake, but both situations can be interpreted as indicating active transport. The present series of experiments has demonstrated that both Si and P transport are by active mechanism.

APPENDIX A

Plant Analytical Methods

Extraction and Digestion Procedures

TCA Extractable Silicon

Soluble Si was extracted from fresh plant material by the TCA (Trichloro-Acetic Acid) method of Fox, et al (1967).

A 10 gram sample of freshly chopped plant material and 100 ml of 2% TCA solution were homogenized at high speed for 10 minutes in a Waring blender. The extract was filtered through a Whatman No. 42 filter paper, collected in a plastic vial, and analyzed for Si immediately. Silicon was determined by the Molybdate blue method described by Kilmer (1965).

Lithium Tetraborate Fusion

A modification of the lithium tetraborate method of Suhr and Ingamells (1966) was used to determine total plant silicon. A 0.5 gram sample of the ground, dried plant material was placed in a platinum crucible and ashed overnight in a muffle furnace at 550°C. After cooling, 0.5 gram lithium tetraborate was mixed with the ash and transferred to a carbon crucible. This was fused in a muffle furnace at 950°C for 15 minutes. The crucible was then removed, gently swirled to coalesce the melt, and the contents immediately poured into a 400 ml beaker containing 100 mls of 0.5 N nitric acid. The mixture was stirred with a magnetic stirrer until the melt completely dissolved, and a 50 ml aliquot was stored in a plastic vial for analysis. Silicon was determined by the Molybdate blue method of Kilmer (1965).

Nitric-Perchloric Acid Digestion

Plant P, K, Ca, Mg, Mn, Al and Fe were determined on the nitric-perchloric acid digest of the plant material (Jackson, 1958). A 1.0 gram sample of ground, dried plant material was weighed into a 100 ml Kjeldahl digestion flask and 15 ml 2:1 nitric-perchloric acid mixture was added. The mixture was allowed to stand overnight and then digested at low temperature for about 30 minutes, then at high temperature until the appearance of white fumes. Digestion was continued at low temperature for 15 minutes to complete dehydration of Si. The mixture was cooled to room temperature, transferred into a 50 ml volumetric flask and made to volume with distilled water.

Chemical Methods

Plant Silicon

Plant silicon was determined by the silicon Molybdate blue method of Kilmer (1965).

An aliquot of sample solution was transferred to a 50 ml volumetric flask, diluted to about 35 mls with distilled water, and 1 ml ammonium Molybdate solution was added with mixing. After 30 minutes, 3 ml 10% oxalic acid solution was added and within two minutes 1 ml of reducing solution (1 amino, 2 napthal, 4 sulphonic acid) was added with mixing and the solution was made to volume. After color had developed for 30 minutes, the optical density was measured at 660 millimicrons on a Coleman spectrophotometer.

TCA extractable Si was determined in the same manner; except that 5 ml 10% ammonium persulphate solution was added prior to the Molybdate addition to prevent premature reduction of the Molybdate yellow complex to the blue complex.

Plant Phosphorus

The Vanadate-Molybdate yellow method of Barton (1948) was used to determine plant P. A suitable aliquot was pipetted into a 50 ml volumetric flask, diluted to about 35 ml with distilled water, then 5 ml Vanadate-Molybdate solution was added. The solution was made to volume with distilled water, and mixed, then color was allowed to develop for 30 minutes and the intensity read on a Coleman spectrophotometer set at 430 millimicrons. Phosphorus concentration was calculated from a standard curve.

Total Plant Nitrogen

Total nitrogen in the corn leaves was determined by the Kjeldahl method. One gram ground plant tissue was weighed into an 800 ml Kjeldahl flask and 30 ml concentrated H_2SO_4, 5 grams Na_2SO_4, 5 drops (0.25 ml) $SeOCl_2$ and a few glass beads were added. The mixture was digested until the solution cleared, then digestion was continued for 30 minutes.

The digest was cooled and diluted with 300 ml of distilled water, then 100 ml of 15N sodium hydroxide was added down the side of the flask without mixing. A few pieces of mossy zinc were added and the mixture was distilled into 50 ml 2% Boric Acid-Indicator solution. About 150-200 ml of the distillate was collected and titrated with standard H_2SO_4.

Soil Analytical Methods

Extraction Methods

Water-Extractable Silicon

Soil Si was extracted by shaking 10 g soil (oven dry basis) with 100 ml water for 4 hours. The extract was filtered through Whatman No. 42 filter paper. Silicon was determined by the Molybdate blue method of Kilmer (1965).

Modified-Truog Extractable Phosphorus

Soil P was extracted by the modified Truog method of Ayres and Hagihara (1952): a 1.5 g soil sample (oven dry basis) was shaken with 150 ml 0.02 N Sulphuric Acid (containing 3 g/liter ammonium sulphate) in a 200 ml flask for 30 minutes. The extract was filtered through Whatman No. 42 filter paper and P in the extract was determined by the Molybdenum blue method of Dickman and Bray (1940). Silicon in the extract was also determined by the Molybdate blue method of Kilmer (1965).

Chemical Methods

Soil Phosphorus

Soil P was determined by the Molybdenum blue method of Dickman and Bray (1940): a 10 ml aliquot of soil extract was transferred to a 50 ml Volumetric flask, diluted to about 30 ml and 10 ml of ammonium molybdate reagent was added and mixed. A 5 ml aliquot of stannous chloride solution (reducing agent) was added, the solution made to volume and mixed. After 10 minutes the optical density was read at 660 millimicron on a spectrophotometer.

Phosphorus Analysis of Plant Samples

Nitric-Perchloric Digest Vs. Lithium Tetraborate Digest

Plant P was determined in digests prepared by the Nitric-perchloric Acid method and by the Lithium tetraborate fusion method. Phosphorus values for the two digests were obtained for all species in both soils and comparison showed that 88% of the values were higher in the lithium tetraborate digest than in the nitric-perchloric digest. High phosphate values obtained in the lithium-tetraborate digests may be due to the interference in color development by other ions, including Si, unfavorable pH or possibly due to release of P trapped in the Si structure. The fusion method solubilizes Si and thus would release elements occluded in the Si structure.

The possibility of interference by Si was investigated by standard curves for P with and without Si using Barton's reagent. The values were not different indicating that at these concentrations (0 to 1 ppm in 50 ml volumetric flask) Si does not interfere with P analysis.

The possibility of release of occluded P was investigated with Kikuyu grass samples from the 4 Si treatments in Paaloa soil. Samples were digested with the nitric-perchloric acid mixture, filtered through Whatman 42 filter paper and the filtered digest analyzed for P. The dehydrated Si was washed twice with 40 ml of distilled water and P was determined in each washing. The filter paper was ashed, the residue fused with lithium tetraborate, the melt dissolved in 100 ml of 0.03% nitric acid and P determined. There was more occluded P at high than at low Si levels (Appendix Table 48) which suggests that the higher P values obtained by the lithium tetraborate method may be due to release of this occluded P. Additional studies with other species may help to clarify this matter.

APPENDIX B

TABLE 1. RESIDUAL EFFECTS OF CALCIUM SILICATE ON Ca, Mg AND K CONCENTRATIONS IN PLANTS GROWN ON KAPAA SOIL

Species	Harvests	Ca in tops T Si/ha (%) 0	0.56	2.2	8.8	Mg in tops T Si/ha (%) 0	0.56	2.2	8.8	K in tops T Si/ha (%) 0	0.56	2.2	8.8
Big trefoil	1	2.61	2.68	2.50	2.82	0.23	0.19	0.19	0.20	2.78	2.44	2.85	3.06
	2	2.55	2.63	2.35	2.81	0.43	0.41	0.35	0.44	2.57	2.54	2.78	3.04
	3	1.39	1.37	1.32	1.52	0.15	0.18	0.17	0.16	2.72	2.84	3.04	3.15
Intortum	1	2.81	2.73	2.76	2.87	0.15	0.14	0.14	0.15	3.15	2.78	2.25	2.37
	2	2.24	3.00	3.22	3.34	0.27	0.38	0.41	0.38	1.92	2.47	2.45	2.29
	3	2.44	2.43	2.60	2.21	0.14	0.13	0.14	0.11	2.01	2.10	1.80	1.55
	4	2.30	2.50	2.36	2.45	0.14	0.15	0.14	0.13	2.97	3.14	2.73	2.44
Kaimi clover	1	2.13	2.33	1.80	2.24	0.10	0.11	0.10	0.11	2.41	2.63	2.39	2.65
	2	0.85	2.14	2.17	2.18	0.54	0.25	0.23	0.26	1.94	2.47	2.36	2.47
Alfalfa	1	2.76	2.79	2.54	3.25	0.13	0.14	0.15	0.15	3.15	2.58	2.06	1.40
	2	3.09	2.34	2.09	2.08	0.35	0.29	0.26	0.31	2.34	2.25	2.33	2.50
Kikuyu grass	1	1.44	1.36	1.03	1.35	0.29	0.30	0.26	0.30	6.60	6.18	4.97	3.81
	2	1.17	1.22	1.12	1.03	0.32	0.66	0.71	0.67	2.66	2.53	2.38	2.23
	3	1.18	1.11	1.06	0.97	0.34	0.35	0.35	0.30	2.25	2.29	2.45	2.80
	4	1.20	1.09	1.09	0.91	0.36	0.30	0.30	0.26	2.27	2.07	2.23	1.99
Bermuda grass	1	2.07	1.79	1.41	1.02	0.24	0.23	0.20	0.14	7.36	5.89	5.31	4.53
	2	2.12	1.58	1.34	0.98	0.22	0.48	0.44	0.36	2.81	2.70	2.86	2.71
	3	1.24	1.15	0.84	0.76	0.17	0.19	0.15	0.14	2.63	2.16	2.56	2.59
Guinea grass	1	1.13	1.66	1.53	1.53	0.26	0.19	0.19	0.19	4.08	2.71	2.75	2.39
	2	2.38	2.65	2.56	2.62	0.42	0.41	0.43	0.32	2.68	2.58	2.29	3.15
	3	2.46	2.79	2.78	2.86	0.36	0.40	0.36	0.35	2.34	2.25	2.54	2.59
	4	2.66	3.08	3.21	3.13	0.28	0.38	0.31	0.30	1.97	1.94	2.16	2.75
Sorghum	1	1.30	1.09	1.04	0.85	0.17	0.18	0.18	0.13	2.57	2.03	2.33	3.69
	2	1.18	1.08	1.15	1.13	0.28	0.34	0.25	0.17	2.46	3.20	2.96	2.93
	3	1.67	1.58	1.31	1.67	0.39	0.36	0.31	0.27	0.31	2.97	2.81	2.77
Lettuce	1	3.13	3.16	3.10	3.53	0.37	0.33	0.39	0.35	-	-	-	-
	2	2.11	2.26	1.97	1.99	0.26	0.30	0.29	0.24	-	-	-	-
	3	2.87	3.51	3.02	3.55	0.30	0.35	0.35	0.37	-	-	-	-
	4	3.59	2.97	4.41	4.52	0.48	0.41	0.47	0.73	-	-	-	-

TABLE 2. RESIDUAL EFFECTS OF CALCIUM SILICATE ON Ca, Mg AND K CONCENTRATIONS IN PLANTS GROWN ON PAALOA SOIL

Species	Harvests	Ca in tops T Si/ha				Mg in tops T Si/ha				K in tops T Si/ha			
		0	0.56	2.2	8.8	0	0.56	2.2	8.8	0	0.56	2.2	8.8
		(%)				(%)				(%)			
Big trefoil	1	1.35	1.55	1.71	2.17	0.39	0.32	0.29	0.17	2.04	2.00	2.11	1.73
	2	1.95	2.09	2.26	2.91	0.27	0.22	0.19	0.16	3.24	3.70	4.70	4.70
	3	1.98	2.15	2.13	3.02	0.26	0.23	0.18	0.18	1.36	1.22	0.58	0.19
Intortum	1	1.18	1.37	1.80	2.16	0.24	0.24	0.23	0.25	3.16	2.80	2.74	2.95
	2	1.85	2.08	2.56	2.92	0.20	0.20	0.18	0.18	5.04	4.06	3.21	3.30
	3	1.85	2.39	2.31	3.15	0.19	0.22	0.15	0.14	2.98	2.84	3.10	2.78
	4	1.81	1.97	2.12	2.37	0.17	0.17	0.14	0.13	3.45	3.20	3.11	3.46
Kaimi clover	1	0.97	1.18	1.37	1.22	0.15	0.15	0.15	0.15	2.45	2.62	2.37	2.06
	2	1.38	1.47	2.32	2.32	0.13	0.12	0.13	0.13	3.06	3.12	3.30	3.06
Alfalfa	1	1.99	2.35	2.49	2.51	0.32	0.29	0.24	0.17	3.28	3.37	3.15	2.90
	2	1.59	1.60	1.67	2.35	0.22	0.18	0.15	0.13	3.47	2.33	3.18	2.61
Kikuyu grass	1	0.26	0.25	0.29	0.46	0.22	0.21	0.22	0.26	2.97	2.95	2.87	3.35
	2	0.57	0.57	0.59	0.60	0.19	0.19	0.19	0.16	3.08	3.26	3.12	3.59
	3	0.59	0.69	0.61	0.63	0.17	0.19	0.19	0.16	2.63	2.72	2.83	2.46
	4	0.78	0.82	0.90	0.83	0.21	0.21	0.24	0.18	3.49	3.88	4.14	3.98
Bermuda grass	1	0.29	0.28	0.31	0.35	0.16	0.15	0.12	0.09	3.17	3.52	3.44	3.19
	2	0.57	0.54	0.55	0.60	0.15	0.14	0.12	0.09	2.76	3.11	3.03	2.39
	3	0.46	0.59	0.57	0.60	0.13	0.15	0.12	0.08	2.54	2.67	2.27	2.19
Guinea grass	1	0.77	0.79	0.82	0.90	0.25	0.25	0.23	0.21	3.03	3.26	2.94	2.95
	2	1.49	1.74	1.63	1.55	0.19	0.20	0.18	0.15	2.70	2.76	2.78	2.60
	3	1.37	1.56	1.74	1.69	0.16	0.16	0.17	0.16	2.70	2.04	1.89	1.61
	4	1.35	1.60	1.96	2.02	0.17	0.18	0.20	0.19	4.49	4.74	3.17	3.50
Sorghum	1	0.65	0.73	0.77	0.99	0.30	0.32	0.30	0.24	3.45	3.57	3.09	3.12
	2	0.84	0.84	0.84	1.00	0.20	0.19	0.17	0.17	2.28	2.72	2.78	3.02
	3	1.18	1.00	1.04	0.97	0.18	0.17	0.18	0.16	1.67	1.94	2.20	1.09
Lettuce	1	1.91	3.92	4.75	4.15	0.31	0.36	0.30	0.63	1.03	1.05	0.98	1.14
	2	1.68	1.96	2.49	3.14	0.30	0.30	0.29	0.27	6.70	7.69	6.59	6.78
	3	0.53	1.60	3.09	3.64	0.18	0.39	0.52	0.45	0.25	0.61	0.57	0.71
	4	1.63	2.29	2.62	4.24	0.48	0.40	0.36	0.42	0.53	0.50	0.52	0.73

TABLE 3. RESIDUAL EFFECTS OF CALCIUM SILICATE ON Mn AND Al CONCENTRATIONS IN PLANTS GROWN ON KAPAA AND PAALOA SOILS

Species	Harvest	Kapaa Soil								Paaloa Soil							
		Mn in tops				Al in tops				Mn in tops				Al in tops			
		T Si/ha				T Si/ha				T Si/ha				T Si/ha			
		0	0.56	2.2	8.8	0	0.56	2.2	8.8	0	0.56	2.2	8.8	0	0.56	2.2	8.8
		(ppm)				(ppm)				(ppm)				(ppm)			
Big trefoil	1	29	24	17	16	108	127	131	63	193	113	69	43	210	232	157	135
	2	26	19	23	17	64	117	107	65	180	131	107	58	131	119	83	71
	3	24	24	27	26	289	497	543	364	164	78	74	25	169	331	218	120
Intortum	1	30	14	16	17	46	44	50	47	177	141	47	19	110	104	118	50
	2	22	19	29	24	72	76	100	121	189	177	115	24	89	60	57	53
	3	18	17	23	21	61	41	40	122	108	128	108	27	46	80	82	93
	4	16	17	21	21	67	27	56	63	216	189	141	28	384	363	198	65
Kaimi clover	1	37	11	17	11	189	189	161	117	125	118	63	12	109	92	64	35
	2	38	25	17	14	167	173	321	183	143	136	114	20	273	210	175	146
Alfalfa	1	21	15	12	19	63	49	44	39	115	108	55	16	99	60	61	52
	2	13	10	18	17	150	175	142	129	110	93	51	14	59	56	48	44
Kikuyu grass	1	28	9	8	8	50	49	44	42	81	53	19	18	47	37	35	18
	2	14	10	11	10	166	87	109	53	82	63	53	17	157	188	157	49
	3	9	8	10	16	51	51	65	46	74	80	65	17	141	184	185	67
	4	15	10	8	10	119	90	88	56	110	88	80	19	62	42	86	6
Bermuda grass	1	7	12	10	21	34	34	28	21	71	78	19	10	64	35	23	17
	2	15	16	20	27	49	50	66	64	90	75	36	10	40	50	52	41
	3	8	8	9	15	141	46	44	41	112	121	71	12	63	72	73	53
Guinea grass	1	22	20	27	12	91	82	75	66	116	92	34	7	94	70	67	40
	2	25	24	27	18	57	72	57	64	156	173	84	13	87	77	53	45
	3	21	22	37	21	55	62	50	52	192	176	120	21	75	69	80	73
	4	21	22	43	18	99	98	91	66	169	165	150	27	29	27	72	54
Sorghum	1	10	11	13	12	122	87	78	77	61	38	26	11	47	42	32	31
	2	17	13	19	11	41	36	35	34	87	60	36	13	35	24	29	29
	3	16	16	21	11	38	34	29	58	109	98	65	7	70	63	71	67

TABLE 4. EFFECTS OF HCC*, TVA† AND TG†† CALCIUM SILICATES ON DRY MATTER YIELDS OF KIKUYU GRASS GROWN ON KAPAA AND PAALOA SOILS

	Kapaa soil									
	Dry matter yield					% of maximum yield				
	T material/A					T material/A				
	0	2	4	8	16	0	2	4	8	16
	(g/pot)					(%)				
Harvest 1										
TVA	12.30	16.10	11.90	13.95	13.68	76	100	74	87	85
HCC	12.30	14.50	11.30	10.80	10.70	85	100	78	74	74
TG	12.30	14.82	15.85	13.75	13.75	78	94	100	87	87
Harvest 2										
TVA	18.72	20.80	19.58	20.36	24.61	76	85	80	83	100
HCC	18.72	21.66	22.05	21.99	21.26	85	98	100	99	96
TG	18.72	20.76	19.79	21.91	26.02	72	80	76	84	100
Harvest 3										
TVA	25.70	27.60	26.95	30.60	33.20	77	83	81	92	100
HCC	25.70	29.80	34.15	28.30	29.45	75	87	100	83	86
TG	25.70	26.40	30.30	36.30	37.60	68	70	81	97	100
Harvest 4										
TVA	9.80	13.05	12.00	14.00	16.40	60	80	73	85	100
HCC	9.80	11.00	12.70	11.40	12.40	77	87	100	90	98
TG	9.80	12.50	14.30	14.90	16.20	60	77	88	92	100

	Paaloa soil										
	Dry matter yield						% of maximum yield				
	T material/A						T material/A				
	0	2	4	8	16	Ave.	0	2	4	8	16
	(g/pot)						(%)				
Harvest 1											
TVA	12.77	13.58	11.60	10.28	11.38		94	100	85	76	84
HCC	12.77	12.51	10.70	11.01	9.88		100	98	84	86	77
TG	12.77	13.00	12.90	11.75	10.96		98	100	99	90	84
Harvest 2											
TVA	16.60	16.50	18.05	18.70	19.80		84	83	91	94	100
HCC	16.60	19.70	16.40	18.90	18.80		84	100	83	96	95
TG	16.60	18.50	18.00	17.80	19.50		85	95	92	91	100
Harvest 3											
TVA	16.70	17.00	18.00	18.30	19.40		86	88	93	94	100
HCC	16.70	18.40	16.10	19.20	21.30		78	86	76	90	100
TG	16.70	16.30	17.80	17.50	20.00		84	82	89	88	100
Harvest 4											
TVA	12.55	13.90	14.81	16.05	17.80	15.02b#	71	78	83	90	100
HCC	12.55	14.73	15.42	16.07	16.54	15.06b	76	89	93	97	100
TG	12.55	13.50	13.36	14.15	14.89	13.69a	84	90	90	95	100

*Hawaiian Cement Corporation Calcium Silicate.
†Tennessee Valley Authority Calcium Silicate.
††Technical Grade Calcium Silicate.
#Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 5. EFFECTS OF HCC*, TVA† AND TG†† CALCIUM SILICATES ON Si AND P CONCENTRATIONS IN KIKUYU GRASS GROWN ON KAPAA AND PAALOA SOILS

	Kapaa soil												Paaloa soil										
	Si in tops						P in tops						Si in tops						P in tops				
	T material/A						T material/A						T material/A						T material/A				
	0	2	4	8	16	Ave.	0	2	4	8	16	Ave.	0	2	4	8	16	Ave.	0	2	4	8	16
	(%)						(%)						(%)						(%)				
Harvest 1																							
TVA	0.10	0.24	0.32	0.38	0.41	0.29a#	0.18	0.17	0.18	0.16	0.16	0.17a	0.27	0.51	0.55	0.73	0.66	0.54a#	0.25	0.29	0.30	0.28	0.27
HCC	0.10	0.51	0.61	0.61	0.63	0.49b	0.18	0.17	0.17	0.21	0.19	0.18ab	0.27	0.57	0.65	0.90	0.74	0.63b	0.25	0.30	0.28	0.29	0.28
TG	0.10	0.43	0.62	0.64	0.91	0.54c	0.18	0.18	0.19	0.20	0.21	0.19b	0.27	0.43	0.59	0.92	1.04	0.61c	0.25	0.28	0.31	0.31	0.29
Harvest 2																							
TVA	0.06	0.19	0.29	0.51	0.52	0.31a	0.18	0.20	0.21	0.22	0.23		0.10	0.32	0.38	0.56	0.60	0.39a	0.22	0.24	0.24	0.24	0.26
HCC	0.06	0.29	0.55	0.59	0.63	0.42b	0.18	0.19	0.23	0.23	0.23		0.10	0.36	0.54	0.91	0.98	0.58b	0.22	0.24	0.26	0.26	0.25
TG	0.06	0.24	0.48	0.65	0.72	0.43b	0.18	0.21	0.21	0.24	0.23		0.10	0.21	0.38	0.51	0.86	0.41a	0.22	0.24	0.24	0.25	0.26
Harvest 3																							
TVA	0.07	0.26	0.43	0.61	0.77	0.43a	0.18	0.19	0.20	0.20	0.19		0.26	0.44	0.64	0.85	0.77		0.26	0.29	0.27	0.26	0.28
HCC	0.07	0.28	0.45	0.90	1.03	0.55b	0.18	0.17	0.18	0.20	0.22		0.26	0.26	0.51	0.95	1.11		0.26	0.28	0.29	0.29	0.29
TG	0.07	0.30	0.42	0.59	1.09	0.49b	0.18	0.20	0.18	0.17	0.17		0.26	0.29	0.47	0.61	1.15		0.26	0.29	0.27	0.27	0.26
Harvest 4																							
TVA	0.06	0.23	0.30	0.47	0.69	0.35a	0.31	0.29	0.29	0.32	0.30		0.13	0.44	0.65	0.76	0.68		0.38	0.35	0.34	0.34	0.34
HCC	0.06	0.26	0.39	0.60	0.95	0.45b	0.31	0.32	0.31	0.33	0.30		0.13	0.26	0.42	0.81	1.04		0.38	0.33	0.35	0.36	0.36
TG	0.06	0.30	0.47	0.68	1.06	0.51c	0.31	0.31	0.29	0.30	0.29		0.13	0.31	0.44	0.57	0.91		0.38	0.37	0.34	0.36	0.35

*Hawaiian Cement Corporation Clacium Silicate.
†Tennessee Valley Authority Calcium Silicate.
††Technical Grade Calcium Silicate.
#Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 6. EFFECTS OF HCC*, TVA† AND TG†† CALCIUM SILICATES ON Ca, Mg AND K CONCENTRATIONS IN KIKUYU GRASS GROWN ON KAPAA SOIL

	Ca in tops						Mg in tops						K in tops				
	T material/A						T material/A						T material/A				
	0	2	4	8	16	Ave.	0	2	4	8	16	Ave.	0	2	4	8	16
	(%)						(%)						(%)				
Harvest 1																	
TVA	0.37	0.39	0.52	0.53	0.46		0.25	0.22	0.23	0.19	0.16		2.49	2.47	2.65	2.82	2.69
HCC	0.37	0.43	0.45	0.47	0.63		0.25	0.25	0.18	0.18	0.20		2.49	2.43	2.58	2.52	2.55
TG	0.37	0.34	0.38	0.43	0.56		0.25	0.21	0.23	0.19	0.22		2.49	2.70	2.60	2.30	2.52
Harvest 2																	
TVA	0.58	0.74	0.83	0.99	0.98	0.82b#	0.32	0.35	0.35	0.39	0.35		2.30	2.14	2.29	2.24	2.05
HCC	0.58	0.67	0.81	0.85	0.95	0.77b	0.32	0.34	0.37	0.35	0.30		2.30	1.75	1.68	2.14	2.28
TG	0.58	0.64	0.69	0.77	0.77	0.69a	0.32	0.35	0.37	0.39	0.39		2.30	2.11	1.86	2.16	1.85
Harvest 3																	
TVA	0.87	1.06	1.10	1.15	1.20	1.08b	0.25	0.27	0.28	0.29	0.29	0.28b	1.92	1.75	1.86	2.02	1.95
HCC	0.87	1.12	0.97	1.14	1.26	1.07b	0.25	0.26	0.24	0.30	0.29	0.27b	1.92	1.85	1.75	1.91	2.28
TG	0.87	1.07	1.09	0.93	0.92	0.98a	0.25	0.26	0.25	0.22	0.26	0.25a	1.92	1.75	1.86	2.02	1.95
Harvest 4																	
TVA	1.17	1.46	1.56	1.68	1.58		0.26	0.25	0.26	0.25	0.27		2.65	2.98	2.63	2.73	2.53
HCC	1.17	1.55	1.50	1.74	1.50		0.26	0.25	0.26	0.29	0.25		2.65	2.52	2.46	2.39	2.38
TG	1.17	1.25	1.45	1.52	1.68		0.26	0.23	0.28	0.25	0.25		2.65	2.54	2.31	2.51	2.91

*Hawaiian Cement Corporation Calcium Silicate.
†Tennessee Valley Authority Calcium Silicate.
††Technical Grade Calcium Silicate.
#Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 7. EFFECTS OF HCC*, TVA† AND TG†† calcium silicates on Ca, Mg AND K CONCENTRATIONS IN KIKUYU GRASS GROWN ON PAALOA SOIL

	Ca in tops T material/A						Mg in tops T material/A					K in tops T material/A				
	0	2	4	8	16	Ave.	0	2	4	8	16	0	2	4	8	16
	(%)						(%)					(%)				
Harvest 1																
TVA	0.29	0.35	0.43	0.55	0.62	0.45b#	0.26	0.25	0.25	0.26	0.24	2.75	2.54	2.72	1.99	2.56
HCC	0.29	0.39	0.46	0.51	0.62	0.45b	0.26	0.26	0.23	0.23	0.26	2.75	2.74	2.58	2.56	2.60
TG	0.29	0.33	0.35	0.44	0.42	0.37a	0.26	0.26	0.26	0.22	0.26	2.75	2.41	2.58	2.49	2.33
Harvest 2																
TVA	0.32	0.45	0.47	0.47	0.47		0.21	0.23	0.20	0.18	0.17	2.49	2.56	2.70	2.54	2.58
HCC	0.32	0.52	0.50	0.45	0.53		0.21	0.24	0.21	0.19	0.18	2.49	2.64	2.96	2.88	2.72
TG	0.32	0.42	0.47	0.51	0.49		0.21	0.22	0.22	0.22	0.20	2.49	2.69	2.61	2.65	2.51
Harvest 3																
TVA	0.54	0.70	0.67	0.69	0.67		0.24	0.25	0.24	0.24	0.26	2.76	2.74	2.70	2.61	2.51
HCC	0.54	0.59	0.71	0.64	0.62		0.24	0.26	0.27	0.24	0.23	2.76	2.49	2.50	2.39	2.52
TG	0.54	0.67	0.73	0.66	0.60		0.24	0.23	0.25	0.24	0.22	2.76	2.23	2.42	2.35	2.34
Harvest 4																
TVA	0.64	0.77	0.85	0.93	0.90	0.82b#	0.33	0.31	0.31	0.31	0.27	2.52	2.80	2.77	2.66	2.52
HCC	0.64	0.81	0.81	0.91	0.86	0.81b	0.33	0.31	0.30	0.30	0.28	2.52	2.61	2.75	2.62	2.61
TG	0.64	0.71	0.75	0.87	0.85	0.76a	0.33	0.28	0.28	0.30	0.28	2.52	2.72	2.85	2.70	2.60

*Hawaiian Cement Corporation Calcium Silicate.
†Tennessee Valley Authority Calcium Silicate.
††Technical Grade Calcium Silicate.
#Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 8. EFFECTS OF HCC*, TVA† AND TG†† CALCIUM SILICATES ON Mn CONCENTRATIONS IN KIKUYU GRASS GROWN ON KAPAA AND PAALOA SOILS

	Kapaa soil						Paaloa soil					
	Mn in tops						Mn in tops					
	T material/A						T material/A					
	0	2	4	8	16	Ave.	0	2	4	8	16	Ave.
	(ppm)						(ppm)					
Harvest 1												
TVA	101	59	33	20	11	45a#	133	99	68	22	14	67a#
HCC	101	59	33	12	9	42a	133	103	40	19	19	63a
TG	101	59	55	34	18	53b	133	115	81	22	45	79b
Harvest 2												
TVA	42	35	26	18	7	26b#	48	40	29	5	6	
HCC	42	34	21	8	5	22a	48	15	13	10	5	
TG	42	37	30	28	21	32c	48	17	16	12	7	
Harvest 3												
TVA	43	30	28	19	11	26a	104	85	68	45	28	
HCC	43	43	32	15	8	28a	104	106	85	42	19	
TG	43	53	44	31	20	38b	104	128	70	66	52	
Harvest 4												
TVA	80	45	44	17	6	38ab	149	92	87	59	31	84a
HCC	80	63	28	24	17	42a	149	111	82	52	23	83a
TG	80	73	41	36	16	49b	149	127	120	92	60	110b

*Hawaiian Cement Corporation Calcium Silicate.
†Tennessee Valley Authority Calcium Silicate.
††Technical Grade Calcium Silicate.
#Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 9. SOIL pH VALUES FOR SAMPLES AFTER THE FOURTH KIKUYU GRASS CROP GROWN ON KAPAA AND PAALOA SOILS

	Kapaa soil						Paaloa soil					
	pH						pH					
	T material/A						T material/A					
	0	2	4	8	16	Ave.	0	2	4	8	16	Ave.
TVA	4.75	5.05	5.00	5.85	6.15	6.36c#	4.65	4.70	5.30	5.80	6.65	5.42b#
HCC	4.75	5.15	5.40	5.75	6.45	5.50b	4.65	4.80	5.35	5.90	6.70	5.48b
TG	4.75	4.95	5.15	5.40	5.95	5.24a	4.65	4.60	4.55	4.85	5.60	4.85a

#Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 10. EFFECTS OF HCC*, TVA† AND TG†† CALCIUM SILICATES ON DRY MATTER YIELDS OF LETTUCE GROWN ON KAPAA AND PAALOA SOILS

	Kapaa soil									
	Dry matter yield					% of maximum yield				
	T material/A					T material/A				
	0	2	4	8	16	0	2	4	8	16
	(g/pot)					(%)				
Harvest 1										
TVA	0.50	1.50	1.60	2.20	1.25	23	68	73	100	57
HCC	0.50	1.45	1.85	2.10	2.00	23	66	84	100	91
TG	0.50	1.20	1.60	1.90	2.50	20	48	64	76	100
Harvest 2										
TVA	0.15	0.90	0.92	0.98	0.33	15	92	94	100	34
HCC	0.15	0.33	1.00	0.45	0.75	15	33	100	45	75
TG	0.15	0.35	0.70	1.02	2.00	8	18	35	51	100
Harvest 3										
TVA	0.04	0.40	0.50	0.95	1.01	4	40	50	95	100
HCC	0.04	0.26	0.55	0.76	0.68	5	34	72	100	89
TG	0.04	0.06	0.13	0.29	1.21	3	5	11	24	100
Harvest 4										
TVA	0.02	0.19	0.28	0.35	0.95	2	20	29	37	100
HCC	0.02	0.12	0.33	0.88	0.63	2	14	38	100	72
TG	0.02	0.01	0.02	0.35	0.51	4	2	4	69	100

	Paaloa soil										
	Dry matter yield						% of maximum yield				
	T material/A						T material/A				
	0	2	4	8	16	Ave.	0	2	4	8	16
	(g/pot)						(%)				
Harvest 1											
TVA	0.145	0.317	1.30	1.75	2.14	1.13ab#	7	15	61	82	100
HCC	0.145	0.835	0.934	2.46	1.88	1.25b	6	34	38	100	76
TG	0.145	0.279	0.567	0.912	2.25	0.83a	6	12	25	41	100
Harvest 2											
TVA	0.70	0.95	1.10	1.00	1.50		47	63	73	67	100
HCC	0.70	0.75	0.60	1.25	1.55		45	48	39	81	100
TG	0.70	0.90	0.65	0.60	1.40		50	64	46	43	100
Harvest 3											
TVA	0.05	0.33	1.09	2.24	1.49	1.04b	2	15	49	100	67
HCC	0.05	0.53	1.30	2.01	1.83	1.14b	2	26	65	100	91
TG	0.05	0.09	0.10	0.65	2.34	0.65a	2	4	4	28	100
Harvest 4											
TVA	0.40	1.00	1.26	2.33	3.20	1.64b	13	31	39	73	100
HCC	0.40	0.85	1.16	2.60	3.45	1.69b	12	25	34	75	100
TG	0.40	0.80	0.73	0.84	0.89	0.73a	45	90	82	94	100

*Hawaiian Cement Corporation Calcium Silicate.
†Tennessee Valley Authority Calcium Silicate.
††Technical Grade Calcium Silicate.
#Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 11. EFFECTS OF HCC*, TVA† AND TG†† CALCIUM SILICATES ON Si AND P CONCENTRATIONS IN LETTUCE GROWN ON KAPAA AND PAALOA SOILS

	Kapaa soil											Paaloa soil										
	Si in tops						P in tops					Si in tops						P in tops				
	T material/A						T material/A					T material/A						T material/A				
	0	2	4	8	16	Ave.	0	2	4	8	16	0	2	4	8	16	Ave.	0	2	4	8	16
	(%)						(%)					(%)						(%)				
Harvest 1																						
TVA	0.02	0.03	0.03	0.03	0.03	0.03a#	0.39	0.43	0.46	0.50	0.39	0.05	0.13	0.06	0.08	0.03		0.33	0.37	0.36	0.33	0.37
HCC	0.02	0.03	0.07	0.05	0.05	0.04b	0.39	0.44	0.45	0.45	0.46	0.05	0.10	0.11	0.05	0.04		0.33	0.32	0.39	0.40	0.32
TG	0.02	0.05	0.06	0.07	0.05	0.05c	0.39	0.32	0.38	0.50	0.59	0.05	0.08	0.09	0.12	0.06		0.33	0.35	0.33	0.43	0.40
Harvest 2																						
TVA	0.03	0.04	0.06	0.05	0.04		0.22	0.23	0.27	0.28	0.27	0.05	0.06	0.08	0.05	0.04	0.05a	0.72	0.60	0.67	0.57	0.78
HCC	0.03	0.11	0.11	0.09	0.06		0.22	0.18	0.20	0.24	0.26	0.05	0.08	0.09	0.08	0.05	0.07b	0.72	0.65	0.61	0.71	0.68
TG	0.03	0.07	0.07	0.06	0.06		0.22	0.22	0.23	0.26	0.27	0.05	0.06	0.10	0.11	0.08	0.08c	0.72	0.30	0.63	0.71	0.72
Harvest 3																						
TVA	0.09	0.10	0.10	0.06	0.05		0.21	0.31	0.26	0.32	0.33	0.05	0.07	0.05	0.04	0.03		0.33	0.41	0.48	0.47	0.53
HCC	0.09	0.11	0.11	0.10	0.08		0.21	0.24	0.29	0.27	0.26	0.05	0.05	0.06	0.04	0.05		0.33	0.41	0.50	0.57	0.48
TG	0.09	0.01	0.01	0.01	0.08		0.21	0.35	0.20	0.27	0.28	0.05	0.06	0.07	0.05	0.05		0.33	0.39	0.31	0.39	0.47
Harvest 4																						
TVA	0.04	0.08	0.05	0.05	0.03		0.42	0.27	0.28	0.32	0.35	0.05	0.06	0.06	0.05	0.04	0.05a	0.48	0.46	0.36	0.44	0.44
HCC	0.04	0.06	0.08	0.06	0.04		0.42	0.37	0.25	0.33	0.30	0.05	0.07	0.06	0.09	0.06	0.07b	0.48	0.36	0.38	0.37	0.47
TG	0.04	0.04	0.10	0.07	0.07		0.42	0.42	0.20	0.23	0.30	0.05	0.06	0.08	0.08	0.12	0.08c	0.48	0.35	0.49	0.35	0.39

*Hawaiian Cement Corporation Calcium Silicate.
†Tennessee Valley Authority Calcium Silicate.
††Technical Grade Calcium Silicate.
#Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 12. EFFECTS OF HCC*, TVA† AND TG†† CALCIUM SILICATES ON Ca AND Mg CONCENTRATIONS IN LETTUCE GROWN ON KAPAA AND PAALOA SOILS

	Kapaa soil											Paaloa soil										
	Ca in tops						Mg in tops					Ca in tops						Mg in tops				
	T material/A						T material/A					T material/A						T material/A				
	0	2	4	8	16	Ave.	0	2	4	8	16	0	2	4	8	16	Ave.	0	2	4	8	16
	(%)						(%)					(%)						(%)				
Harvest 1																						
TVA	0.96	1.82	2.55	3.61	3.66	2.52b#	0.46	0.45	0.46	0.48	0.48	-	-	-	-	-		-	-	-	-	-
HCC	0.96	1.99	2.75	3.01	3.81	2.50b	0.46	0.43	0.45	0.45	0.46	-	-	-	-	-		-	-	-	-	-
TG	0.96	1.39	1.50	2.89	3.89	2.13a	0.46	0.44	0.45	0.48	0.53	-	-	-	-	-		-	-	-	-	-
Harvest 2																						
TVA	1.67	1.93	2.35	2.87	3.22		0.51	0.46	0.34	0.33	0.34	1.47	2.65	3.97	4.51	5.25	3.57b	0.65	0.60	0.68	0.53	0.56
HCC	1.67	3.06	2.91	1.86	4.18		0.51	0.44	0.39	0.16	0.31	1.47	2.92	3.46	5.36	5.20	3.68b	0.65	0.82	0.71	0.64	0.52
TG	1.67	2.12	2.04	1.76	2.48		0.51	0.48	0.37	0.39	0.36	1.47	1.98	2.84	4.25	4.90	3.09a	0.65	0.44	0.84	0.58	0.63
Harvest 3																						
TVA	3.75	3.41	4.43	3.54	4.37		0.46	0.52	0.53	0.42	0.44	1.20	2.11	2.76	3.36	3.88	2.66b	0.37	0.44	0.40	0.49	0.45
HCC	3.75	3.50	4.80	4.39	5.46		0.46	0.51	0.57	0.44	0.40	1.20	1.78	2.61	3.71	3.72	2.60b	0.37	0.38	0.41	0.49	0.45
TG	3.75	6.60	4.58	4.98	3.60		0.46	0.56	0.60	0.61	0.49	1.20	1.36	1.33	2.36	3.10	1.87a	0.37	0.43	0.29	0.39	0.45
Harvest 4																						
TVA	2.35	2.88	3.03	4.15	2.97		0.88	0.42	0.42	0.43	0.38	1.46	3.41	3.65	4.16	4.23	3.38b	0.67	0.64	0.52	0.44	0.56
HCC	2.35	4.18	3.55	3.45	3.59		0.88	0.67	0.45	0.42	0.37	1.46	2.64	3.66	4.38	4.86	3.40b	0.67	0.48	0.46	0.43	0.39
TG	2.35	1.90	2.53	2.76	3.69		0.88	0.50	0.49	0.38	0.42	1.46	0.50	1.22	3.02	5.86	2.41a	0.67	0.18	0.68	0.64	0.69

*Hawaiian Cement Corporation Calcium Silicate.
†Tennessee Valley Authority Calcium Silicate.
††Technical Grade Calcium Silicate.
#Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 13. EFFECTS OF HCC*, TVA† AND TG†† CALCIUM SILICATE ON Mn CONCENTRATIONS IN LETTUCE GROWN ON KAPAA AND PAALOA SOILS

	Kapaa soil						Paaloa soil					
	Mn in tops						Mn in tops					
	T material/A						T material/A					
	0	2	4	8	16	Ave.	0	2	4	8	16	Ave.
	(ppm)						(ppm)					
Harvest 1												
TVA	691	505	324	161	105	357ab#	-	-	-	-	-	
HCC	691	360	242	218	44	311a	-	-	-	-	-	
TG	691	516	356	348	115	405b	-	-	-	-	-	
Harvest 2												
TVA	858	428	187	69	46		1065	725	620	291	41	548a
HCC	858	336	208	34	25		1065	1012	784	172	40	615a
TG	858	728	464	63	42		1065	655	1296	1962	297	1055b
Harvest 3												
TVA	1020	1008	509	110	43		900	705	483	68	25	436a
HCC	1020	769	557	141	31		900	640	490	46	21	419a
TG	1020	2500	1340	869	80		900	1200	1095	678	99	794b
Harvest 4												
TVA	1600	1077	513	135	67		960	1059	490	414	132	611a
HCC	1600	1278	559	211	29		960	956	566	334	66	576a
TG	1600	1000	1182	709	169		960	709	298	1099	1179	849b

*Hawaiian Cement Corporation Calcium Silicate.
†Tennessee Valley Authority Calcium Silicate
††Technical Grade Calcium Silicate
#Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 14. pH VALUES AFTER EACH LETTUCE HARVEST ON KAPAA AND PAALOA SOILS

	Kapaa soil					Paaloa soil					
	pH					pH					
	T material/A					T material/A					
	0	2	4	8	16	0	2	4	8	16	
Harvest 1											
TVA	4.70	5.00	5.25	5.70	6.15	-	-	-	-	-	
HCC	4.70	5.05	5.40	5.95	6.80	-	-	-	-	-	
TG	4.70	4.70	4.85	5.20	5.80	-	-	-	-	-	
Harvest 2											
TVA	4.45	4.80	5.10	5.50	6.00	4.15	4.35	4.80	5.25	6.15	4.94b
HCC	4.45	4.95	5.10	5.60	6.40	4.15	4.35	4.65	5.40	6.45	5.00b
TG	4.45	4.45	4.65	4.95	5.55	4.15	4.20	4.20	4.40	5.05	4.40a
Harvest 3											
TVA	4.30	4.65	5.10	5.60	5.90	4.20	4.40	4.70	5.20	5.95	4.89b
HCC	4.30	4.50	4.90	5.45	6.35	4.20	4.50	4.55	5.35	6.10	4.94b
TG	4.30	4.30	4.50	4.95	5.45	4.20	4.30	4.20	4.40	5.05	4.43a
Harvest 4											
TVA	4.00	4.30	4.70	5.40	5.75	4.10	4.40	4.55	5.00	5.90	4.79b
HCC	4.00	4.45	4.60	5.10	6.05	4.10	4.30	4.30	4.95	6.05	4.74b
TG	4.00	4.00	4.10	4.50	5.15	4.10	4.35	4.55	4.45	4.75	4.44a

Tennessee Valley Authority (TVA)
Hawaiian Cement Corporation (HCC)
Technical Grade (TG)

TABLE 15. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON THE TOTAL DRY WEIGHT OF ONE-MONTH-OLD CORN*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha) 112	pH 5.5 P (kg/ha) 280	pH 5.5 P (kg/ha) 1120	pH 6.0 P (kg/ha) 112	pH 6.0 P (kg/ha) 280	pH 6.0 P (kg/ha) 1120	pH 6.5 P (kg/ha) 112	pH 6.5 P (kg/ha) 280	pH 6.5 P (kg/ha) 1120	pH 5.0 P (kg/ha) 112	pH 5.0 P (kg/ha) 280	pH 5.0 P (kg/ha) 1120	pH 6.0 P (kg/ha) 0
0	23.12	28.12	72.10	29.76	43.02	73.44	29.14	40.36	65.22				4.20
833	36.04	47.66	77.62	43.78	49.32	71.98	33.14	55.74	76.58	35.06	49.28	78.32	7.16
1666	39.46	73.10	83.38	39.88	49.34	79.44	42.92	49.24	71.86				7.64

Si x pH††

Si (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
0	41.11	48.74	44.90	44.91
833	53.77	55.02	55.15	54.64
1666	65.31	56.22	54.67	58.73
Ave.	53.39	53.32	51.54	

Si x P††

Si (kg/ha)	P (kg/ha) 112	P (kg/ha) 280	P (kg/ha) 1120	Ave.
0	27.34	37.16	70.25	44.91
833	37.65	50.90	75.39	54.64
1666	40.75	57.22	78.22	58.73
Ave.	35.24	48.42	74.62	

P x pH††

P (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
112	32.87	37.80	35.06	35.24
280	49.62	47.22	48.44	48.42
1120	77.70	74.95	71.22	74.62
Ave.	53.39	53.32	51.54	

Control Plot 3.14

* Dry wt/plant in grms.
† Means of 3 observations.
†† Means of 9 observations.

TABLE 16. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON TOTAL Si CONCENTRATION IN ONE-MONTH-OLD CORN*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 6.0 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	1038	1610	3041	1252	1377	2574	948	823	1306				1216
833	4418	5062	5474	3721	3524	4472	2594	3184	3005	5653	3971	5903	5456
1666	7459	6762	7656	5903	5849	6762	4794	3882	4615				7441

Si x pH††

Si (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
0	1896	1735	1025	1552
833	4984	3905	2927	3938
1666	7292	6171	4430	5964
Ave.	4724	3937	2794	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	1079	1270	2307	1552
833	3577	3923	4317	3939
1666	6082	5497	6344	5974
Ave.	3579	3563	4322	

P x pH††

P (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
112	4305	3625	2778	3569
280	4478	3583	2629	3563
1120	5390	4603	2975	4322
Ave.	4724	3937	2794	

Control Plot 1395

*Expressed as ppm Si.
†Means of 3 observations.
††Means of 9 observations.

TABLE 17. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON Si UPTAKE BY ONE-MONTH-OLD CORN*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 6.0 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	23.99	45.27	219.25	37.25	59.23	189.18	27.90	33.21	85.17				5.10
833	159.22	241.25	424.89	162.90	173.80	321.89	85.96	177.47	230.12	198.19	195.69	462.32	39.06
1666	294.33	494.30	638.35	235.41	288.58	537.17	205.75	191.14	331.63				56.84

Si x pH††

Si (kg/ha)	pH 5.5	6.0	6.5	Ave.
0	96.17	95.22	48.76	80.05
833	275.12	219.53	164.51	219.72
1666	475.66	353.72	242.84	357.40
Ave.	282.31	222.49	152.03	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	29.71	45.90	164.53	80.04
833	136.02	197.50	325.63	219.71
1666	245.16	324.67	502.38	357.40
Ave.	136.96	189.35	330.84	

P x pH††

P (kg/ha)	pH 5.5	6.0	6.5	Ave.
112	159.18	145.18	106.53	136.96
280	260.27	173.87	133.60	189.24
1120	427.49	349.41	215.64	330.84
Ave.	282.31	222.82	151.92	

Control Plot 4.38

*Expressed as mg/plant.
†Means of 3 observations.
††Means of 9 observations.

TABLE 18. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON P CONCENTRATION IN ONE-MONTH-OLD CORN*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha) 112	pH 5.5 280	pH 5.5 1120	pH 6.0 P (kg/ha) 112	pH 6.0 280	pH 6.0 1120	pH 6.5 P (kg/ha) 112	pH 6.5 280	pH 6.5 1120	pH 5.0 P (kg/ha) 112	pH 5.0 280	pH 5.0 1120	pH 6.0 P (kg/ha) 0
0	2354	2468	3166	2544	2999	2923	2848	2984	3075				1647
833	2698	2680	3378	2482	2696	3113	2620	2839	3303	2620	2839	3227	1936
1666	2581	2551	3067	2624	2657	3037	2611	3089	3227				1921

Si x pH††

Si (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
0	2662	2845	2969	2825
833	2915	2763	2920	2866
1666	2733	2776	2975	2828
Ave.	2770	2795	2955	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	2582	2817	3054	2817
833	2600	2738	3264	2867
1666	2608	2766	3110	2828
Ave.	2596	2773	3142	

P x pH††

P (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
112	2544	2553	2693	2596
280	2566	2784	2970	2773
1120	3203	3024	3201	3142
Ave.	2770	2787	2955	

Control Plot 1731

* Expressed as ppm P.
† Means of 3 observations.
†† Means of 9 observations.

TABLE 19. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON P UPTAKE BY ONE-MONTH-OLD PLANTS*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha) 112	pH 5.5 280	pH 5.5 1120	pH 6.0 P (kg/ha) 112	pH 6.0 280	pH 6.0 1120	pH 6.5 P (kg/ha) 112	pH 6.5 280	pH 6.5 1120	pH 5.0 P (kg/ha) 112	pH 5.0 280	pH 5.0 1120	pH 6.0 P (kg/ha) 0
0	54.42	69.40	228.26	75.70	129.01	214.06	82.99	120.63	200.55				6.91
833	97.23	127.72	262.20	108.66	132.96	224.07	86.82	158.24	252.94	91.85	139.90	252.73	13.86
1666	101.84	186.47	255.72	105.04	131.09	241.25	112.06	152.10	231.89				14.67

Si x pH††

Si (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
0	117.36	139.79	134.65	130.60
833	162.38	155.23	166.00	161.20
1666	181.34	159.12	165.35	168.60
Ave.	153.69	151.38	155.33	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	71.03	106.28	214.49	130.60
833	97.57	139.64	246.40	161.20
1666	106.31	156.55	242.95	168.60
Ave.	91.63	134.15	234.61	

P x pH††

P (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
112	84.49	96.46	93.95	91.63
280	127.86	131.02	143.59	134.15
1120	248.72	226.66	228.46	234.61
Ave.	153.69	151.38	155.33	

Control Plot 4.64

* Expressed as mg/plant.
† Means of 3 observations.
†† Means of 9 observations.

TABLE 20. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON Ca CONCENTRATION IN ONE-MONTH-OLD CORN*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 6.0 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	4992	6038	6702	6170	5445	6865	5621	5959	7480				5906
833	4552	5141	6355	4503	5726	7058	5752	5959	7309	5493	6540	6839	6650
1666	5418	5317	5291	6329	6570	5471	5880	5906	8585				5752

Si x pH††

Si (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
0	5910	6160	6353	6141
833	5349	5762	6338	5816
1666	5342	6123	6790	6085
Ave.	5533	6015	6493	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	5594	5814	7015	6141
833	4935	5608	6907	5816
1666	5875	5931	6449	6085
Ave.	5468	5784	6790	

P x pH††

P (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
112	4987	5667	5751	5468
280	5498	5913	5941	5784
1120	6116	6464	7791	6790
Ave.	5533	6015	6493	

Control Plot 2661.

* Expressed as ppm Ca.
† Means of 3 observations.
†† Means of 9 observations.

TABLE 21. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON Al CONCENTRATION IN ONE-MONTH-OLD CORN*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha) 112	pH 5.5 280	pH 5.5 1120	pH 6.0 P (kg/ha) 112	pH 6.0 280	pH 6.0 1120	pH 6.5 P (kg/ha) 112	pH 6.5 280	pH 6.5 1120	pH 5.0 P (kg/ha) 112	pH 5.0 280	pH 5.0 1120	pH 6.0 P (kg/ha) 0
0	104	101	31	111	50	32	73	74	9				335
833	50	51	50	67	83	30	84	22	35	92	68	20	328
1666	31	44	43	43	66	15	66	47	23				406

Si x pH††

Si (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
0	79	64	52	65
833	50	60	47	52
1666	39	41	45	41
Ave.	56	55	48	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	96	75	24	65
833	67	52	38	52
1666	46	52	27	41
Ave.	70	60	30	

P x pH††

P (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
112	61	73	74	70
280	65	66	47	60
1120	41	26	22	30
Ave.	56	55	48	

Control Plot 242

* Expressed as ppm Al.
† Means of 3 observations.
†† Means of 9 observations.

TABLE 22. INFLUENCE OF RESIDUAL S , P AND SOIL pH ON Si CONCENTRATION IN CORN LEAVES SAMPLED AT SILKING*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha) 112	280	1120	pH 6.0 P (kg/ha) 112	280	1120	pH 6.5 P (kg/ha) 112	280	1120	pH 5.0 P (kg/ha) 112	280	1120	pH 6.0 P (kg/ha) 0
0	2047	2564	3202	1806	1727	3359	1673	1487	2016				2504
833	5875	7735	6507	5122	4804	6712	3750	4653	3612	7862	8614	7988	6008
1666	8780	9198	9573	8373	7916	9168	6327	5514	6116				11082

Si x pH††

Si (kg/ha)	pH 5.5	6.0	6.5	Ave.
0	2604	2297	1725	2209a
833	6706	5546	4005	5419b
1666	9184	8486	5985	7885c
Ave.	6164	5443	3905	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	1842	1926	2859	2209
833	4916	5730	5610	5419
1666	7827	7542	8286	7885
Ave.	4871a	5066ab	5679b	

P x pH††

P (kg/ha)	pH 5.5	6.0	6.5	Ave.
112	5567	5100	3917	4861
280	6499	4816	3884	5066
1120	6427	6413	3914	5585
Ave.	6164c	5443b	3905a#	

Control Plot 1995

* Expressed as ppm Si.
† Means of 3 observations.
†† Means of 9 observations.
# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 23. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON P CONCENTRATION IN CORN LEAVES SAMPLED AT SILKING*

Si x P x pH†

Si	pH 5.5			pH 6.0			pH 6.5			pH 5.0			pH 6.0
(kg/ha)	P (kg/ha)			P (kg/ha)			P (kg/ha)			P (kg/ha)			P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	2729	3006	3492	3000	3338	3654	2919	3431	3683				1718
833	2876	3289	3659	2932	3308	3801	2883	3307	3800	2655	2901	3449	1786
1666	2925	3061	3283	2796	3209	4179	2913	3493	3967				1774

Si x pH††

Si	pH			Ave.
(kg/ha)	5.5	6.0	6.5	
0	3075	3330	3344	3249
833	3274	3347	3330	3317
1666	3089	3394	3457	3313
Ave.	3146	3357	3377	

Si x P††

Si	P (kg/ha)			Ave.
(kg/ha)	112	280	1120	
0	2885	3258	3609	3249
833	2897	3301	3753	3317
1666	2878	3254	3809	3313
Ave.	2885a	3271b	3723c#	

P x pH††

P	pH			Ave.
(kg/ha)	5.5	6.0	6.5	
112	2843	2909	2905	2885
280	3118	3285	3410	3271
1120	3474	3878	3816	3722
Ave.	3145	3357	3377	

Control Plot 1044.

* Expressed as ppm P.
† Means of 3 observations.
†† Means of 9 observations.
# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 24. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON Ca CONCENTRATION IN CORN LEAVES SAMPLES AT SILKING*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 6.0 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	4312	4605	5589	4991	4786	5188	4913	5563	5523				3632
833	4860	4888	5563	4859	5355	5464	5387	5498	5481	4603	4572	5004	3727
1666	4289	4847	5929	4783	4860	5753	5018	5595	5420				4034

Si x pH††

Si (kg/ha)	pH 5.5	6.0	6.5	Ave.
0	4835	4988	5333	5052
833	5104	5226	5455	5262
1666	5022	5132	5344	5166
Ave.	4987	5115	5377	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	5739	4985	5433	5052
833	5035	5247	5503	5262
1666	4697	5101	5701	5166
Ave.	4824a	5111b	5545c	

P x pH††

P (kg/ha)	pH 5.5	6.0	6.5	Ave.
112	4487	4878	5106	4824
280	4780	5000	5552	5111
1120	5693	5468	5475	5545
Ave.	4987	5115	5377	

Control Plot 2720

* Expressed as ppm Ca.
† Means of 3 observations.
†† Means of 9 observations.
# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 25. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON K IN CORN LEAVES SAMPLED AT SILKING*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 6.0 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	1.81	1.56	1.44	1.39	1.71	1.32	1.46	1.26	1.55				1.46
833	1.45	1.46	1.25	1.79	1.58	1.48	1.50	1.37	1.40	1.41	1.47	1.64	1.94
1666	2.06	1.55	1.31	1.60	1.46	1.45	1.27	1.54	1.30				1.94

Si x pH††

Si (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
0	1.60	1.47	1.42	1.50
833	1.39	1.62	1.42	1.48
1666	1.64	1.50	1.37	1.50
Ave.	1.54	1.53	1.40	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	1.55	1.51	1.44	1.50
833	1.58	1.47	1.38	1.48
1666	1.64	1.52	1.35	1.50
Ave.	1.59b	1.50ab	1.39a#	

P x pH††

P (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
112	1.77	1.59	1.41	1.59
280	1.52	1.58	1.39	1.50
1120	1.33	1.42	1.42	1.39
Ave.	1.54	1.53	1.40	

Control Plot 2.80.

* Expressed as % K.
† Means of 3 observations.
†† Means of 9 observations.
\# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 26. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON N CONCENTRATION IN CORN LEAVES AT SILKING*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha) 112	pH 5.5 P (kg/ha) 280	pH 5.5 P (kg/ha) 1120	pH 6.0 P (kg/ha) 112	pH 6.0 P (kg/ha) 280	pH 6.0 P (kg/ha) 1120	pH 6.5 P (kg/ha) 112	pH 6.5 P (kg/ha) 280	pH 6.5 P (kg/ha) 1120	pH 5.0 P (kg/ha) 112	pH 5.0 P (kg/ha) 280	pH 5.0 P (kg/ha) 1120	pH 6.0 P (kg/ha) 0
0	2.72	2.86	2.78	2.81	2.83	2.68	2.83	2.82	2.77				2.43
833	2.75	2.74	2.64	2.77	2.71	2.72	2.75	2.79	2.68	2.76	2.70	2.63	2.45
1666	2.70	2.59	2.68	2.73	2.82	2.64	2.77	2.76	2.75				2.47

Si x pH††

Si (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
0	2.78	2.77	2.81	2.79 b#
833	2.71	2.74	2.74	2.73 a
1666	2.66	2.73	2.76	2.72 a
Ave.	2.72	2.75	2.77	

Si x P††

Si (kg/ha)	P (kg/ha) 112	P (kg/ha) 280	P (kg/ha) 1120	Ave.
0	2.78	2.84	2.75	2.79
833	2.76	2.75	2.68	2.73
1666	2.73	2.72	2.69	2.72
Ave.	2.76	2.77	2.71	

P x pH††

P (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
112	2.72	2.77	2.78	2.76
280	2.73	2.79	2.79	2.77
1120	2.70	2.68	2.74	2.71
Ave.	2.72	2.75	2.77	

Control Plot 2.17

*Expressed as % N.
†Means of 3 observations.
††Means of 9 observations.
#Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 27. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON Al IN CORN LEAVES SAMPLED AT SILKING*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha) 112	pH 5.5 P (kg/ha) 280	pH 5.5 P (kg/ha) 1120	pH 6.0 P (kg/ha) 112	pH 6.0 P (kg/ha) 280	pH 6.0 P (kg/ha) 1120	pH 6.5 P (kg/ha) 112	pH 6.5 P (kg/ha) 280	pH 6.5 P (kg/ha) 1120	pH 5.0 P (kg/ha) 112	pH 5.0 P (kg/ha) 280	pH 5.0 P (kg/ha) 1120	pH 6.0 P (kg/ha) 0
0	32	28	25	19	27	27	25	23	15				114
833	27	18	16	32	23	20	26	26	23	27	18	15	65
1666	20	24	20	23	25	25	21	15	22				51

Si x pH††

Si (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
0	28	24	21	24
833	20	25	25	23
1666	21	24	19	21
Ave.	23	24	21	

Si x P††

Si (kg/ha)	P (kg/ha) 112	P (kg/ha) 280	P (kg/ha) 1120	Ave.
0	25	26	22	24
833	28	22	19	23
1666	21	21	22	21
Ave.	25	23	21	

P x pH††

P (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
112	26	24	24	25
280	23	25	21	23
1120	20	24	20	21
Ave.	23	24	21	

Control Plot 215

* Expressed as ppm Al.
† Means of 3 observations.
†† Means of 9 observations.

TABLE 28. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON Fe IN CORN LEAVES SAMPLED AT SILKING*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha) 112	pH 5.5 280	pH 5.5 1120	pH 6.0 P (kg/ha) 112	pH 6.0 280	pH 6.0 1120	pH 6.5 P (kg/ha) 112	pH 6.5 280	pH 6.5 1120	pH 5.0 P (kg/ha) 112	pH 5.0 280	pH 5.0 1120	pH 6.0 P (kg/ha) 0
0	119	102	106	110	86	72	90	79	82				108
833	81	71	81	85	88	65	96	74	75	91	87	66	80
1666	76	47	61	73	58	69	54	63	56				76

Si x pH††

Si (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
0	109	89	84	94 c#
833	78	79	82	80 b
1666	61	67	58	62 a
Ave.	83	78	74	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	106	89	87	94
833	87	78	74	80
1666	68	56	62	62
Ave.	87b	74a	74a#	

P x pH††

P (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
112	92	89	80	87
280	73	77	72	74
1120	83	68	71	74
Ave.	83	78	74	

Control Plot 135

* Expressed as ppm Fe.
† Means of 3 observations.
†† Means of 9 observations.
\# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 29. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON YIELD OF EAR CORN*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 6.0 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	4.49	4.86	5.24	5.42	5.56	5.88	5.14	3.97	5.58				2.42
833	5.04	5.20	5.18	5.57	5.68	5.98	5.02	4.60	6.06	6.13	6.31	5.82	3.45
1666	3.16	5.08	5.70	4.91	4.61	6.78	4.62	5.68	5.04				3.58

Si x pH††

Si (kg/ha)	pH 5.5	6.0	6.5	Ave.
0	4.86	5.62	4.90	5.13
833	5.14	5.74	5.23	5.37
1666	4.65	5.43	5.11	5.06
Ave.	4.88	5.60	5.08	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	5.02	4.80	5.57	5.13
833	5.21	5.16	5.74	5.37
1666	4.23	5.12	5.84	5.06
Ave.	4.82	5.03	5.71	

P x pH††

P (kg/ha)	pH 5.5	6.0	6.5	Ave.
112	4.23	5.30	4.92	4.82
280	5.05	5.28	4.75	5.03
1120	5.37	6.21	5.56	5.71
Ave.	4.88	5.60	5.08	

Control Plot 0.90

* Expressed on oven-dried basis in Tons (metric)/ha
† Means of 3 observations.
†† Means of 9 observations.

TABLE 30. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON YIELD OF CORN STOVER*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 6.0 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	7.05	8.60	10.40	8.37	8.18	8.50	9.14	9.60	9.51				4.83
833	8.83	10.10	10.26	8.21	9.34	10.06	9.06	9.49	9.92	9.11	11.19	10.60	6.16
1666	10.71	9.52	10.85	8.55	9.41	10.08	9.41	10.08	8.48				6.74

Si x pH††

Si (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
0	8.68	8.35	9.41	8.82 a#
833	9.73	9.20	9.49	9.47 b
1666	10.36	9.36	9.32	9.68 b
Ave.	9.59	8.97	9.41	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	8.19	8.79	9.47	8.82
833	8.70	9.64	10.08	9.47
1666	9.56	9.67	9.81	9.68
Ave.	8.81a	9.37ab	9.79b#	

P x pH††

P (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
112	8.86	8.38	9.20	8.81
280	9.41	8.98	9.72	9.37
1120	10.50	9.55	9.30	9.79
Ave.	9.59	8.97	9.41	

Control Plot 2.62

* Expressed on oven-dried basis in Tons (metric)/ha.
† Means of 3 observations.
†† Means of 9 observations.
# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 31. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON TOTAL CORN YIELD (STOVER + EARS)*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 6.0 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	11.54	13.46	15.64	13.76	13.74	14.39	14.28	13.57	15.09				7.25
833	13.87	15.31	15.44	13.78	15.02	16.04	14.07	14.09	15.98	15.24	17.48	16.43	9.62
1666	13.87	14.60	16.55	13.46	14.05	16.86	14.03	15.77	13.52				10.32

Si x pH††

Si (kg/ha)	pH 5.5	6.0	6.5	Ave.
0	13.54	13.96	14.31	13.94
833	14.87	14.95	14.71	14.84
1666	15.01	14.79	14.44	14.75
Ave.	14.47	14.57	14.49	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	13.19	13.59	15.04	13.94
833	13.91	14.81	15.82	14.84
1666	13.79	14.81	15.64	14.75
Ave.	13.63	14.40	15.50	

P x pH††

P (kg/ha)	pH 5.5	6.0	6.5	Ave.
112	13.09	13.67	14.12	13.63
280	14.46	14.27	14.48	14.40
1120	15.88	15.76	14.86	15.50
Ave.	14.47	14.57	14.49	

Control Plot 3.13

* Expressed on oven-dried basis in Tons (metric)/ha.
† Means of 3 observations.
†† Means of 9 observations.

TABLE 32. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON WATER-EXTRACTABLE SOIL Si (SAMPLED IN JANUARY 1969 AFTER CORN HARVEST)*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 6.0 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	0.56	0.65	0.69	0.53	0.48	0.83	0.50	0.43	0.66				0.60
833	1.31	1.50	1.31	1.39	1.21	1.39	0.89	1.14	1.16	1.34	1.16	1.18	1.23
1666	2.11	1.98	1.66	1.88	1.61	1.78	1.63	1.46	1.78				1.80

Si x pH††

Si (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
0	0.64	0.61	0.53	0.59 a#
833	1.38	1.33	1.06	1.26 b
1666	1.92	1.76	1.63	1.77 c
Ave.	1.31	1.23	1.07	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	0.53	0.52	0.73	0.59
833	1.20	1.29	1.29	1.26
1666	1.87	1.69	1.74	1.77
Ave.	1.20	1.16	1.25	

P x pH††

P (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
112	1.33	1.27	1.00	1.20
280	1.38	1.10	1.01	1.16
1120	1.22	1.33	1.20	1.25
Ave.	1.31b	1.23b	1.07a#	

Control Plot 0.48.

* Expressed as ppm Si in 1:10 soil:water extract.
† Means of 3 observations
†† Means of 9 observations.
\# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 33. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON MODIFIED-TRUOG EXTRACTABLE SOIL Si (SAMPLED IN JANUARY 1969 AFTER CORN HARVEST)*

Si x P x pH†

Si	pH 5.5			pH 6.0			pH 6.5			pH 5.0			pH 6.0
(kg/ha)	P (kg/ha)			P (kg/ha)			P (kg/ha)			P (kg/ha)			P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	22	26	24	34	27	36	55	41	42				31
833	68	63	45	84	74	54	99	89	103	62	51	38	71
1666	92	83	57	116	86	78	170	150	144				93

Si x pH††

Si	pH			Ave.
(kg/ha)	5.5	6.0	6.5	
0	24	32	46	34 a#
833	59	71	97	76 b
1666	78	94	154	108 c
Ave.	53	66	99	

Si x P††

Si	P (kg/ha)			Ave.
(kg/ha)	112	280	1120	
0	37	31	34	34
833	84	76	68	76
1666	126	106	93	108
Ave.	82b	71a	65a	

P x pH††

P	pH			Ave.
(kg/ha)	5.5	6.0	6.5	
112	61	78	108	82
280	57	63	93	71
1120	42	56	96	65
Ave.	53a	66a	99b	

Control Plot 28

* Expressed as ppm Si.
† Means of 3 observations.
†† Means of 9 observations.
\# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 34. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON MODIFIED-TRUOG EXTRACTABLE SOIL P (SAMPLED IN JANUARY 1969 AFTER CORN HARVEST)*

Si x P x pH†

Si	pH 5.5			pH 6.0			pH 6.5			pH 5.0			pH 6.0
(kg/ha)	P (kg/ha)			P (kg/ha)			P (kg/ha)			P (kg/ha)			P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	23	47	235	29	59	236	26	42	178				14
833	29	72	188	31	56	196	28	55	217	31	50	178	16
1666	24	52	172	28	51	221	33	48	260				12

Si x pH††

Si	pH			Ave.
(kg/ha)	5.5	6.0	6.5	
0	102	108	82	97
833	96	95	100	97
1666	83	100	114	99
Ave.	94	101	98	

Si x P††

Si	P (kg/ha)			Ave.
(kg/ha)	112	280	1120	
0	26	49	216	97
833	29	61	200	97
1666	28	50	218	99
Ave.	28a	54b	212c#	

P x pH††

P	pH			Ave.
(kg/ha)	5.5	6.0	6.5	
112	25	30	29	28
280	57	55	48	54
1120	198	218	218	212
Ave.	94	101	98	

Control Plot 10

* Expressed as ppm P.
† Means of 3 observations.
†† Means of 9 observations.
\# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 35. SOIL pH VALUES FROM SAMPLES (0-15 CM) TAKEN AFTER CORN HARVEST

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha) 112	pH 5.5 P (kg/ha) 280	pH 5.5 P (kg/ha) 1120	pH 6.0 P (kg/ha) 112	pH 6.0 P (kg/ha) 280	pH 6.0 P (kg/ha) 1120	pH 6.5 P (kg/ha) 112	pH 6.5 P (kg/ha) 280	pH 6.5 P (kg/ha) 1120	pH 5.0 P (kg/ha) 112	pH 5.0 P (kg/ha) 280	pH 5.0 P (kg/ha) 1120	pH 6.0 P (kg/ha) 0
0	5.43	5.40	5.48	5.93	6.07	5.96	6.71	6.66	6.30				5.87
833	5.45	5.52	5.38	6.03	6.01	5.94	6.64	6.27	6.64	5.12	5.14	5.17	5.95
1666	5.53	5.53	5.46	6.15	6.03	6.02	6.52	6.61	6.50				5.79

Si x pH††

Si (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
0	5.43	6.04	6.56	5.99
833	5.42	5.99	6.52	5.98
1666	5.51	6.08	6.55	6.04
Ave.	5.46a	6.02b	6.55c#	

Si x P††

Si (kg/ha)	P (kg/ha) 112	P (kg/ha) 280	P (kg/ha) 1120	Ave.
0	6.03	6.05	5.92	5.99
833	6.01	5.94	5.99	5.98
1666	6.07	6.07	5.99	6.04
Ave.	6.03	6.02	5.97	

P x pH††

P (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
112	5.44	6.03	6.62	6.03
280	5.48	6.05	6.52	6.02
1120	5.44	5.98	6.48	5.97
Ave.	5.46	6.02	6.54	

Control Plot 4.89

† Means of 3 observations.
†† Means of 9 observations
# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 36. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON Si IN CORN GRAIN AT HARVEST*

Si x P x pH†

Si	pH 5.5			pH 6.0			pH 6.5			pH 5.0			pH 6.0
(kg/ha)	P (kg/ha)			P (kg/ha)			P (kg/ha)			P (kg/ha)			P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	18	34	10	14	3	11	4	4	8				10
833	37	35	19	20	6	16	5	5	13	21	15	24	21
1666	54	43	33	24	7	26	21	24	17				36

Si x pH††

Si	pH			Ave.
(kg/ha)	5.5	6.0	6.5	
0	20	9	5	11
833	30	14	8	17
1666	43	19	21	28
Ave.	31	14	11	

Si x P††

Si	P (kg/ha)			Ave.
(kg/ha)	112	280	1120	
0	12	14	9	11
833	20	15	16	17
1666	33	25	25	28
Ave.	21	18	17	

P x pH††

P	pH			Ave.
(kg/ha)	5.5	6.0	6.5	
112	36	19	10	21
280	37	5	11	18
1120	21	17	13	17
Ave.	31	14	11	

Control Plot 6.5

* Expressed as ppm Si.
† Means of 3 observations.
†† Means of 9 observations.

TABLE 37. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON Si IN CORN COBS AT HARVEST*

Si x P x pH†

Si	pH 5.5			pH 6.0			pH 6.5			pH 5.0			pH 6.0
(kg/ha)	P (kg/ha)			P (kg/ha)			P (kg/ha)			P (kg/ha)			P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	117	193	164	86	119	99	102	90	103				133
833	389	371	402	347	361	283	200	242	243	465	519	618	585
1666	755	722	666	560	556	400	435	328	383				842

Si x pH††

Si	pH			Ave.
(kg/ha)	5.5	6.0	6.5	
0	158	101	98	119 a#
833	387	330	228	315 b
1666	714	505	382	534 c
Ave.	420	312	236	

Si x P††

Si	P (kg/ha)			Ave.
(kg/ha)	112	280	1120	
0	102	134	122	119
833	312	325	309	315
1666	332	535	483	534
Ave.	249	331	305	

P x pH††

P	pH			Ave.
(kg/ha)	5.5	6.0	6.5	
112	420	331	246	332
280	429	345	220	331
1120	411	261	243	305
Ave.	420	312	236	

Control Plot 178 .

* Expressed as ppm Si.
† Means of 3 observations.
†† Means of 9 observations.
# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 38. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON Si IN CORN STOVER AT HARVEST*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 6.0 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	1463	1757	2155	1216	1288	2263	1222	1180	1589				1475
833	3840	4852	4274	3046	3786	4455	2552	2769	2649	4394	4876	4599	4260
1666	5815	5707	5743	5123	5165	5923	3293	3293	4099				7531

Si x pH††

Si (kg/ha)	pH 5.5	6.0	6.5	Ave.
0	1791	1589	1330	1570 a#
833	4322	3762	2656	3580 b
1666	5755	5403	3561	4906 c
Ave.	3956	3584	2516	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	1300	1408	2002	1570
833	3146	3802	3792	3580
1666	4743	4721	5255	4906
Ave.	3063a	3380ab	3657b	

P x pH††

P (kg/ha)	pH 5.5	6.0	6.5	Ave.
112	3706	3128	2355	3063
280	4105	3413	2414	3311
1120	4057	4213	2779	3683
Ave.	3956b	3584b	2516a#	

Control Plot 1697

* Expressed as ppm Si.
† Means of 3 observations.
†† Means of 9 observations.
# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 39. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON P IN CORN GRAIN AT HARVEST*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 6.0 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	3746	4817	4505	4192	3701	4817	4148	4014	5530				713
833	4192	3434	4594	4728	4638	4373	4193	4773	5174	2632	2408	3791	1962
1666	3434	4682	5843	2051	5505	5887	3345	5174	5664				2810

Si x pH††

Si (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
0	4356	4237	4563	4386
833	4073	4579	4713	4456
1666	4653	4481	4728	4621
Ave.	4361	4433	4668	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	4029	4177	4951	4386
833	4371	4281	4713	4456
1666	2943	5120	5798	4621
Ave.	3781a	4526b	5154c#	

P x pH††

P (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
112	3791	3765	3895	3781
280	4311	4615	4654	4526
1120	4980	5026	5456	5154
Ave.	4361	4433	4668	

Control Plot 1605.

* Expressed as ppm P.
† Means of 3 observations.
†† Means of 9 observations.
# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 40. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON P IN CORN COBS AT HARVEST*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha) 112	280	1120	pH 6.0 P (kg/ha) 112	280	1120	pH 6.5 P (kg/ha) 112	280	1120	pH 5.0 P (kg/ha) 112	280	1120	pH 6.0 P (kg/ha) 0
0	566	557	665	441	610	743	486	513	700				410
833	504	571	633	716	576	744	593	682	754	580	513	754	522
1666	714	714	639	500	678	656	622	771	682				633

Si x pH††

Si (kg/ha)	pH 5.5	6.0	6.5	Ave.
0	596	598	566	587
833	569	679	676	641
1666	689	611	692	664
Ave.	618	629	645	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	498	560	702	587
833	604	610	710	641
1666	611	721	659	664
Ave.	571a	630ab	691b#	

P x pH††

P (kg/ha)	pH 5.5	6.0	6.5	Ave.
112	595	552	567	571
280	614	621	655	630
1120	645	714	712	691
Ave.	618	629	645	

Control Plot 635

* Expressed as ppm P.
† Means of 3 observations.
†† Means of 9 observations.
# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 41. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON P IN CORN STOVER AT HARVEST*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 6.0 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	782	867	1166	782	1109	1217	944	1259	1412				664
833	797	812	1351	787	877	1349	852	1212	1520	669	699	1012	595
1666	892	870	1364	992	1227	1269	850	1124	1549				610

Si x pH††

Si (kg/ha)	pH 5.5	6.0	6.5	Ave.
0	938	1036	1205	1060
833	986	1004	1194	1062
1666	1042	1162	1174	1126
Ave.	989	1067	1191	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	836	1078	1265	1060
833	812	967	1406	1062
1666	911	1073	1394	1126
Ave.	853a	1039b	1355c#	

P x pH††

P (kg/ha)	pH 5.5	6.0	6.5	Ave.
112	823	853	882	853
280	849	1071	1198	1039
1120	1294	1278	1493	1355
Ave.	988a	1067ab	1193b#	

Control Plot 484

* Expressed as ppm P.
† Means of 3 observations.
†† Means of 9 observations.
\# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 42. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON Ca IN CORN STOVER AT HARVEST*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 6.0 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	3478	3648	3478	3768	3992	4045	4431	4191	4289				3331
833	3290	3534	3472	3442	3935	4730	4179	4249	4394	3434	3761	3756	3703
1666	3364	3371	3733	3349	3935	4144	4033	4668	4757				3588

Si x pH††

Si (kg/ha)	pH 5.5	pH 6.0	pH 6.5	Ave.
0	3535	3935	4304	3925
833	3432	4036	4274	3914
1666	3489	3810	4486	3928
Ave.	3485	3926	4355	

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	3893	3944	3947	3925
833	3637	3906	4199	3914
1666	3582	3992	4211	3928
Ave.	3704a	3947ab	4116b#	

P x pH††

P (kg/ha)	pH 5.5	6.0	6.5	Ave.
112	3378	3520	4215	3704a
280	3518	3954	4370	3947ab
1120	3561	4306	4480	4116b
Ave.	3485a	3926b	4355c	

Control Plot 2577

* Expressed as ppm Ca.
† Means of 3 observations.
†† Means of 9 observations.
# Means not followed by the same letter are significantly different from each other at the 5% level.

TABLE 43. INFLUENCE OF RESIDUAL Si, P AND SOIL pH ON Al IN CORN STOVER AT HARVEST*

Si x P x pH†

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 6.0 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	273	231	388	316	371	313	307	413	456				267
833	256	360	363	205	230	275	255	495	313	250	200	187	264
1666	233	244	218	256	354	216	331	298	246				316

Si x pH††

Si (kg/ha)	pH 5.5	6.0	6.5	Ave.
0	297	333	392	340
833	326	236	355	306
1666	231	275	291	265
Ave.	284	281	346	303

Si x P††

Si (kg/ha)	P (kg/ha) 112	280	1120	Ave.
0	254	259	297	270
833	278	318	402	332
1666	323	268	335	308
Ave.	285	281	346	

P x pH††

P (kg/ha)	pH 5.5	6.0	6.5	Ave.
112	254	259	297	270
280	278	318	402	332
1120	323	268	335	308
Ave.	285	281	346	

Control Plot 353

* Expressed as ppm Al.
† Means of 3 observations.
†† Means of 9 observations.

TABLE 44. CORRELATION COEFFICIENTS OBTAINED FROM A STEP-WISE REGRESSION ANALYSIS OF APPLIED Si, P AND pH, THEIR SQUARES, THEIR INTERACTIONS AND SOIL AND PLANT VARIABLES ON YIELD AS INDICATED BY R, R^2 x 100, AND SIMPLE CORRELATION COEFFICIENTS BETWEEN THOSE FACTORS AND YIELD

1. Soil and Plant Variables vs Ear Corn Yield

Variable	R[a]	R^2 x 100	Simple Correlation Coefficients (γ)
Soil P	0.377	14	0.377**
Stover P	0.595	35	-0.145
Leaf Ca	0.691	48	0.350**
Soil pH	0.714	51	0.104
Leaf P	0.729	53	0.268*
Leaf K	0.743	55	0.081

2. Soil and Plant Variables vs Stover Yield

Variable	R[a]	R^2 x 100	Simple Correlation Coefficients (γ)
H_2O Sol Soil Si	0.310	10	0.310**
Applied P	0.400	16	0.270*
Stover Al	0.433	19	0.108
P x pH	0.466	22	0.252*
pH^2	0.502	25	-0.039
Modified-Truog Si	0.533	28	0.081
Stover Si	0.552	31	0.268*
Grain P	0.574	33	0.195
Leaf P	0.594	35	0.227*
Leaf Fe	0.613	38	-0.017

3. Soil and Plant Variables vs Total Yield (Stover + Ears)

Variable	R[a]	R^2 x 100	Simple Correlation Coefficients (γ)
Soil P	0.421	18	0.421**
Stover P	0.493	24	0.045
Leaf Ca	0.565	32	0.342**
H_2O Sol Si	0.601	36	0.237*
Leaf P	0.625	39	0.341**
Leaf Fe	0.638	41	0.095
Stover Al	0.647	42	0.105

[a]The R value applies to the relationship between the variable opposite it as well as all those above it and yield in a multiple regression analysis.

*Significant at 5% level.

**Significant at 1% level.

TABLE 45. CORRELATION COEFFICIENTS OBTAINED FROM A STEP-WISE REGRESSION ANALYSIS OF APPLIED Si, P AND pH, THEIR SQUARES, THEIR INTERACTIONS, AND LEAF NUTRIENTS ON YIELD AS INDICATED BY R, R^2 x 100, AND SIMPLE CORRELATION COEFFICIENTS BETWEEN THOSE FACTORS AND YIELD

1. Leaf Nutrients vs Ear Corn Yield

Variable	R[a]	R^2 x 100	Simple Correlation Coefficients (γ)
Leaf Ca	0.350	12	0.350**
Leaf K	0.401	16	-0.025
Leaf P	0.438	19	0.268*
Leaf Al	0.479	23	0.081
Leaf Fe	0.501	25	0.166

2. Leaf Nutrients vs Stover Yield

Variable	R	R^2 x 100	Simple Correlation Coefficients (γ)
Leaf Si	0.298	9	0.299**
Leaf P	0.365	13	0.227*
Leaf Fe	0.412	17	-0.017

3. Leaf Nutrients vs Total Yield (Stover + Ears)

Variable	R[a]	R^2 x 100	Simple Correlation Coefficients (γ)
Leaf Ca	0.341	12	0.342**
Leaf P	0.419	18	0.341**
Leaf Si	0.458	21	0.214
Leaf Fe	0.528	28	0.095
Leaf K	0.548	30	-0.060

[a]The R value applies to the relationship between the variable opposite it as well as all those above it and yield in a multiple regression analysis.

**Significant at 1% level.

*Significant at 5% level.

TABLE 46. EFFECT OF DARK AND LIGHT ON TRANSPIRATION AND CONCENTRATIONS OF SOLUBLE Si, TOTAL Si AND TOTAL P IN PLANTS

Species	Treatment	Mls of H_2O lost in 48 hrs	Soluble Si µg/g		Total Si µg/g		Total P µg/g		Soluble Si / Total Si	
			Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
Tomato	D	47	19	6	743	120	1505	1606	0.026	0.050
	D+L	127	13	8	570	239	818	1881	0.023	0.033
	L	145	21	5	284	239	1172	1296	0.074	0.021
Alfalfa	D	34	7	3	175	92	857	1050	0.040	0.033
	D+L	198	9	14	114	134	1355	627	0.079	0.104
	L	215	6	9	55	144	1038	609	0.109	0.063
D. intortum	D	54	45	12	1968	174	1495	1194	0.023	0.069
	D+L	82	53	19	1395	200	1660	667	0.038	0.095
	L	100	25	22	1336	309	1232	630	0.019	0.071
Corn	D	7	69	15	1427	57	-1303	1326	0.048	0.263
	D+L	72	30	25	721	432	-1040	930	0.042	0.059
	L	79	22	26	430	524	-1132	762	0.051	0.050
Sugarcane	D	63	11	44	1433	1619	1359	1101	0.008	0.027
	D+L	222	13	75	577	4171	652	1349	0.023	0.018
	L	360	15	30	218	3584	294	1238	0.069	0.008

*Average of 3 replications.

D = Dark
D+L = Dark + Light
L = Light

TABLE 47. EFFECT OF METABOLIC INHIBITORS ON THE CONCENTRATION OF TOTAL AND SOLUBLE Si IN PLANTS

	Soluble Si	Total Si		Soluble Si / Total Si
	Shoot	Root	Shoot	
	(μg/g)	(μg/g)		
Tomato				
Si + 0 inhibitor	4	5758	126	0.031
Si + 10^{-5} NaF	5	3850	324	0.015
Si + 10^{-3} NaF	2	3006	53	0.037
Si + 10^{-5} NaCN	7	3925	315	0.022
Si + 10^{-3} NaCN	10	2599	622	0.016
Corn				
Si + 0 inhibitor	32	5917	608	0.052
Si + 10^{-5} NaF	23	7996	561	0.040
Si + 10^{-3} NaF	23	5332	483	0.047
Si + 10^{-5} NaCN	25	9266	382	0.065
Si + 10^{-3} NaCN	9	6086	139	0.064

TABLE 48. DETERMINATION OF OCCLUDED P INSIDE SILICON STRUCTURES

Applied Si	ppm P					% P Recovered			
kg/ha	Filtered Digest	1st Wash	2nd Wash	Occluded P	Total P	Filtered Digest	1st Wash	2nd Wash	Occluded* P
0	2656	64	8	48	2776	95.6	2.3	0.3	1.7
0.55	2618	72	8	48	2746	95.4	2.6	0.3	1.7
2.2	2576	112	16	64	2768	93.1	4.0	0.6	2.3
8.8	2696	96	16	64	2872	93.9	3.3	0.6	2.3

*P inside silicon structures.

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