RESPONSE OF TWO SPECIES OF *Stylosanthes* Sw. TO LEVELS OF LIME, PHOSPHORUS, POTASSIUM, AND BORON ON THREE MINERAL SOILS

By

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Abstract of Dissertation Presented to the Graduate Council
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A greenhouse experiment was conducted to study the response of stylo (*Stylosanthes guianensis* (Aubl.) Sw.) cv. Schofield and Caribbean stylo (*Stylosanthes hamata* (L.) Taub.) cv. Verano to levels of lime, P, K, and B on three Florida mineral soils: Orangeburg loamy sand (fine-loamy, siliceous, thermic Typic Paleudult); Astatula sand (hyperthermic uncoated Typic Quartzipsament); and Myakka fine sand (sandy, siliceous, hyperthermic Aeric Haplaquod). The set of experimental treatments was a modified central composite in four factors each at five levels arranged in a response surface design.

Before planting each pot was leached with 1 liter of distilled water to remove nitrates + nitrites + ammonium accumulated from N mineralization during incubation period. Leachate and soil samples were taken at this time.

Mineralization of organic matter, pH, exchangeable Ca, extractable P, and ECEC increased with increasing levels of lime in

all three soils; exchangeable H and Al, and extractable Fe decreased.

Extractable Ca and pH of all three soils were lower at harvest time than at planting time at all levels of lime. Extractable K also decreased to extremely low levels even in the treatments that received the highest rate of K. Extractable Ca and pH values were lower when the soils were grown with stylo than with Caribbean stylo.

Stylo yielded more than Caribbean stylo in all three soils, and its Ca concentration was also higher.

Caribbean stylo was more responsive to lime than stylo. In the Ultisol, Caribbean stylo yields increased with low but decreased with higher lime levels. Meanwhile, lime depressed stylo yields starting from the first level. In the Entisol and Spodosol, Caribbean stylo responded to the highest lime level while stylo responded only to intermediate levels and decreased at the higher levels. Decreases in pH and extractable Ca during cropping may have accounted for the higher response to lime in the Entisol and Spodosol. Each species showed a large response to P and K in all three soils. Herbage K concentrations in the treatments without or with low levels of K were very low and the plants showed distinct symptoms of K deficiency.

Increasing B levels decreased stylo yield and produced distinct foliar symptoms of toxicity as B levels increased. Caribbean stylo yield was not affected, although it showed distinct symptoms of toxicity at the highest levels of B.

Increasing levels of P increased N concentration of each species. Consequently total N increased. Increasing levels of K tended to reduce N concentrations in each species, but since increasing levels of K had larger positive effects on dry matter yields, increased total N resulted.

A very low N concentration and content of each species in the unlimed Spodosol coincided with a lack of nodulation. An intense and general chlorosis and leaf drop indicated a very acute N deficiency caused by lack of N fixation.

Sodium concentrations in herbage of stylo were very low and increased very little with increasing levels of NaH_2PO_4. Conversely, the roots were very high in Na and Na increased progressively with increasing levels of NaH_2PO_4, indicating that stylo has a mechanism that impairs the translocation of absorbed Na to plant tops.

Increasing levels of lime decreased B, Zn, Mn and Cu concentrations in herbage of each species in all three soils.

INTRODUCTION

The contribution of legumes to the improvement of mixed pastures and their importance as sources of protein for grazing animals are well known. In mixed pastures, deficiencies in soil N could be offset by the presence of legumes in association with efficient N-fixing rhizobia. According to Whyte, Moir and Cooper (1959), to maintain an efficient legume in the pasture, the first goal in pasture management should be to stimulate a vigorous growth of the legume by utilizing an adequate grazing system and by supplying adequate quantities of all the nutrients necessary for N fixation by the legume-Rhizobium association.

One of the most troublesome problems in establishing a program of fertilization for a forage legume is to determine the best level of lime to use in acid soils to achieve the maximum yield and N fixation of the legume.

The application of lime has been found to be of tremendous importance in the growth and N fixation of temperate legumes. This is not only the result of an increase in the soil pH and availability of some nutrient elements in the soil, but also a direct effect of the addition of Ca and Mg, and the neutralization of the toxic effects of Al and Mn.

Investigations on the effect of liming on the growth of legumes from tropical climates, despite being more restricted than for temperate ones, have shown that most of the tropical legumes do not require as high a pH to show their maximum production and N fixation as the legumes of temperate climates.

Stylo (Stylosanthes guianensis (Aubl.) Sw.) is the most widely distributed species of the genus. Its natural distribution extends from Mexico to Argentina ('t Mannetje, 1977) and it has been introduced into most tropical countries for use as a cover crop and a pasture legume. The CIAT (1973) in Colombia has been evaluating around 180 Stylosanthes species and ecotypes. In tropical Australia, stylo cv. Schofield is one of the most widespread legumes in mixed pastures; Winter (1976) found it to be, among the legumes studied, the one with the greatest capacity to persist in mixed pastures in the northern Cape York peninsula of Australia.

Caribbean stylo (Sylosanthes hamata (L.) Taub.) is another species of the genus that is of interest and, according to Mohlenbrock (1957), it is native to Colombia, Venezuela, Mexico, Florida, and the Caribbean region. It has been tested intensively in Australia in recent years.

In a study conducted by Edye et al. (1975b), Caribbean stylo (cv. Verano) was superior in dry matter yield over all sites, to the other accessions, including two S. humilis H.B.K. cultivars.

Other experiments conducted by Edye et al. (1973), Burt et al. (1974), Edye et al. (1975a) and McKeague et al. (1978) have demonstrated the superior adaptability and productivity of the perennial S. hamata when compared with S. humilis in dry tropical environments where the latter has long been used.

At the Agricultural Research Center, Fort Pierce, Florida, Brolmann (1978) has been studying several accessions of stylo, Caribbean stylo, and other *Stylosanthes* species; some of them have shown promise for the part of Florida not subjected to severe frosts.

The objectives of this study were (a) to determine the levels of lime necessary to give the best pH range for nodulation, N fixation, and production of two species of *Stylosanthes* using three acid soils of Florida; (b) to determine the effect of P levels on the yield and N fixation of the two *Stylosanthes* species, and to measure the effect of the increasing levels of lime on P availability in three acid soils of Florida; (c) to evaluate the effect of levels of liming on the availability of the micronutrients (Zn, Cu, Fe, B, and Mn) by determining the concentration of these micronutrients in the plant tissues of the two *Stylosanthes* accessions; (d) to determine the effect of levels of B on the nodulation, N fixation and production of the two *Stylosanthes* accessions, and to observe if B would produce visual signs of toxicity on the *Stylosanthes* plants when applied at high levels; (e) to determine, by using increasing levels of K, if this element can counteract the possible deleterious effect of the application of high levels of B on soils of low pH, upon the nodulation and production of the two *Stylosanthes* accessions; and (f) to determine the best combination of lime, P, K, and B, for nodulation, N fixation, and production of the two *Stylosanthes* accessions on the three soils.

LITERATURE REVIEW

Phosphorus Deficiency

Phosphorus is probably the most deficient plant nutrient in tropical soils. Therefore, crop establishment and development in tropical acid soils is often impossible without P applications (Olson and Engelstad, 1972; Teitzel and Bruce, 1972a, 1973a, 1973b; Blue, 1974).

In legume plants, besides the functions that P plays in the growth of the plant itself, it is required also for the nodulation and N fixation by the legume-*Rhizobium* association. According to Andrew and Robins (1969a), N concentrations in the tops of tropical legumes increase with P supply even after maximum growth has been reached. This implies a direct requirement of P for legume nodulation. Gates (1974) showed that nodule development and symbiotic N fixation begin earlier with increasing P supply.

Several other papers in the literature demonstrate the definite effect of P fertilization on yield, nodulation, and N fixation by tropical legumes (Jones, 1968; Souto and Dobereiner, 1968; Jones and Freitas, 1970; Jones et al., 1970; Carvalho et al., 1971; Werner and Mattos, 1972; Werner and Monteiro, 1974; Bishop, 1974; Bruce and Teitzel, 1978; Snyder et al., 1978) among others.

Phosphorus Requirements for Different Species

Tropical legumes differ in their response to applied P (Andrew and Robins, 1969a; Jones and Freitas, 1970; Andrew and Johansen, 1978). According to Andrew and Robins (1969b) and Andrew and Johansen (1978), Stylosanthes humilis is one of the less responsive tropical legumes to applied P. Jones and Freitas (1970) compared the response of stylo, Centrosema pubescens Benth., Glycine wightii (R. Grah. ex Wight & Arm.) Verdc., Macroptilium atropurpureum (DC.) Urb. to P, K, and lime, when grown in Red-Yellow Latosols of the Campo Cerrado, Brazil. All of the legumes responded to P, but the response of stylo was much less than the other three species.

There is also variation in response between different plant populations within species as shown by Jones (1974) who studied responses to P of a wide range of accessions from the genus Stylosanthes. One experiment conducted in Colombia (CIAT, 1976), however, did not show differences in response to P between species and ecotypes of Stylosanthes studied. All 13 species and ecotypes responded well to 87.3 kg of P/ha.

Phosphorus Availability and Liming

One of the potential effects of liming acid soils is to increase the availability of P to plants. However, in some instances plant growth is decreased and plants exhibit P deficiency when the soil is limed in excess of the real needs of the plant. Fox et al. (1964) found that liming an aluminous ferruginous latosol to pH 6.0 increased the uptake of fertilizer P, but liming to pH 7.0 markedly decreased P uptake by greenleaf desmodium (Desmodium intortum (Mill.) Urb.) and sorghum (Sorghum bicolor (L.) Moench.).

According to Woodruff and Kamprath (1965) and Reeve and Summer (1970a), rates of lime which neutralize exchangeable Al result in more efficient uptake of P from Ultisols and Oxisols. The primary beneficial effect of lime on P availability would be through the development of a more extensive plant root system due to the neutralization of the exchangeable Al. Plant roots then make contact with larger soil volumes which enhances nutrient uptake.

Responses of S. guianensis and S. hamata to P Fertilization

There is not much literature dealing with the application of P to stylo and Caribbean stylo. However, data found show that these two species are responsive to P applied to soils with low levels of this element.

Teitzel (1969) studied the responses to P, Cu, and K on a granite loam soil of the wet tropical coast of Queensland. In one experiment, a mixed pasture of Panicum maximum Jack. var. Typica and S. guianensis ssp guianensis was planted in an area that had previously received some P fertilization.

Stylo did not show significant yield increases with P application, but its P concentration was very low from plots which did not receive P. The legume responded to Cu only in the presence of additional P, and to K only in the presence of both P and Cu.

Jones and Freitas (1970) studied the response of stylo and three other tropical legumes to P, K, and lime when grown in

Red-Yellow Latosols of the Campo Cerrado, Brazil. All of the legumes responded to P, reaching near maximum yields between 100 and 200 kg of P/ha. Stylo presented the smallest response, and its P concentration ranged from about 0.10 to 0.25%.

Carvalho et al. (1971) studied the response of six tropical legumes grown on a Dark-Red Latosol from a Cerrado area to several nutrients. Stylo was one of the legumes and in all of them, both dry matter production and nodule weight increased with P fertilization.

Eira et al. (1972) studied the nutritional factors limiting legume growth in a Red-Yellow podzolic soil. Phosphorus increased dry matter yield, nodulation, and total N production of the three tropical legumes studied (perennial soybean, Siratro, and stylo).

Teitzel and Bruce (1971, 1972a, 1972b, 1973a, 1973b) reported a series of fertility studies of pasture soils in the wet tropical coast of Queensland. Guineagrass, stylo (cultivars Endeavour, Cook, and Schofield), and other tropical legumes were used as indicator plants. A large plant growth response to P was measured in almost every experiment where the effect of fertilizer P was studied. This was even the case in soils that had a history of P fertilization, though the response on the latter areas was smaller than that recorded on virgin soils.

Bruce (1974) studied the growth response of stylo cv. Schofield topdressed with superphosphate in three field experiments in north Queensland. Yields of control plots ranged from 36 to 84% of the highest yielding plots.

Jones (1974) studied the P responses of a wide range of accessions from the genus Stylosanthes grown on a P-deficient soil in northern Australia. There were several accessions of S. guianensis, two accessions of S. hamata, and several accessions of other Stylosanthes species. Differences in growth and P uptake under conditions of severe deficiency were fairly small. However, with progressive improvement in the supply of P, large differences developed between the groups in growth and P uptake. Accessions of stylo and Caribbean stylo did not show the same response to P as did the other legumes.

Steel and Humphreys (1974) studied the growth and P response of centro, stylo, and Lotononis bainesii Baker grown on a loamy fine sand soil at Kuta, Bali. In a pot experiment using soil from the 0- to 30-cm horizon, centro and stylo showed positive quadratic responses to P addition over the range of 10 to 80 kg of P/Ha. L. bainesii was less responsive. Growth of these legumes under coconuts in the field was independent of P application. According to the authors, this was presumably because of increased P availability with soil depth.

Researchers at CIAT (1975) in Colombia studied the effect of Ca and P concentrations in nutrient solution on Al toxicity in Caribbean stylo. Increase in P concentration in the nutrient solution stimulated root and top growth in the presence of Al but did not eliminate the darkening and deformation of the roots caused by the Al.

Mosse et al. (1976) at the Rothamsted Experimental Station, England, studied the interactions between vesicular-arbuscular mycorrhiza, rock phosphate and symbiotic N fixation in three legumes (Trifolium repens L., stylo, and centro). Inoculation with vesicular-arbuscular endophytes increased P uptake in all host plants in all the soils when the indigenous endophytes had been removed by irradiation. But appreciable increases in plant dry weight only occurred when P concentrations in tissues from uninoculated plants were low, generally below 0.15%. In acid soils, adding rock phosphate generally improved growth of the non-mycorrhizal plants, and inoculation with the vesicular-arbuscular endophytes greatly improved its utilization. In neutral and alkaline soils, rock phosphate was unavailable to non-mycorrhizal plants and remained so after inoculation with vesicular-arbuscular endophytes.

Miller and Jones (1977) studied the nutrient requirements of stylo cv. Endeavour pastures on a Euchrozen in north Queensland. Sulphur was strongly deficient in this soil, but the absence of P response was notable. According to the authors, the Euchrozems studied have acid-extractable P levels above that at which responses would be expected.

Bruce and Teitzel (1978) conducted two fertilizer experiments with stylo in two deep sandy soils in north Queensland. In one of the experiments, with cultivar Schofield, maximum dry matter yields were achieved at 25 kg of P/ha, but yields were reduced by 100 and 200 kg of P/ha. Monosodium orthophosphate gave higher yields than superphosphate. In the second experiment, where the cultivar Endeavour was used, 50 kg of P/ha combined with 56 kg of K/ha gave maximum dry matter yields. Higher rates of P and K reduced yields. Symptoms of P toxicity were observed on seedlings soon after emergence in 100 and 200 kg of P/ha treatments in both experiments. Plants fertilized with superphosphate had higher P and Ca percentages, but lower Mg and N percentages than plants fertilized with monosodium orthophosphate.

Snyder et al. (1978) at the Agricultural Research Center, Fort Pierce, Florida, studied the field response of four tropical legumes to lime and superphosphate. The study was conducted in an Arenic Haplaquod. All four tropical legumes (*Desmodium heterocarpon* DC., Siratro, centro and stylo) responded to P. Calculated optimum P rates ranged from 45 for *D. heterocarpon* and 78 kg/ha for stylo. Response to P was improved by liming.

Concentrations of Phosphorus in *S. guianensis* and *S. hamata*

Andrew and Johansen (1978) state that critical concentrations of P in plant tissues may be used to estimate the internal requirements of P for plant growth.

According to Andrew and Robins (1969b), an important prerequisite for the accurate assessment of critical percentages of an element is that all other essential plant nutrients must be adequate at all levels of treatment. Multi-element determinations are considered indispensable in the assessment of nutrient balance and ionic interactions within the plant resulting from increasing applications of one of the nutrients. These authors determined the critical P concentrations in the tops of 10 tropical legumes. The values ranged between 0.17 and 0.25%. Stylosanthes humilis had the lowest value. These values refer to the whole plant tops harvested at the immediate pre-flowering stage of growth. Jones (1968) also quotes a value of 0.16 to 0.17% for the critical level of P in S. humilis when harvested at the flowering stage.

The stage of development of the plant, the plant part sampled, the physiological age of the tissue sampled, the time of the year, weather conditions, type of soil, etc., are factors that influence the critical levels of one nutrient, besides the adequacy of the others (Jones, 1968; Andrew and Robins, 1969b; Bruce, 1974; Bruce and Teitzel, 1978).

According to Andrew and Johansen (1978) there is no clear relationship between plant responsiveness to P and critical P concentration, although species like S. humilis with the least relative response (Andrew and Robins, 1969b) also had the lowest critical P concentration of the legumes studied.

The critical P concentrations referred to in the literature apply to maximum dry matter production. However, if N production by the legume is the prime aim, then plant requirements for P tend to increase, as shown by Andrew and Robins (1969a) and Gates (1974).

There are studies in the literature in which P concentrations in stylo and Caribbean stylo have been related to levels of P fertilizer applied or soil P levels. There are also studies with the aim of determining critical P levels for these two species.

Teitzel (1969) studied the responses to P, Cu, and K of a guineagrass-stylo pasture grown on a granite loam soil of the wet tropical coast of Queensland. Chemical analysis showed increased P and K concentrations with increasing P and K fertilizer applications. Phosphorus in stylo ranged from 0.11% without P fertilizer to 0.15% with 72 kg of P/ha.

Santhirasegaram (1974) studying the P status of some pastures in the Peruvian tropics found 0.110, 0.156, and 0.336% P for stylo pastures grown on an Ultisol fertilized with 0, 100, and 500 kg of superphosphate/ha, respectively.

Steel and Humphreys (1974) observed that the P concentration in centro was quadratically related and in stylo and L. bainesii linearly related to levels of applied P. The P concentration in stylo ranged between 0.126 and 0.272%.

Bruce (1974) studied the growth response, critical percentage of P, and seasonal variation of P concentration in stylo cv. Schofield topdressed with superphosphate. Two types of plant samples were collected from field experiments at 4-week intervals in the first year and at 2-week intervals in the second and third years: (1) erect stems cut about 5 cm above ground level or above the woody basal branches, referred to as "tops," and (2) samples cut about 25 cm from the growing point of erect stems, referred to as "tips." For tips, the critical concentration was 0.16% P and for tops it was 0.12% P, both for samples taken at the time of first flowering. Tips were favored for diagnostic use because of the slightly better relationship between yield and percentage P and because they are easier to recognize and sample in a grazed pasture. The author mentiond also that a marked fluctuation in P percentage during the 2 months prior to flowering was found; this emphasized the importance of rigid standardization of sampling time. The effect was more pronounced in tips than tops.

Werner et al. (1975) studied the effect of micronutrients on the growth and N production from three tropical legumes grown in pots with a Dark Red Latosol. The macronutrients were applied in abundance in order to prevent deficiencies. The levels of P in stylo cv. IRY 1022 were in the range of 0.32 to 0.36%.

Mosse et al. (1976), who studied plant growth responses to vesicular-arbuscular mycorrhiza and their interaction with rock phosphate, observed that in stylo and centro nodulation and nitrogenase activity were negligible when plant P concentration was much below 0.2%, and virtually no nodules formed on plants containing about 0.1% P. Where plant P concentration, with or without added rock phosphate, was around 0.1%, inoculation always improved growth, but where it was near 0.2%, growth increases were generally negligible.

Bruce and Teitzel (1978) studied the nutrition of stylo cv. Endeavour and Schofield on two sandy soils in north Queensland. Phosphorus concentrations increased with P application in the two harvests effected. The authors presented the P percentages only for cv. Endeavour. In the first harvest, they ranged from 0.31 to 0.48% with increasing levels of P applied, and from 0.14 to 0.22% at harvest two.

Brolmann and Sonoda (1975), at the Agricultural Research Center, Fort Pierce, Florida, studied the response of three stylo accessions to three levels of K. Plant phosphorus contents were adversely affected, being smallest at high levels of K and greatest at low levels of K. A reduction of P contents in stylo and Siratro with increasing levels of K was also reported by Teitzel and Bruce (1973a, 1973b). This was probably a dilution effect. In the treatments with no or low K application the plants did not grow well, there was a concentration of the applied P in their tissues. As levels of applied K increased, plants grew normally causing a dilution of the P absorbed by the plants.

Some Causes of Soil Acidity

Before the late 1950s, exchangeable H was believed to be the cause of soil acidity. Later this belief changed because of the recognition that the presence of exchangeable Al^{3+} and the loss of basic cations are responsible for development of acid soils. Yuan (1960) displaced the exchangeable cations in four Florida soils with various unbuffered salt solutions at several pH values and found that Al accounted for most of the acidity in these soils. Yuan (1963) also stated that there is more H than Al in virgin Florida soils where the pH in 1 N KCl is less than 3.7. As the pH increased, there was more Al than H, and above pH 5.8 both H and Al were insignificant. Carlisle and Fiskell (1962) found that the source of soil acidity of Florida Flatwood soils was primarily Al with low amounts of exchangeable H. Fiskell and Zelazny (1972) concluded that the acidity in the major soil orders in Florida was derived initially from exchangeable Al and then from H formed by the release of protons from

Al polymers and organic matter. Coleman et al. (1959), Thomas (1960), and Coleman and Thomas (1967), working with other soils, also reported that exchangeable Al is the dominant cation associated with soil acidity.

Tisdale and Nelson (1975) illustrate the reactions of Al in soils by the following equations:

$$Al^{3+} + H_2O \text{ —— } Al(OH)^{2+} + H^+$$

$$Al(OH)^{2+} + H_2O \text{ —— } Al(OH)_2^+ + H^+$$

$$Al(OH)_2^+ + H_2O \text{ —— } Al(OH)_3 + H^+$$

These equations explain that the hydrolysis of Al is responsible for low pH of solutions containing Al ions and for the buffering capacity of soils. The production of OH^- from hydrolysis of lime neutralizes the H^+, but as more lime is applied, Ca displaces more exchangeable Al. A portion of it hydrolyzes with the production of H^+ which is neutralized by the OH^- (Blue and Dantzman, 1977).

Exchangeable Al is in equilibrium with Al ions in the soil solution. Kamprath (1970) showed that there was less than 2.4 ppm Al in the soil solution when the Al saturation was lower than 60%, but the Al in the soil solution rose sharply beyond 60% saturation to 4.5 ppm.

Effects of Soil Acidity on Plant Growth

Soil acidity affects plant growth via several mechanisms. Positive identification and separation of the different factors have been made difficult by the interdependence of soil pH, exchangeable Al, exchangeable bases, water-soluble Mn, and availability of inorganic plant nutrients, especially Ca and P (Jackson, 1967). However, it is a widely accepted concept that pH per se is not the major factor responsible for poor plant growth in acid soils (Adams and Pearson, 1967). Poor growth of plants on acid soils is more often related to the toxic effects of Al and Mn. Calcium and other nutrients may be seriously deficient in highly leached acid soils. Molybdenum under acid conditions tends to be held quite tightly by soil clays and hydrated oxides of Al and Fe, and its availability to plants may be inadequate (Kamprath, 1972). Also, according to Kamprath (1972), Mg deficiencies have been observed on sandy soils where the pH is 5.0 or less and exchangeable Al saturation is relatively high.

According to Black (1968), Al toxicity represents a combination of effects of which inhibition of root growth is perhaps the most obvious. As a result the plant may have multiple nutrient deficiencies. Ragland and Coleman (1959) reported that the growth of grain sorghum (Sorghum bicolor (L.) Moench.) roots into unlimed subsoils from the Norfolk Catena was related inversely to the amounts of exchangeable Al. Root growth into the subsoils increased substantially when lime sufficient to cause hydrolysis of exchangeable Al was added. Foy and Brown (1963) reported that excess Al in nutrient solution caused decreased uptake of P, Ca, K, Fe, Mn, Na, and B, by cotton (Gossipium hirsutum L.) plants. In fact, the restricted root system frequently limits water absorption which causes plants to wilt.

Black (1968) reported that the Al x P interaction in plant nutrition may be explained in part on the basis that Al and phosphate ions interact chemically to form sparingly soluble salts. If the concentration of either component of this salt in the solution is high, the concentration of the other component must be low. Foy and Brown (1964) demonstrated that foliar symptoms of Al toxicity in plants grown in nutrient solutions were similar to those of severe P deficiency.

Lime Requirement of Tropical Soils

Several methods have been reported for the determination of the lime requirement of acid soils. However, it is now generally accepted that the most reliable one for predicting lime requirement of soils of tropical regions is based on the quantity of exchangeable Al (Reeve and Summer, 1970b; Kamprath, 1970, 1972; Evans and Kamprath, 1970; Blue, 1974; Sanchez, 1976; Amedee and Peech, 1976).

Exchangeable Al is determined by extracting soils with unbuffered normal salt solutions such as 1 N KCl, and titrating the extract with a base (Lin and Coleman, 1960). Exchangeable Al is precipitated at a pH of about 5.5 to 6.6. Little or no exchangeable Al is found at higher soil pH values (Coleman and Thomas, 1967; Sanchez, 1976).

A useful soil fertility measurement is to evaluate the percentage Al saturation of the effective cation exchange capacity (ECEC). Effective cation exchange capacity of the soil is the sum of bases extracted with an unbuffered salt solution such as 1 N KCl, determined at the actual pH of the soil (Coleman and Thomas, 1967).

Response of Tropical Legumes to Liming

The generalization that tropical legumes show little or no response to lime, even in acid soils low in Ca, is often made. The best evidence that tropical legumes tolerate acid soils better than temperates is the greenhouse experiment conducted by Andrew and Norris (1961) in a markedly Ca-deficient soil. They studied the response of five tropical and four temperate legumes to Ca ($CaCO_3$) application, and concluded that the tropical legumes presented much more capacity to extract Ca from the soil low in this element than the temperate ones. But, among the tropicals, the response was not the same. Stylo was the most efficient in obtaining its Ca from the soil, and *Desmodium uncinatum* (Jack.) DC. the least efficient. Nevertheless, the tropical legumes did respond to the $CaCO_3$ application, and both tropical and temperate legumes appeared to have optimum dry matter production at about the same liming rates. The maximum N concentration and N yield (mg/pot) generally occurred at higher levels of $CaCO_3$ than the ones for maximum dry matter production. This difference was particularly expressive in stylo in which the maximum dry matter yield occurred with relatively low levels of $CaCO_3$ (which raised the soil pH to 5.8), and decreased with higher levels of $CaCO_3$ applied. But the N concentration and N yield of the species continued to increase to a higher level of $CaCO_3$ applied (which raised the pH to 6.5). This was also reported by Odu et al. (1971), and by Vargas and Dobereiner (1974), who suggest the importance of separating the nutrition for plant growth and for legume-*Rhizobium* symbiosis.

Munns and Fox (1977a) studied the comparative lime requirements of 18 tropical and temperate legumes in a field trial where $CaCO_3$ was applied to a N-deficient Hawaiian Oxisol at rates which increased soil pH from 4.7 up to 7.1. Lime response curves showed no distinct general difference between tropical and temperate legumes. Within each group, individual species varied. Among the tropical species the most responsive were *Leucaena leucocephala* (Lam.) De Wit, perennial soybean, *Macrotyloma axillare* (E. Mey) Verdc., and *Desmodium intortum* (Mill.) Urb. Among the temperates the most unresponsive were *Trifolium subterraneum* L., *Glycine max* (L.) Merr., and *Lotus corniculatus* L. None of these legumes were included in the work by Andrew and Norris (1961). Munns and Fox (1977a) commented that the apparent differentiation between the two groups in Andrew and Norris's experiment may have been due to restricted sampling of species and soils. The relative tendency of different species to respond to lime would depend on the relative importance of Al, Mn, pH, Ca, Mo, or other pH-related factors in the particular soil and also the behavior of each species and its associated *Rhizobium* in relation to each factor (Munns and Fox, 1977a).

Norris (1959) showed that the Ca need of *Rhizobium*, if any, must be so small that it is capable of satisfaction from trace impurities in the growth medium. Rhizobia were, however, shown to be very sensitive to Mg deficiency. The role of Ca supply in the formation of nodules and their proper functioning is, however, a different matter. This is an effect on the host legume, not on the bacteria. Norris's view that acid-tolerant symbiotic relationships which characterize tropical legumes were related to their association with rhizobia of the primitive, promiscuous cowpea group. More specialized inoculants are now recommended for many important tropical legumes. These specialized rhizobia and their hosts could have lost the primitive tolerance to soil acidity, as Norris supposed the temperate legumes have done (Norris, 1967; Munns and Fox, 1977a).

The growth of legumes as related to soil acidity is mostly affected by deficiencies of Ca, Mg and Mo, and toxicities of Al and Mn. Soil acidity has several components potentially harmful to rhizobia. In addition to high concentrations of H^+ ions, acid soils often have high available Mn and Al and low available Mo, Mg and Ca concentrations. Application of lime will modify all of these properties. Of acid soil properties, the high concentration of H^+ and the low concentrations of Ca and Mg ions appear to be the most important factors for the growth and survival of rhizobia (Robson and Loneragan, 1978). Norris (1965) showed that the slow-growing type of rhizobia that normally infect tropical legumes form alkali which allows them to persist in acid soils. According to 't Mannetje et al. (1978), Al toxicity is generally less severe in tropical than in temperate legumes, but there is much variation within these groups; Medicago spp. are less tolerant of high Al than Trifolium spp. and of the tropical legumes, perennial soybean is rather intolerant of high Al. They also pointed out that there are similar differences between legumes in tolerance to Ca deficiency. Generally, the tropical species are less sensitive than the temperate ones, but there is much variation within each group. In the wet tropics L. leucocephala and centro responded positively to additions of lime on acid soils, but stylo growth was reduced because of induced Zn deficiency. Perennial soybean is the most sensitive to low Ca of all cultivated tropical legumes.

Responses of S. guianensis and S. hamata to Lime, Compared with Other Species

Munns and Fox (1976), studying the response of 18 legume species to increasing rates of $CaCO_3$ (0 to 22 metric tons/ha) in a field experiment, reported that early growth or nodulation of certain species was depressed when a Hawaiian Oxisol was limed at rates above 6 metric tons/ha (pH 6.0). In eight legumes, the depression later gave way to positive response. This was evident in plant weights of Desmodium intortum, Glycine wightii var. Cooper, and in pod weights of Phaseolus vulgaris L. A transient depression was observed visually in Desmodium canum Schinz & Thell., Macrotyloma axillare, Glycine wightii var. Tinaroo, and Trifolium subterranium L. In. S. guianensis and S. fruticosa (Retz.) Alston, the depression persisted throughout the experiment (6 months). Growth was not depressed in Arachis hypogea L., Coronilla varia L., Glycine max, Leucaena leucocephala, Medicago sativa L., Trifolium repens, or Vigna sinensis (L.) Hassk. For S. guianensis and S. fruticosa, the yield data showed a sharp growth optimum at pH 5.5 and this response persisted in the regrowth. Nodule numbers and weight also declined above pH 5.5 in the two Stylosanthes species (Munns and Fox, 1977b).

Freitas and Pratt (1969) measured, in a greenhouse trial, the response of alfalfa, Siratro, and stylo to lime application on four Latosols and four Red-Yellow Podzols of the State of São Paulo, Brazil. Alfalfa responded to lime in the pH range of 4.5 to 6.0, with maximum yields at pH 6.4, in all soils. The average maximum yield of Siratro for all soils was at pH 6.1, and for stylo it was at pH 6.4. The yields of each of these legumes were reduced as the pH increased above 6.2 to 6.4.

Jones and Freitas (1970) studied the response of four tropical legumes to P, K, and lime, applied to a very acid, P-deficient Red-Yellow Latosol soil of Campo Cerrado, from São Paulo. Lime applied in small increments gave marked increases in yield. Maximum stylo yield was obtained with only 250 kg of Ca/ha. Maximum yields for the other three (centro, perennial soybean, and Siratro) occurred at the level of 1000 kg of Ca/ha. A depression in yield occurred with higher rate of lime, apparently not due to induced nutrient imbalances caused by a surplus of Ca ions, according to the authors. Analysis of the plant material for Mn, Zn, Cu, Fe, and B, as well as for the macronutrients, indicated that all were within normal limits.

Jones et al. (1970) studied, in a greenhouse trial with a Red Latosol of Campo Cerrado from São Paulo, Brazil, the response of alfalfa and seven tropical legumes to lime and other mineral nutrients. The pH of the soil was 4.15; Ca + Mg equaled 0.38 meq/100 g, and exchangeable Al was 2.3 meq/100 g of soil. All the species, including stylo, responded to lime. The concentrations of Fe, Mn, Cu, and B were determined on the lime-no lime and micronutrient-no micronutrient treatments where sufficient material was available for analysis. The levels of Mn, Zn, and B, particularly in stylo, were very high in the "minus lime" treatment.

Odu et al. (1971) studied the effect of pH on the growth, nodulation, and N fixation of C. pubescens and S. guianensis in a greenhouse experiment with two soils in Nigeria. Centro grew best on a soil having final pH values of 6.1, while stylo grew best on a soil having a final pH value of 5.7. Nodulation followed a similar trend, but was increasingly suppressed by increases in pH beyond those levels, with complete supression in some cases at pH 8.0. Maximum N fixation for both legumes occurred at a pH value of about 6.0. The differences in the optimum pH for growth, nodulation, and N fixation, according to the authors, may be explained on the assumption that while a pH value of 5.7 is desirable for maximum growth of the plant, a higher pH value, in the range of 6.0 to 6.5, is needed for maximum N fixation. It can be observed in the paper by Andrew and Norris (1961) that the maximum dry matter production of stylo occurred with a relatively low level of $CaCO_3$ which raised the pH to 5.8, decreasing with higher levels of $CaCO_3$ applied. But the plant N concentration and N yield (mg/pot) of the species continued to increase to a higher level of $CaCO_3$ which raised the pH to 6.5.

Vargas and Dobereiner (1974) studied in a series of greenhouse experiments, the effects of rates of liming, Mn, Mg, and B on nodulation, N fixation, and growth of stylo using an acid Red-Yellow Podzolic soil. The higher liming levels reduced both the number of nodules and yield of stylo. However, the dry weight of nodules (mg/pot) and N fixation increased with liming up to pH 6.2. These conflicting results, according to the authors, show the importance of separating the nutrition for growth of the host plant from that for N fixation by the legume-Rhizobium symbiosis.

Eira et al. (1972) studied the growth of three tropical legumes (perennial soybean cv. Tinaroo, Siratro, and stylo) in a greenhouse trial with a Red-Yellow Podzolic soil. This soil had a pH 5.4, Ca + Mg 3.1 meq, and Al 0.1 meq/100 ml of soil. Liming increased the N concentration of Siratro and perennial soybean but not that of stylo. The dry matter yield, however, did not increase in any of the three legumes when the soil was limed.

Santhirasegaram (1974) studied the capacity of several tropical grasses and legumes to develop in the Peruvian tropics on acid Ultisols and Oxisols containing high levels of exchangeable Al. He concluded that among the legumes studied, stylo was the best suited to be grown under those conditions; it was not seriously affected by the high levels of exchangeable Al.

At CIAT (1973) in Colombia, a series of greenhouse experiments was conducted to determine optimum levels of lime for four tropical legumes (including stylo) and three grasses. Maximum yields were achieved for all the four legumes, at 150 kg of lime/ha. According to the authors, it appeared that lime was required primarily as a source of Ca and/or Mg for the tropical forages included in those trials, despite the use of a very acid, highly Al-saturated Oxisol. The effect of 150 kg equivalent of $CaCO_3$/ha decreased the levels of Zn and Mn in the plant tissues; with 1000 and 2000 kg of $CaCO_3$/ha, the levels of Zn and Mn continued to decrease. The higher rates of lime resulted in a depression in yield for the first cut when compared with the 150 kg/ha level, but this effect was not observed for the means of the three cuttings.

Soares et al. (1975) presented results of an experiment with stylo grown on a Dark-Red Latosol at the Brasilia Experiment Station, Brazil. For the first three cuttings there was a significant increase in dry matter in response to the application of 5 metric tons of $CaCO_3$/ha and there tended to be a reduction in yield at 10 metric tons/ha. In the fourth and fifth cuttings, dry matter yields tended to be higher with the original application of 10 than with 5 metric tons of $CaCO_3$/ha, although this yield increase was not significant by the Duncan's test. Nevertheless, the total dry matter production over the five cuttings was reduced by a lime application of 10 metric tons/ha in comparison with 5 metric tons/ha. The application of 5 metric tons/ha reduced exchangeable Al to about 10% saturation, raising the pH to 5.6 and increased the concentration of Ca in the plant tissue by nearly 30%. Ten metric tons/ha raised the pH to 6.6 but did not increase the Ca concentration in plant tissues above the ones achieved with 5 metric tons.

Snyder and Kretschmer (1975) compared the response of one temperate and four tropical legumes to lime and superphosphate applied to an Oldsmar fine sand soil from South Florida. The tropical legumes (*D. heterocarpon*, Siratro, centro, and stylo cv. Endeavour) made appreciable growth even in virgin soil, whereas the temperate legume (*Trifolium alexandrinum* L.) made little growth unless lime and superphosphate were added. Nevertheless, according to the authors, to obtain optimum early growth, the tropical legumes appeared to require about the same lime and P rates as the temperate.

Dradu (1974), conducting some fertility studies on loam soils for pasture development in Uganda, used *D. intortum* and *S. guianensis* as indicator plants. Dry matter and N uptake of greenleaf desmodium tops significantly increased with rates of lime. Dry matter yield of stylo tops declined as lime rates increased in the absence and in the presence of P + S + Cu + Mo treatments; the reduction was greater when deficient nutrients were added. Although insignificant, there was an apparent increase in N uptake at the second level of lime, in the absence of P + S + Cu + Mo. The soil used originally had a pH 5.9, and Ca 6.9, Mg 2.0 and CEC 14.7 meq/100 g of soil.

At CIAT (1975) one experiment was carried out with solution culture to determine if *Stylosanthes* cultivars differ in Al tolerance. One selection of stylo collected from an allic soil in the Llanos Orientales of Colombia, and a selection of *S. hamata* collected from a nearly neutral soil in Venezuela clearly differed in Al tolerance, according to the acidity of the soil of origin. The effects of Ca and P concentrations on Al toxicity were also studied. A fivefold increase in Ca concentration greatly reduced Al toxicity symptoms of *S. hamata*.

Between and within species variations in response to pH and Al status in soil were observed in Stylosanthes accessions, corroborating the findings of the solution-culture experiment. At Santander, a local ecotype of stylo and another accession from the Colombian Llanos tolerated low pH and high Al levels, but one accession of S. hamata and another accession of stylo performed poorly, exhibiting general yellowing of the plant tops. Liming an allic soil (pH 4.4) to pH 6.1 reduced the dry weight of tops and roots of S. capitata and stylo ecotypes which originated from allic soil sites. One accession of stylo from a site with pH 6.4, and centro responded positively to lime application (4 metric tons of $CaCO_3$/ha) when grown in the allic soil. Stylosanthes capitata did not produce root nodules in the limed treatment, but nodulated normally at soil pH 4.4 and at an exchangeable Al level of 3.0 meq/100 g of soil.

Teitzel and Bruce (1971, 1972a, 1972b, 1973a, 1973b) reported some fertility studies in the wet tropical coast of Queensland, Australia. Guineagrass, three cultivars of stylo, and other tropical legumes were used as indicator plants. Plant growth, in some trials, was increased with the $CaCO_3$ applied. In other trials, plant growth was decreased or not affected by lime. The yield depression recorded with $CaCO_3$ application appears to have been due chiefly to immobilization of Zn, as significant response to Zn occurred only in the presence of additional $CaCO_3$ and there was no yield depression with $CaCO_3$ in presence of additional Zn. In some cases where there was growth increase with $CaCO_3$ applied, it would appear that lime was primarily functioning in the release of Mo.

Evidence for this is that Ca and Mo treatments increased the N content of the legume to approximately the same level and that there was no further increase when both elements were applied together. In another trial, it was suggested that the positive effect occurred because $CaCO_3$ may have been functioning in overcoming an induced Mn toxicity. Response to $CaCO_3$ was significant only in the presence of the applied bulk treatment which contained Mn, B, and Cu. In another instance the function of $CaCO_3$ treatment was thought to be in overcoming Al toxicity. The soils where Ca appeared to affect plant growth other than in the release of Mo, had pH below 5.0 and Al/cation sum ratio greater than 40%, while the soils which did not show this effect had pH values higher than 5.0 and Al/cation sum ratio less than 40%. Low exchangeable Ca in some of the soils suggested also that a nutritional deficiency of Ca was quite possible.

Bruce and Teitzel (1978) studied, in a field experiment, the response to P, K, and lime of stylo cv. Schofield grown in a granitic sandy soil in Queensland, Australia. Its pH was 5.1, and Ca 0.6 and CEC 5.0 meq/100 g of soil. Lime increased yield, plant N and Ca concentration in stylo.

Snyder et al. (1978) investigated the effect of liming an acid virgin Spodosol in southern Florida with some tropical legumes. Significant yield responses to lime and P were observed. Centro, D. heterocarpon, Siratro, and stylo required lime applications of about 2200 kg/ha. Liming beyond the optimum rate appeared to seriously reduce production of desmodium and stylo. The surface

15 cm of soil had a pH (H_2O) of 5.0 and pH (KCl) of 3.7; NH_4OAc (pH 4.8) extractable Ca was 0.48 meq/100 g, and exchangeable Al (by titration) was 0.30 meq/100 g of soil. The pH corresponding to the optimum rate of liming (2200 kg/ha) was 5.7 and the highest rate of lime raised the pH to 6.2. The maximum yield occurred at a pH at which exchangeable Al is absent or present in such small amounts that it is not harmful to plants (Kamprath, 1970, 1972; Reeve and Summer, 1970b; Sanchez, 1976).

Potassium Requirements of Tropical Legumes

It is generalized that temperate legumes have a higher requirement for K than temperate grasses in a mixed pasture (Andrew, 1962; Jones, 1966; Robson and Loneragan, 1978). This is also true for the tropical legumes and grasses, although, in some instances pot or short-term field plot experiments with the legume growing as a single crop do not show the response of the legume to K fertilization, even in soils with relatively low content of available K; responses that would occur if the legumes were mixed with a grass (Werner and Mattos, 1972; Werner and Monteiro, 1974; Blue, 1974; Robson and Loneragan, 1978).

Differences between grasses and legumes in sensitivity to K deficiency may result in marked effects of K deficiency on botanical composition. Potassium-deficient pastures are generally grass dominant, and K application markedly increases the legume component of both temperate and tropical pastures (Gammon and Blue, 1952; Jones, 1966; Robson and Loneragan, 1978).

Robson and Loneragan (1978) reported that the growth of a tropical grass--*Setaria anceps* tapf ex Massey--responded more to K than did the growth of a tropical legume--*Desmodium intortum*--when grown as single crops. However, when these two species were grown together, growth of the legume was markedly depressed by the grass at low, but not at high K supply.

Also, considerable variation in K response occurs within the tropical legumes (Andrew and Robins, 1969c; Brolmann and Sonoda, 1975; Robson and Loneragan, 1978).

Response of *S. guianensis* to K Fertilization and Levels of K in the Plant

Teitzel (1969) studied the responses to P, Cu, and K of a guineagrass-stylo pasture in the wet tropical coast of Queensland, Australia. The legume responded to K only in the presence of both Cu and P. Guineagrass responded to K only when the P status was adequate.

Greenhouse experiments with cerrado soils in Brazil, using several tropical legumes, including stylo, showed that dry matter production and N fixation were not affected by the omission of K (Jones and Freitas, 1970; Jones et al., 1970; Carvalho et al., 1971).

Teitzel and Bruce (1971, 1972a, 1972b, 1973b) in their fertility studies in the wet tropical coast of Queensland, concluded that addition of K, brought about significant plant growth increases in all plant-indicator species in several of the soils and locations used.

Andrew and Robins (1969c) studied the effect of K on the growth and chemical composition of some pasture legumes. Critical K levels are given for the 10 legumes studied. The critical level for S. humilis (the only species from the genus Stylosanthes included in the study) was 0.60% K. In another paper, Andrew and Pieters (1970) described the visual deficiency symptoms of K in these same 10 tropical pasture legumes.

Jones and Clay (1976) studied the foliar symptoms of nutrient disorders in S. humilis. They described the K deficiency symptoms in the following way:

> The symptoms begin on leaves of medium age, as small brown patches generally between the veins, but otherwise randomly distributed over the leaf surface. The brown patches then become necrotic, as do the tips of the leaflets. The tip necrosis gradually spreads towards the petiole and the necrotic leaflet curls inwards and eventually falls off, leaving the green petiole. (Jones and Clay, 1976, p. 4)

This progression is very similar to that described by Andrew and Pieters (1970). Another symptom described by the former authors occurs at very low levels of K when the youngest leaves developed grey "water-soaked" areas between the veins near the base of each leaflet. These areas then became necrotic, merged and spread until the entire leaf was affected. Plants showing this symptom usually showed the first symptom as well.

Brolmann and Sonoda (1975) studied the differential response of three S. guianensis accessions to three levels of K at the Agricultural Research Center, Fort Pierce, Florida. The severity and nature of K deficiency symptoms differed with the varieties involved. Analysis showed that leaves of healthy plants contained 0.70% K and leaves of deficient plants contained only 0.35% K.

Werner et al. (1975) studied the effect of micronutrients on growth and N yield of three tropical legumes grown in pots with a Dark Red Latosol. The macronutrients were applied in abundance to prevent their being limiting factors. The levels of K in the tops of S. guianensis were high and ranged from 2.59 to 2.71%.

Miller and Jones (1977) studied the nutrient requirements of S. guianensis pastures on a Euchrozem in north Queensland, Australia, in a series of field plot experiments. The legume did not respond to the K application in any of the experiments. Surface soil (0 to 10 cm) had pH 6.1 and an exchangeable K content of 1.60 meq/100 g of soil.

Bruce and Teitzel (1978) conducted fertilizer experiments with S. guianensis on two deep sandy soils in north Queensland. In experiment one, with cultivar Schofield, K rates increased yields of the plants. Potassium rates also tended to increase plant K concentration, but the effect was not significant. Exchangeable K in the soil was generally within the range of 8 to 20 ppm regardless of treatment, sampling depth or sampling time. In experiment two, with cultivar Endeavour, 56 kg of K/ha combined with 50 kg of P/ha gave maximum dry matter yield. Plant K concentrations were not affected by K rates at the first harvest, but were increased at the second harvest. Where no K was applied, plant K decreased from 0.80 to 0.51% from the first to the second harvest. Soil analysis for

K showed small increases due to K fertilization. Potassium deficiency symptoms were observed on stylo plants at low K rate treatments in both experiments.

Importance of Boron in Legume Nutrition and Concentrations of the Element in Plants

Boron is essential for the development of plant roots and for the formation of root nodules on leguminous plants in addition to other roles in plant growth. In the absence of B, only rudimentary nodules are formed which are unable to fix N (Mulder, 1948; Whittington, 1959; Andrew, 1962). Boron is required for the maintenance of the apical growing points by stimulating the division and elongation of the apical cells (Whittington, 1959; Andrew, 1962).

However, in the soil, the range is very narrow between deficient and toxic levels for plants. Also, the availability of B for plants varies with soil pH, increasing as the soil pH decreases (Adams and Pearson, 1967; Black, 1968; Murphy and Walsh, 1972).

Tiffin (1972) mentioned that B translocates readily in the xylem, but when it arrives in the leaves, it becomes one of the least mobile of the micronutrients. Thus, a particular leaf may contain sufficient or even excess B, while a leaf on the same stem is deficient.

Boron toxicity at high B levels decreases markedly with increasing concentrations of Ca (Reeve and Shive, 1944; Olsen, 1972). However, the relationship of K to B has been studied less. Reeve and Shive (1944) studied this relationship in tomatoes (*Lycopersicon* esculentum Mill.) grown in nutrient solution. The severity of the B deficiency symptoms in the plants supplied with low levels of B increased progressively with increase in the K concentration in the nutrient solution. However, the plants supplied with a solution containing high levels of B (5.0 ppm) presented visual signs of B toxicity and the toxicity increased in severity with the increase in K concentration in the nutrient solution.

Jones (1972) reports that B deficiency occurs in a wide variety of plants when its level is less than 15 ppm in the dry matter. Adequate but not excessive B occurs from 20 to 100 ppm B. Boron toxicity occurs normally when the plant level exceeds 200 ppm B, although toxicities may occur at lower levels for those plants that are particularly sensitive. Murphy and Walsh (1972) listed the concentrations of B for some plants that were related with decreased yields and toxicity symptoms. Wolf (1971) studied methods of determination of B in plants, soils and water, and quoted adequate and toxic plant levels.

Response of Stylosanthes Species to Boron, and Concentrations of the Element in the Plant

It seems that Stylosanthes species are very sensitive to B excess, showing symptoms of toxicity in the presence of only moderate rates of the element.

Bishop (1974), studying the nutritional requirements of S. humilis grown in the sandy forest country of northwest Queensland, Australia, found that Cu + B treatment was associated with yield depression of this legume. According to the author, the dry matter depression in the presence of Cu + B is thought to be a toxic effect from the 22 kg/ha level of borax used (1.21 ppm B).

Vargas and Dobereiner (1974) studied in a series of greenhouse experiments the effect of levels of liming, Mg, Mn, and B upon nodulation, N fixation, and growth of stylo, using an acid Red-Yellow Podzolic soil. In the experiment with levels of lime, the authors used, among other micronutrients, B at a rate of 0.17 ppm, as a general fertilization for all treatments. The plants of stylo showed, principally at the first stages of growth, a generalized chlorosis and necrosis of the leaflet tips. They supposed that it was due to B deficiency. In another experiment where they studied levels of Mn, they increased the quantities of B, applying for all treatments 2 ppm of this element and also included two extra treatments in which the micronutrients were applied as FTE (B being furnished at the rate of 0.85 ppm). All the treatments but the two which received FTE showed the same symptoms of chlorosis and necrosis mentioned previously, leading to the supposition of B toxicity instead of deficiency. In another experiment, they combined increasing levels of lime and B (0, 1, 2, 3, and 4 ppm B). They obtained a significant interaction between lime and B. Boron toxicity occurred in the absence and presence of low levels of lime, while in presence of the higher levels of lime, application of the intermediate levels of B increased the growth of stylo.

Jones et al. (1970) conducted greenhouse experiments with Cerrado soils from Brazil. In one experiment the yields of four tropical legumes were compared where five micronutrients were withheld individually and altogether. Perennial soybean responded to B but Siratro, centro and stylo did not. In another experiment where levels of Fe, Mn, Cu, Zn, and B were determined in three treatments, the levels of B in stylo were 100 and 187 ppm in the "complete" and "minus lime" treatments, respectively. The "minus micronutrient" treatment had insufficient material for B determination.

Teitzel and Bruce (1971, 1972a, 1972b, 1973a, 1973b), in fertility studies in the wet tropical coast of Queensland, Australia, did not obtain response to B, from the stylo cultivars used (Schofield, Endeavour and Cook) in any of the several soils and areas studied. The only significant response to B in this series of experiments was obtained from Siratro grown on one soil derived from beach sand.

De-Polli and Dobereiner (1974) studied micronutrient deficiencies in a Red-Yellow Podzolic soil and their correction with pellets of fritted trace elements (FTE). Applications of FTE in pellets, coating the seeds, initially induced chlorosis in the seedlings of the four legumes studied (Siratro, perennial soybean, centro, and stylo). The chlorosis was almost completely eliminated by pelleting with FTE mixed with lime or by layering the pellets with FTE and lime.

Werner et al. (1975) studied the application of micronutrients in the form of FTE and in the usual form, using three tropical legumes. Visual signs of Mn toxicity were observed in perennial soybean and in stylo, symptoms attributed to B excess. The B levels in the tops of stylo were 54, 114, and 87 ppm for the control treatment, micronutrients as FTE, and micronutrients in the usual form, respectively. The symptoms observed in this experiment were confirmed by the authors[1] in another experiment where increasing levels of Mn and B (separately) were applied to three tropical legumes. Perennial soybean was the most sensitive to Mn toxicity and stylo the least. However, stylo was the most sensitive to B excess, presenting visual signs of B toxicity (reduction of growth and chlorosis and necrosis of the leaflet tips).

Jones and Clay (1976) studied foliar symptoms of nutrient disorders in Townsville stylo in solution culture. For B and Mn, they studied both symptoms of deficiency and symptoms caused by high levels. They described the symptoms of B toxicity in the following way:

> Boron toxicity is first shown on the older leaves of a plant as a necrosis of the tip which gradually progresses towards the petiole. A characteristic feature of this toxicity is the short duration and small extent of any chlorosis on the leaves. Affected leaflets are usually healthy dark green at their bases and completely chlorotic at their tips, with only a narrow brownish transition zone between the two. In severe cases, the younger expanded leaves show these symptoms, while emerging leaves are distorted and have brownish patches on their margins. (Jones and Clay, 1976, p. 9)

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[1] Werner, J. C., F. A. Monteiro, and H. B. Mattos. Levels of Mn and B in three tropical legumes. Unpublished.

MATERIALS AND METHODS

The surface layers (0 to 15 cm) of three Florida mineral soils were used in a greenhouse experiment to determine the effects of $CaCO_3$, P, K, and B on growth, nodulation, N yield and chemical composition of two *Stylosanthes* species: stylo (*Stylosanthes guianensis* (Aubl.) Sw.) cv. Schofield, and Caribbean stylo (*Stylosanthes hamata* (L.) Taub.) cv. Verano. The soils used were Orangeburg loamy sand (fine-loamy, siliceous, thermic Typic Paleudult) collected at the Agricultural Research and Education Center, Quincy, Florida; Astatula sand (hyperthermic, uncoated Typic Quartzipsament) collected at the Bullock-Huber Ranch, Williston, Florida; and Myakka fine sand (sandy, siliceous, hyperthermic Aeric Haplaquod) collected at the Beef Research Unit near Gainesville, Florida.

Treatments and Experimental Design

The set of experimental treatments was a modified central composite in four factors ($CaCO_3$, P, K, and B) each at five levels arranged in a Response Surface Design.

The total number of treatment combinations was $(2^k + 2^k + 2k + 1) = 41$, where k = number of factors. The arrangement of the 41 treatments consisted of 16 factorial, 16 corner, eight axial and one center point. The factorial and the axial points were not replicated. However, the center point was replicated six times and the corner points were replicated twice in the Entisol and Spodosol and three times in the Ultisol. In this way there were 78 pots for each species in the Ultisol and 62 pots for each species in each of the other two soils. The pots from each species and soil were placed in different benches in the greenhouse and within each bench they were assigned completely at random for the first time, and rotated in a serpentine fashion, every 3 days, to avoid effect of greenhouse position.

Table 1 shows the 41 treatment combinations in coded levels. The actual levels of K and B corresponding to the coded levels used in the three soils are shown in Table 2. In the same way the actual levels of P corresponding to the coded levels are shown in Table 3.

The levels of $CaCO_3$ used in each soil are shown in Table 4. The level zero received no lime so as to maintain the original pH of the soil. The highest level received lime to raise the pH to 7.0. The amount varied from soil to soil and was determined by the method of incubation with increasing quantities of $CaCO_3$ incorporated into 100 g of soil contained in beakers, during 40 days. The three intermediate levels received $CaCO_3$ in amounts equally spaced from zero to the amount necessary to raise the pH to 7.0.

Lime Procedure and Incubation Period

The soils were collected from the first 15-cm surface layers, after cleaning the superficial litter at several points in the site. After being screened with a stainless steel 5-mm screen, the

Table 1. Treatment combinations in coded levels.

Corner points $2^k = 2^4 = 16$				Factorial points $2^k = 2^4 = 16$				Axial points $2k = 2 \times 4 = 8$			
L	P	K	B	L	P	K	B	L	P	K	B
4	4	4	4	3	3	3	3	4	2	2	2
4	4	4	0	3	3	3	1	0	2	2	2
4	4	0	4	3	3	1	3	2	4	2	2
4	4	0	0	3	3	1	1	2	0	2	2
4	0	4	4	3	1	3	3	2	2	4	2
4	0	4	0	3	1	3	1	2	2	0	2
4	0	0	4	3	1	1	3	2	2	2	4
4	0	0	0	3	1	1	1	2	2	2	0
0	4	4	4	1	3	3	3				
0	4	4	0	1	3	3	1				
0	4	0	4	1	3	1	3	Center point			
0	4	0	0	1	3	1	1				
0	0	4	4	1	1	3	3	2	2	2	2
0	0	4	0	1	1	3	1				
0	0	0	4	1	1	1	3				
0	0	0	0	1	1	1	1				

Note: L = Lime ($CaCO_3$).

Table 2. Levels of K and B used in the three soils

Coded levels	Actual K levels	Actual B levels
	---------------- ppm	----------------
0	0	0.00
1	20	0.25
2	40	0.50
3	60	0.75
4	80	1.00

Note: K used as KCl and B as H_3BO_3.

Table 3. Levels of P used in the three soils.

Coded levels	Entisol and Spodosol	Ultisol
	-------------------- ppm	-----------------
0	0	0
1	10	15
2	20	30
3	30	45
4	40	60

Note: P used as $NaH_2PO_4 \cdot H_2O$.

Table 4. Amounts of $CaCO_3$ used in each soil.

Coded levels	Ultisol	Spodosol	Entisol
	------	meq/100 g soil = metric tons/ha	------
0	0.0	0.0	0.0
1	1.0	0.9	0.5
2	2.0	1.8	1.0
3	3.0	2.7	1.5
4	4.0	3.6	2.0

Table 5. Amount and source of the nutrients applied as a basal solution.

Nutrient	ppm[a]	Source
Mg	15	$MgSO_4 \cdot 7H_2O$
S	20	$MgSO_4 \cdot 7H_2O$
Cu	1	$CuSO_4 \cdot 5H_2O$
Zn	1	$ZnSO_4 \cdot 7H_2O$
Mn	2	$MnSO_4 \cdot H_2O$
Mo	0.2	$Na_2MoO_4 \cdot 2H_2O$

[a] Concentration on soil basis.

Table 6. Dates of sowing for each species in each soil.

	Ultisol	Spodosol	Entisol
S. hamata	09-02-77	09-03-77	09-03-77
S. guianensis	09-05-77	09-04-77	09-04-77

soils were air dried and well mixed. Lime (analytical grade $CaCO_3$) was incorporated into the soil using a concrete mixer with capacity to mix 40 kg of soil. After the soil was mixed with $CaCO_3$, 2 kg of soil were weighed and put into plastic pots having holes in the bottom, for free drainage. The bottom 4 to 5 cm of each pot was filled with 1.3 kg of washed gravel to avoid loss of soil and facilitate drainage of excess irrigation water. The gravel was first washed in tap water, soaked during 48 hours in a 0.5 N HCl solution to dissolve any limestone that could be mixed with the gravel, and washed with distilled water.

After the pots were filled they were irrigated with distilled water to bring the soil moisture to field capacity. They were covered with brown paper to reduce evaporation. A period of about 40 days was allowed for the lime to react and reach a stable pH before leaching and sowing.

Leaching the Pots Before Sowing

Before sowing each pot was leached with 1 liter of distilled water to remove nitrates + nitrites + ammonium accumulated from N mineralization during the incubation period. The leachate of some pots (three replications for each level of lime in each soil, chosen at random) was used to determine the mineral N present in the leachate, by using the Magnesium Oxide-Devarda Alloy steam distillation method (Bremner, 1965).

A set of extra pots (one for each level of lime in each soil) was used for soil sampling before leaching and after leaching. These samples were used for measuring the effect of lime levels on the pH status and other chemical characteristics of the three soils, at the time of sowing.

Sowing and Fertilization

After leaching, the soil in the pots was left to dry before sowing. The seeds of the two stylo species were scarified and inoculated with appropriate strains of Rhizobium furnished by Nitragin Company (Milwaukee, Wisconsin) in a peat-base medium. The inoculant for S. guianensis consisted of a mixture of the strains 150 E1; 15021 and 150 D10. A mixture of the strains 150 D1 and 150 D2 was used for S. hamata.

The seeds were sown at a depth of 1 to 2 cm. Twenty to 25 seeds per pot for S. hamata and 30 to 35 seeds per pot for S. guianensis were used based on previous germination tests. This gave a population of 10 to 12 seedlings per pot permitting a thinning later to five plants per pot.

To avoid desiccation of the inoculated Rhizobium, the nutrients were applied in solution immediately after sowing each species in each soil. Phosphorus, K, and B were applied in amounts according to the treatment combinations, by pipetting aliquote of stock solutions into beakers. A basal solution of Mg, S, Cu, Zn, Mn, and Mo in amounts and sources shown in Table 5 was also added for each treatment. Distilled water to complete a volume necessary to wet the soil to field capacity was added in each beaker before pouring the solutions into the pots. The dates of sowing and nutrient applications are shown in Table 6.

When needed, the pots were watered with distilled water to maintain soil moisture at or near the field capacity.

Ten days after sowing the plants were thinned, leaving the strongest 9 plants per each pot. Ten days later the plants were thinned again, leaving 7 plants per pot, and 10 days later plants were thinned to 5 per pot.

To control an infestation of red spider that emerged about 50 days after germination, the plants were sprayed with Kelthane (1,1-bis-(p-Chlorophenyl)-2,2,2-Trichloroethanol).

Harvest

Caribbean stylo plant tops were harvested 73, 76, and 77 days after planting, in the Spodosol, Ultisol, and Entisol, respectively. Stylo plant tops were also harvested 79, 87, and 85 days after planting, in the Spodosol, Ultisol, and Entisol, respectively. At the time of harvest, S. hamata was in the flowering stage and S. guianensis in the Ultisol was just starting to set the first blossoms. The plants were cut at the soil surface, and the root systems were removed from the pots and washed thoroughly. After washing the roots, a visual estimation of nodulation was made using scores from 1 to 5 for none, poor, fair, good, and excellent nodulation, respectively. A soil sample was taken from each pot after the harvest and before removal of roots. Plant tops and roots plus nodules were placed in separate paper bags, dried at 70° C, and weighed.

Herbage and Root Analysis

The plant material (tops or roots) was ground in a stainless steel Wiley mill to pass a 20-mesh screen. One or two-gram samples of oven-dry material, depending on the amount available, were ashed in a muffle furnace at 450° C for 4 hours. The ash was cooled before adding 20 ml of 5 N HCl. Solutions were evaporated to dryness on a hot plate to dehydrate silica. Residues were redissolved in 2.5 ml of 5 N HCl, brought to a volume of approximately 20 ml with distilled water, and heated to boiling. The solutions were filtered through Whatman No. 41 filter paper into 50-ml volumetric flasks and made to volume with distilled water. Where insufficient plant sample was available, 0.5 g was processed to 25 ml. In a few cases, replications of the same treatment were combined to obtain enough material for 0.5 g.

Phosphorus was determined by the aminonaphtholsulfonic acid-reduced molybdophosphoric blue method (Fiske and Subbarow, 1925). Potassium was determined by flame spectrophotometry (Jackson, 1958). Calcium, Mg, Na, Mn, Cu, Zn and Fe were determined with atomic absorption spectrophotometry.

Nitrogen was determined by a micro-Kjeldahl procedure which included salicylic acid and sodium thiosulfate for reduction of nitrate. It was used around 0.5 g for the samples with no limitation of material and 0.1 to 0.2 g in cases of samples with limited material.

Boron was determined (only in the plant tops) by the Azomethine-H method (Wolf, 1971); 0.5 or 1.0 g samples of oven-dry material, depending on the B concentration, were dry ashed in quartz crucibles. The temperature of the muffle furnace was initially set at 300° C. After this temperature was reached it was increased by 50° C every hour to 450° C; ashing was continued overnight. The ash was cooled and extracted for 4 hours with 10 ml of 0.1 N HCl at room temperature and filtered through Whatman No. 40 filter paper into suitable polyethylene bottles. A 2-ml aliquot of this extract was pipetted in another polyethylene bottle to which 4 ml of buffer-masking reagent was added and mixed well, and then 4 ml of the reagent solution was added. The color was measured spectrophotometrically at 420 nm in a spectronic 10-Bausch & Lomb instrument, after 1 hour standing, using a flowthrough cuvette.

Soil Analyses

Soil samples taken after the incubation period and before planting as well as soil samples taken from each pot after harvesting, were air dried, and crushed to pass a 2-mm screen. Soil pH was determined with a Fisher Accumet, Model 320 pH-Meter in a 1:2 soil-water suspension, and in a 1:2 soil-1 N KCl solution. Double-acid (0.05 N HCl + 0.025 N H_2SO_4, Mehlich, 1953) was used to extract Ca, K, Mg, Fe, Zn, Mn, Cu, and P. Analytical procedures for these elements were the same as for plants. Phosphorus was determined by the ascorbic acid method (Watanabe and Olsen, 1965). Total acidity was determined by leaching the soil samples with 1 N KCl and titrating the leachates with 0.02 N NaOH. The solutions were also used to determine exchangeable Al by back titrating with 0.0286 N HCl, after addition of 10 ml of 4% NaF. Exchangeable H was the difference between total acidity and exchangeable Al (McLean, 1965). Exchangeable Ca and Mg were determined in the same solutions by atomic absorption spectrophotometry. Exchangeable Al, H, Ca, and Mg were summed to obtain the effective cation exchange capacity (ECEC) of the soil. Cation exchange capacity (CEC) was determined by extraction with a neutral buffered 1 N NH_4OAc solution, and Kjeldahl distillation of the adsorbed NH_4 using Na^+ as displacing ion (Chapman, 1965). Organic matter was determined by the Walkley-Black, wet-combustion method as modified by Walkley (1947). Boron was determined in soil samples in the following way: 20-ml portion of through 2-mm sieve crushed soil was extracted with 40-ml hot water for 15 minutes and filtered through Watman No. 40 filter paper into suitable polyethylene bottles. A treatment with 0.5 cm^3 activated charcoal for 2 hours was made in the event of colored extracts. Boron determination in the soil extracts followed the same procedures as for plant extracts.

In the samples taken after the harvest, only the pH in water and KCl and double-acid extractable nutrients (Ca, Mg, K, P, Zn, Cu, Mn, and Fe) were determined.

Statistical Analysis

Computations for the statistical analyses of the data were performed by using the ANOVA and GLM procedures of the Statistical Analysis System (Barr et al., 1976).

The data of soil analysis before planting were analyzed as a split-plot design shown in Appendix Table 44. Tests of significance for the sources of variation soil and lime levels were performed using the mean square for the soil x lime levels interaction as an error term. The other sources of variation were tested using the interaction soil x leaching x lime levels as the error term. The mathematical validity of these tests assumes there is no real soil x lime interaction. No true replication was performed, so that no true error terms are available.

The equations for the contours on soil data, N concentration, and content in the plants were obtained choosing from the model of Appendix Tables 19 through 24 the terms that were significant ($P<0.05$). In the case where there was no linear effect of a single factor ($P>0.05$), that factor was included in the model if there was a first-order interaction ($P<0.05$) of that factor with some other factor under study.

The contour figures were plotted using a Fortran IV G-Level program.

RESULTS AND DISCUSSION

Effects of Lime on Soil Chemical Characteristics Measured at the Planting Time

Application of lime resulted in increased mineralization of organic matter during the incubation period. This is shown by mineral N in water extracts from leaching the soils before planting (43 days after application of lime). The results (Table 7) also showed that rates of mineralization varied among the three soils, being greater in the Ultisol and least in the Spodosol. The effect of lime in increasing mineralization of organic matter is an important point when working with legumes. In some instances the increase in growth and N content due to lime application may not be an effect of lime upon biological N fixation but of increased mineralization of N already present in the soil. In the establishment of mixed pastures where the grass has greater capacity to absorb N, this effect will not likely be observed. If the legume does not start fixing N biologically immediately the effect of lime can be detrimental by increasing organic matter mineralization which will stimulate a more vigorous growth of the grass which will compete more strongly with the legume during establishment.

The changes in other chemical characteristics in the soils as a consequence of liming are shown in Tables 8, 9, and 10. The first increment of lime generally raised the pH more than subsequent

Table 7. Concentrations of nitrogen (nitrates + nitrites + ammonium) in soil leachates 43 days after incubation with lime.

$CaCO_3$	Soil orders		
levels	Ultisol	Spodosol	Entisol
	---------- ppm ----------		
0	12.2	4.2	4.8
1	22.0	4.4	7.5
2	20.5	3.7	9.1
3	23.8	7.4	11.1
4	17.5	6.5	11.7
Average	19.2	5.2	8.8

Table 8. Effects of lime and leaching following 43 days of incubation on chemical characteristics of the Florida Ultisol.

$CaCO_3$	pH			1 N KCl exch. cations						Double-acid ext. nutr.			
applied	H_2O	KCl	OM	Ca	Mg	H	Al	ECEC	CEC	Ca	Mg	K	P
meq/100 g			%	---------------- meq/100 g ----------------						-------- ppm---------			
						Before leaching							
0	5.30	4.80	2.53	2.17	0.56	0.14	0.00	2.87	4.33	440	60	29	8.8
1.0	5.80	5.25	2.52	2.80	0.53	0.07	0.00	3.40	4.87	556	55	26	7.7
2.0	6.10	5.60	2.52	3.69	0.49	0.06	0.00	4.24	4.87	804	58	28	8.6
3.0	6.40	5.90	2.52	4.13	0.43	0.06	0.00	4.62	5.23	940	54	28	9.4
4.0	6.85	6.40	2.38	4.94	0.38	0.05	0.00	5.37	5.05	1136	52	28	9.8
Mean	6.10	5.60	2.49	3.55	0.48	0.08	0.00	4.10	4.87	776	56	28	8.9
						After leaching							
0	5.65	4.75	2.52	1.97	0.40	0.11	0.00	2.52	4.51	364	43	24	8.8
1.0	6.00	5.25	2.58	2.68	0.44	0.09	0.00	3.21	4.60	540	52	24	8.8
2.0	6.30	5.60	2.52	3.25	0.39	0.07	0.00	3.71	4.78	692	48	24	10.6
3.0	6.60	5.90	2.65	4.00	0.38	0.06	0.00	4.44	5.23	900	50	26	9.6
4.0	7.10	6.40	2.65	4.63	0.37	0.05	0.00	5.05	4.87	1064	47	25	10.6
Mean	6.30	5.60	2.58	3.31	0.40	0.08	---	3.80	4.80	712	48	25	9.7

Table 9. Effects of lime and leaching following 43 days of incubation on chemical characteristics of the Florida Spodosol.

$CaCO_3$	pH			1 N KCl exch. cations						Double-acid ext. nutr.			
applied	H_2O	KCl	OM	Ca	Mg	H	Al	ECEC	CEC	Ca	Mg	K	P
meq/100 g			%	---------------		meq/100 g	-----------------			---------	ppm	--------	
						Before leaching							
0.0	5.30	3.70	2.12	0.18	0.04	0.33	0.41	0.96	2.70	30	6.0	12	2.7
0.9	5.90	4.40	2.05	0.88	0.04	0.15	0.07	1.14	2.70	184	6.0	13	3.7
1.8	6.35	5.15	2.05	1.69	0.03	0.11	0.00	1.83	2.79	308	4.8	10	3.9
2.7	6.55	5.65	1.98	2.08	0.04	0.10	0.00	2.22	2.79	388	4.8	9	3.7
3.6	7.00	6.35	1.98	2.75	0.03	0.07	0.00	2.85	2.70	628	4.8	10	6.2
Mean	6.22	5.05	2.04	1.52	0.04	0.15	--	1.80	2.74	308	5.3	11	4.0
						After leaching							
0.0	5.50	3.75	2.05	0.19	0.04	0.36	0.38	0.96	2.70	28	6.0	11	2.0
0.9	6.10	4.40	1.91	0.92	0.04	0.14	0.07	1.17	2.70	172	7.2	11	3.2
1.8	6.55	5.15	1.91	1.69	0.03	0.10	0.00	1.82	2.88	284	6.0	11	3.6
2.7	6.65	5.65	1.84	2.16	0.03	0.07	0.00	2.26	2.70	388	6.0	10	3.4
3.6	7.05	6.30	1.78	2.76	0.03	0.05	0.00	2.83	2.79	576	6.0	9	4.1
Mean	6.37	5.05	1.90	1.54	0.03	0.14	--	1.81	2.75	290	6.2	10	3.3

Table 10. Effects of lime and leaching following 43 days of incubation on chemical characteristics of the Florida Entisol.

$CaCO_3$	pH			1 N KCl exch. cations						Double-acid ext. nutr.			
applied	H_2O	KCl	OM	Ca	Mg	H	Al	ECEC	CEC	Ca	Mg	K	P
meq/100 g			%	---------------- meq/100 g					------------------	-------- ppm			---------
						Before leaching							
0.0	5.25	4.35	1.02	0.27	0.06	0.10	0.27	0.70	1.62	70	6.0	12	5.5
0.5	5.70	4.80	0.89	0.61	0.05	0.10	0.04	0.80	1.71	144	6.0	13	6.6
1.0	6.05	5.30	0.96	1.02	0.05	0.07	0.00	1.14	1.71	196	4.8	11	5.5
1.5	6.50	5.90	0.89	1.51	0.04	0.06	0.00	1.61	1.80	304	6.0	12	8.9
2.0	6.80	6.25	0.96	1.88	0.04	0.05	0.00	1.97	1.80	364	6.0	12	8.6
Mean	6.06	5.32	0.94	1.06	0.05	0.08	--	1.24	1.73	216	5.8	12	7.0
						After leaching							
0.0	5.50	4.35	0.89	0.25	0.05	0.09	0.27	0.66	1.62	50	4.8	9	5.6
0.5	5.90	4.75	0.82	0.58	0.04	0.08	0.06	0.77	1.62	120	4.8	8	4.9
1.0	6.25	5.30	0.82	1.01	0.04	0.06	0.00	1.11	1.71	216	4.8	9	6.6
1.5	6.65	5.85	0.82	1.46	0.04	0.05	0.00	1.55	1.89	320	6.0	11	8.6
2.0	6.95	6.25	0.75	1.79	0.03	0.03	0.00	1.85	1.98	400	6.0	10	10.2
Mean	6.25	5.30	0.82	1.02	0.04	0.06	--	1.19	1.76	222	5.3	9	7.2

increments, both in samples taken before and after leaching. The tendencies for pH changes were the same in water and in 1 N KCl. The pH values in 1 N KCl were always lower than in water; this difference was large in unlimed soils and decreased with increasing lime levels. Martinez (1977) working with three identical Florida soils found similar results. According to Coleman and Thomas (1967), the difference between pH values in water and 1 N KCl is caused by replacement of adsorbed Al by K; subsequently the Al^{3+} in the soil solution hydrolizes to produce H^+. Also the difference in 1 N KCl and water pH was larger in Spodosol than in the Entisol, and larger in Entisol than in Ultisol. The water pH values of the three soils were about the same when unlimed and in each of the four levels of lime applied. However, the 1 N KCl pH values were lower in the Spodosol, intermediate in the Entisol, and higher in the Ultisol when unlimed and when limed at low rates. At the highest rates of lime, the 1 N KCl pH values were similar in the three soils. The water pH values were somewhat higher after leaching than before leaching, but the 1 N KCl pH values were not affected by leaching.

Exchangeable Al was reduced sharply by lime in the three soils. There was no exchangeable Al in the unlimed Ultisol before leaching and 0.04 meq/100 g after leaching; this was neutralized with the first increment of lime. Exchangeable Al decreased from 0.41 and 0.38 before and after leaching, respectively, to 0.07 meq/100 g in the Spodosol, and similarly in the Entisol. With the second increment of lime, none of the soils had exchangeable Al. Exchangeable hydrogen also decreased with increasing lime rates. With the first increment of lime the pH (in water) increased to a range of 5.7 to 6.1 in the three soils, both before and after leaching. Yuan (1963) pointed out that exchangeable H and Al were negligible above pH 5.8. Martinez (1977) also found similar results working with three soils identical to the ones of the present work.

The ECEC increased with each increasing lime level in each of the three soils, both before and after the leaching treatment. The ECEC was highest in the Ultisol, intermediate in the Spodosol, and lowest in the Entisol at all pH values. There was an effect of leaching treatment ($P<0.01$). However, the interaction soil x leaching was also significant ($P<0.01$). This can be explained because the ECEC decreased with the leaching treatment in the Entisol and Ultisol, at all levels of lime but this did not occur in the Spodosol.

The CEC determined by NH_4OAc (pH 7.0) was different ($P<0.01$) among the three soils (highest in Ultisol, intermediate in Spodosol, and lowest in the Entisol) but was not affected by the leaching treatment. The CEC values for each soil were relatively constant regardless of lime level, and they were higher than ECEC values at low pH. However, as the pH increased, both CEC and ECEC values were similar, and at the highest lime level ECEC values were slightly higher than CEC values in all soils except the Entisol after leaching. Pratt (1961), working with $BaCL_2$-triethanolamine (pH 8.2), concluded that the difference between ECEC and CEC values is equivalent to the pH-dependent acidity.

Exchangeable Ca increased progressively with lime levels and pH increase because Ca is adsorbed by H-preferring, pH-dependent charges once the permanent-charge CEC is saturated with Ca. However, exchangeable Mg showed a constant decrease, possibly due to the competitive effect of Ca as lime was increased. Exchangeable Mg at all levels of lime as well as exchangeable Ca in unlimed soils was extremely low in the Spodosol and Entisol. Liming these soils with calcitic limestone can cause problems of Mg deficiency if this element is not supplied. Leaching following incubation with lime caused small but significant decreases in exchangeable Ca and Mg in the Ultisol and Entisol but not in the Spodosol; this explains the significant soil x leaching interaction.

Extractable Ca increased progressively with each increasing lime rate in each of the three soils. Extractable Mg and K did not change significantly ($P>0.05$), despite the slight tendency of K to decrease in the Spodosol, and Mg in the Ultisol. According to Khomvilai and Blue (1977) the retention of K in these soils may be somewhat dependent on pH. They found that K retention was increased slightly by low rates of lime but was decreased as lime rates were increased above 1 or 2 meq/100 g. The leaching treatment decreased ($P<0.05$) the extractable K in the Ultisol and Entisol and extractable Mg in the Ultisol. The decrease in extractable Ca, although small, was also significant in the Ultisol ($P<0.05$) and Entisol ($P<0.01$) with the leaching treatment.

Extractable P increased ($P<0.05$) progressively with increasing levels of lime in each of the three soils. The leaching treatment did not change extractable P. Extractable P values were higher in the Ultisol, intermediate in the Entisol and lower in the Spodosol.

Organic matter percentage was highest in the Ultisol, intermediate in the Spodosol, and lowest in the Entisol ($P<0.05$). Lime levels did not change the organic matter percentage of the three soils. However, it was decreased ($P<0.05$) with leaching treatment in the Entisol and Spodosol but not in the Ultisol.

Double-acid extractable Zn and Cu showed much variation and none of the factors affected ($P>0.05$) their values (Table 11). Extractable Fe decreased with increasing levels of lime in each of the three soils ($P<0.05$) and the soils were different ($P<0.05$). The Spodosol had the most extractable Fe and the Entisol the least. Leaching did not affect Fe concentrations. Manganese concentrations were extremely low in the Spodosol, low in the Entisol and normal in the Ultisol. Increasing lime levels did not change ($P>0.05$) Mn concentration in any of the three soils. Leaching reduced ($P<0.05$) the Mn concentrations only in the Ultisol.

Boron concentrations (Table 12) were extremely variable and did not show a definite trend with increasing lime levels and leaching. Boron concentrations were significantly higher in the Ultisol than in the Spodosol and Entisol.

Effect of Treatment Combinations and Cropping on Some Soil Chemical Characteristics Measured at Harvesting Time

Soil pH values measured in samples taken at harvest time were lower than those measured at planting time at all levels of lime. This

Table 11. Effects of lime and leaching following 43 days of incubation on the concentration of Zn, Fe, Cu, and Mn of three Florida soils.

$CaCO_3$	Ultisol				Spodosol				Entisol			
levels	Zn	Fe	Cu	Mn	Zn	Fe	Cu	Mn	Zn	Fe	Cu	Mn
	ppm											
	Before leaching											
0	0.96	13	0.16	37	4.60	30	0.20	0.4	0.52	10	0.16	3.2
1	0.84	16	0.24	40	0.84	39	0.08	0.4	0.42	12	0.04	4.8
2	1.40	12	0.12	37	1.36	29	0.24	0.4	0.64	7	tr.	3.2
3	2.32	10	0.20	34	0.40	27	0.24	0.4	0.36	8	0.20	4.0
4	1.64	11	0.16	45	0.44	21	0.12	0.4	2.16	8	0.12	4.8
Mean	1.43	12	0.18	39	1.53	29	0.18	0.4	0.82	9	0.10	4.0
	After leaching											
0	2.52	13	0.24	30	1.00	37	0.04	0.4	0.92	11	0.08	3.6
1	0.84	17	0.20	38	3.68	36	0.04	0.4	0.92	8	0.12	2.8
2	1.72	12	0.28	31	5.40	28	0.08	0.4	0.20	7	0.16	2.8
3	1.68	10	0.28	32	2.72	26	0.12	0.4	1.64	8	0.20	4.4
4	3.48	10	0.20	40	3.20	22	0.12	0.4	0.92	8	0.20	4.4
Mean	2.05	12	0.24	34	3.20	30	0.08	0.4	0.92	8	0.15	3.6

Note: Zinc, Fe, Cu, and Mn extracted with double-acid (0.025 N H_2SO_4 and 0.05 N HCl).

Table 12. Effect of lime and leaching following 43 days of incubation on the content of B in three Florida soils.

$CaCO_3$ levels	Ultisol		Spodosol		Entisol	
	Before leaching	After leaching	Before leaching	After leaching	Before leaching	After leaching
	ppm					
0	0.30	0.66	0.17	0.22	0.15	0.22
1	0.26	0.44	0.08	0.22	0.30	0.15
2	0.82	0.40	0.55	0.06	0.35	0.08
3	0.54	0.40	0.06	0.25	0.55	0.08
4	0.22	0.30	0.06	0.06	0.22	0.17
Average	0.43	0.44	0.18	0.16	0.31	0.14

difference was greater in the Spodosol and Entisol than in the Ultisol. Also the pH values in all soils and at each lime rate were lower when cropped with stylo than with Caribbean stylo. Data in Tables 13 and 14 show the main effects of the lime levels on water and KCl pH for the three soils cropped with the two Stylosanthes species.

The differences in pH values were likely caused by two primary factors as follows: (a) the salts of S, Mg, Mn, Cu, and Zn which were applied as sulfates in the general fertilization as well as the KCl used to provide K, present an acidifying effect, and (b) secondly, and more important, the absorption of Ca by growing plants from a relatively small soil volume. In some treatments, with no limitation of P and K, more than half of the Ca applied was removed by the plants. The yield of stylo was higher than of Caribbean stylo in all three soils and its Ca concentration was also higher. Due to greater Ca uptake, the concentrations of the element in the soils where stylo was cropped were lower than where Caribbean stylo was cropped (Table 15) which resulted in a lower pH.

As would be expected, the effect of increasing levels of lime resulted in increased pH and extractable Ca in all three soils. However, due to the effect of cropping and fertilizer application, pH values were lower than those determined after the incubation period. For instance, at the highest level of lime, water pH was around 7.0 in all three soils, before planting (Tables 8, 9, and 10); they declined to approximately 6.0 in the Entisol and Spodosol, and to 6.5 in the Ultisol (Tables 13 and 14). Also, the Ca content, which was very low in the unlimed Entisol and Spodosol, dropped to extremely low

Table 13. Effect of lime levels on the pH (H_2O) of three Florida soils following the removal of a crop of S. guianensis and S. hamata.

$CaCO_3$	Ultisol		Spodosol		Entisol	
levels	S. guianensis	S. hamata	S. guianensis	S. hamata	S. guianensis	S. hamata
0	5.3[a]	5.5	4.3	4.4	4.9	5.0
1	5.6	5.9	4.6	4.7	5.0	5.4
2	5.8	6.0	5.0	5.1	5.2	5.6
3	6.2	6.4	5.6	5.6	5.6	5.9
4	6.5	6.7	6.1	6.2	6.0	6.2

[a] Means are averages over P, K, and B combinations.

Table 14. Effect of lime levels on the pH (KCl) of three Florida soils following the removal of a crop of *S. guianensis* and *S. hamata*.

$CaCO_3$	Ultisol		Spodosol		Entisol	
levels	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*
0	4.3[a]	4.5	3.2	3.3	3.9	3.9
1	4.7	5.0	3.5	3.7	4.0	4.1
2	5.0	5.3	4.0	4.2	4.2	4.6
3	5.4	5.7	4.8	5.1	4.7	5.0
4	5.8	6.0	5.6	5.8	5.2	5.4

[a] Means are averages over P, K, and B combinations.

Table 15. Effect of lime levels on extractable calcium in three Florida soils following the removal of a crop of _S_. _guianensis_ and _S_. _hamata_.

$CaCO_3$	Ultisol		Spodosol		Entisol	
levels	_S_. _guianensis_	_S_. _hamata_	_S_. _guianensis_	_S_. _hamata_	_S_. _guianensis_	_S_. _hamata_
	ppm					
0	219	233	17	21	15	21
1	381	457	86	90	39	68
2	582	601	176	192	85	131
3	712	625	236	317	162	200
4	896	841	394	495	255	315

Note: Calcium extracted with double-acid (0.025 N H_2SO_4 and 0.05 N HCl); means are averages over P, K, and B combinations.

levels after cropping with the two Stylosanthes species (Table 15). Martinez (1977), working with the same soils, did not observe such a decrease. But she applied as a general fertilization, concentrated superphosphate that carries a considerable amount of Ca. The difference between the Ultisol and the two other soils is that the former had a much higher Ca content than the Spodosol and Entisol, and it also received more lime per each unit of coded level due to its higher buffering capacity.

Extractable P in all three soils, increased with increasing levels of applied P and also with lime levels (Table 16). However, the P content was slightly higher when the soils were cropped with Caribbean stylo than with stylo. This was likely caused by the higher dry matter yield and P uptake of the stylo which reduced extractable soil P.

Increasing levels of K and B did not indicate a definitive trend in the soil extractable P.

Contours of extractable soil P as effected by lime and P fertilization applied to the Entisol cropped with stylo are presented in Fig. 1. These data illustrate the general trend described above which occurred in all three cropped soils.

Extractable K in soil samples taken at harvest time was extremely low in all three soils (Table 17). Even soil with treatment combinations with the highest level of K had low extractable K. The Ultisol cropped with stylo and fertilized with the highest rate of K contained less extractable K than at planting time (Table 8), and the Entisol contained approximately the same amount (Table 10).

Table 16. Effects of lime and P levels on extractable P in three Florida soils following the removal of a crop of *S. guianensis* or *S. hamata*.

Entisol - *S. guianensis*

P levels	CaCO$_3$ levels 0	1	2	3	4
	--------	--------	ppm	--------	--------
0	5.7		6.7		8.2
1		7.2		10.8	
2	10.1		12.3		13.5
3		11.6		14.2	
4	15.2		14.7		22.3

Entisol - *S. hamata*

P levels	CaCO$_3$ levels 0	1	2	3	4
	--------	--------	ppm	--------	--------
0	6.0		6.1		9.5
1		8.8		12.5	
2	9.4		13.6		16.9
3		17.2		19.4	
4	17.9		19.7		31.3

Spodosol - *S. guianensis*

P levels	CaCO$_3$ levels 0	1	2	3	4
	--------	--------	ppm	--------	--------
0	1.4		1.3		2.2
1		2.8		3.6	
2	3.0		5.0		9.1
3		6.6		8.7	
4	6.2		12.2		17.7

Spodosol - *S. hamata*

P levels	CaCO$_3$ levels 0	1	2	3	4
	--------	--------	ppm	--------	--------
0	1.8		1.7		2.9
1		4.2		5.7	
2	5.1		10.5		11.8
3		11.0		16.1	
4	10.2		13.5		31.6

Ultisol - *S. guianensis*

P levels	CaCO$_3$ levels 0	1	2	3	4
	--------	--------	ppm	--------	--------
0	4.4		6.4		6.3
1		5.4		10.0	
2	15.1		14.0		13.1
3		14.9		18.7	
4	15.7		18.0		25.2

Ultisol - *S. hamata*

P levels	CaCO$_3$ levels 0	1	2	3	4
	--------	--------	ppm	--------	--------
0	4.6		5.8		6.4
1		8.5		8.6	
2	9.8		13.8		14.4
3		19.5		18.5	
4	18.3		22.5		27.5

Note: a. Phosphorus extracted with Double-acid (0.025N H_2SO_4 and 0.05N HCl).
b. Means are averages over K and B combinations.

Figure 1. Contours of extractable soil P (ppm) as affected by levels of lime and P applied to a Florida Entisol cropped with _S. guianensis_, for B=1.

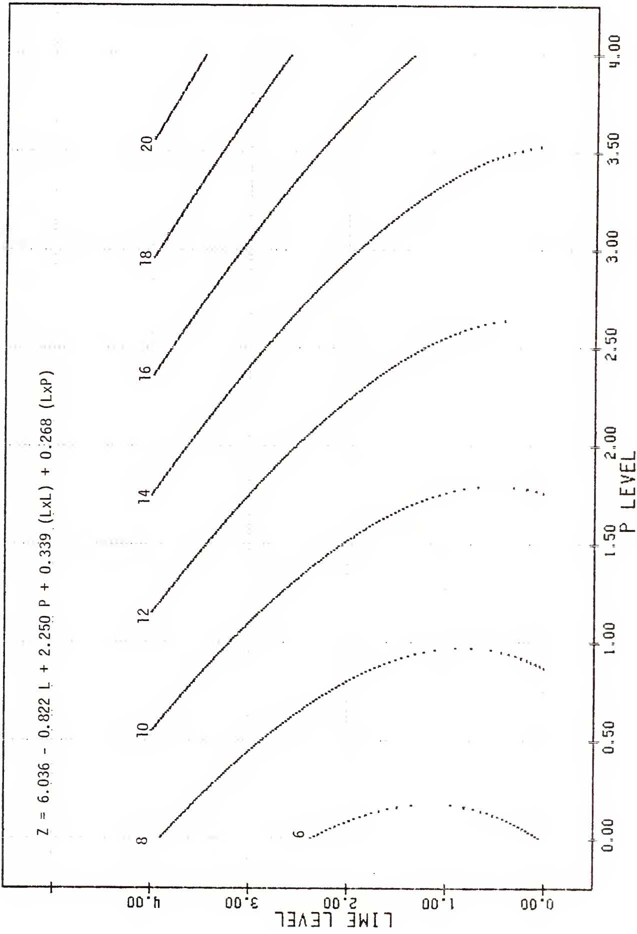

Z = 6.036 - 0.822 L + 2.250 P + 0.339 (LxL) + 0.268 (LxP)
6
8
10
12
14
16
18
20
P LEVEL
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
LIME LEVEL
0.00
1.00
2.00
3.00
4.00

Table 17. Effect of applied K on extractable K in three Florida soils following the removal of a crop of *S. guianensis* and *S. hamata*.

K	Ultisol		Spodosol		Entisol	
levels	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*
ppm	ppm					
0	10.9	6.8	3.9	3.6	4.0	4.2
20	11.5	9.5	3.4	3.2	5.6	5.6
40	14.1	13.1	5.2	4.6	7.4	7.8
60	12.9	17.5	4.8	6.1	7.9	15.1
80	17.8	27.6	22.6	29.5	11.1	22.8

Note: Potassium extracted with double-acid (0.025 N H_2SO_4 and 0.05 N HCl); means are averages over lime, P, and B levels.

The high amount of K uptake by plants, the relatively low soil volume in each pot, and the low potential of these sandy soils to supply native K to the plants (Gammon and Blue, 1952; Khomvilai and Blue, 1977) are the main reasons for this high K depletion. Indeed, in the experimental design used, the highest level of K applied was combined with treatments with none and the highest levels of lime, P, and B. The absence of P in all three soils, and absence of lime in the Entisol and particularly in the Spodosol seriously limited the growth of the two Stylosanthes species, and consequently their K uptake. Extractable K in treatment combinations which received the highest level of K were higher not only because of the amount of K applied but also because of less growth and K uptake by the plants.

Data in Table 18 show the relationship of increasing levels of lime and K, and Table 19 the relationship of increasing levels of P and K, which influenced the amount of extractable K in the three Florida soils following the two Stylosanthes croppings.

The contours of extractable soil K due to the effect of P and K levels applied to Entisol cropped with S. guianensis are shown in Fig. 2. The contours of this element due to the effect of lime and K levels applied to the Spodosol cropped with S. guianensis are shown in Fig. 3. The same general trend occurred in all three soils cropped with both the two Stylosanthes species.

Extractable Mg did not show the same trend with the effect of the fertilizer treatment combinations applied to the three soils, cropped either with one or the other species of Stylosanthes studied.

Table 18. Effects of lime and K levels on extractable K in three Florida soils following the removal of a crop of S. guianensis or S. hamata.

Entisol - S. guianensis

K	$CaCO_3$ levels				
levels	0	1	2	3	4
	ppm				
0	4.1		4.0		3.9
1		4.5		6.8	
2	5.0		7.7		7.0
3		7.2		8.5	
4	10.8		10.0		11.2

Entisol - S. hamata

K	$CaCO_3$ levels				
levels	0	1	2	3	4
	ppm				
0	3.8		3.0		4.8
1		5.5		5.8	
2	8.0		7.7		8.0
3		14.2		16.0	
4	19.9		13.0		26.2

Spodosol - S. guianensis

K	$CaCO_3$ levels				
levels	0	1	2	3	4
	ppm				
0	5.2		3.0		2.8
1		4.0		2.8	
2	14.0		4.4		4.0
3		5.0		4.5	
4	33.5		6.0		13.8

Spodosol - S. hamata

K	$CaCO_3$ levels				
levels	0	1	2	3	4
	ppm				
0	4.6		4.0		2.6
1		2.5		4.0	
2	10.0		4.1		4.0
3		6.0		6.2	
4	34.1		5.0		27.9

Ultisol - S. guianensis

K	$CaCO_3$ levels				
levels	0	1	2	3	4
	ppm				
0	9.3		12.0		12.4
1		9.2		13.8	
2	12.0		14.6		12.0
3		12.0		13.8	
4	15.2		18.0		20.3

Ultisol - S. hamata

K	$CaCO_3$ levels				
levels	0	1	2	3	4
	ppm				
0	5.9		7.0		7.8
1		9.8		9.2	
2	10.0		13.4		13.0
3		21.2		13.8	
4	26.3		27.0		28.4

Note: a. Potassium extracted with Double-acid (0.025N H_2SO_4 and 0.05N HCl).
b. Means are averages over P and B levels.

Table 19. Effects of P and K levels on extractable K in three Florida soils following the removal of a crop of *S. guianensis* or *S. hamata*.

Entisol - *S. guianensis*

K	P levels				
levels	0	1	2	3	4
	ppm				
0	4.2		4.0		3.8
1		5.8		5.5	
2	8.0		7.5		6.0
3		8.5		7.2	
4	13.9		10.0		8.5

Entisol - *S. hamata*

K	P levels				
levels	0	1	2	3	4
	ppm				
0	3.8		3.0		4.8
1		5.5		5.8	
2	7.0		7.8		8.0
3		13.8		16.5	
4	23.2		18.0		22.9

Spodosol - *S. guianensis*

K	P levels				
levels	0	1	2	3	4
	ppm				
0	3.8		3.0		4.2
1		3.5		3.2	
2	5.0		5.3		4.0
3		4.2		5.2	
4	27.8		6.0		19.5

Spodosol - *S. hamata*

K	P levels				
levels	0	1	2	3	4
	ppm				
0	3.8		4.0		3.5
1		3.5		3.0	
2	5.0		4.7		3.0
3		6.0		6.2	
4	35.8		5.0		26.2

Ultisol - *S. guianensis*

K	P levels				
levels	0	1	2	3	4
	ppm				
0	10.3		12.0		11.4
1		11.0		12.0	
2	13.0		14.2		14.0
3		12.8		13.0	
4	18.5		13.0		17.0

Ultisol - *S. hamata*

K	P levels				
levels	0	1	2	3	4
	ppm				
0	6.9		7.0		6.2
1		10.0		9.0	
2	11.0		13.6		10.0
3		18.0		17.0	
4	27.5		27.0		27.8

Note: a. Potassium extracted with Double-acid (0.025N H_2SO_4 and 0.05N HCl).
b. Means are averages over lime and B levels.

Figure 2. Contours of extractable soil K (ppm) as affected by levels of P and K applied to a Florida Entisol cropped with *S. guianensis*, for lime=2.

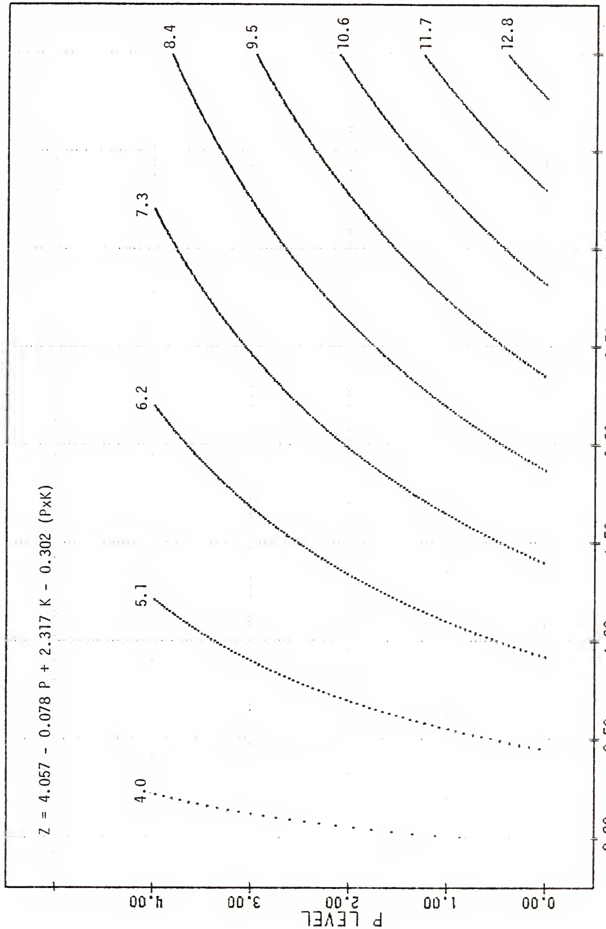
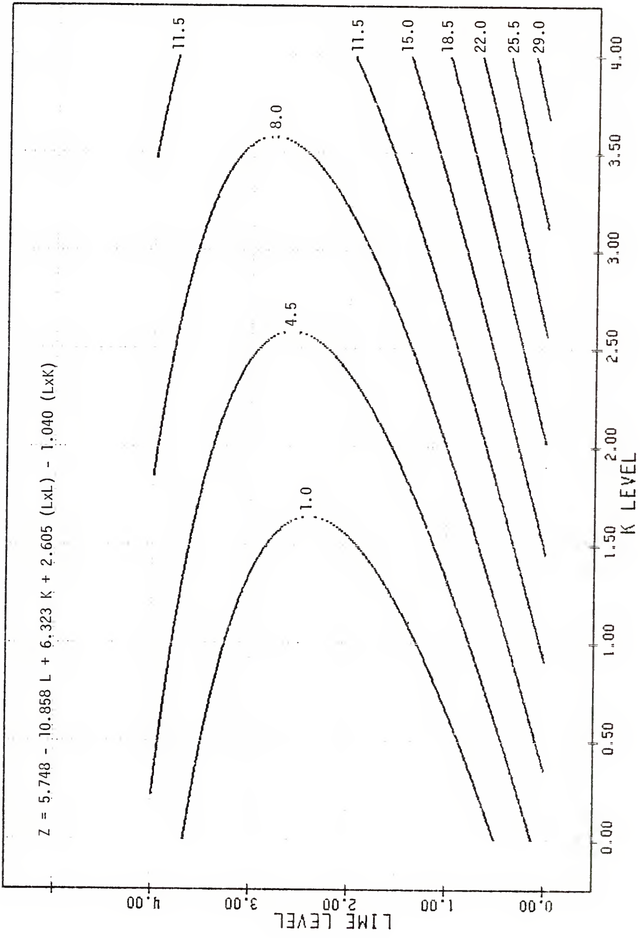

Z = 4.057 - 0.078 P + 2.317 K - 0.302 (PxK)
4.0
5.1
6.2
7.3
8.4
9.5
10.6
11.7
12.8
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
K LEVEL
0.00
1.00
2.00
3.00
4.00
P LEVEL

Figure 3. Contours of extractable soil K (ppm) as affected by levels of lime and K applied to a Florida Spodosol, for P=2.


Z = 5.748 - 10.858 L + 6.323 K + 2.605 (LxL) - 1.040 (LxK)
11.5
8.0
4.5
1.0
11.5
15.0
18.5
22.0
25.5
29.0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
K LEVEL
0.00
1.00
2.00
3.00
4.00
LIME LEVEL

However, there was a positive linear effect of lime upon extractable Mg, except in the Spodosol cropped with stylo; the linear effect of lime was negative, but the quadratic effect was positive (Appendix Tables 19 through 21). The effect of lime on extractable Mg was probably an antagonistic one in that with high Ca less Mg was absorbed by the plants and more remained in the soil. The extractable Mg was much higher in the Ultisol than in the Spodosol and the Entisol (Appendix Tables 1 through 6).

The double-acid extractable Fe concentration of all three soils decreased with increasing levels of lime (Table 20). However, the effect was not significant ($P>0.05$) in the Entisol cropped with stylo. The extractable Fe concentration was higher in the Spodosol than in the Ultisol and Entisol.

The contents of either Mn, Cu, or Zn double-acid extracted did not show the same trends in the three soils, cropped with both species, due to the effect of the lime and fertilizer treatment combinations. Data in Appendix Tables 1 through 6 show that extractable Mn was higher in the Ultisol than in the Entisol and Spodosol.

The Ca/Mn ratio increased progressively with increasing lime levels (Table 21). It was much larger in the Spodosol than in the Ultisol and Entisol. This was due primarily to the low levels of Mn determined in the Spodosol.

Dry-Matter Yield

Tops

Dry-matter yields of stylo were higher than those of Caribbean stylo in all three soils. This cannot be attributed solely to a

Table 20. Effect of lime levels on the Fe content in three Florida soils following the removal of a crop of *S. guianensis* or *S. hamata*.

$CaCO_3$	Ultisol		Spodosol		Entisol	
levels	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*
	ppm					
0	12.1	9.8	27.8	26.3	8.6	8.3
1	11.6	10.8	27.8	27.3	8.1	7.4
2	11.6	10.1	30.1	27.2	8.8	6.9
3	10.1	8.1	20.1	21.1	8.2	6.6
4	9.6	7.9	18.2	18.2	7.9	6.5

Note: Iron extracted with double-acid (0.025 N H_2SO_4 and 0.05 N HCl); means are averages over P, K, and B levels.

Table 21. Effect of lime levels on the Ca/Mn ratio in three Florida soils following the removal of a crop of *S. guianensis* and *S. hamata*.

$CaCO_3$	Ultisol		Spodosol		Entisol	
levels	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*
0	10	12	18	20	4	6
1	16	18	83	74	10	18
2	21	23	177	133	16	31
3	27	30	254	337	30	44
4	33	34	480	444	52	61

Note: Calcium and Mn extracted with double-acid (0.025 N H_2SO_4 and 0.05 N HCl); means are averages over P, K, and B combinations.

differential response between species. It was also caused by a slightly later time of harvesting (Caribbean stylo was harvested first as it started to flower), and to a differential response to lime and fertilizer treatments.

The response to increasing lime levels varied among soils and between the two species. Caribbean stylo was more responsive to lime application than stylo. In the Ultisol, for instance, the yield of Caribbean stylo increased with low levels of lime, decreasing only with higher levels. Meanwhile, lime depressed the stylo yield starting from the first level. In the Entisol and Spodosol, the Caribbean stylo responded to the highest lime levels used while stylo responded only to the intermediate levels and decreased at the higher levels.

The contours of predicted yields from increasing levels of lime and P are shown in Figs. 4, 5, and 6 for Caribbean stylo on the Ultisol, stylo on the Ultisol, and Caribbean stylo on the Entisol, respectively. These contours also show that Caribbean stylo responded to the highest level of P applied to the Ultisol while stylo did not. In the other two soils (Fig. 6), responses of Caribbean stylo and stylo were similar in that their yields increased to the highest level of P applied.

The interaction lime x P was positive in the Spodosol ($P<0.01$), negative in the Entisol ($P<0.01$), and not significant in the Ultisol ($P>0.05$) for each species. Yields of the two species in the three soils as affected by lime and P levels are shown in Appendix Table 28.

Figure 4. Contours of predicted herbage yields (g/pot) of *S. hamata* on a Florida Ultisol as affected by lime and P levels for K=3 and B=2.

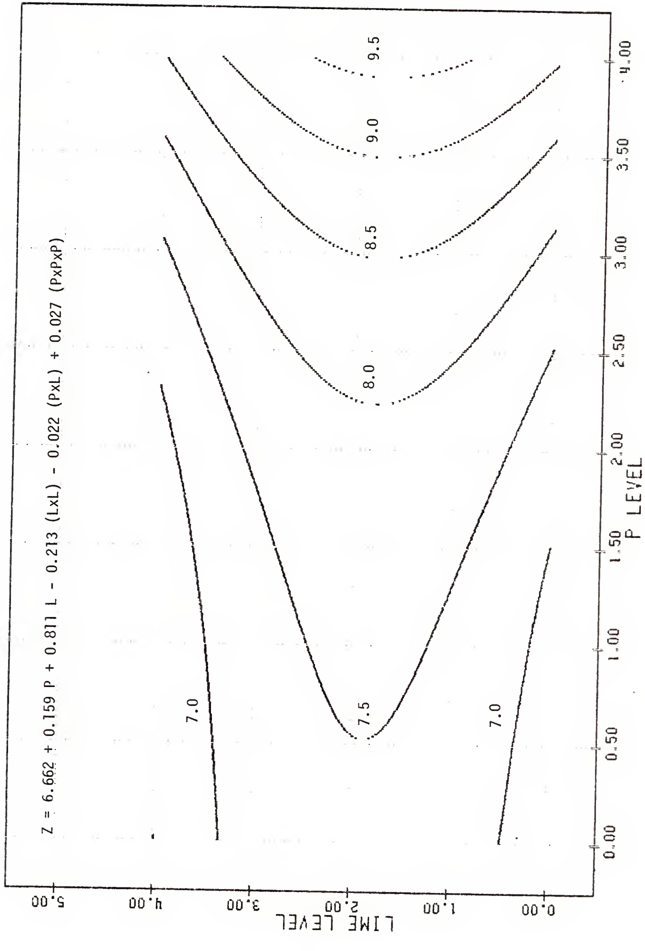

Z = 6.662 + 0.159 P + 0.811 L - 0.213 (LxL) - 0.022 (PxL) + 0.027 (PxPxP)
7.0
7.5
7.0
8.0
8.5
9.0
9.5
P LEVEL
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
LIME LEVEL
0.00
1.00
2.00
3.00
4.00
5.00

Figure 5. Contours of predicted herbage yields (g/pot) of *S. guianensis* on a Florida Ultisol as affected by lime and P levels for K=3 and B=1.

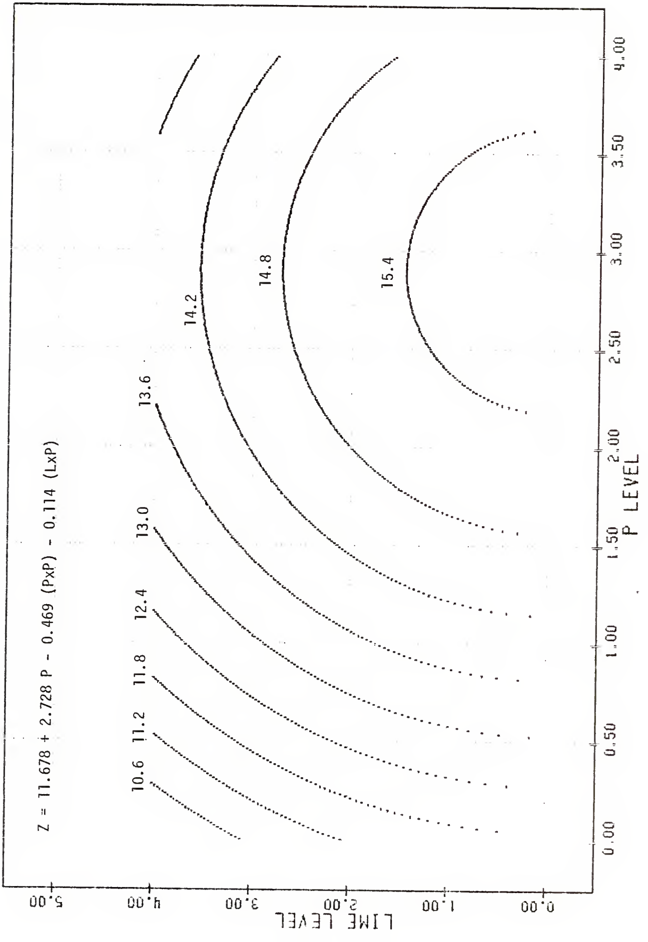
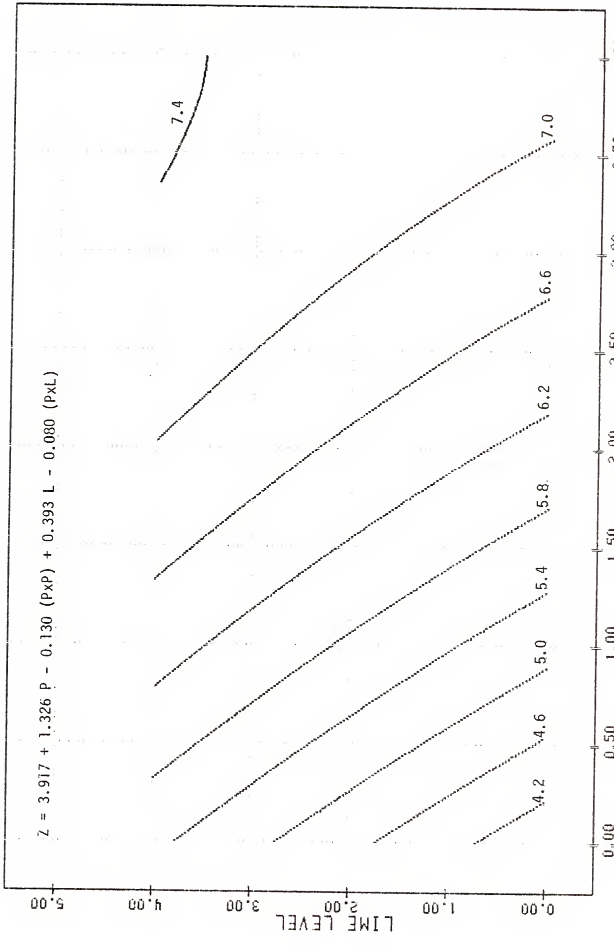

Z = 11.678 + 2.728 P - 0.469 (PxP) - 0.114 (LxP)
10.6
11.2
11.8
12.4
13.0
13.6
14.2
14.8
15.4
P LEVEL
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
LIME LEVEL
0.00
1.00
2.00
3.00
4.00
5.00

Figure 6. Contours of predicted herbage yields (g/pot) of S. hamata on a Florida Entisol as affected by lime and P levels for K=2 and B=2.


Z = 3.917 + 1.326 P - 0.130 (PxP) + 0.393 L - 0.080 (PxL)
4.2
4.6
5.0
5.4
5.8
6.2
6.6
7.0
7.4
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
P LEVEL
0.00
1.00
2.00
3.00
4.00
5.00
LIME LEVEL

The large response to P is in accord with the findings and concepts of Andrew and Robins (1969b), Jones and Freitas (1970), CIAT (1976), Andrew and Johansen (1978), and others which show that *Stylosanthes* species do respond to applied P in spite of the capacity of some to establish in soils low in P. The difference in response of the two species to rates of P applied in the Ultisol also is in accordance with Jones (1974) and Andrew and Johansen (1978), who report differential response to applied P among *Stylosanthes* accessions.

The relatively high response to lime observed in the Entisol and Spodosol was surprising. Data in the literature concerning the response of *Stylosanthes* species to lime are confusing. Sometimes high responses are reported. In other cases no response or even deleterious effect of lime on the yield of *Stylosanthes* species are reported.

The decreases in pH and extractable Ca which occurred during cropping may have accounted for this high response. At harvest time, pH in soil with unlimed treatment combinations and at all levels of lime was almost one unit lower than the pH at planting time in the Spodosol and about one-half unit lower in the Entisol. Soils with treatment combinations that did not contain exchangeable Al at planting time may have developed some because of the decrease in soil pH caused by plant growth and Ca uptake; other adverse factors as a consequence of low pH cannot be eliminated.

Experimenters who base their discussion of results only on the pH values taken before planting, principally if the soil volume used is very small and the soil has low ECEC, may draw misleading conclusions about the pH range at which the species respond or not to lime. Unfortunately, some papers in the literature do not indicate the exact time at which soil samples were taken.

These results and others in the literature (Andrew and Norris, 1961; Odu et al., 1971; Vargas and Dobereiner, 1974; Snyder et al., 1978; and others) show, however, that Caribbean stylo and stylo do respond to moderate levels of lime applied to acid soils containing exchangeable Al. But levels that increase pH above 5.5 to 6.0 can be harmful for these species (Freitas and Pratt, 1969; Jones and Freitas, 1970; CIAT, 1973; Munns and Fox, 1976, 1977b).

Increasing levels of K increased yield of both species up to the highest level applied in all three soils except for Caribbean stylo cropped in the Ultisol where its yield did not increase to the highest level of K applied. It did so at rates around levels 2 and 3 (40 to 60 ppm of K), as shown by the contours of predicted yields affected by lime and K levels (Fig. 7), and by P and K levels (Fig. 8). The general situation where yield increased to the highest rate of K applied is illustrated by Fig. 9. These data show the contours of predicted yield of stylo cropped in the Ultisol as affected by levels of P and K applied.

The response to the highest level of K applied was caused by the low levels of native extractable K present in the three soils, particularly in the Entisol and Spodosol, before the application of K (Gammon and Blue, 1952; Khomvilai and Blue, 1977). The small volume

Figure 7. Contours of predicted herbage yields (g/pot) of _S_. _hamata_ on a Florida Ultisol as affected by lime and K levels for P=3 and B=2.

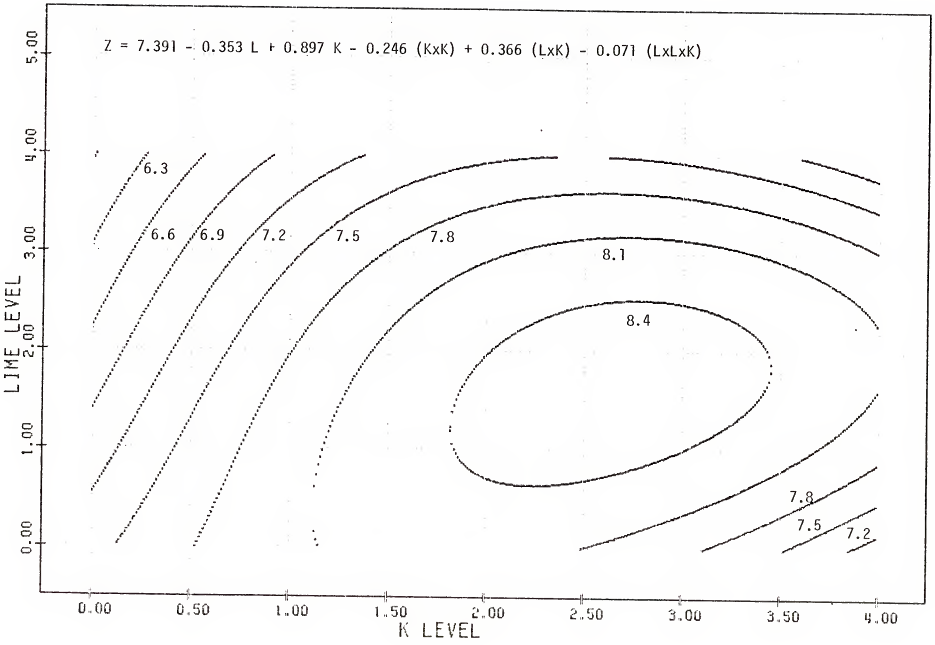

Z = 7.391 - 0.353 L + 0.897 K - 0.246 (KxK) + 0.366 (LxK) - 0.071 (LxLxK)
6.3
6.6
6.9
7.2
7.5
7.8
8.1
8.4
7.8
7.5
7.2
LIME LEVEL
0.00
1.00
2.00
3.00
4.00
5.00
K LEVEL
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00

Figure 8. Contours of predicted herbage yields (g/pot) of _S_. _hamata_ on a Florida Ultisol as affected by P and K levels for lime=2 and B=2.

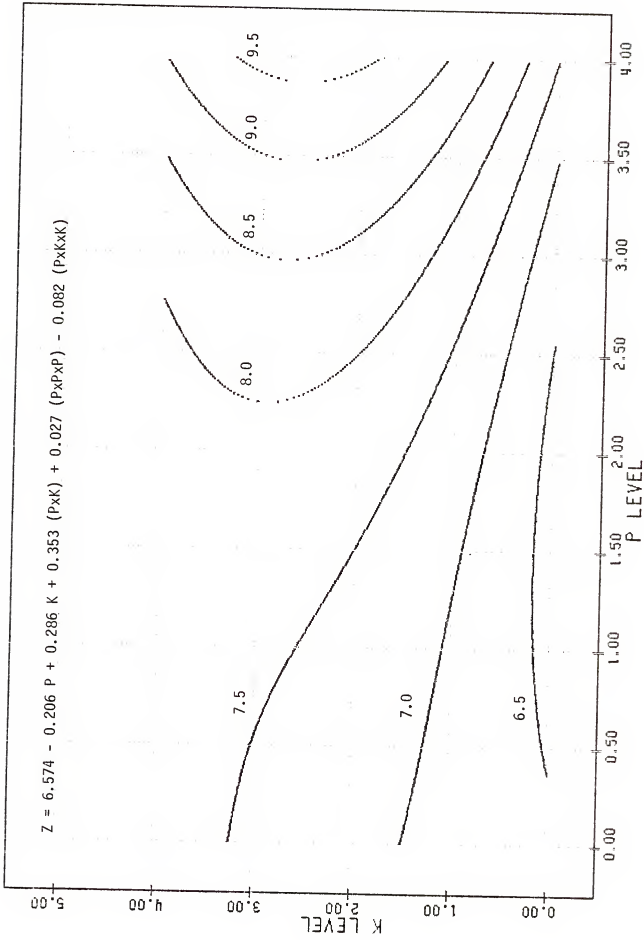
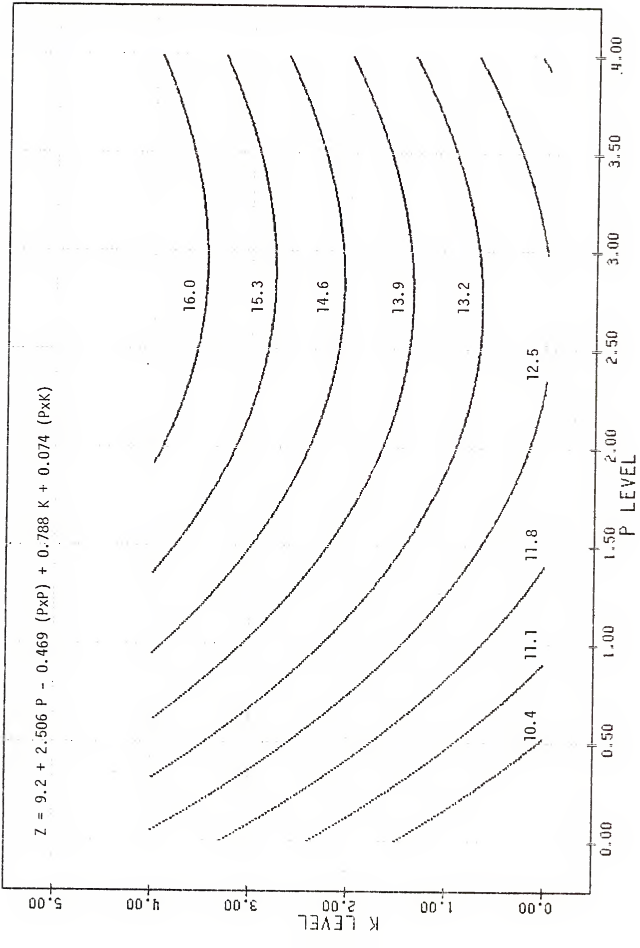

Z = 6.574 - 0.206 P + 0.286 K + 0.353 (PxK) + 0.027 (PxPxP) - 0.082 (PxKxK)
9.5
9.0
8.5
8.0
7.5
7.0
6.5
P LEVEL
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
K LEVEL
0.00
1.00
2.00
3.00
4.00
5.00

Figure 9. Contours of predicted herbage yields (g/pot) of *S. guianensis* on a Florida Ultisol as affected by P and K levels for lime=1 and B=1.


Z = 9.2 + 2.506 P - 0.469 (PxP) + 0.788 K + 0.074 (PxK)
16.0
15.3
14.6
13.9
13.2
12.5
11.8
11.1
10.4
P LEVEL
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
K LEVEL
0.00
1.00
2.00
3.00
4.00
5.00

of soil used also contributed. In fact, the two Stylosanthes species extracted K from the three soils to such an extent that soil extractable K was reduced to very low values even in the treatments that received the highest level of K (combined with adequate levels of lime and P). The treatments that received the highest level of K in combination either with level zero of P (in the three soils), or levels zero of P and zero of lime (Spodosol and Entisol) gave low yields (Tables 22 and 23). Consequently, the soil extractable K in these treatment combinations was depleted only slightly as was shown in the discussion of soil analysis (Tables 18 and 19).

Caribbean stylo yielded much less than stylo when cropped in the Ultisol (Tables 22 and 23). But the K content of the former was higher than that of the latter (Appendix Tables 1 and 2). This resulted in greater soil K depletion by Caribbean stylo than by stylo at the lower levels of K applied, but the reverse was true at the highest rates (Tables 18 and 19).

The effect of B levels on the yield of Caribbean stylo was not significant (Appendix Tables 22 through 24), although there was a slight trend for yield decrease with the highest rates of B. The general trend of the effect of B on the yield of Caribbean stylo in the three Florida soils is illustrated in Fig. 10. This figure shows the contours of predicted yield of Caribbean stylo on a Florida Ultisol, as affected by lime and B levels.

The effect of B levels on the yield of stylo was significant (Appendix Tables 22 through 24), and depression in yield began with

Table 22. Effects of lime and K levels on herbage yields of two *Stylosanthes* species grown on three Florida soils.

Entisol - *S. guianensis*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
	--------	--------	g/pot	--------	--------
0	5.0		5.6		5.2
1		9.9		10.5	
2	10.4		12.5		10.6
3		11.5		12.8	
4	9.1		13.3		11.6

Entisol - *S. hamata*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
	--------	--------	g/pot	--------	--------
0	3.8		4.4		4.5
1		5.4		5.8	
2	6.1		6.7		7.6
3		5.8		6.2	
4	5.4		7.9		6.5

Spodosol - *S. guianensis*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
	--------	--------	g/pot	--------	--------
0	2.0		3.7		2.6
1		6.1		7.2	
2	2.4		9.6		5.8
3		7.2		10.2	
4	2.8		11.4		5.8

Spodosol - *S. hamata*

K	CaCO$_3$ levels				
levels	0	1	3	2	4
	--------	--------	g/pot	--------	--------
0	1.3		3.9		2.5
1		6.0		7.2	
2	2.1		8.8		6.2
3		6.4		6.6	
4	1.9		11.3		3.8

Ultisol - *S. guianensis*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
	--------	--------	g/pot	--------	--------
0	10.5		11.5		9.8
1		12.1		12.2	
2	14.3		13.3		12.3
3		14.6		14.2	
4	14.0		14.4		11.6

Ultisol - *S. hamata*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
	--------	--------	g/pot	--------	--------
0	7.6		6.4		6.3
1		7.2		6.8	
2	7.5		7.8		7.3
3		7.7		7.8	
4	7.5		8.3		7.0

Note: Means are averages over P and B combinations.

Table 23. Effect of P and K levels on herbage yields of two *Stylosanthes* species grown on three Florida soils.

Entisol - *S. guianensis*

K	P levels				
levels	0	1	2	3	4
	--------		g/pot		----------
0	4.5		5.6		5.7
1		9.2		11.2	
2	6.9		12.5		14.5
3		10.2		14.2	
4	8.0		13.3		12.7

Entisol - *S. hamata*

K	P levels				
levels	0	1	2	3	4
	--------		g/pot		---------
0	3.8		4.4		4.5
1		5.1		6.0	
2	5.1		6.8		7.9
3		5.4		6.6	
4	5.1		7.9		6.9

Spodosol - *S. guianensis*

K	P levels				
levels	0	1	2	3	4
	--------		g/pot		----------
0	2.1		3.7		2.4
1		6.3		7.0	
2	4.2		9.0		10.4
3		7.6		9.8	
4	2.7		9.8		5.9

Spodosol - *S. hamata*

K	P levels				
levels	0	1	2	3	4
	--------		g/pot		---------
0	1.7		3.9		2.2
1		6.2		7.0	
2	5.0		8.1		11.0
3		6.0		7.0	
4	2.0		11.3		3.7

Ultisol - *S. guianensis*

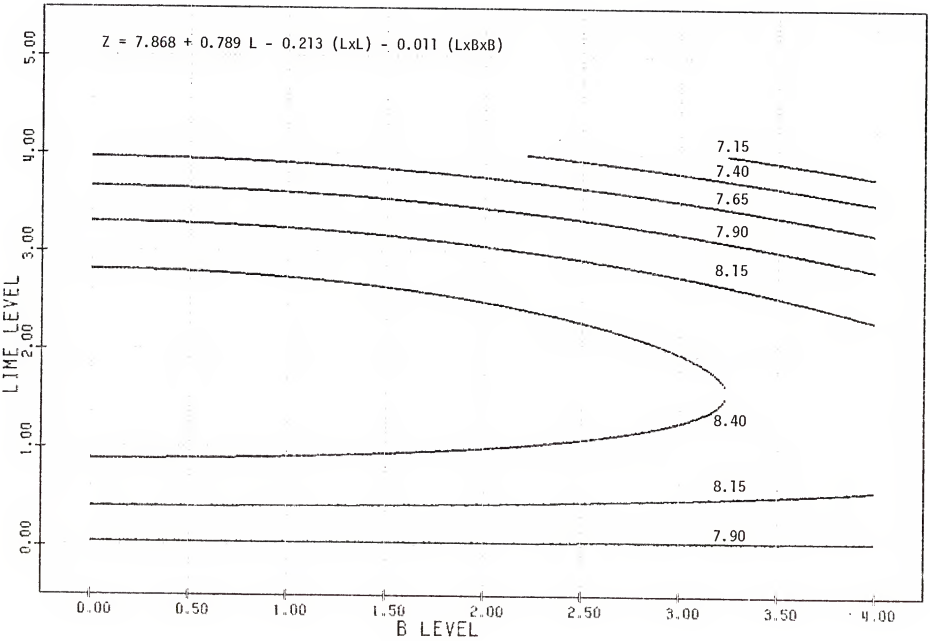
K	P levels				
levels	0	1	2	3	4
	--------		g/pot		----------
0	8.9		11.5		11.5
1		11.6		12.7	
2	10.3		13.6		13.9
3		13.4		15.4	
4	11.0		14.4		14.6

Ultisol - *S. hamata*

K	P levels				
levels	0	1	2	3	4
	--------		g/pot		---------
0	6.5		6.4		7.4
1		6.4		7.6	
2	6.9		7.6		9.8
3		7.2		8.4	
4	6.6		8.3		7.8

Note: Means are averages over Lime and B combinations.

Figure 10. Contours of predicted herbage yields (g/pot) of *S. hamata* on a Florida Ultisol as affected by lime and B levels for P=3 and K=3.


Z = 7.868 + 0.789 L - 0.213 (LxL) - 0.011 (LxBxB)
7.15
7.40
7.65
7.90
8.15
8.40
8.15
7.90
LIME LEVEL
0.00
1.00
2.00
3.00
4.00
5.00
B LEVEL
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00

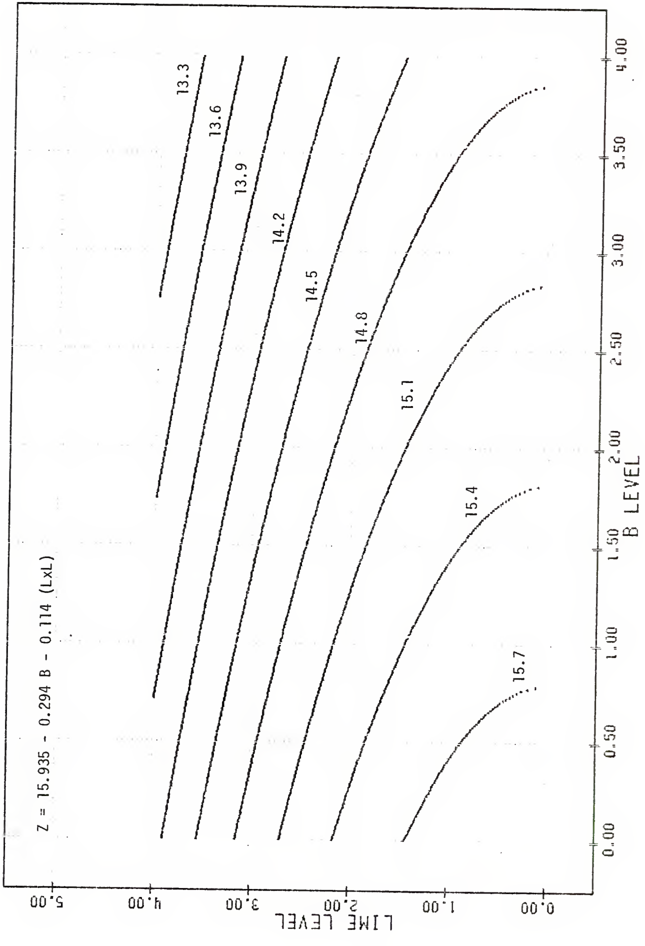
the first increment of B applied (0.25 ppm). Contours of the predicted yield of stylo on a Florida Ultisol, as affected by lime and B levels, are shown in Fig. 11. The same pattern occurred in the other two soils with respect to B response. Although the interaction of lime x B was not significant, Fig. 11 shows that with increasing levels of B the decrease in yield was larger at lower levels of lime than at higher levels.

Vargas and Dobereiner (1974) report B toxicity effects in stylo; liming acted to overcome toxicity effects. Bishop (1974) also reported depression of S. humilis growth associated with Cu and B fertilization. Werner et al. (1975) observed visual symptoms of B toxicity in stylo cv. IRI 1022.

In the present study, yield depression of stylo, with increasing levels of B was associated with distinct foliar symptoms of toxicity of this element. This occurred also in Caribbean stylo, although with less intensity, and only at the higher levels of applied B. Although B is an important element for plant growth and N fixation, it seems that stylo has a very low requirement for this element, and it is very sensitive to moderate or high rates.

The interaction K x B was not significant ($P>0.05$) and a clear relationship of K to B was not found like the one detected by Reeve and Shive (1944) in tomatoes. Yields of the two Stylosanthes species, cropped in the three Florida soils, as affected by K and B levels, are shown in Appendix Table 29. Potassium increased and B decreased yield. This relationship can be seen clearly when we look at the

Figure 11. Contours of predicted herbage yields (g/pot) of S. *guianensis* on a Florida Ultisol as affected by lime and B levels for P=3 and K=3.


Z = 15.935 - 0.294 B - 0.114 (LxL)
13.3
13.6
13.9
14.2
14.5
14.8
15.1
15.4
15.7
B LEVEL
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
LIME LEVEL
0.00
1.00
2.00
3.00
4.00
5.00

treatment combinations on the factorial points (combinations of levels 1 and 3) that do not have the limitation of growth from the absence of the other two factors (P in the three soils and lime in the Spodosol and Entisol). The same can be seen by examining the axial and center points, comparing the yield of levels 0, 2 and 4 of one factor combined with level 2 of the other.

Roots and Nodules

The weight of roots + nodules was greater on stylo than on Caribbean stylo in all three soils (Table 24). The effect of the treatment combinations on the growth of the roots, in general, followed the pattern already described for the plant tops. It calls attention to the very low weight of the roots of both species cropped in the Spodosol, in the treatment combinations with zero lime and or zero P (Appendix Table 30). Nodulation was also poor in these treatment combinations (Appendix Tables 15 and 16). Black (1968) mentioned that Al toxicity represents a combination of effects, of which inhibition of root growth is perhaps the most obvious. In fact, the Spodosol had a very low content of exchangeable Ca and a high content of exchangeable Al in relation to its very low ECEC at planting time. With plant growth and Ca extraction this adverse situation was aggravated to a point that root growth and nodulation of the two *Stylosanthes* species were impaired in this soil.

Nitrogen Concentration and N Content

The N concentration of plant tops was generally higher in Caribbean stylo than in stylo. However, this cannot be attributed to

Table 24. Dry weights of roots + nodules of two *Stylosanthes* species cropped in three Florida soils.

Soil orders	*S. guianensis* Mean		*S. guianensis* SD	*S. hamata* Mean		*S. hamata* SD
	g/pot					
Entisol	1.77	±	0.50	0.84	±	0.14
Spodosol	1.15	±	0.57	0.86	±	0.38
Ultisol	1.77	±	0.32	0.95	±	0.14

Note: Means are averages over all treatment combinations; SD--standard deviation.

differential species response because Caribbean stylo was harvested first in each of the soils, and consequently at a younger stage of development. In consequence of a greater dry matter yield, stylo showed greater N content (tops + roots + nodules) than Caribbean stylo in the Entisol and Ultisol, but not in the Spodosol.

Increasing levels of P always increased N concentration of both species in all soils (Appendix Table 31). Consequently, the N content always increased with increasing levels of P applied (Appendix Table 32). Conversely, increasing levels of K tended to reduce the N concentration in both species (Appendix Table 31). But since K had a positive effect on dry matter yields, increased N content resulted with increasing levels of K applied (Appendix Table 32). The effect of P and K levels on N concentrations and N contents described above, can be seen clearly for the Spodosol, if only the factorial points are considered (treatment combinations with levels 1 and 3 of each factor). The N concentrations and N contents of the corner points (treatment combinations with levels 0 and 4 of each factor) as affected by P and K suffer the interference of the limited growth and N fixation due to lack of lime and excess of B. Data in Figs. 12 and 13 show the effect of P and K on N concentrations and contents, respectively, free from that interference; that is, lime is fixed at a level that did not limit plant growth in that soil and B at a level that did not depress it.

The herbage N concentrations, and total N (tops + roots + nodules) of stylo tended to decrease with increasing levels of lime applied to the Ultisol (Appendix Tables 33 and 34). Caribbean stylo

Figure 12. Contours of predicted herbage N concentration (%) of S. guianensis on a Florida Spodosol as affected by P and K levels for lime=2 and B=1.

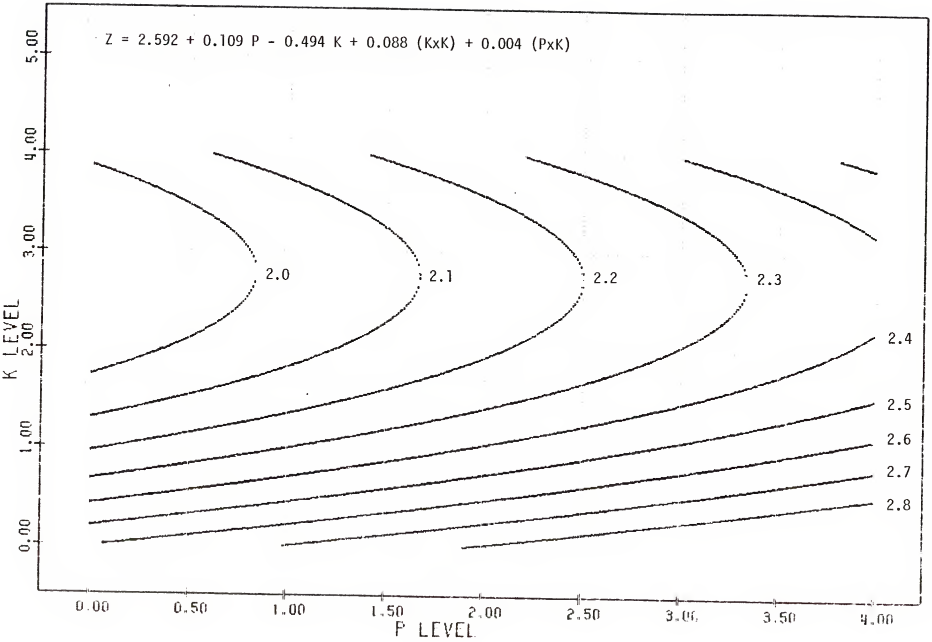
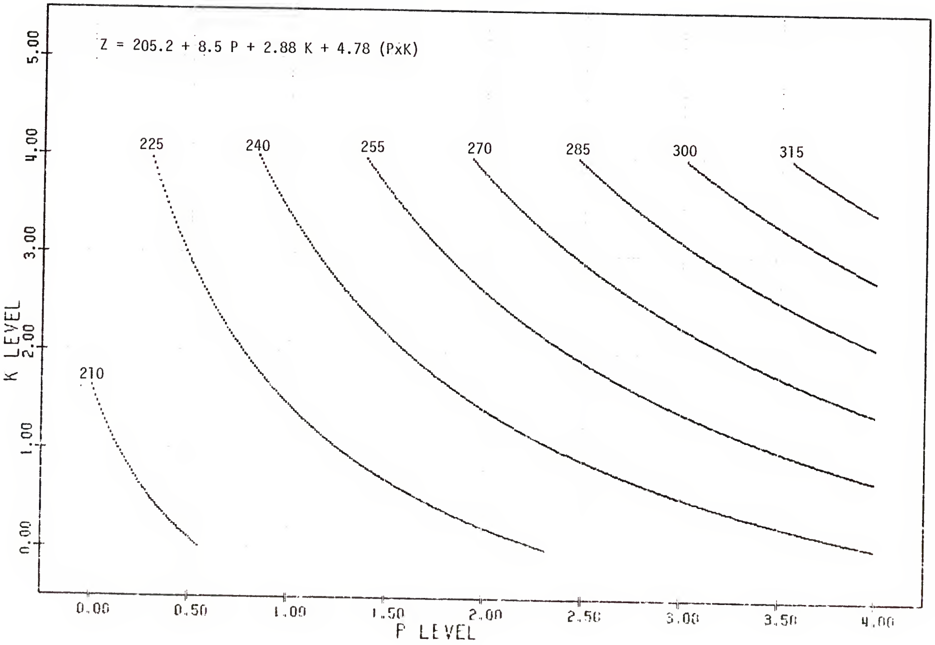

Z = 2.592 + 0.109 P - 0.494 K + 0.088 (KxK) + 0.004 (PxK)
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
K LEVEL
0.00
1.00
2.00
3.00
4.00
5.00
P LEVEL
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00

Figure 13. Contours of predicted N content (mg/pot) of _S_. _guianensis_ on a Florida Spodosol as affected by levels of P and K for lime=2 and B=1.

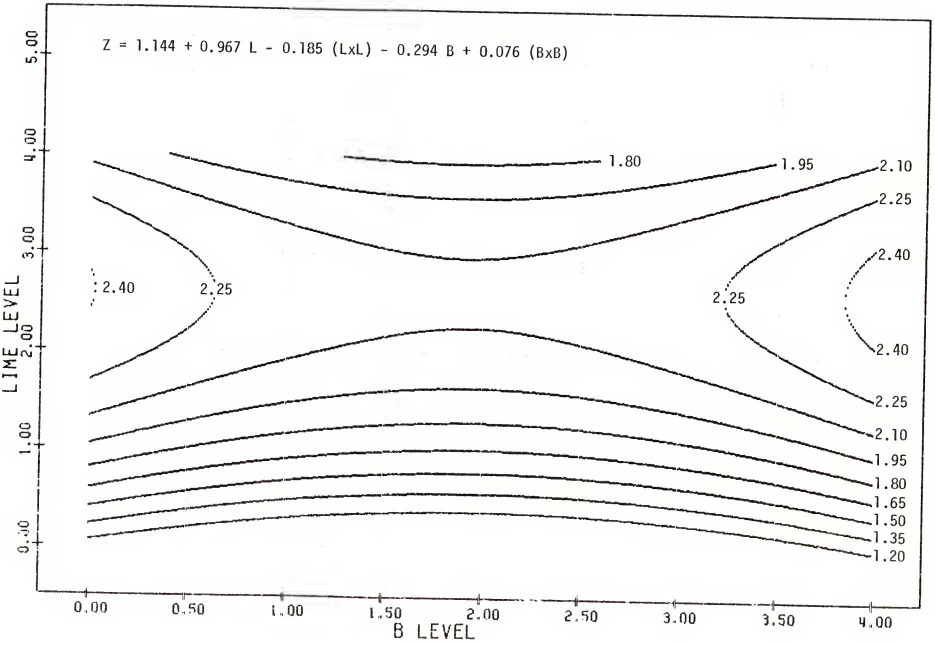

Z = 205.2 + 8.5 P + 2.88 K + 4.78 (PxK)
210
225
240
255
270
285
300
315
K LEVEL
0.00
1.00
2.00
3.00
4.00
5.00
P LEVEL
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00

increased its N concentration and content to a certain level of lime followed by decreases. In the Spodosol, N concentration of Caribbean stylo increased to the highest level of lime applied but the total N decreased at the highest level because of the decrease in dry matter yield. The N concentrations and total N of stylo grown in the Spodosol increased with increasing levels of lime up to a certain level and then decreased (Fig. 14, and Appendix Tables 33 and 34), following the same trend obtained for dry matter yield. The N concentration in both species grown in the Entisol did not show a clear trend with increasing levels of lime (Appendix Tables 33 and 34) but if one examines the factorial points (levels 1 and 3) it can be seen, mainly in Caribbean stylo, that the increasing levels of lime increased the N concentration of the plants in this soil.

Boron levels did not show a definite trend on the N concentration and N content of both species cropped in the three Florida soils as shown in Appendix Tables 33 and 34. However, data in Fig. 14 show that increasing levels of B in the Spodosol did not appreciably influence the N concentration of stylo at low or high levels of lime. But at the intermediate levels of lime, the first increments of B decreased N concentration, but the highest levels increased it again.

Both species had a very low N concentration and content in the unlimed Spodosol (Appendix Table 34). In fact, nodulation of each species in the unlimed Spodosol was almost absent and the plants showed a very intense and general chlorosis, dropping leaves indicating a very acute N deficiency, long before harvest. This occurred also with less intensity with the first level of lime applied.

Figure 14. Contours of predicted herbage N concentration (%) of *S. guianensis* on a Florida Spodosol as affected by levels of lime and B for P=2 and K=3.

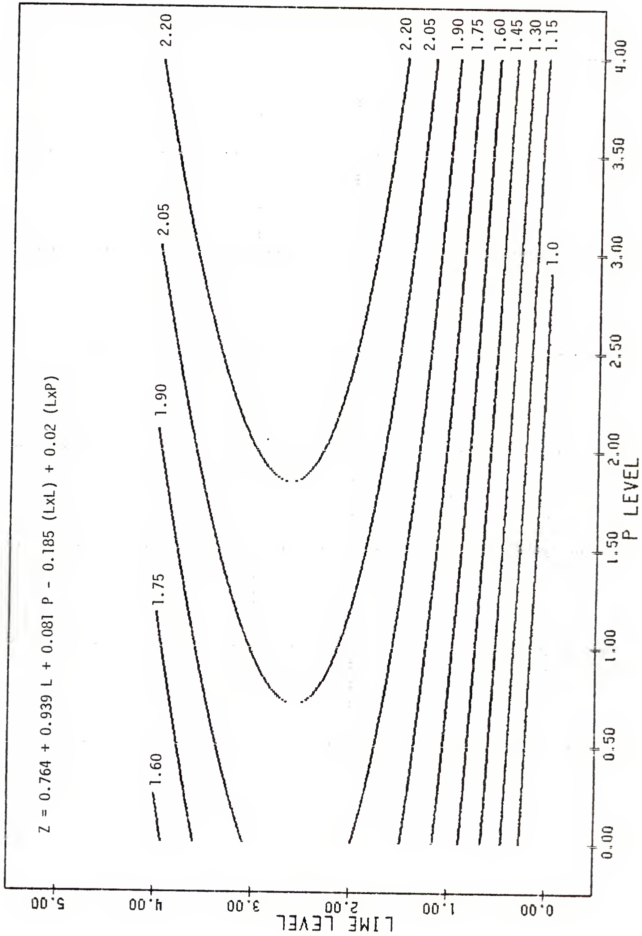

Z = 1.144 + 0.967 L - 0.185 (LxL) - 0.294 B + 0.076 (BxB)
LIME LEVEL
0.00
1.00
2.00
3.00
4.00
5.00
B LEVEL
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
1.80
1.95
2.10
2.25
2.40
2.40
2.25
2.10
1.95
1.80
1.65
1.50
1.35
1.20
2.40
2.25
2.25

These results are in accordance with Snyder et al. (1978) who reported a response of stylo and other tropical legumes to lime application in a virgin Florida Spodosol with low extractable Ca and 0.30 meq of exchangeable Al/100 g of soil. These results are also in accord with those of Norris (1967), Freitas and Pratt (1969), Jones and Freitas (1970), Odu et al. (1971), Soares et al. (1975), Snyder and Kretschmer (1975) and other papers, demonstrating that *Stylosanthes* species do respond to lime in very acid soils low in Ca, by more growth and N fixation. But high rates of lime that increase pH above 5.5 to 6.0, which would be adequate for other tropical legumes, are deleterious for *Stylosanthes* species.

Data in Fig. 15 show the contours of predicted N concentrations in herbage of stylo as affected by lime and P levels applied to the Florida Spodosol. The same pattern was observed for N contents. This demonstrated that in the unlimed Spodosol, and also with low levels of lime, N fixation was not increased even with high rates of P application. The plants were able to utilize the applied P to increase N fixation only after adequate levels of lime eliminated the harmful effects of very low pH.

The large increase in yield, N concentrations, and N contents of the two *Stylosanthes* species in response to applied P, confirmed the findings and concepts of Jones et al. (1968), Andrew and Robins (1969a), Blue (1974), Gates (1974), Bruce and Teitzel (1978), which demonstrated the definite effect of P fertilization, on yield, nodulation, and N concentration of tropical legumes.

Figure 15. Contours of predicted herbage N concentration (%) of _S_. _guianensis_ on a Florida Spodosol as affected by levels of lime and P for K=3 and B=1.


Z = 0.764 + 0.939 L + 0.081 P - 0.185 (LxL) + 0.02 (LxP)
1.60
1.75
1.90
2.05
2.20
2.20
2.05
1.90
1.75
1.60
1.45
1.30
1.15
1.0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
P LEVEL
0.00
1.00
2.00
3.00
4.00
5.00
LIME LEVEL

The N concentrations in the roots of both species followed the same general trend discussed for the N concentrations in tops. The data for N concentration in the roots, treatment by treatment, are included in Appendix Tables 13 through 18.

Plant Phosphorus Concentrations and Contents

Phosphorus Concentrations

Phosphorus concentration in tops of both stylo and Caribbean stylo increased with increasing levels of P applied. But P concentrations were also strongly influenced by dilution effect from plant growth. Where plants did not grow well because of a limitation of either K or lime the plants contained high P concentrations. This can be seen clearly in the unlimed Spodosol and Entisol (Table 25); and also in all soils with treatment combinations without K (Table 26). This dilution effect can also be seen by examining the factorial points which had levels 1 and 3 of K in the Entisol and Spodosol (Table 26). In the Ultisol, where the limitation of growth due to K deficiency was not as extreme as in the other two soils, the dilution effect did not occur in the factorial points.

Increasing levels of lime increased P concentration of both species grown in the Entisol and Ultisol (Appendix Table 25) as it did with extractable soil P (Table 16). But, in the Spodosol, the dilution effect seemed larger. The plants at lime level 1 contained higher P concentration than at level 3, because at the first level, the plants grew less than at level 3.

Table 25. Phosphorus concentrations in herbage of two *Stylosanthes* species as affected by levels of lime and P.

Entisol - *S. guianensis*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
			%		
0	0.07		0.06		0.12
1		0.07		0.08	
2	0.08		0.09		0.12
3		0.10		0.14	
4	0.20		0.18		0.28

Entisol - *S. hamata*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
			%		
0	0.07		0.07		0.11
1		0.07		0.08	
2	0.07		0.09		0.10
3		0.09		0.10	
4	0.12		0.12		0.18

Spodosol - *S. guianensis*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
			%		
0	0.07		0.07		0.10
1		0.15		0.13	
2	0.40		0.19		0.17
3		0.35		0.26	
4	0.79		0.30		0.34

Spodosol - *S. hamata*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
			%		
0	0.10		0.07		0.10
1		0.14		0.11	
2	0.29		0.14		0.15
3		0.20		0.16	
4	0.38		0.17		0.21

Ultisol - *S. guianensis*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
			%		
0	0.08		0.07		0.08
1		0.08		0.08	
2	0.08		0.10		0.12
3		0.13		0.13	
4	0.15		0.14		0.19

Ultisol - *S. hamata*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
			%		
0	0.11		0.12		0.12
1		0.12		0.14	
2	0.14		0.14		0.15
3		0.14		0.16	
4	0.16		0.17		0.19

Note: Means are averages over K and B combinations.

Table 26. Phosphorus concentrations in herbage of two *Stylosanthes* species as affected by levels of K and B.

Entisol - *S. guianensis*

B	K levels				
levels	0	1	2	3	4
			%		
0	0.24		0.08		0.10
1		0.11		0.08	
2	0.21		0.09		0.08
3		0.11		0.08	
4	0.22		0.09		0.10

Entisol - *S. hamata*

B	K levels				
levels	0	1	2	3	4
			%		
0	0.14		0.09		0.10
1		0.09		0.08	
2	0.12		0.09		0.08
3		0.09		0.08	
4	0.14		0.08		0.10

Spodosol - *S. guianensis*

B	K levels				
levels	0	1	2	3	4
			%		
0	0.43		0.17		0.23
1		0.27		0.18	
2	0.39		0.19		0.15
3		0.25		0.19	
4	0.40		0.18		0.24

Spodosol - *S. hamata*

B	K levels				
levels	0	1	2	3	4
			%		
0	0.22		0.14		0.18
1		0.15		0.14	
2	0.18		0.15		0.12
3		0.16		0.15	
4	0.19		0.14		0.19

Ultisol - *S. guianensis*

B	K levels				
levels	0	1	2	3	4
			%		
0	0.14		0.10		0.10
1		0.10		0.10	
2	0.14		0.10		0.10
3		0.12		0.10	
4	0.14		0.10		0.11

Ultisol - *S. hamata*

B	K levels				
levels	0	1	2	3	4
			%		
0	0.15		0.15		0.14
1		0.14		0.13	
2	0.18		0.14		0.13
3		0.14		0.14	
4	0.14		0.13		0.14

Note: Means are averages over lime and P combinations.

The P concentrations in the herbage of stylo were generally a little higher than in Caribbean stylo in the Entisol and Spodosol, but slightly lower in the Ultisol (Table 25).

Boron levels did not have a significant effect on P concentrations in the tops of either species in any of the soils (Appendix Tables 22 through 24).

The P concentrations in the roots of both species in all three soils followed, in general, the same pattern as for tops (Appendix Tables 13 through 18).

Phosphorus Contents

Stylo contained more P than Caribbean stylo (Appendix Table 36) when grown in the Entisol and Spodosol. This was probably a consequence of larger yields and of slightly higher P concentrations in plant tissues. In the Ultisol both species contained about the same total P without applied P. But, stylo again contained more P than Caribbean stylo when the Ultisol received P fertilization.

Phosphorus uptake by both species increased with increasing levels of P in all three soils, and with increasing levels of lime in the Entisol (Appendix Table 36). In the Spodosol, it increased through the intermediate levels and decreased again with the highest levels of lime as occurred with dry matter yield. In the Ultisol, P uptake did not indicate a consistent trend.

Plant Calcium Concentrations and Contents

Calcium Concentrations

Calcium concentrations in herbage of stylo were higher than in Caribbean stylo, denoting a greater ability of the former to absorb soil Ca; this also explains why stylo was less responsive to lime application than Caribbean stylo.

Calcium concentration in herbage of both species increased progressively with increasing levels of lime applied to the three Florida soils (Tables 27 and 28). The incremental increase varied from soil to soil, being very steep in the Spodosol, intermediate in the Entisol, and less in the Ultisol.

Herbage Ca concentrations of both species grown in the unlimed Spodosol were very low; while in the unlimed Entisol they were intermediate and in the Ultisol relatively high.

These same trends in exchangeable and extractable Ca were found in soil samples taken before planting (Tables 8 through 10); this explains the larger response of both species to lime applied to the Spodosol, intermediate response in the Entisol, and little (Caribbean stylo) or no response (stylo) to lime application in the Ultisol.

Calcium concentrations in herbage decreased with increasing levels of P (Table 27) and increasing levels of K (Table 28). This can be attributed to an antagonistic effect of cations (P was applied as NaH_2PO_4) and/or to a dilution effect from increased growth, since zero or low levels of P and or K limited plant growth. With adequate levels of these elements, plants grew normally thereby diluting the absorbed Ca in their tissues.

Table 27. Calcium concentrations in herbage of two *Stylosanthes* species as affected by levels of lime and P.

Entisol - *S. guianensis*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	1.57		1.99		3.32
1		1.82		2.29	
2	0.82		1.97		2.31
3		1.60		2.35	
4	0.96		1.76		2.73

Entisol - *S. hamata*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	1.14		1.51		2.24
1		1.42		1.78	
2	0.85		1.55		1.84
3		1.37		1.75	
4	0.78		1.53		1.85

Spodosol - *S. guianensis*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	0.62		2.05		2.98
1		1.90		2.80	
2	0.66		2.30		2.78
3		1.88		2.66	
4	0.64		2.13		2.69

Spodosol - *S. hamata*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	0.43		1.54		1.96
1		1.46		1.65	
2	0.44		1.51		1.76
3		1.40		1.64	
4	0.35		1.42		1.64

Ultisol - *S. guianensis*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	2.33		2.04		2.67
1		2.01		2.15	
2	1.59		2.10		2.25
3		1.92		2.12	
4	1.92		1.94		2.57

Ultisol - *S. hamata*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	1.63		1.83		1.93
1		1.60		1.81	
2	1.67		1.73		1.89
3		1.58		1.74	
4	1.42		1.67		1.78

Note: Means are averages over K and B combinations.

Table 28. Calcium concentrations in herbage of two Stylosanthes species as affected by levels of lime and K.

Entisol - *S. guianensis*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	1.62		3.14		3.79
1		1.90		2.56	
2	0.82		1.87		2.31
3		1.52		2.08	
4	0.90		1.66		2.27

Entisol - *S. hamata*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	1.06		1.70		2.40
1		1.44		1.88	
2	0.85		1.53		1.84
3		1.35		1.66	
4	0.86		1.47		1.69

Spodosol - *S. guianensis*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	0.73		2.92		3.33
1		2.06		3.09	
2	0.66		2.24		2.78
3		1.72		2.37	
4	0.53		1.92		2.34

Spodosol - *S. hamata*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	0.42		1.85		1.92
1		1.44		1.65	
2	0.44		1.48		1.76
3		1.42		1.64	
4	0.36		1.46		1.68

Ultisol - *S. guianensis*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	2.58		3.07		3.09
1		2.14		2.30	
2	1.59		1.99		2.25
3		1.80		1.97	
4	1.67		1.94		2.14

Ultisol - *S. hamata*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	1.51		1.84		1.99
1		1.62		1.81	
2	1.67		1.74		1.89
3		1.56		1.73	
4	1.55		1.62		1.73

Note: Means are averages over P and B combinations.

Boron application had no effect on Ca concentrations in the herbage of either species grown in the three soils, except for Caribbean stylo grown in the Entisol where the linear effect of B was significant ($P<0.05$).

Herbage Ca concentrations of both species were 3 to 5 times that in the roots + nodules (Appendix Table 37). The effect of the treatment combinations on Ca concentrations in roots + nodules followed a pattern similar to that found in the herbage. It also calls attention to the very low values in both species grown in the unlimed Spodosol.

Calcium Contents

Calcium contents of tops + roots + nodules of stylo were higher than those of Caribbean stylo grown in all three soils (Table 29). This explains why stylo decreased the soil pH more than Caribbean stylo.

Calcium contents of both species increased with increasing levels of lime, but this did not always occur through the highest rate of lime, particularly in the Spodosol. The highest level of lime (level 4) was combined, in the experimental design, with levels zero and 4 of the other elements. Zero levels of P and K tremendously limited growth, and consequently Ca uptake.

Calcium contents of both species grown in the three soils increased with increasing levels of P and K. This was a result of a greater dry matter yield brought about by the application of increasing levels of these elements, since they caused a decrease in

Table 29. Calcium contents in biomass from two *Stylosanthes* species as affected by levels of lime and P.

Entisol - *S. guianensis*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	mg/pot				
0	75		146		230
1		168		248	
2	89		243		256
3		203		313	
4	83		267		244

Entisol - *S. hamata*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	mg/pot				
0	42		80		113
1		71		106	
2	54		106		145
3		90		113	
4	45		125		109

Spodosol - *S. guianensis*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	mg/pot				
0	14		91		76
1		125		217	
2	17		226		168
3		134		267	
4	17		231		153

Spodosol - *S. hamata*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	mg/pot				
0	8		81		39
1		82		115	
2	10		136		113
3		98		122	
4	6		161		75

Ultisol - *S. guianensis*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	mg/pot				
0	247		220		252
1		249		282	
2	235		292		286
3		286		295	
4	268		280		316

Ultisol - *S. hamata*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	mg/pot				
0	117		131		126
1		112		128	
2	129		137		144
3		134		140	
4	120		170		131

Note: Means are averages over K and B combinations.

Ca concentration of both species, due to dilution effect already discussed.

The Ca content of Caribbean stylo was not affected by increasing levels of B, but Ca content of stylo was decreased ($P<0.05$; Appendix Table 35). This was due to the decrease in dry matter yield of stylo with increasing levels of B, since Ca concentration of both species was not affected by increasing levels of this micronutrient.

Plant Potassium Concentrations and Contents

Potassium Concentrations

Potassium concentrations in herbage of both species grown in the three soils increased with increasing levels of K applied. It was decreased with increasing levels of P through the higher levels, except in the corner points, with level 4 of P where the K concentration of both species increased again (Table 30). This can be explained as a dilution effect since the corner points which received P level 4 yielded less than some other treatments, due to the combination of the factors in the experimental design. Increasing levels of lime also showed similar effects on herbage K concentrations in both species grown in all three soils.

Boron levels showed a significant and positive effect in increasing the herbage K concentrations of stylo grown in the three soils but not of Caribbean stylo (Appendix Tables 22 through 24). This was also likely caused by dilution, since increasing levels of B decreased stylo yield.

The K concentration in herbage of stylo was less than that of Caribbean stylo in all three soils with almost all treatment combinations (Table 30). This was probably due to the smaller yield of the latter compared to the former.

Herbage K concentrations, ranging from 0.60 to 0.50% or less from both species, were associated with treatments where plants showed visual symptoms of K deficiency in their leaves before harvesting. But treatment combinations having as much as 0.70 to 0.80% K produced less than treatment combinations having higher concentrations. Andrew and Robins (1969c) mentioned 0.60% K as a critical level for S. humilis. Brolmann and Sonoda (1975) reported that leaves from healthy plants of three S. guianensis accessions contained 0.70% K and leaves of deficient plants contained only 0.35% K.

Potassium concentrations in roots + nodules of both species generally showed the same trend of variation as in herbage. The values for roots were in general about half of the values for herbage (Appendix Tables 13 through 18).

Potassium Contents

Potassium contents of the two Stylosanthes species increased with increasing levels of K applied in all three soils (Appendix Table 38). These increases were caused by both increases in yield and increases in plant K concentrations.

Increasing levels of P increased K contents of both species only when combined with level 2 or more of K; this likely explains significant P x K interaction that occurred in all three soils and two species

Table 30. Potassium concentrations in herbage of two *Stylosanthes* species as affected by levels of P and K.

Entisol - *S. guianensis*

K levels	P levels 0	1	2	3	4
			%		
0	0.41		0.30		0.38
1		0.48		0.40	
2	0.88		0.64		0.53
3		0.98		0.75	
4	1.30		0.94		1.17

Entisol - *S. hamata*

K levels	P levels 0	1	2	3	4
			%		
0	0.48		0.42		0.39
1		0.97		0.80	
2	1.30		1.13		1.06
3		1.34		1.33	
4	1.43		1.34		1.39

Spodosol - *S. guianensis*

K levels	P levels 0	1	2	3	4
			%		
0	0.44		0.27		0.43
1		0.55		0.51	
2	1.23		0.80		0.58
3		1.13		0.99	
4	1.84		1.00		1.75

Spodosol - *S. hamata*

K levels	P levels 0	1	2	3	4
			%		
0	0.54		0.22		0.41
1		0.68		0.57	
2	1.23		0.93		0.65
3		1.51		1.43	
4	2.10		1.20		1.98

Ultisol - *S. guianensis*

K levels	P levels 0	1	2	3	4
			%		
0	0.42		0.37		0.39
1		0.59		0.56	
2	0.87		0.72		0.72
3		0.92		0.88	
4	1.34		1.12		1.18

Ultisol - *S. hamata*

K levels	P levels 0	1	2	3	4
			%		
0	0.76		0.63		0.68
1		1.12		0.98	
2	1.37		1.33		1.16
3		1.56		1.50	
4	1.75		1.64		1.73

Note: Means are averages over lime and B combinations.

(Appendix Table 35). Increasing levels of lime also showed similar effects on K contents of both species grown in the Entisol and Spodosol but not in the Ultisol (Appendix Table 39).

Potassium content of both species was very low when grown in the Spodosol and Entisol without K applied (Appendix Tables 38 and 39), confirming the findings by Gammon and Blue (1952), and Khomvilai and Blue (1977) which showed the very low capacity of these unfertilized sandy soils to furnish K to plants. The plants grown in the Ultisol without applied K contained as much as four times more K than plants from the Spodosol. This difference reflected the higher initial K status of the Ultisol and its greater potential to supply K to plants. However, plant yields, and K concentrations and contents from the Ultisol were increased by K fertilization.

Plant Sodium Concentrations and Contents

Sodium concentrations and contents in stylo herbage were much lower than those in Caribbean stylo in all three soils. But in the roots + nodules, the Na concentrations of both species were much higher than those in the herbage and were not different ($P>0.05$) from each other (Table 31). However, the Na contents of roots + nodules from each of the three soils were much higher in stylo than in Caribbean stylo ($P<0.01$) due to the larger dry weight of stylo roots.

Sodium concentrations in Caribbean stylo herbage increased greatly with increasing levels of NaH_2PO_4, especially in treatment combinations without K or with low levels of this element (Appendix

Table 31. Sodium concentrations and contents in herbage and roots + nodules of two *Stylosanthes* species grown in three Florida soils.

Plant	Ultisol		Spodosol		Entisol	
part	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*
	Concentrations (ppm)					
Herbage	120	650	87	1126	64	661
Roots	5300	4800	5300	5200	4200	3500
	Contents (mg/pot)					
Herbage	1.5	4.8	0.4	4.4	0.6	3.4
Roots	9.7	4.6	6.7	5.2	7.2	3.0
	# of Observations					
	77	78	55	52	62	62

Note: Means are averages over each soil and species.

Table 40). But, increasing levels of applied K greatly decreased Na concentration of this species. On the other hand, stylo did not show much increase in Na concentration of its herbage with increasing levels of NaH_2PO_4, nor much decrease with increasing levels of K.

The concentrations of Na in the roots of both species were high and increased with increasing levels of NaH_2PO_4 and decreased with increasing levels of K applied (Appendix Table 41). The results suggest that stylo has a mechanism that impairs translocation of absorbed Na to the tops.

Plant Boron Concentrations

Boron concentrations in herbage of stylo were higher than those of Caribbean stylo in all three soils. Also the increase in B concentration for each increment of B applied was larger in stylo than in Caribbean stylo (Table 32).

Boron concentration decreased with increasing levels of lime (Appendix Table 42). In the Entisol and Spodosol, this could have been caused not only by the effect of lime in decreasing soil B availability to plants, but also by a dilution effect, since both species had limited growth in the unlimed Entisol and especially in the unlimed Spodosol.

The yield of stylo grown in the Ultisol decreased with increasing levels of lime, while its B concentration decreased, showing that lime also decreased B availability.

Boron concentrations of approximately 50 ppm or more in the herbage of both species grown in the Spodosol and Entisol were

Table 32. Boron concentrations in herbage of two *Stylosanthes* species as affected by levels of B.

B	Ultisol		Spodosol		Entisol	
levels	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*
	ppm					
0	27	25	31	24	13	12
1	39	25	44	30	28	26
2	46	38	58	42	42	38
3	56	38	78	52	60	48
4	60	44	132	74	101	63

Note: Means are averages over lime, P and K combinations.

associated with B toxicity symptoms. In Caribbean stylo, this effect did not result in reduction of yield, and in the Ultisol, toxicity symptoms in stylo leaves were not as clear as in plants from the other two soils. Symptoms in Caribbean stylo were almost absent. This was probably a consequence of higher extractable Ca in this soil and higher Ca concentrations in plants grown in it (Reeve and Shive, 1944; Olsen, 1972; Vargas and Dobereiner, 1974). Werner et al. (1975) reported toxicity symptoms of B in leaves of _S. guianensis_ cv. IRI 1022 which contained 87 and 114 ppm of B. Plants from the control treatment which contained 54 ppm of B were healthy. Jones (1972) reported that B toxicity occurs normally when plant levels exceed 200 ppm B, although toxicities may occur at lower levels for those plants that are particularly sensitive. Jones (1972) also reported that B deficiency occurs in a wide variety of plants when its level is less than 15 ppm in the dry matter. Levels well below these were found in both species grown in the untreated Entisol (Appendix Table 42), and the plants apparently did not show any sign of B deficiency nor yield decrease in the treatment combinations where B was at the zero level. This leads to the conclusion that _Stylosanthes_ species, particularly stylo, have low B requirement and application of B in amounts that would be adequate for other species are excessive for them.

Plant Concentrations of Zn, Mn, Fe, and Cu

The levels of significance for sources of variation affecting concentrations of Zn, Mn, Fe, and Cu are included in Appendix Tables 22 through 24. Lime and its interaction with the other factors were sources of variation that showed significant effects with most frequency. Lime decreased the concentration of Zn, Mn, and Cu, in herbage of both species grown in the three soils (Tables 33 through 35). Iron concentration did not show the same pattern (Table 36). Zinc and particularly Mn were very high in the plants grown in the unlimed Spodosol, but with the highest level of lime herbage Mn concentration decreased to a very low level.

The concentrations of Fe and Cu, especially Fe, were much higher in roots than in the herbage for both species grown in all three soils (Table 37).

Plant Calcium to Mn Ratios

Calcium to Mn ratios in the herbage of both species increased with increasing levels of lime applied to all three soils.

This ratio was very narrow in the unlimed Spodosol (Appendix Table 43) and became very large with the highest level of lime applied. The very narrow plant Ca/Mn ratios were due to high absorption of Mn and low absorption of Ca, resulting from a similar ratio of these cations in the unlimed Spodosol. This can be considered as one of the reasons for the high response to lime shown by both species in the Spodosol (Norris, 1967; Jackson, 1967; Jones et al., 1970; Munns and Fox, 1977a).

On the other hand, the very large Ca/Mn ratio in plants grown in the Spodosol limed at the highest level was due to a relatively high Ca concentration and a very low Mn concentration in the

Table 33. Concentrations of Zn in herbage of two *Stylosanthes* species as affected by levels of lime.

$CaCO_3$	Ultisol		Spodosol		Entisol	
levels	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*
	ppm					
0	24	22	202	148	56	31
1	17	20	72	53	24	16
2	14	20	45	29	15	14
3	12	20	30	22	12	11
4	14	19	26	27	14	11

Note: Means are averages over P, K, and B combinations.

Table 34. Concentrations of Mn in herbage of two *Stylosanthes* species as affected by levels of lime.

$CaCO_3$	Ultisol		Spodosol		Entisol	
levels	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*
	ppm					
0	128	110	499	342	310	177
1	86	81	166	113	108	58
2	74	76	98	52	80	43
3	63	61	56	28	68	41
4	52	52	26	18	56	37

Note: Means are averages over P, K, and B combinations.

Table 35. Concentrations of Cu in herbage of two *Stylosanthes* species as affected by levels of lime.

$CaCO_3$	Ultisol		Spodosol		Entisol	
levels	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*
	ppm					
0	5.3	6.3	7.7	7.4	5.2	3.2
1	4.0	5.7	4.5	3.8	3.5	2.4
2	3.3	5.7	4.2	3.0	2.9	2.0
3	3.4	5.5	3.8	3.1	2.4	2.0
4	3.9	4.9	4.2	2.9	3.6	2.3

Note: Means are averages over P, K, and B combinations.

Table 36. Concentrations of Fe in herbage of two *Stylosanthes* species as affected by levels of lime.

$CaCO_3$	Ultisol		Spodosol		Entisol	
levels	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*	*S. guianensis*	*S. hamata*
	----------	----------	---------- ppm	----------	----------	----------
0	61	56	56	50	47	46
1	59	73	46	60	41	51
2	59	68	53	57	43	53
3	54	74	45	65	43	60
4	58	61	61	66	49	62

Note: Means are averages over P, K, and B combinations.

Table 37. Concentrations of Fe and Cu in herbage and roots + nodules of two <u>Stylosanthes</u> species grown in three Florida soils.

Soil orders	Plant species	Fe		Cu	
		Herbage	Roots	Herbage	Roots
		-------------	------------- ppm	-------------	-------------
Ultisol	S. guianensis	59	676	4.2	8.6
	S. hamata	63	1409	5.6	11.5
Spodosol	S. guianensis	54	423	5.1	12.5
	S. hamata	59	780	4.2	11.6
Entisol	S. guianensis	45	413	3.7	13.3
	S. hamata	54	542	2.5	10.0

Note: Means are averages over all treatment combinations.

herbage of both species. This could also be one of the explanations for the yield decrease of both species grown in the Spodosol limed at the highest level.

Foliar Symptoms of P, Ca, and K Deficiency, and B Toxicity

Phosphorus Deficiency

In the younger stages, plants of both species grew slowly and presented a darker green color than normal. In the last stages of growth, P-deficient stylo plants had reddish-colored petioles and stems.

Calcium Deficiency

Plants of both species grown in the unlimed soils developed normally at first, but after 40 to 50 days of growth, plants grown in the unlimed Spodosol showed a yellow-green color and less development than plants from treatments which included lime. At harvest time, plants in the unlimed Spodosol were stunted; their leaves showed a very intense chlorosis (Fig. 16), and leaves abscissed. The nodulation of stylo in the unlimed Spodosol was very poor and completely absent in Caribbean stylo. Both species in the unlimed Spodosol showed extremely low N concentrations in addition to Ca. Thus one cannot determine whether the symptoms described are truly Ca deficiency or N deficiency due to lack of N fixation caused by Ca deficiency.

Both species grown in the unlimed Entisol also showed the same symptoms, but with much less intensity.

Figure 16. Plants of S. guianensis grown in the unlimed Spodosol

Potassium Deficiency

Potassium deficiency symptoms first appeared in plants of both species grown in treatment combinations without K in both Spodosol and Entisol. In the Ultisol plants began to show K deficiency symptoms only about two weeks before harvest. The symptoms began on leaves of medium age, as small brown patches randomly distributed over the leaf surface. The brown patches then became necrotic as did the tips of some leaflets. Most of the leaves showing brown patches became chlorotic, the brown patches enlarged, the tip necrosis gradually spread in an irregular pattern toward the petiole, the necrotic leaflets curled inwards and eventually abscissed, leaving the green petiole (Fig. 17).

In the last two weeks before the harvest these symptoms also appeared, although with less intensity, in plants that received the two lowest levels of K (20 and 40 ppm) in the Spodosol and Entisol.

The symptoms described are similar to those reported by Andrew and Pieters (1970), and Jones and Clay (1976), for K deficiency in *S. humilis*.

Boron Toxicity

Plants of both species, receiving levels 3 and 4 of B (0.75 and 1.00 ppm, respectively) showed at the first stages of growth, a generalized chlorosis and necrosis of the leaflet tips. The cotyledons, after becoming chlorotic with necrotic borders, wilted and abscissed while the cotyledons of plants with lower B levels or without B stayed green for a longer period.

Figure 17. Symptoms of K deficiency in S. guianensis

Figure 18. Symptoms of B toxicity in S. guianensis

After some time the generalized chlorosis disappeared and the leaves became normally green, but maintained chlorotic and necrotic leaflet tips in the older leaves. As new leaves appeared, a chlorosis appeared in their tips; these areas gradually became necrotic. Chlorosis in the older leaves gradually progressed toward the petiole leaving behind the necrotic tip. Affected leaflets were usually healthy dark green at their bases and completely necrotic at their tips with only a narrow chlorotic transition between the two (Fig. 18). In stylo, leaves showing these B toxicity symptoms did not absciss as frequently as those with K deficiency, but in the Caribbean stylo, leaves showing B toxicity fell with more frequency. At harvest time, stylo plants that received level 2 of B (0.5 ppm) also showed toxicity symptoms.

The symptoms described were also reported by Vargas and Dobereiner (1974) for stylo plants in the first stages of growth, and by Werner et al. (1975) for mature plants. Jones and Clay (1976) also described B toxicity symptoms for _S_. _humilis_ quite similar to those described here.

Figure 19 shows a healthy stylo plant that received adequate levels of lime, P, K, and no B, to contrast with the deficiency and toxicity symptoms described.

Figure 19. Healthy plants of S. guianensis

SUMMARY AND CONCLUSIONS

A greenhouse experiment was conducted to study the response of stylo (Stylosanthes guianensis (Aubl.) Sw.) cv. Schofield and Caribbean stylo (Stylosanthes hamata (L.) Taub.) cv. Verano to levels of lime, P, K, and B on three Florida mineral soils. The soils used were Orangeburg loamy sand (fine-loamy, siliceous, thermic Typic Paleudult); Astatula sand (hyperthermic uncoated Typic Quartzipsament); Myakka fine sand (sandy, siliceous hyperthermic Aeric Haplaquod). The set of experimental treatments was a modified central composite in four factors ($CaCO_3$, P, K, and B), each at five levels, arranged in a response surface design. Calcium carbonate was applied at rates of 0, 1.0, 2.0, 3.0, and 4.0 meq/100 g of soil to the Ultisol; 0, 0.9, 1.8, 2.7, and 3.6 meq/100 g to the Spodosol; and 0, 0.5, 1.0, 1.5, and 2.0 meq/100 g of soil to the Entisol. Phosphorus was applied as NaH_2PO_4 at rates of 0, 15, 30, 45, and 60 ppm to the Ultisol, and 0, 10, 20, 30, and 40 ppm to the Spodosol and Entisol. Potassium was applied as KCl at rates of 0, 20, 40, 60, and 80 ppm to all three soils. Boron was applied as H_3BO_3 at rates of 0, 0.25, 0.50, 0.75, and 1.0 ppm to all three soils.

Lime was allowed to react with the soils for approximately 40 days before planting; each pot was leached with 1 liter of distilled water to remove nitrates + nitrites + ammonium accumulated from N mineralization during the incubation period. Leachate and soil samples were taken at this time.

Mineralization of organic matter, pH, exchangeable Ca, and ECEC increased with increasing levels of lime in each of the three soils; exchangeable H and Al decreased. Extractable P increased progressively with increasing levels of lime, and extractable Fe decreased. Magnesium and K either did not change or showed slight tendencies to decrease. Zinc, Cu, and B were extremely variable and together with Mn did not change with increasing levels of lime.

The pH values of soil samples at harvest time were lower than those measured at planting time at all levels of lime. This difference was larger in the Spodosol and Entisol than in the Ultisol. The pH values and extractable Ca were lower when the soils were cropped with stylo than with Caribbean stylo. Extractable Ca, which was very low in the unlimed Entisol and Spodosol, decreased to extremely low levels after cropping with the two Stylosanthes species. Extractable K also decreased to extremely low levels in all three soils following the removal of crops of each species, even in the treatments that received the highest level of K fertilization.

Stylo yielded more than Caribbean stylo in all three soils, and its Ca concentration was also higher.

The response to increasing lime levels varied among soils and between the two species. Caribbean stylo was more responsive to lime application than stylo. In the Ultisol, the yield of Caribbean stylo increased with low levels of lime and decreased only with the higher levels. Meanwhile, lime depressed the stylo yield starting from the first level. In the Entisol and Spodosol, the Caribbean stylo responded to the highest lime levels while the stylo responded only to the intermediate levels and decreased at the higher levels. Decreases in pH and extractable Ca which occurred during cropping may have accounted for the high response to lime in the Entisol and Spodosol.

Both species showed large responses to P applied to all three soils.

Increasing levels of K increased yields of both species through the highest level applied in all three soils except for Caribbean stylo grown in the Ultisol. The herbage K concentration of both species in the treatments without K or with low levels of K was very low and the plants showed distinct symptoms of K deficiency in their leaves.

Increasing B levels decreased stylo herbage yield and produced distinct foliar symptoms of toxicity of the element. Herbage yield of Caribbean stylo was not affected, although it showed distinct symptoms of toxicity at the highest levels.

Increasing levels of P always increased N concentration of both species in all soils. Consequently, total N always increased. Increasing levels of K tended to reduce the N concentration in both species, but since increasing K levels had larger positive effects on dry matter yields, increased total N resulted.

Herbage N concentration and total N in stylo tended to decrease with increasing levels of lime applied to the Ultisol.

Caribbean stylo tended to have increased N concentration and total N to a certain level of lime after which both decreased. In the Spodosol, N concentration of Caribbean stylo increased to the highest level of lime applied but the total N decreased at the highest level because of the decrease in dry matter yield. The N concentrations and contents of stylo cropped in the Spodosol increased with lime to a range between levels 2 and 3 and then decreased. A very low N concentration and content of both species in the unlimed Spodosol coincided with an almost absence of nodulation, and a very intense and general chlorosis; and leaf drop indicated a very acute N deficiency caused by lack of N fixation.

Increasing levels of NaH_2PO_4 increased herbage Na concentration of both species, but the increase in stylo was very small compared with Caribbean stylo; Na concentration in herbage of stylo was very low, while in the roots, it was very high, showing that stylo has a mechanism that impairs the translocation of absorbed Na to plant tops.

Increasing levels of lime decreased B, Zn, Mn, and Cu concentrations in the herbage of both species in all three soils.

APPENDIX

Appendix Table 1. Treatment combinations, and pH and extractable nutrients of a Florida Ultisol following the removal of a crop of *S. guianensis*.

L	P	K	B	Rep	pH		Double-acid extracted nutrients								
					H_2O	KCl	P	Ca	Mg	K	Fe	Mn	Cu	Zn	Ca/Mn
Coded levels				No.			ppm								
0	0	0	0	3	5.2	4.2	4.6	223	32	9	13	26	0.9	0.8	8.7
0	0	0	4	3	5.3	4.3	4.1	228	34	10	10	20	0.7	0.8	11.3
0	0	4	0	3	5.2	4.3	4.0	193	31	14	12	19	0.6	0.6	10.2
0	0	4	4	3	5.2	4.3	4.8	233	37	16	12	23	0.6	0.7	10.3
0	4	0	0	3	5.4	4.2	15.2	203	27	10	12	22	0.6	0.9	9.3
0	4	0	4	3	5.5	4.3	14.7	211	29	8	11	21	0.4	0.7	10.2
0	4	4	0	3	5.3	4.2	17.8	237	36	13	13	27	0.8	0.9	8.9
0	4	4	4	3	5.3	4.3	15.2	216	33	17	13	25	1.1	0.8	8.8
4	0	0	0	3	6.4	5.8	5.7	741	36	10	8	23	1.0	0.7	31.7
4	0	0	4	3	6.5	5.9	6.9	968	47	12	10	29	0.5	0.9	33.8
4	0	4	0	3	6.6	5.9	6.0	868	43	20	8	24	0.6	1.0	35.7
4	0	4	4	3	6.5	5.8	6.7	871	47	23	9	25	0.6	1.4	34.9
4	4	0	0	3	6.5	5.7	26.0	901	40	15	10	28	0.7	1.3	32.0
4	4	0	4	3	6.5	5.7	24.2	897	43	12	9	26	0.5	1.5	35.0
4	4	4	0	3	6.4	5.7	28.5	963	49	18	11	32	0.8	1.2	30.4
4	4	4	4	3	6.5	5.7	26.0	943	45	20	12	32	0.6	1.1	29.8
1	1	1	1	1	5.6	4.7	7.6	336	35	8	11	21	0.5	0.7	16.0
1	1	1	3	1	5.6	4.7	8.2	376	38	8	11	22	0.6	0.8	17.1
1	1	3	1	1	5.6	4.7	8.8	408	44	14	11	24	0.6	0.8	17.0
1	1	3	3	1	5.5	4.7	8.8	400	43	12	11	24	0.5	0.7	16.7
1	3	1	1	1	5.6	4.6	15.3	392	37	12	12	27	0.5	1.0	14.5
1	3	1	3	1	5.6	4.7	13.9	384	36	9	11	21	0.5	0.8	18.3
1	3	3	1	1	5.6	4.6	16.8	404	38	13	14	33	0.8	0.9	12.2
1	3	3	3	1	5.6	4.7	13.5	348	32	9	12	24	0.5	0.8	14.5
3	1	1	1	1	6.2	5.4	9.8	676	41	12	9	25	0.8	0.8	27.0
3	1	1	3	1	6.1	5.4	11.1	752	44	16	11	28	1.0	1.2	26.9
3	1	3	1	1	6.1	5.3	9.1	604	36	12	10	28	0.6	0.7	21.6
3	1	3	3	1	6.2	5.4	9.8	656	40	13	10	20	0.5	1.0	28.5
3	3	1	1	1	6.2	5.4	20.0	832	43	17	10	30	0.6	1.0	27.7
3	3	1	3	1	6.2	5.4	18.4	768	42	10	10	26	0.8	1.0	29.5
3	3	3	1	1	6.1	5.4	16.4	676	39	14	10	24	0.7	0.9	28.2
3	3	3	3	1	6.1	5.4	20.0	728	43	16	11	28	0.9	1.2	26.0
0	2	2	2	1	5.2	4.3	15.1	248	41	12	14	27	1.1	1.0	9.2
4	2	2	2	1	6.4	5.8	13.1	956	40	12	11	30	0.9	0.8	31.9
2	0	2	2	1	5.8	5.1	6.4	552	48	13	12	26	0.6	0.8	21.2
2	4	2	2	1	5.9	5.0	18.0	604	44	14	11	27	0.8	1.0	22.4
2	2	0	2	1	5.9	5.0	13.5	572	41	12	12	25	0.8	0.7	22.9
2	2	4	2	1	5.3	5.0	15.6	584	46	18	12	29	1.0	1.0	20.1
2	2	2	0	1	5.8	5.0	17.4	612	48	17	12	29	0.3	1.5	21.1
2	2	2	4	1	5.3	5.0	14.7	604	48	18	12	28	0.3	1.0	21.6
2	2	2	2	5	5.8	5.0	13.0	574	44	14	11	27	0.8	0.7	21.1

Appendix Table 2. Treatment combinations, and pH and extractable nutrients of a Florida Ultisol following the removal of a crop of <u>S</u>. <u>hamata</u>.

L	P	K	B	Rep	pH		Double-acid extracted nutrients								
					H_2O	KCl	P	Ca	Mg	K	Fe	Mn	Cu	Zn	Ca/Mn
Coded levels				No.			---------- ppm ----------								
0	0	0	0	3	5.5	4.5	4.0	221	31	6	9	19	0.6	0.6	11.7
0	0	0	4	3	5.5	4.5	4.4	223	30	6	10	19	0.8	0.7	11.9
0	0	4	0	3	5.4	4.5	4.7	223	31	25	10	19	0.7	0.8	11.6
0	0	4	4	3	5.4	4.5	5.1	237	35	28	10	21	0.7	0.7	11.0
0	4	0	0	3	5.6	4.5	18.4	205	27	5	9	17	0.5	0.8	12.0
0	4	0	4	3	5.6	4.5	17.2	247	31	7	9	20	0.6	0.8	12.1
0	4	4	0	3	5.6	4.5	21.8	292	41	31	12	25	0.8	1.2	11.7
0	4	4	4	3	5.6	4.5	15.6	223	30	23	9	20	0.8	0.8	11.2
4	0	0	0	3	6.7	6.0	5.9	784	34	7	7	23	0.6	0.8	33.6
4	0	0	4	3	6.6	5.9	6.7	881	42	9	8	26	0.6	1.0	33.9
4	0	4	0	3	6.7	6.1	5.6	733	38	27	7	21	0.7	0.8	35.0
4	0	4	4	3	6.7	6.1	6.8	783	41	30	8	24	0.7	0.8	33.0
4	4	0	0	3	6.7	6.0	24.9	835	40	8	8	24	0.7	1.0	34.8
4	4	0	4	3	6.8	6.0	25.9	923	40	7	8	24	0.7	1.0	38.0
4	4	4	0	3	6.7	6.0	28.5	875	45	26	8	27	0.8	1.3	32.0
4	4	4	4	3	6.7	6.0	30.6	925	46	29	10	31	0.8	1.4	29.8
1	1	1	1	1	5.9	5.0	8.5	432	41	10	11	23	0.4	0.6	18.8
1	1	1	3	1	5.8	5.0	7.3	428	40	9	10	24	0.7	0.6	17.8
1	1	3	1	1	5.9	5.0	9.8	452	46	23	11	26	0.8	0.9	17.4
1	1	3	3	1	5.8	4.9	8.5	416	45	17	9	24	0.8	0.8	17.3
1	3	1	1	1	5.8	4.9	17.4	476	48	10	10	26	0.8	1.3	18.3
1	3	1	3	1	5.9	5.0	18.5	448	45	10	12	27	0.6	1.0	16.6
1	3	3	1	1	5.9	5.0	19.7	500	52	20	11	28	0.4	1.2	17.8
1	3	3	3	1	5.9	5.0	22.5	504	56	25	12	30	0.4	1.4	16.8
3	1	1	1	1	6.4	5.6	10.4	772	45	11	10	28	0.5	0.9	27.6
3	1	1	3	1	6.4	5.7	8.3	772	43	10	8	24	0.4	0.8	32.2
3	1	3	1	1	6.3	5.6	8.2	604	40	17	9	22	0.5	0.8	27.5
3	1	3	3	1	6.4	5.7	7.0	532	32	15	7	17	0.5	0.5	31.3
3	3	1	1	1	6.4	5.6	19.7	476	23	6	7	16	0.7	0.9	30.0
3	3	1	3	1	6.4	5.7	16.9	732	40	10	8	24	0.4	0.8	30.5
3	3	3	1	1	6.4	5.7	16.9	536	30	12	8	17	0.4	0.5	31.5
3	3	3	3	1	6.4	5.7	20.4	576	32	11	8	19	0.3	0.7	30.3
0	2	2	2	1	5.5	4.5	9.2	224	29	10	10	18	0.6	0.6	12.4
4	2	2	2	1	6.5	5.9	14.4	808	43	13	8	23	0.3	1.0	35.1
2	0	2	2	1	6.0	5.2	5.8	488	37	11	8	20	0.2	0.7	24.4
2	4	2	2	1	6.0	5.2	22.5	540	43	10	10	25	0.5	1.0	21.6
2	2	0	2	1	6.1	5.4	12.6	568	44	7	10	25	0.3	0.8	22.7
2	2	4	2	1	6.1	5.3	14.7	640	52	27	11	28	0.2	0.9	23.9
2	2	2	0	1	6.1	5.3	13.1	572	43	12	11	25	0.4	0.8	22.9
2	2	2	4	1	6.1	5.3	15.1	552	44	12	11	26	0.5	1.1	21.2
2	2	2	2	6	6.0	5.3	13.7	642	48	15	10	27	0.5	0.9	24.0

Appendix Table 3. Treatment combinations, and pH and extractable nutrients of a Florida Spodosol following the removal of a crop of *S. guianensis*.

L	P	K	B	Rep	pH		Double-acid extracted nutrients								
					H_2O	KCl	P	Ca	Mg	K	Fe	Mn	Cu	Zn	Ca/Mn
Coded levels				No.			ppm								
0	0	0	0	2	4.3	3.2	1.2	19	7	4	28	1.0	0.7	1.1	20
0	0	0	4	2	4.2	3.2	1.1	19	6	4	30	1.0	0.6	0.8	19
0	0	4	0	2	4.2	3.2	1.8	18	7	36	32	1.2	0.8	1.5	15
0	0	4	4	2	4.2	3.2	1.4	18	7	34	33	1.0	0.7	0.9	17
0	4	0	0	2	4.5	3.2	6.0	16	5	5	26	1.0	0.5	0.8	19
0	4	0	4	2	4.4	3.2	6.6	18	6	8	26	1.0	0.7	0.9	17
0	4	4	0	2	4.2	3.0	5.8	14	5	34	26	0.7	0.5	0.7	21
0	4	4	4	2	4.4	3.1	6.6	16	6	30	25	0.9	0.6	0.8	18
4	0	0	0	2	6.2	5.6	2.1	358	6	2	18	0.6	0.6	0.8	670
4	0	0	4	2	6.0	5.6	2.2	440	8	4	22	0.8	0.8	1.0	524
4	0	4	0	2	6.1	5.6	2.4	376	7	20	20	0.8	0.8	0.9	470
4	0	4	4	2	6.1	5.6	2.1	368	9	20	18	0.8	0.8	0.9	435
4	4	0	0	2	6.2	5.7	20.2	412	12	3	17	1.3	0.9	1.3	333
4	4	0	4	2	6.3	5.7	17.2	362	8	2	15	0.8	0.6	0.8	454
4	4	4	0	2	6.0	5.3	13.2	376	5	8	18	0.8	0.8	0.7	507
4	4	4	4	2	6.1	5.4	20.4	454	9	6	20	1.2	0.9	-	394
1	1	1	1	1	4.5	3.5	2.2	64	3	4	23	0.7	0.4	0.5	91
1	1	1	3	1	4.7	3.6	3.3	100	6	4	28	1.2	0.4	0.9	83
1	1	3	1	1	4.5	3.5	3.0	88	7	4	30	1.4	0.7	0.9	63
1	1	3	3	1	4.6	3.5	2.8	72	6	5	24	1.0	0.5	1.1	72
1	3	1	1	1	4.7	3.5	5.6	104	4	4	32	0.8	0.3	0.4	130
1	3	1	3	1	4.7	3.5	6.4	88	5	4	28	1.1	0.4	0.7	80
1	3	3	1	1	4.7	3.5	6.4	100	6	6	33	1.1	0.6	0.6	91
1	3	3	3	1	4.7	3.6	7.9	76	6	5	24	1.4	0.6	0.9	54
3	1	1	1	1	5.6	4.9	3.3	224	5	3	21	0.8	0.6	0.6	280
3	1	1	3	1	5.6	4.9	3.8	260	6	3	23	0.8	0.7	0.7	325
3	1	3	1	1	5.6	4.8	2.6	180	6	3	17	0.7	0.6	0.6	257
3	1	3	3	1	5.6	4.8	4.5	240	6	5	22	1.0	1.0	1.0	240
3	3	1	1	1	5.7	4.9	7.9	204	4	2	17	0.8	0.6	0.5	255
3	3	1	3	1	5.6	4.8	9.1	224	6	3	17	1.2	0.9	0.8	187
3	3	3	1	1	5.5	4.6	8.8	280	6	5	23	1.2	0.8	0.8	233
3	3	3	3	1	5.6	4.7	9.1	280	6	5	21	1.1	0.7	0.9	254
0	2	2	2	1	4.3	3.2	3.0	16	5	14	22	1.0	0.5	0.5	16
4	2	2	2	1	6.1	5.6	9.1	408	5	4	17	0.7	0.6	0.6	583
2	0	2	2	1	5.1	4.2	1.3	160	5	5	26	0.8	0.7	0.6	200
2	4	2	2	1	5.0	4.0	12.2	176	5	4	32	1.4	1.0	1.2	126
2	2	0	2	1	5.3	4.2	8.5	224	7	3	31	1.5	0.6	1.2	149
2	2	4	2	1	4.9	3.9	4.5	132	4	6	28	0.9	0.7	0.6	147
2	2	2	0	1	4.9	3.8	4.3	124	4	4	26	1.0	0.6	0.7	124
2	2	2	4	1	5.1	4.0	5.3	164	5	5	28	1.0	0.8	0.7	164
2	2	2	2	6	5.0	4.1	4.5	188	4	4	32	0.9	0.8	0.8	203

Appendix Table 4. Treatment combinations, and pH and extractable nutrients of a Florida Spodosol following the removal of a crop of S. hamata.

L	P	K	B	Rep	pH		Double-acid extracted nutrients								
					H_2O	HCl	P	Ca	Mg	K	Fe	Mn	Cu	Zn	Ca/Mn
Coded levels				No.			ppm								
0	0	0	0	2	4.4	3.3	0.9	18	6	5	28	0.8	0.6	1.0	21
0	0	0	4	2	4.4	3.3	1.7	22	7	6	30	1.0	0.8	0.9	24
0	0	4	0	2	4.3	3.3	2.6	24	6	32	32	1.2	1.0	1.2	20
0	0	4	4	2	4.2	3.3	2.2	23	8	39	30	1.3	0.8	1.1	18
0	4	0	0	2	4.5	3.2	6.9	18	6	4	22	0.8	0.3	1.0	23
0	4	0	4	2	4.5	3.3	11.2	22	9	4	22	1.3	0.5	1.2	17
0	4	4	0	2	4.4	3.2	11.2	20	7	29	24	1.1	1.0	1.0	18
0	4	4	4	2	4.2	3.2	11.6	24	7	36	25	1.2	1.0	1.4	22
4	0	0	0	2	6.2	5.8	2.4	504	9	3	16	0.9	1.0	1.3	590
4	0	0	4	2	6.4	6.0	2.8	444	8	2	18	0.9	1.1	0.9	506
4	0	4	0	2	6.3	5.9	2.6	460	10	33	18	1.2	1.4	1.2	371
4	0	4	4	2	6.3	5.9	3.6	532	12	38	19	1.2	1.0	1.0	443
4	4	0	0	2	6.3	5.8	32.8	554	13	3	18	1.5	1.1	1.6	387
4	4	0	4	2	6.4	5.8	32.3	516	12	3	18	1.3	1.2	1.7	405
4	4	4	0	2	6.3	5.8	32.2	508	12	19	18	1.3	0.9	2.3	390
4	4	4	4	2	6.2	5.7	29.1	516	9	21	20	1.1	0.8	1.0	468
1	1	1	1	1	4.8	3.8	5.1	104	7	3	30	1.5	1.2	1.8	69
1	1	1	3	1	4.7	3.8	3.8	92	6	3	24	1.2	1.1	1.0	77
1	1	3	1	1	4.7	3.8	3.5	96	6	4	28	0.9	1.0	1.2	107
1	1	3	3	1	4.3	3.6	4.5	80	6	9	25	1.1	0.8	1.0	73
1	3	1	1	1	4.7	3.6	11.5	92	6	3	28	1.4	1.1	1.9	66
1	3	1	3	1	4.3	3.6	11.5	80	6	1	25	1.4	0.9	1.1	57
1	3	3	1	1	4.6	3.6	10.4	92	6	6	28	1.3	1.0	1.6	71
1	3	3	3	1	4.7	3.6	10.4	88	6	5	30	1.2	0.8	1.0	73
3	1	1	1	1	5.6	5.0	5.3	368	6	4	26	0.8	1.0	1.3	460
3	1	1	3	1	5.6	5.1	6.1	384	7	4	23	1.0	1.1	1.1	384
3	1	3	1	1	5.6	5.1	5.3	236	5	4	20	0.8	0.6	1.2	295
3	1	3	3	1	5.6	5.1	6.1	240	6	7	18	1.0	1.0	1.0	240
3	3	1	1	1	5.6	5.0	14.7	324	6	4	20	1.0	0.8	1.3	324
3	3	1	3	1	5.7	5.0	18.9	380	3	4	23	1.0	0.5	1.4	380
3	3	3	1	1	5.7	5.1	15.6	300	8	8	19	1.1	0.9	2.4	273
3	3	3	3	1	5.7	5.1	15.1	304	6	6	20	0.9	0.8	1.7	338
0	2	2	2	1	4.4	3.2	5.1	14	4	10	23	1.0	0.4	1.4	14
4	2	2	2	1	6.0	5.5	11.8	348	6	4	17	0.8	0.6	1.6	435
2	0	2	2	1	5.2	4.4	1.7	188	5	5	27	1.2	1.2	3.6	157
2	4	2	2	1	5.2	4.1	13.5	152	5	3	23	1.0	1.0	1.0	152
2	2	0	2	1	5.2	4.3	13.9	260	13	4	28	2.1	1.3	1.7	124
2	2	4	2	1	5.0	4.0	6.4	136	5	5	22	0.9	0.6	0.8	151
2	2	2	0	1	5.2	4.3	13.5	232	8	4	29	1.9	1.7	1.8	122
2	2	2	4	1	5.1	4.2	8.5	164	6	4	24	1.2	0.7	1.0	137
2	2	2	2	6	5.1	4.1	10.4	196	7	4	29	1.6	1.0	1.8	126

Appendix Table 5. Treatment combinations, and pH and extractable nutrients of a Florida Entisol following the removal of a crop of *S. guianensis*.

L	P	K	B	Rep	pH		Double-acid extracted nutrients								
					H_2O	KCl	P	Ca	Mg	K	Fe	Mn	Cu	Zn	Ca/Mn
Coded levels				No.			ppm								
0	0	0	0	2	4.8	3.9	5.4	12	5	4	8	3.6	1.0	0.6	3.3
0	0	0	4	2	4.9	4.0	5.1	14	6	5	8	3.6	1.0	0.5	4.1
0	0	4	0	2	4.8	3.9	6.4	15	3	12	10	3.9	0.9	0.6	3.9
0	0	4	4	2	4.8	3.9	5.8	16	5	17	8	3.7	0.9	0.6	4.4
0	4	0	0	2	5.1	3.9	15.6	18	4	4	9	4.2	0.8	2.0	4.2
0	4	0	4	2	5.1	3.9	12.8	18	6	4	8	4.2	0.6	0.7	4.4
0	4	4	0	2	4.8	3.8	16.8	14	3	7	10	4.4	0.9	0.7	3.2
0	4	4	4	2	4.8	3.8	15.4	14	4	7	9	5.0	0.9	1.0	2.9
4	0	0	0	2	6.0	5.2	7.6	258	8	4	8	4.4	0.8	0.8	59.2
4	0	0	4	2	6.1	5.3	7.9	250	8	4	8	4.9	0.9	0.7	50.9
4	0	4	0	2	6.0	5.2	9.2	252	10	14	8	5.8	1.2	1.1	44.2
4	0	4	4	2	6.0	5.2	8.2	252	10	13	9	4.8	0.8	0.7	52.9
4	4	0	0	2	6.2	5.3	21.1	238	10	4	8	4.4	1.0	1.3	54.7
4	4	0	4	2	6.3	5.4	21.4	270	10	4	6	4.2	0.6	0.8	64.2
4	4	4	0	2	5.9	5.1	21.0	257	8	9	8	5.6	0.7	0.8	46.0
4	4	4	4	2	5.8	5.0	25.8	260	11	11	9	6.1	1.1	1.3	43.0
1	1	1	1	1	5.0	4.0	7.3	40	6	5	8	4.4	0.8	0.7	9.1
1	1	1	3	1	5.0	4.1	7.3	44	6	4	9	4.2	0.6	0.7	10.5
1	1	3	1	1	4.9	4.0	7.3	27	6	8	8	4.2	0.8	0.6	6.4
1	1	3	3	1	5.0	4.1	6.7	44	7	8	7	3.4	0.6	0.6	12.9
1	3	1	1	1	5.0	4.0	9.9	48	5	4	7	3.8	1.0	0.7	12.6
1	3	1	3	1	5.1	4.1	11.0	44	5	5	8	3.9	0.9	0.7	11.3
1	3	3	1	1	4.9	4.0	13.9	32	6	7	10	5.1	1.4	1.0	6.3
1	3	3	3	1	5.0	4.0	11.4	34	5	6	8	4.1	0.9	0.6	8.3
3	1	1	1	1	5.6	4.7	11.0	164	9	8	10	6.5	1.2	0.8	25.2
3	1	1	3	1	5.7	4.8	11.8	196	8	6	9	5.5	0.7	0.6	35.6
3	1	3	1	1	5.7	4.8	9.4	140	7	7	7	4.6	0.8	0.7	30.4
3	1	3	3	1	5.8	4.9	11.1	192	9	11	8	5.2	0.8	0.9	36.9
3	3	1	1	1	5.6	4.6	13.5	136	8	6	8	5.6	1.4	1.2	24.3
3	3	1	3	1	5.7	4.7	14.8	168	8	7	8	6.0	1.5	1.4	28.0
3	3	3	1	1	5.6	4.6	13.9	164	7	8	8	5.2	1.2	0.8	31.5
3	3	3	3	1	5.5	4.7	14.7	140	7	8	8	5.4	1.5	1.0	25.9
0	2	2	2	1	4.8	3.9	10.1	11	3	5	9	4.5	0.9	0.7	2.4
4	2	2	2	1	5.9	5.1	13.5	256	10	7	7	5.4	1.2	1.0	47.4
2	0	2	2	1	5.3	4.4	6.7	100	9	8	8	4.2	1.4	1.0	23.8
2	4	2	2	1	5.2	4.1	14.7	68	6	6	8	5.4	1.2	1.0	12.6
2	2	0	2	1	5.5	4.4	14.7	108	10	4	8	5.0	1.5	1.5	21.6
2	2	4	2	1	5.2	4.2	11.5	76	7	10	9	5.1	1.1	0.8	14.9
2	2	2	0	1	5.2	4.2	11.1	80	6	7	9	5.1	1.2	1.3	15.7
2	2	2	4	1	5.2	4.2	11.1	80	7	6	15	4.7	1.0	1.5	17.0
2	2	2	2	6	5.2	4.2	12.5	85	7	8	8	5.6	1.3	1.1	15.3

Appendix Table 6. Treatment combinations, and pH and extractable nutrients of a Florida Entisol following the removal of a crop of *S. hamata*.

L	P	K	B	Rep	pH		Double-acid extracted nutrients								
					H_2O	KCl	P	Ca	Mg	K	Fe	Mn	Cu	Zn	Ca/Mn
Coded levels				No.			----------------------				ppm			----------------------	
0	0	0	0	2	4.9	3.9	6.1	20	6	4	8	3.8	0.5	0.4	5.4
0	0	0	4	2	4.8	3.8	5.8	20	6	2	8	3.2	0.6	0.7	6.4
0	0	4	0	2	5.0	3.9	6.0	18	5	20	8	3.4	0.8	0.5	5.6
0	0	4	4	2	4.9	3.9	6.0	19	4	22	8	3.6	0.8	0.4	5.2
0	4	0	0	2	5.0	3.9	17.6	21	14	4	8	4.2	1.2	1.0	5.0
0	4	0	4	2	5.0	4.9	15.8	28	8	5	8	4.0	0.8	0.6	6.9
0	4	4	0	2	5.0	3.8	17.9	20	6	18	9	3.8	0.7	0.6	5.4
0	4	4	4	2	5.0	3.8	20.4	24	6	20	8	4.3	0.8	1.0	5.6
4	0	0	0	2	6.2	5.4	9.4	312	12	4	6	4.6	0.8	0.7	68.1
4	0	0	4	2	6.3	5.6	9.5	358	12	5	6	4.9	1.0	1.0	73.2
4	0	4	0	2	6.3	5.6	9.6	320	12	26	7	4.6	1.1	0.9	69.6
4	0	4	4	2	6.4	5.5	9.6	304	13	26	7	4.7	1.0	0.7	64.7
4	4	0	0	2	6.4	5.4	29.5	340	14	4	7	5.6	1.0	0.8	61.0
4	4	0	4	2	6.3	5.4	30.6	324	14	6	6	5.5	1.1	1.0	60.4
4	4	4	0	2	6.2	5.3	33.2	306	14	26	7	6.0	1.6	1.2	51.0
4	4	4	4	2	6.2	5.3	32.0	278	14	28	7	5.8	1.0	1.0	48.4
1	1	1	1	1	5.3	4.2	9.4	76	10	6	8	3.8	1.0	1.4	20.0
1	1	1	3	1	5.3	4.2	9.4	72	10	5	7	3.8	0.5	1.5	18.9
1	1	3	1	1	5.3	4.1	9.1	60	8	14	8	3.8	0.7	0.7	15.8
1	1	3	3	1	5.3	4.1	7.3	56	7	9	6	3.0	0.6	0.4	18.7
1	3	1	1	1	5.4	4.1	15.3	60	8	6	6	3.7	0.8	1.2	16.2
1	3	1	3	1	5.3	4.1	14.8	64	8	5	7	4.0	1.2	1.0	16.0
1	3	3	1	1	5.4	4.1	18.9	76	11	18	9	4.6	1.1	2.4	16.5
1	3	3	3	1	5.5	4.2	20.0	76	12	16	8	4.6	1.1	1.0	16.5
3	1	1	1	1	5.8	5.0	11.1	196	8	5	8	4.8	0.6	0.5	40.8
3	1	1	3	1	5.9	5.0	12.6	208	10	6	7	4.6	0.7	0.7	45.2
3	1	3	1	1	6.0	5.1	10.8	200	11	15	7	3.9	0.6	0.7	51.3
3	1	3	3	1	6.1	5.2	15.6	232	22	17	6	5.4	2.8	2.4	43.0
3	3	1	1	1	5.9	4.9	20.0	192	12	6	6	4.8	0.9	0.9	40.0
3	3	1	3	1	5.9	4.9	21.2	212	14	6	7	4.9	1.0	1.2	43.3
3	3	3	1	1	5.9	5.0	17.4	184	13	19	6	4.1	0.7	0.5	44.9
3	3	3	3	1	5.9	4.8	18.9	172	12	13	6	4.2	0.8	0.8	41.0
0	2	2	2	1	5.1	3.9	9.4	20	5	8	8	3.9	0.5	0.7	5.1
4	2	2	2	1	6.1	5.3	16.9	268	16	8	6	5.4	1.1	0.8	49.6
2	0	2	2	1	5.6	4.6	6.1	116	9	7	7	3.7	0.9	0.6	31.4
2	4	2	2	1	5.6	4.5	19.7	120	12	8	7	4.4	1.4	1.5	27.3
2	2	0	2	1	5.7	4.7	13.5	156	9	3	8	4.2	0.6	0.8	37.1
2	2	4	2	1	5.6	4.5	13.1	120	10	18	8	4.2	0.8	0.8	28.6
2	2	2	0	1	5.7	4.6	14.2	152	10	9	8	4.9	0.8	1.1	31.0
2	2	2	4	1	5.6	4.6	13.5	136	12	8	7	4.0	0.9	1.0	34.0
2	2	2	2	6	5.6	4.6	13.6	129	11	8	6	4.2	1.0	0.9	30.3

Appendix Table 7. Treatment combinations, and herbage yields and nutrient concentrations of *S. guianensis* grown in a Florida Ultisol.

L	P	K	B	Reps	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	B	Ca/Mn
Coded levels				#	g/pot	%					ppm						
0	0	0	0	3	10.1	1.96	0.08	3.02	0.51	0.38	68	61	160	5.8	27	37	190
0	0	0	4	3	8.6	2.06	0.09	2.83	0.50	0.49	80	77	125	6.8	24	81	227
0	0	4	0	3	12.2	1.87	0.07	1.75	0.22	1.33	94	55	85	4.6	26	32	206
0	0	4	4	3	11.3	1.95	0.07	1.73	0.23	1.37	86	61	89	4.9	22	65	195
0	4	0	0	3	12.8	2.41	0.19	2.22	0.54	0.34	141	64	168	5.9	26	28	133
0	4	0	4	3	10.6	2.40	0.18	2.26	0.53	0.40	147	61	161	6.3	25	74	140
0	4	4	0	3	17.0	2.10	0.12	1.63	0.28	1.07	105	53	129	4.4	21	27	127
0	4	4	4	3	15.4	2.20	0.12	1.58	0.28	1.17	113	60	116	4.3	21	60	137
4	0	0	0	3	8.9	1.90	0.08	3.31	0.40	0.40	77	55	58	4.0	13	28	575
4	0	0	4	3	8.1	1.87	0.08	3.21	0.38	0.42	78	54	49	4.0	15	51	651
4	0	4	0	3	10.2	1.89	0.08	2.09	0.18	1.37	93	56	35	3.5	12	23	599
4	0	4	4	3	10.1	1.84	0.07	2.06	0.18	1.30	90	57	36	3.8	14	43	573
4	4	0	0	3	11.6	2.24	0.23	2.95	0.48	0.39	152	63	73	4.8	14	22	405
4	4	0	4	3	10.8	2.25	0.22	2.90	0.46	0.43	238	60	67	4.4	16	52	435
4	4	4	0	3	13.6	2.12	0.16	2.14	0.26	1.23	109	59	52	3.7	14	23	409
4	4	4	4	3	12.4	2.13	0.17	2.29	0.26	1.27	137	64	51	3.7	13	51	450
1	1	1	1	1	12.1	1.74	0.08	2.19	0.33	0.57	75	56	86	3.5	17	39	255
1	1	1	3	1	10.0	2.05	0.10	2.37	0.36	0.72	85	75	94	4.8	21	71	252
1	1	3	1	1	13.2	1.84	0.07	1.84	0.22	0.94	85	61	80	3.8	15	35	230
1	1	3	3	1	13.5	1.87	0.07	1.64	0.22	0.92	85	50	62	3.2	14	50	265
1	3	1	1	1	15.5	2.01	0.11	2.00	0.36	0.44	112	52	92	3.5	16	40	217
1	3	1	3	1	10.8	2.24	0.17	1.98	0.41	0.71	138	55	86	5.2	20	66	230
1	3	3	1	1	16.7	2.10	0.11	1.79	0.29	0.86	118	57	90	3.8	16	38	199
1	3	3	3	1	15.0	2.23	0.12	1.92	0.32	0.94	162	64	98	3.3	18	52	196
3	1	1	1	1	12.0	1.72	0.08	2.29	0.32	0.53	150	52	64	3.2	11	41	358
3	1	1	3	1	12.2	1.76	0.08	2.32	0.32	0.54	150	48	64	3.2	12	52	362
3	1	3	1	1	15.1	1.73	0.08	1.98	0.24	0.80	170	55	50	3.2	12	36	396
3	1	3	3	1	11.9	1.86	0.08	2.00	0.22	1.01	188	50	53	3.2	11	30	377
3	3	1	1	1	12.5	2.09	0.14	2.29	0.36	0.50	262	58	78	3.5	12	43	294
3	3	1	3	1	12.0	2.08	0.15	2.30	0.36	0.58	202	55	74	3.8	14	60	311
3	3	3	1	1	13.6	2.21	0.12	2.13	0.29	0.94	172	58	65	3.8	14	42	328
3	3	3	3	1	16.3	1.92	0.11	1.78	0.25	0.77	155	55	57	3.0	12	46	312
0	2	2	2	1	14.3	1.89	0.08	1.59	0.28	0.69	125	51	114	3.8	18	47	139
4	2	2	2	1	12.3	1.87	0.12	2.25	0.31	0.80	102	57	53	3.2	12	44	425
2	0	2	2	1	10.3	1.84	0.07	2.04	0.24	0.87	88	57	55	3.2	12	44	371
2	4	2	2	1	13.9	2.19	0.14	1.94	0.33	0.72	142	78	79	3.5	14	46	246
2	2	0	2	1	11.5	2.19	0.14	3.07	0.52	0.37	168	62	118	4.8	17	50	260
2	2	4	2	1	14.4	2.04	0.10	1.94	0.24	1.12	132	57	67	3.2	14	41	290
2	2	2	0	1	14.1	1.93	0.10	2.07	0.31	0.70	175	53	74	3.2	13	25	280
2	2	2	4	1	14.5	1.89	0.10	1.96	0.29	0.65	162	50	70	3.2	14	64	280
2	2	2	2	6	13.5	1.93	0.10	1.98	0.29	0.73	88	59	70	3.1	14	46	284

Appendix Table 8. Treatment combinations, and herbage yields and nutrient concentrations of *S. hamata* grown in a Florida Ultisol.

L	P	K	B	Reps	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	B	Ca/Mn
Coded levels				#	g/pot			%					ppm				
0	0	0	0	3	7.1	2.40	0.11	1.65	0.53	0.75	213	51	93	5.8	22	29	178
0	0	0	4	3	6.6	2.46	0.11	1.68	0.54	0.75	237	53	92	6.2	22	69	182
0	0	4	0	3	6.9	2.51	0.11	1.61	0.27	1.72	105	55	112	6.3	23	24	243
0	0	4	4	3	7.0	2.37	0.11	1.58	0.26	1.67	96	54	117	6.1	26	41	136
0	4	0	0	3	8.4	2.66	0.16	1.37	0.50	0.64	2033	51	105	5.9	21	26	131
0	4	0	4	3	8.4	2.66	0.15	1.32	0.48	0.58	2066	51	106	5.6	18	45	125
0	4	4	0	3	7.7	2.85	0.16	1.53	0.32	1.72	516	66	125	7.5	23	28	123
0	4	4	4	3	8.2	2.88	0.16	1.47	0.30	1.71	464	61	128	6.5	22	39	116
4	0	0	0	3	6.5	2.53	0.12	2.16	0.50	0.76	212	55	49	4.9	17	25	444
4	0	0	4	3	5.7	2.63	0.12	2.10	0.49	0.81	210	53	48	4.9	17	50	436
4	0	4	0	3	6.6	2.64	0.11	1.76	0.24	1.76	93	61	50	4.5	16	21	350
4	0	4	4	3	6.1	2.56	0.13	1.72	0.24	1.86	107	59	52	5.7	21	32	334
4	4	0	0	3	6.7	2.81	0.21	1.85	0.49	0.76	2066	57	51	5.2	19	24	363
4	4	0	4	3	6.2	2.68	0.20	1.84	0.45	0.75	2297	60	51	4.7	16	40	364
4	4	4	0	3	7.9	2.77	0.17	1.70	0.27	1.73	308	73	59	4.7	21	20	288
4	4	4	4	3	7.4	2.79	0.18	1.74	0.26	1.76	281	69	56	4.9	22	35	309
1	1	1	1	1	6.3	2.40	0.11	1.61	0.38	1.21	342	69	68	5.0	21	25	237
1	1	1	3	1	6.5	2.75	0.12	1.71	0.39	1.17	450	67	76	6.0	20	40	225
1	1	3	1	1	6.6	2.76	0.13	1.54	0.27	1.64	192	73	89	6.0	22	25	173
1	1	3	3	1	7.4	2.67	0.13	1.54	0.26	1.60	200	82	82	6.0	20	44	188
1	3	1	1	1	7.9	2.62	0.15	1.60	0.41	0.97	1122	74	89	5.5	21	25	180
1	3	1	3	1	8.2	2.67	0.16	1.57	0.41	0.97	1365	73	84	5.8	21	39	187
1	3	3	1	1	9.8	2.51	0.12	1.52	0.29	1.36	405	70	87	5.0	16	25	175
1	3	3	3	1	7.0	2.62	0.15	1.62	0.29	1.70	368	73	75	6.5	20	36	216
3	1	1	1	1	6.8	2.75	0.14	1.76	0.38	1.00	538	91	62	5.8	19	28	284
3	1	1	3	1	6.0	2.84	0.15	1.95	0.39	1.11	610	73	64	5.5	18	42	305
3	1	3	1	1	8.1	2.76	0.12	1.69	0.24	1.37	185	68	62	5.0	16	25	273
3	1	3	3	1	6.7	2.94	0.15	1.83	0.26	1.65	190	72	68	6.0	28	36	269
3	3	1	1	1	6.2	2.76	0.18	1.80	0.38	1.06	1230	75	62	7.0	20	25	290
3	3	1	3	1	8.1	2.56	0.15	1.74	0.39	0.92	935	69	57	4.5	20	31	305
3	3	3	1	1	8.4	2.67	0.15	1.75	0.30	1.43	318	68	62	5.8	21	23	282
3	3	3	3	1	8.2	2.76	0.15	1.66	0.29	1.53	312	76	52	4.5	20	32	319
0	2	2	2	1	7.5	2.82	0.14	1.67	0.38	1.32	530	65	111	7.0	22	38	150
4	2	2	2	1	7.3	2.80	0.15	1.89	0.34	1.34	545	68	56	4.8	18	37	338
2	0	2	2	1	6.9	2.70	0.12	1.83	0.34	1.37	122	70	70	6.2	21	42	261
2	4	2	2	1	9.8	2.93	0.17	1.67	0.40	1.16	1000	68	77	5.5	18	38	217
2	2	0	2	1	6.4	2.77	0.18	1.84	0.50	0.63	1758	70	70	6.5	22	40	263
2	2	4	2	1	8.3	3.22	0.13	1.62	0.24	1.64	215	68	78	5.2	18	33	208
2	2	2	0	1	7.2	2.72	0.15	1.70	0.37	1.34	528	72	70	6.0	19	28	243
2	2	2	4	1	7.8	2.67	0.13	1.73	0.37	1.34	512	62	68	5.2	23	45	254
2	2	2	2	6	7.8	2.74	0.14	1.74	0.34	1.33	474	68	79	5.6	19	38	220

Appendix Table 9. Treatment combinations, and herbage yields and nutrient concentrations of *S. guianensis* grown in a Florida Spodosol.

L	P	K	B	Reps	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	B	Ca/Mn
Coded levels				#	g/pot	%					ppm						
0	0	0	0	2	2.0	1.54	0.08	0.72	0.70	0.42	18	52	502	10.8	210	45	14
0	0	0	4	2	2.0	1.80	0.08	0.69	0.76	0.44	15	55	671	12.5	254	134	10
0	0	4	0	2	2.5	1.22	0.06	0.50	0.38	1.74	70	47	443	7.0	206	43	11
0	0	4	4	2	2.4	1.36	0.07	0.56	0.39	1.86	70	48	476	7.5	202	136	12
0	4	0	0	2	2.0	2.26	1.08	0.79	1.05	0.44	242	79	686	6.8	240	56	12
0	4	0	4	2	1.9	2.34	0.97	0.71	0.96	0.50	278	78	490	6.2	200	170	14
0	4	4	0	2	3.5	1.23	0.54	0.49	0.50	1.90	122	46	346	5.2	144	40	14
0	4	4	4	2	3.0	1.38	0.58	0.58	0.54	2.04	145	50	424	5.8	171	142	14
4	0	0	0	2	2.2	2.47	0.12	3.72	0.40	0.44	48	61	28	6.0	31	21	1363
4	0	0	4	2	2.1	2.26	0.12	3.75	0.36	0.44	85	69	34	6.5	32	152	1148
4	0	4	0	2	3.0	1.93	0.07	2.14	0.12	1.84	70	56	18	3.2	28	15	1165
4	0	4	4	2	2.9	1.89	0.08	2.32	0.12	1.88	82	58	20	3.2	30	140	1136
4	4	0	0	2	3.2	2.96	0.45	2.87	0.34	0.34	222	70	32	4.5	24	22	885
4	4	0	4	2	2.7	2.88	0.42	2.99	0.33	0.42	272	66	32	4.8	27	116	934
4	4	4	0	2	10.6	2.53	0.25	2.48	0.16	1.26	82	48	24	2.8	18	11	1035
4	4	4	4	2	6.6	2.64	0.25	2.42	0.16	1.82	95	60	26	2.8	20	85	958
1	1	1	1	1	6.4	1.82	0.17	2.08	0.30	0.52	25	39	211	6.0	96	53	99
1	1	1	3	1	5.0	1.57	0.16	2.01	0.32	0.60	30	42	180	4.5	30	89	112
1	1	3	1	1	7.4	1.74	0.13	1.76	0.21	1.07	30	46	154	4.5	70	50	114
1	1	3	3	1	6.6	1.50	0.15	1.76	0.22	1.17	30	52	132	4.5	64	77	133
1	3	1	1	1	6.1	2.10	0.45	2.20	0.36	0.60	45	51	225	5.5	94	50	98
1	3	1	3	1	6.8	1.91	0.37	1.97	0.34	0.48	55	50	185	4.0	70	89	106
1	3	3	1	1	7.5	1.63	0.29	1.67	0.22	1.14	60	38	105	3.5	44	47	159
1	3	3	3	1	7.2	1.66	0.30	1.70	0.23	1.18	65	50	136	3.5	56	89	125
3	1	1	1	1	7.3	2.47	0.14	3.22	0.24	0.49	55	46	86	5.0	43	41	374
3	1	1	3	1	6.4	2.33	0.15	3.19	0.25	0.58	50	50	67	4.5	36	77	476
3	1	3	1	1	9.0	2.23	0.11	2.34	0.16	1.04	60	46	42	3.5	26	35	557
3	1	3	3	1	7.6	2.24	0.11	2.46	0.16	1.24	85	44	40	3.5	24	73	615
3	3	1	1	1	7.4	2.61	0.32	3.02	0.28	0.51	55	48	63	4.5	34	43	479
3	3	1	3	1	7.3	2.53	0.30	2.92	0.24	0.46	90	42	61	3.5	28	77	479
3	3	3	1	1	12.6	2.25	0.21	2.36	0.16	0.79	80	45	44	3.0	24	29	536
3	3	3	3	1	11.8	2.57	0.21	2.33	0.16	0.86	65	40	41	3.0	23	35	568
0	2	2	2	1	2.4	0.86	0.40	0.66	0.58	1.72	45	42	404	7.5	185	92	16
4	2	2	2	1	5.8	1.97	0.17	2.78	0.20	1.14	70	54	20	3.5	16	57	1390
2	0	2	2	1	4.2	1.61	0.07	2.05	0.16	1.23	50	47	70	4.5	44	75	293
2	4	2	2	1	10.4	2.29	0.30	2.13	0.20	0.58	70	40	94	3.0	37	52	227
2	2	0	2	1	3.7	2.85	0.39	2.92	0.44	0.27	75	65	102	6.5	54	84	286
2	2	4	2	1	11.4	2.17	0.15	1.92	0.14	1.00	50	38	71	3.0	34	49	270
2	2	2	0	1	12.2	2.36	0.17	2.3	0.18	0.50	55	39	116	4.0	44	16	198
2	2	2	4	1	8.6	2.56	0.18	2.32	0.21	0.74	80	49	103	4.0	41	86	225
2	2	2	2	6	10.1	2.22	0.16	2.26	0.20	0.65	35	60	104	4.2	47	48	218

Appendix Table 10. Treatment combinations, and herbage yields and nutrient concentrations of S. hamata grown in a Florida Spodosol.

N	P	K	B	Reps	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	B	Ca/Mn
Coded levels				#	g/pot	------------		%		-------------	------------			ppm	-------------		
0	0	0	0	2	1.6	2.37	0.11	0.52	0.78	0.54	465	56	428	11.8	190	36	13
0	0	0	4	2	1.6	2.26	0.12	0.47	0.70	0.54	508	53	378	10.2	161	100	13
0	0	4	0	2	1.8	1.37	0.10	0.36	0.44	2.18	190	44	420	9.2	180	33	9
0	0	4	4	2	1.8	1.68	0.10	0.35	0.40	2.24	118	40	362	9.2	160	84	10
0	4	0	0	2	1.2	2.11	0.42	0.37	0.57	0.52	4945	57	241	3.8	130	36	15
0	4	0	4	2	1.0	2.52	0.36	0.26	0.53	0.63	6300	76	173	2.5	83	88	15
0	4	4	0	2	1.7	1.32	0.37	0.32	0.38	2.20	790	42	276	5.5	121	32	12
0	4	4	4	2	2.1	1.22	0.38	0.41	0.48	2.00	598	44	340	5.2	131	88	12
4	0	0	0	2	1.8	2.38	0.10	2.20	0.36	0.56	680	68	22	3.2	34	26	1013
4	0	0	4	2	1.8	2.52	0.10	2.24	0.32	0.50	718	54	18	3.8	35	64	1279
4	0	4	0	2	1.8	2.64	0.10	1.67	0.17	2.07	168	65	18	3.0	38	21	932
4	0	4	4	2	2.4	2.32	0.10	1.72	0.16	1.91	110	60	21	2.8	31	63	889
4	4	0	0	2	2.9	2.87	0.24	1.56	0.20	0.34	4922	64	14	2.5	22	18	1077
4	4	0	4	2	3.6	2.82	0.26	1.70	0.23	0.25	4545	77	20	2.5	22	69	829
4	4	4	0	2	5.0	2.91	0.18	1.61	0.14	1.88	328	70	17	2.3	18	10	951
4	4	4	4	2	5.9	2.73	0.18	1.71	0.14	1.84	290	70	16	2.5	19	50	1102
1	1	1	1	1	5.3	1.79	0.14	1.49	0.31	0.72	570	46	141	4.0	68	32	106
1	1	1	3	1	4.7	1.71	0.15	1.58	0.34	0.87	725	69	143	4.5	65	62	110
1	1	3	1	1	6.5	1.88	0.11	1.34	0.20	1.31	170	92	109	3.0	52	30	123
1	1	3	3	1	5.4	1.92	0.14	1.44	0.22	1.53	195	56	127	4.5	55	57	113
1	3	1	1	1	7.8	2.19	0.18	1.27	0.23	0.49	1565	43	93	3.0	46	32	137
1	3	1	3	1	6.0	1.91	0.20	1.43	0.27	0.66	1715	46	106	4.0	52	54	135
1	3	3	1	1	6.7	2.14	0.20	1.50	0.23	1.44	540	48	101	4.0	46	30	149
1	3	3	3	1	6.3	2.10	0.20	1.38	0.21	1.41	565	76	83	3.0	42	52	166
3	1	1	1	1	8.3	2.43	0.10	1.61	0.20	0.49	680	64	36	2.5	22	27	447
3	1	1	3	1	6.4	2.52	0.11	1.68	0.22	0.65	780	66	26	3.5	23	47	646
3	1	3	1	1	7.0	2.46	0.10	1.59	0.16	1.39	155	61	34	2.5	26	25	468
3	1	3	3	1	5.2	2.70	0.13	1.70	0.16	1.81	200	64	29	3.5	23	51	586
3	3	1	1	1	7.3	2.73	0.18	1.67	0.22	0.54	1695	58	29	2.5	22	36	576
3	3	1	3	1	6.7	2.62	0.17	1.64	0.20	0.60	1650	65	26	3.5	23	52	631
3	3	3	1	1	6.4	2.58	0.14	1.66	0.14	1.50	475	71	19	3.0	18	32	874
3	3	3	3	1	7.9	2.63	0.14	1.60	0.16	1.38	525	63	25	4.0	19	44	640
0	2	2	2	1	2.1	1.10	0.29	0.44	0.54	1.63	340	43	411	6.0	144	55	11
4	2	2	2	1	6.2	2.87	0.15	1.76	0.20	1.21	795	74	18	4.0	21	37	978
2	0	2	2	1	5.0	1.94	0.07	1.54	0.16	1.23	70	60	55	3.5	33	42	280
2	4	2	2	1	11.0	2.41	0.17	1.42	0.16	0.65	1275	56	59	2.5	26	36	241
2	2	0	2	1	3.9	2.77	0.18	1.85	0.28	0.22	2715	60	58	3.5	39	62	319
2	2	4	2	1	11.3	2.56	0.12	1.46	0.14	1.20	330	64	46	2.5	23	37	317
2	2	2	0	1	8.5	2.64	0.14	1.44	0.19	0.81	895	58	50	3.5	19	15	288
2	2	2	4	1	7.7	2.12	0.14	1.52	0.18	0.88	735	54	47	3.0	29	60	323
2	2	2	2	6	9.4	2.40	0.13	1.48	0.18	0.79	709	55	52	2.9	29	38	288

Appendix Table 11. Treatment combinations, and herbage yields and nutrient concentrations of S. guianensis grown in a Florida Entisol.

L	P	K	B	Reps	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	B	Ca/Mn
Coded levels				#	g/pot	-----------		%		-------------	------------			ppm		-----------	
0	0	0	0	2	4.2	2.02	0.08	2.07	0.46	0.43	38	48	377	9.1	88	23	55
0	0	0	4	2	3.8	2.02	0.08	2.01	0.46	0.42	40	42	275	5.4	68	124	74
0	0	4	0	2	5.6	1.66	0.05	1.04	0.20	1.37	56	42	422	4.5	53	17	25
0	0	4	4	2	4.7	1.74	0.06	1.14	0.24	1.65	54	40	411	4.4	55	96	28
0	4	0	0	2	6.3	3.00	0.29	1.19	0.41	0.32	44	52	236	5.7	68	19	50
0	4	0	4	2	5.6	3.21	0.27	1.22	0.42	0.36	74	59	179	5.2	48	112	68
0	4	4	0	2	12.5	2.06	0.12	0.72	0.20	1.19	69	46	328	4.0	39	12	22
0	4	4	4	2	12.5	2.01	0.11	0.71	0.20	1.20	81	47	290	3.6	36	65	25
4	0	0	0	2	5.1	2.46	0.19	4.39	0.42	0.38	44	52	66	5.1	17	12	669
4	0	0	4	2	4.6	2.54	0.16	4.50	0.42	0.42	50	56	58	4.9	17	136	780
4	0	4	0	2	10.7	1.62	0.07	2.17	0.14	1.06	48	43	41	2.4	11	10	533
4	0	4	4	2	10.0	1.65	0.08	2.24	0.14	1.14	43	42	45	2.4	10	83	499
4	4	0	0	2	6.2	2.75	0.38	3.24	0.36	0.38	101	52	68	5.4	19	9	480
4	4	0	4	2	4.9	2.70	0.40	3.02	0.35	0.46	183	51	61	4.5	18	131	502
4	4	4	0	2	13.6	1.82	0.16	2.23	0.16	1.10	65	44	56	2.8	10	7	400
4	4	4	4	2	12.2	1.92	0.18	2.42	0.17	1.18	62	53	60	2.7	10	78	407
1	1	1	1	1	9.1	1.67	0.08	2.00	0.21	0.52	50	48	109	5.8	34	32	183
1	1	1	3	1	7.9	1.70	0.08	2.00	0.22	0.59	48	38	94	3.8	28	71	213
1	1	3	1	1	10.7	1.57	0.06	1.56	0.15	0.95	45	37	94	3.5	27	29	166
1	1	3	3	1	8.0	1.77	0.06	1.73	0.16	1.18	48	41	76	3.2	23	67	228
1	3	1	1	1	12.2	1.85	0.11	1.70	0.22	0.40	55	37	118	3.5	21	28	144
1	3	1	3	1	10.4	2.03	0.12	1.92	0.24	0.41	55	41	134	3.2	23	66	143
1	3	3	1	1	14.6	1.75	0.09	1.36	0.17	0.75	58	40	126	2.5	21	28	108
1	3	3	3	1	12.7	1.82	0.09	1.42	0.17	0.81	58	44	111	2.2	18	54	128
3	1	1	1	1	10.0	1.67	0.09	2.52	0.21	0.38	58	46	81	2.8	11	33	311
3	1	1	3	1	9.6	1.76	0.09	2.52	0.22	0.41	58	40	59	2.5	14	58	427
3	1	3	1	1	11.9	1.53	0.07	1.99	0.15	0.86	65	42	49	2.0	12	29	406
3	1	3	3	1	10.0	1.62	0.07	2.12	0.17	0.92	70	50	54	2.0	14	61	393
3	3	1	1	1	11.7	2.17	0.17	2.64	0.22	0.37	95	44	79	3.5	14	26	334
3	3	1	3	1	10.6	1.96	0.15	2.56	0.23	0.40	95	38	75	2.2	12	50	341
3	3	3	1	1	14.9	1.77	0.11	2.05	0.17	0.71	72	41	73	2.0	10	22	280
3	3	3	3	1	14.6	1.86	0.12	2.15	0.17	0.72	78	41	77	2.2	12	49	279
0	2	2	2	1	10.4	1.76	0.08	0.82	0.21	0.75	55	43	225	4.8	46	47	36
4	2	2	2	1	10.6	1.72	0.12	2.31	0.19	0.66	68	42	48	2.2	9	46	481
2	0	2	2	1	6.9	1.55	0.06	1.99	0.16	0.88	52	45	52	2.2	14	50	383
2	4	2	2	1	14.5	1.91	0.13	1.76	0.18	0.53	75	41	100	2.2	14	38	176
2	2	0	2	1	5.6	2.60	0.21	3.14	0.42	0.30	72	53	84	6.2	27	55	374
2	2	4	2	1	13.3	1.68	0.08	1.66	0.14	0.94	60	41	79	2.2	14	38	210
2	2	2	0	1	13.3	1.74	0.08	1.90	0.18	0.56	75	39	90	2.2	14	7	211
2	2	2	4	1	12.3	2.32	0.09	1.86	0.19	0.64	68	40	77	2.5	16	63	242
2	2	2	2	6	13.0	1.71	0.09	1.86	0.18	0.63	52	43	79	2.9	14	39	236

Appendix Table 12. Treatment combinations, and herbage yields and nutrient concentrations of *S. hamata* grown in a Florida Entisol.

L	P	K	B	Reps	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	B	Ca/Mn
Coded levels				#	g/pot	-----------		%	-------------		---------		ppm	-------------			
0	0	0	0	2	3.5	1.70	0.07	1.22	0.48	0.48	104	38	116	2.9	40	18	105
0	0	0	4	2	3.2	1.88	0.07	1.27	0.48	0.55	125	41	120	3.2	44	71	106
0	0	4	0	2	4.2	1.92	0.07	1.00	0.26	1.56	119	44	301	3.8	38	16	33
0	0	4	4	2	3.5	1.79	0.07	1.06	0.25	1.53	110	41	295	3.8	40	48	36
0	4	0	0	2	4.3	2.23	0.14	0.87	0.31	0.34	3740	50	98	3.4	22	16	89
0	4	0	4	2	4.2	2.39	0.15	0.88	0.30	0.39	2665	52	99	3.4	23	70	89
0	4	4	0	2	7.0	2.18	0.09	0.69	0.22	1.41	616	50	206	2.7	21	12	33
0	4	4	4	2	7.0	2.10	0.08	0.68	0.21	1.38	724	49	193	2.7	19	56	35
4	0	0	0	2	4.4	2.10	0.13	2.58	0.34	0.41	118	55	35	2.8	10	10	766
4	0	0	4	2	3.9	2.11	0.14	2.96	0.36	0.46	101	66	40	2.4	9	80	740
4	0	4	0	2	6.2	1.98	0.10	1.60	0.18	1.37	101	58	32	2.1	12	9	492
4	0	4	4	2	6.4	1.96	0.09	1.70	0.18	1.28	98	64	36	1.9	10	51	474
4	4	0	0	2	4.9	2.22	0.21	1.92	0.26	0.43	2508	55	32	2.5	14	10	602
4	4	0	4	2	4.7	2.27	0.21	2.03	0.24	0.41	2740	55	36	2.8	13	70	572
4	4	4	0	2	7.0	2.12	0.16	1.68	0.18	1.39	244	64	40	2.2	12	9	415
4	4	4	4	2	5.7	2.20	0.15	1.78	0.19	1.38	272	81	44	2.2	12	56	404
1	1	1	1	1	4.4	1.87	0.07	1.48	0.23	1.02	180	47	47	2.2	18	25	315
1	1	1	3	1	4.3	1.81	0.07	1.46	0.23	1.03	180	44	42	2.5	20	50	348
1	1	3	1	1	5.2	1.85	0.06	1.36	0.19	1.34	142	52	64	2.5	16	23	212
1	1	3	3	1	5.3	1.90	0.07	1.40	0.20	1.37	150	54	62	2.8	18	42	226
1	3	1	1	1	6.4	2.03	0.10	1.49	0.26	0.74	678	50	57	2.2	15	28	261
1	3	1	3	1	6.3	1.97	0.09	1.35	0.24	0.74	670	49	51	2.5	14	48	265
1	3	3	1	1	6.4	2.00	0.08	1.39	0.19	1.30	258	52	75	2.2	13	25	185
1	3	3	3	1	6.2	2.04	0.08	1.26	0.20	1.33	320	57	62	2.5	13	48	203
3	1	1	1	1	6.5	2.22	0.09	1.89	0.24	0.82	320	53	40	2.2	12	28	472
3	1	1	3	1	5.2	2.32	0.09	1.92	0.25	1.02	242	56	39	2.2	12	52	492
3	1	3	1	1	5.8	1.84	0.08	1.64	0.17	1.39	140	68	36	2.0	10	23	456
3	1	3	3	1	5.4	2.61	0.08	1.69	0.19	1.25	132	58	36	1.8	11	47	469
3	3	1	1	1	5.8	2.42	0.11	1.82	0.23	0.85	822	62	44	2.2	10	28	414
3	3	1	3	1	5.6	2.05	0.11	1.89	0.22	0.86	782	58	42	2.0	9	51	450
3	3	3	1	1	6.8	2.00	0.10	1.64	0.18	1.35	210	67	45	2.0	10	25	364
3	3	3	3	1	7.0	2.13	0.10	1.66	0.19	1.35	220	62	43	2.0	11	44	386
0	2	2	2	1	6.1	1.92	0.07	0.85	0.30	1.17	208	50	156	2.8	31	40	54
4	2	2	2	1	7.6	2.02	0.10	1.84	0.19	1.16	248	62	36	1.8	10	40	511
2	0	2	2	1	5.1	1.83	0.07	1.51	0.18	1.30	83	52	35	2.5	14	33	431
2	4	2	2	1	7.9	2.12	0.12	1.53	0.18	1.06	620	55	55	1.8	13	37	278
2	2	0	2	1	4.4	2.07	0.12	1.70	0.28	0.42	2235	43	41	2.8	14	45	415
2	2	4	2	1	7.9	1.94	0.08	1.47	0.17	1.34	180	56	50	2.0	16	32	294
2	2	2	0	1	6.7	2.00	0.09	1.46	0.19	1.21	212	54	40	2.0	12	11	365
2	2	2	4	1	6.5	1.96	0.08	1.57	0.19	1.22	185	51	40	2.0	12	60	392
2	2	2	2	66	6.9	1.91	0.08	1.54	0.20	1.08	170	52	42	1.9	14	38	372

Appendix Table 13. Treatment combinations, and root-nodule yields and nutrient concentrations of <u>S. guianensis</u> grown in a Florida Ultisol.

L	P	K	B	Reps	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	Ca/Mn	Nod⁺
Coded levels				No.	g/pot	%					ppm						
0	0	0	0	3	1.7	1.96	0.10	0.61	0.70	0.27	1068	754	217	8.7	22	29	2.0
0	0	0	4	3	1.5	2.68	0.11	0.47	0.78	0.29	1458	761	157	9.0	23	31	2.0
0	0	4	0	3	1.9	1.83	0.08	0.37	0.62	0.81	548	445	98	8.2	20	39	2.3
0	0	4	4	3	1.9	1.76	0.09	0.37	0.51	0.93	568	476	106	8.3	18	36	2.3
0	4	0	0	3	1.9	2.14	0.15	0.39	0.30	0.23	10900	979	178	10.7	24	23	3.3
0	4	0	4	3	1.8	2.18	0.15	0.41	0.29	0.24	9873	910	141	11.2	25	29	2.3
0	4	4	0	3	2.2	2.13	0.14	0.37	0.44	0.46	8182	637	149	9.0	23	25	4.7
0	4	4	4	3	2.2	2.15	0.14	0.35	0.42	0.54	8317	667	134	9.0	21	26	4.7
4	0	0	0	3	1.4	1.90	0.10	0.63	0.58	0.34	977	406	63	7.3	16	102	2.0
4	0	0	4	3	1.2	1.98	0.11	0.64	0.63	0.37	1105	590	68	8.2	18	94	2.0
4	0	4	0	3	1.6	1.74	0.10	0.52	0.52	1.16	573	410	52	6.7	15	101	2.7
4	0	4	4	3	1.5	1.71	0.10	0.55	0.54	1.29	533	442	57	7.0	15	95	2.7
4	4	0	0	3	1.7	2.15	0.17	0.58	0.31	0.25	10230	586	86	10.5	20	68	3.3
4	4	0	4	3	1.5	2.45	0.19	0.59	0.30	0.32	10320	700	70	10.8	23	86	2.7
4	4	4	0	3	1.7	2.27	0.16	0.50	0.33	0.65	7260	648	54	8.2	16	98	4.3
4	4	4	4	3	1.6	2.37	0.16	0.47	0.33	0.74	7483	498	56	8.0	22	87	4.0
1	1	1	1	1	1.8	1.88	0.10	0.48	0.52	0.34	4150	692	118	8.0	20	41	2.0
1	1	1	3	1	1.5	1.90	0.11	0.44	0.56	0.32	5155	497	104	9.0	22	42	2.0
1	1	3	1	1	2.6	1.79	0.11	0.42	0.53	0.66	3335	498	94	7.5	17	45	3.0
1	1	3	3	1	1.6	1.84	0.11	0.40	0.42	0.72	3330	374	65	10.5	18	62	3.0
1	3	1	1	1	2.4	2.04	0.14	0.45	0.36	0.29	7925	1308	177	9.5	28	25	4.0
1	3	1	3	1	1.3	2.39	0.16	0.40	0.26	0.32	9165	886	70	13.5	20	57	3.0
1	3	3	1	1	2.2	2.02	0.21	0.58	0.38	0.34	6355	736	112	6.5	24	52	5.0
1	3	3	3	1	1.8	1.97	0.14	0.36	0.42	0.39	7700	582	96	7.0	20	38	4.0
3	1	1	1	1	1.6	2.39	0.14	0.52	0.42	0.57	4535	776	73	9.0	20	71	3.0
3	1	1	3	1	1.6	2.00	0.11	0.52	0.40	0.45	4220	474	80	7.5	18	65	3.0
3	1	3	1	1	1.9	1.88	0.11	0.48	0.46	0.58	3505	555	81	7.0	16	59	4.0
3	1	3	3	1	1.5	1.83	0.11	0.47	0.38	0.70	3300	442	58	7.0	18	81	4.0
3	3	1	1	1	1.6	2.57	0.18	0.50	0.28	0.42	6820	673	64	9.5	23	78	4.0
3	3	1	3	1	1.6	2.28	0.15	0.52	0.28	0.33	8030	989	78	9.0	17	67	3.0
3	3	3	1	1	1.9	2.25	0.15	0.50	0.34	0.53	6830	774	71	7.5	20	70	5.0
3	3	3	3	1	2.1	2.28	0.15	0.50	0.38	0.52	7420	982	93	8.0	18	54	5.0
0	2	2	2	1	2.3	1.89	0.10	0.36	0.48	0.35	5975	893	176	8.0	18	20	3.0
4	2	2	2	1	1.6	1.91	0.14	0.57	0.44	0.43	7175	784	72	7.5	14	79	3.0
2	0	2	2	1	1.8	1.82	0.09	0.54	0.59	0.67	755	781	76	7.0	18	71	2.0
2	4	2	2	1	2.0	2.17	0.16	0.50	0.37	0.39	9735	907	92	8.5	21	54	4.0
2	2	0	2	1	1.7	2.20	0.15	0.56	0.40	0.27	8110	873	118	10.5	24	47	3.0
2	2	4	2	1	2.0	1.95	0.15	0.50	0.40	0.66	4725	578	87	7.0	19	57	4.0
2	2	2	0	1	2.0	2.13	0.12	0.48	0.36	0.39	5705	1010	91	8.0	22	53	4.0
2	2	2	4	1	2.2	2.02	0.12	0.52	0.44	0.44	5760	736	99	8.0	25	53	4.0
2	2	2	2	6	2.0	2.08	0.12	0.50	0.39	0.41	6222	844	89	8.6	19	57	4.4

+ Visual evaluation of nodulation, 1 = none, 5 = excellent.

Appendix Table 14. Treatment combinations, and root-nodule yields and nutrient concentrations of *S. hamata* grown in a Florida Ultisol.

L	P	K	B	Reps	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	Ca/Mn	Nod+
Coded levels				No.	g/pot	%					ppm						
0	0	0	0	3	1.0	2.6	0.14	0.45	0.47	0.23	1800	1753	192	13.3	25	24	2.3
0	0	0	4	3	1.0	2.15	0.14	0.41	0.43	0.24	1900	1235	147	13.3	23	29	2.7
0	0	4	0	3	0.9	2.35	0.14	0.46	0.29	1.07	1050	1292	272	11.7	23	17	3.7
0	0	4	4	3	1.0	2.03	0.14	0.49	0.27	1.11	1133	1275	260	13.3	24	19	3.7
0	4	0	0	3	1.2	2.40	0.19	0.41	0.29	0.19	7550	1271	172	13.3	24	24	4.0
0	4	0	4	3	1.2	2.66	0.20	0.42	0.29	0.20	7508	1137	147	14.0	26	29	3.7
0	4	4	0	3	0.9	2.84	0.21	0.47	0.21	0.65	7667	1069	255	13.3	28	19	4.0
0	4	4	4	3	0.9	2.46	0.19	0.43	0.20	0.64	7167	1058	227	10.0	26	19	4.0
4	0	0	0	3	0.9	2.26	0.15	0.65	0.47	0.22	1483	1327	177	10.0	25	37	2.7
4	0	0	4	3	0.8	2.23	0.15	0.81	0.42	0.23	1417	1484	177	10.0	24	47	3.0
4	0	4	0	3	0.8	2.16	0.15	0.62	0.27	1.08	567	1322	183	8.3	23	34	3.3
4	0	4	4	3	0.8	2.28	0.17	0.82	0.26	1.14	537	1562	165	14.0	32	50	3.7
4	4	0	0	3	0.8	2.13	0.25	0.71	0.23	0.20	8867	1757	212	8.3	20	34	3.7
4	4	0	4	3	0.9	2.43	0.26	0.57	0.24	0.22	8933	1932	215	11.7	24	27	3.0
4	4	4	0	3	0.9	3.05	0.24	0.59	0.19	0.92	6967	1378	272	10.0	23	22	4.3
4	4	4	4	3	0.9	2.64	0.23	0.59	0.19	0.94	6633	1339	223	10.0	21	27	4.7
1	1	1	1	1	0.9	2.21	0.14	0.54	0.38	0.36	5600	1042	140	10.0	20	39	4.0
1	1	1	3	1	1.0	2.30	0.14	0.48	0.30	0.28	6250	1422	200	10.0	22	24	4.0
1	1	3	1	1	1.0	2.44	0.16	0.45	0.24	0.84	4250	1688	215	15.0	25	21	4.0
1	1	3	3	1	1.0	2.38	0.16	0.44	0.24	0.78	4000	1488	200	15.0	26	22	4.0
1	3	1	1	1	1.1	2.38	0.19	0.50	0.26	0.27	7550	1598	205	10.0	27	24	4.0
1	3	1	3	1	1.0	2.32	0.20	0.42	0.28	0.25	8300	1732	175	10.0	20	24	4.0
1	3	3	1	1	1.3	2.18	0.16	0.45	0.22	0.50	5950	1650	190	10.0	20	24	4.0
1	3	3	3	1	1.0	2.34	0.18	0.45	0.22	0.63	6800	1452	235	10.0	26	19	4.0
3	1	1	1	1	0.9	2.44	0.18	0.46	0.34	0.30	6000	1358	180	13.0	28	26	4.0
3	1	1	3	1	0.7	2.40	0.19	0.55	0.28	0.31	6850	1498	205	10.0	30	27	3.0
3	1	3	1	1	0.9	2.57	0.17	0.54	0.21	0.58	2900	1446	155	10.0	23	35	4.0
3	1	3	3	1	0.8	2.48	0.18	0.59	0.21	0.62	3300	1485	165	5.0	26	36	4.0
3	3	1	1	1	0.9	2.40	0.22	0.63	0.23	0.26	7000	1527	200	10.0	33	32	3.0
3	3	1	3	1	1.0	2.63	0.19	0.64	0.24	0.26	6500	1274	135	5.0	22	47	4.0
3	3	3	1	1	1.0	2.40	0.19	0.60	0.24	0.58	5350	1144	185	10.0	22	32	5.0
3	3	3	3	1	0.8	2.51	0.19	0.66	0.20	0.63	5750	1148	145	10.0	32	46	5.0
0	2	2	2	1	1.1	2.23	0.16	0.40	0.24	0.32	5850	1337	215	15.0	22	19	4.0
4	2	2	2	1	0.9	2.69	0.18	0.67	0.23	0.30	5300	1359	175	15.0	22	38	4.0
2	0	2	2	1	0.9	2.46	0.16	0.54	0.39	0.52	1450	1352	150	15.0	26	36	3.0
2	4	2	2	1	1.2	2.64	0.20	0.55	0.24	0.24	7200	1712	180	15.0	25	31	5.0
2	2	0	2	1	0.9	2.32	0.20	0.59	0.26	0.18	5700	1450	190	10.0	25	31	3.0
2	2	4	2	1	1.0	2.65	0.18	0.49	0.18	0.68	3250	1358	140	5.0	30	35	5.0
2	2	2	0	1	0.8	2.42	0.20	0.48	0.24	0.46	5650	1504	165	5.0	25	29	4.0
2	2	2	4	1	1.0	2.38	0.17	0.56	0.24	0.34	4900	1348	135	10.0	24	41	4.0
2	2	2	2	6	1.0	2.42	0.17	0.57	0.24	0.34	5258	1490	178	11.7	24	33	4.2

+ Visual evaluation of nodulation, 1 = none, 5 = excellent.

Appendix Table 15. Treatment combinations, and root-nodule yields and nutrient concentrations of _S. guianensis_ grown in a Florida Spodosol.

L	P	K	B	Reps	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	Ca/Mn	Nod+
Coded levels				#	g/pot	----------	%	---------------			----------		ppm	----------			
0	0	0	0	2	0.6	2.18	0.11	0.14	0.60	0.26	1750	405	85	15.0	180	17	1.5
0	0	0	4	2	0.6	2.24	0.12	0.14	0.56	0.26	1600	411	89	13.5	202	16	1.5
0	0	4	0	2	0.8	1.74	0.10	0.14	0.12	2.07	175	324	33	20.0	87	44	1.5
0	0	4	4	2	0.7	1.64	0.10	0.14	0.12	2.00	226	270	38	17.0	96	37	1.5
0	4	0	0	2	0.6	2.12	0.26	0.18	0.18	0.16	12356	590	53	19.5	100	33	1.5
0	4	0	4	2	0.6	1.86	0.26	0.20	0.16	0.18	11900	664	42	15.0	80	48	2.0
0	4	4	0	2	0.9	1.63	0.27	0.15	0.13	1.68	1825	401	36	17.5	69	41	2.0
0	4	4	4	2	0.8	1.74	0.26	0.16	0.13	1.54	1800	411	30	17.5	60	51	1.5
4	0	0	0	2	0.5	1.66	0.11	0.71	0.70	0.20	1600	386	22	5.0	33	323	2.0
4	0	0	4	2	0.5	1.64	0.11	0.77	0.60	0.22	1950	354	26	5.0	31	296	2.0
4	0	4	0	2	0.7	1.51	0.12	0.46	0.15	2.52	325	323	15	7.5	33	312	2.0
4	0	4	4	2	0.7	1.60	0.10	0.53	0.12	2.47	506	350	14	8.0	27	395	2.0
4	4	0	0	2	0.5	1.86	0.22	0.70	0.14	0.12	18050	506	20	5.0	30	350	2.5
4	4	0	4	2	0.5	1.94	0.22	0.72	0.16	0.14	17900	1048	20	10.0	32	360	2.5
4	4	4	0	2	1.7	1.97	0.19	0.58	0.22	0.60	10000	361	18	10.0	28	329	5.0
4	4	4	4	2	1.2	2.00	0.22	0.58	0.28	1.24	10125	375	18	7.5	34	331	4.5
1	1	1	1	1	1.4	1.90	0.16	0.34	0.38	0.48	4450	339	100	15.0	115	34	3.0
1	1	1	3	1	1.4	1.82	0.16	0.36	0.40	0.57	4750	479	60	15.0	82	60	3.0
1	1	3	1	1	1.4	1.80	0.16	0.30	0.40	1.08	3000	287	110	10.0	110	27	4.0
1	1	3	3	1	1.5	1.78	0.16	0.32	0.41	1.30	3300	308	65	15.0	82	49	4.0
1	3	1	1	1	1.6	1.77	0.20	0.28	0.28	0.30	9550	795	70	15.0	98	40	5.0
1	3	1	3	1	1.5	1.88	0.21	0.33	0.50	0.33	8750	520	60	15.0	81	55	4.0
1	3	3	1	1	1.7	1.78	0.20	0.33	0.50	0.76	6650	560	32	10.0	98	103	5.0
1	3	3	3	1	1.6	2.02	0.21	0.32	0.29	0.91	6600	357	50	15.0	72	64	4.0
3	1	1	1	1	1.4	1.86	0.15	0.63	0.40	0.26	5000	402	65	15.0	46	97	4.0
3	1	1	3	1	1.2	1.72	0.14	0.66	0.37	0.30	4100	336	40	15.0	50	165	4.0
3	1	3	1	1	1.5	2.23	0.14	0.54	0.35	0.78	3500	298	29	5.0	47	186	4.0
3	1	3	3	1	1.3	1.78	0.13	0.57	0.38	0.88	3950	274	30	15.0	47	190	4.0
3	3	1	1	1	1.4	1.78	0.21	0.66	0.28	0.22	11000	498	38	10.0	48	174	3.0
3	3	1	3	1	1.6	1.94	0.19	0.64	0.23	0.27	8950	428	30	5.0	41	213	4.0
3	3	3	1	1	1.9	1.95	0.19	0.60	0.22	0.40	5900	388	25	10.0	50	240	5.0
3	3	3	3	1	2.2	2.07	0.17	0.62	0.22	0.38	5600	402	26	10.0	49	238	5.0
0	2	2	2	1	0.6	1.46	0.25	0.16	0.19	1.68	1600	474	32	20.0	110	50	1.0
4	2	2	2	1	1.2	1.87	0.18	0.54	0.38	0.67	8850	353	18	10.0	40	300	4.0
2	0	2	2	1	1.0	1.57	0.10	0.49	0.45	1.17	1350	380	36	15.0	38	136	3.0
2	4	2	2	1	2.2	2.01	0.18	0.44	0.16	0.28	8000	774	34	10.0	46	129	5.0
2	2	0	2	1	0.7	1.86	0.18	0.52	0.17	0.19	-	455	39	14.0	116	133	2.0
2	2	4	2	1	2.0	1.87	0.15	0.44	0.24	0.76	3300	416	37	10.0	48	119	5.0
2	2	2	0	1	2.4	1.95	0.15	0.54	0.20	0.28	4900	702	70	15.0	76	77	5.0
2	2	2	4	1	1.8	2.01	0.16	0.52	0.27	0.46	6650	348	44	10.0	49	118	4.0
2	2	2	2	6	1.9	2.03	0.16	0.49	0.26	0.41	4633	366	62	11.7	74	86	4.2

+ Visual evaluation of nodulation, 1 = none, 5 = excellent.

Appendix Table 16. Treatment combinations, and root-nodule yields and nutrient concentrations of S. *hamata* grown in a Florida Spodosol.

L	P	K	B	Reps	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	Ca/Mn	Nod+
Coded levels				#	g/pot	---------- %				-------------	---------- ppm			------------			
0	0	0	0	2	0.4	2.13	0.14	0.15	0.28	0.22	3750	756	110	20.0	110	14	1.0
0	0	0	4	2	0.4	2.18	0.13	0.15	0.26	0.22	3900	658	100	20.0	98	15	1.0
0	0	4	0	2	0.7	1.84	0.10	0.14	0.09	1.41	525	987	58	17.5	80	24	1.0
0	0	4	4	2	0.7	1.73	0.11	0.14	0.08	1.50	625	903	69	27.5	59	22	1.0
0	4	0	0	2	0.4	2.58	0.51	0.18	0.17	0.19	11438	769	42	12.0	70	43	1.0
0	4	0	4	2	0.3	1.94	0.43	0.16	0.18	0.20	10800	470	59	10.0	56	27	1.0
0	4	4	0	2	0.6	1.54	0.54	0.15	0.10	1.92	2600	510	55	15.0	50	27	1.0
0	4	4	4	2	0.7	1.71	0.52	0.16	0.10	1.92	1850	738	46	13.5	56	36	1.0
4	0	0	0	2	0.4	2.16	0.12	0.66	0.36	0.18	2950	1179	31	15.0	40	213	2.0
4	0	0	4	2	0.5	2.97	0.12	0.51	0.30	0.16	2250	1446	28	15.0	36	182	2.0
4	0	4	0	2	0.5	2.22	0.10	0.53	0.09	1.34	375	1601	13	12.0	28	408	2.0
4	0	4	4	2	0.6	2.00	0.08	0.42	0.08	1.08	400	793	12	10.0	24	350	2.5
4	4	0	0	2	0.6	2.97	0.30	0.64	0.16	0.14	9600	1070	16	15.0	32	400	2.5
4	4	0	4	2	0.8	2.24	0.34	0.62	0.19	0.16	9575	1262	20	12.5	33	300	3.0
4	4	4	0	2	0.7	2.70	0.26	0.46	0.12	1.58	3550	575	22	7.5	30	218	4.5
4	4	4	4	2	0.8	2.66	0.25	0.46	0.12	1.33	3550	815	17	15.0	34	273	5.0
1	1	1	1	1	1.2	1.97	0.21	0.30	0.27	0.34	6200	1462	55	10.0	57	55	4.0
1	1	1	3	1	0.9	2.14	0.22	0.28	0.22	0.36	6500	415	65	10.0	49	43	3.0
1	1	3	1	1	1.2	2.20	0.18	0.28	0.22	1.04	3700	508	60	5.0	40	47	4.0
1	1	3	3	1	0.8	2.23	0.19	0.28	0.14	1.09	2800	453	46	10.0	36	61	3.0
1	3	1	1	1	1.5	2.38	0.31	0.30	0.16	0.21	7200	1381	44	5.0	42	68	5.0
1	3	1	3	1	1.0	2.70	0.38	0.28	0.18	0.24	8400	500	46	10.0	43	61	4.0
1	3	3	1	1	1.3	2.15	0.34	0.28	0.15	0.88	7500	578	48	10.0	40	58	5.0
1	3	3	3	1	1.2	2.39	0.30	0.28	0.14	0.56	5950	768	46	5.0	36	61	4.0
3	1	1	1	1	1.9	2.06	0.14	0.41	0.22	0.16	3050	785	31	10.0	36	132	4.0
3	1	1	3	1	1.2	2.53	0.16	0.42	0.22	0.20	4550	882	27	10.0	36	156	3.0
3	1	3	1	1	1.1	2.16	0.14	0.40	0.22	0.64	3250	856	60	5.0	32	67	4.0
3	1	3	3	1	0.6	2.28	0.19	0.44	0.17	1.04	2400	734	34	10.0	32	129	3.0
3	3	1	1	1	1.0	3.36	0.31	0.52	0.21	0.20	12400	690	34	10.0	46	153	5.0
3	3	1	3	1	1.2	2.68	0.25	0.55	0.18	0.18	9800	980	35	5.0	33	157	4.0
3	3	3	1	1	1.0	2.24	0.21	0.52	0.14	0.76	12150	872	25	10.0	31	208	4.0
3	3	3	3	1	1.1	2.36	0.22	0.41	0.22	0.53	8850	673	33	10.0	42	124	4.0
0	2	2	2	1	0.6	1.48	0.34	0.18	0.12	1.46	1550	458	40	25.0	57	45	1.0
4	2	2	2	1	0.9	2.90	0.23	0.44	0.20	0.34	6500	640	24	15.0	34	183	3.0
2	0	2	2	1	1.0	1.99	0.09	0.40	0.24	0.58	1050	544	48	5.0	44	83	2.0
2	4	2	2	1	1.4	3.65	0.32	0.36	0.18	0.26	7200	818	44	20.0	40	82	5.0
2	2	0	2	1	1.1	4.64	0.24	0.46	0.17	0.11	6950	606	30	10.0	35	153	3.0
2	2	4	2	1	1.4	2.61	0.18	0.37	0.16	0.55	7250	668	42	5.0	32	88	5.0
2	2	2	0	1	1.2	2.58	0.20	0.36	0.14	0.28	4800	467	24	5.0	30	150	5.0
2	2	2	4	1	1.2	2.47	0.21	0.38	0.18	0.32	6850	530	44	5.0	36	86	5.0
2	2	2	2	6	1.3	2.69	0.21	0.39	0.18	0.30	6017	576	40	7.5	43	103	4.5

+ Visual evaluation of nodulation, 1 = none, 5 = excellent.

Appendix Table 17. Treatment combinations, and root-nodule yields and nutrient concentrations of *S. guianensis* grown in a Florida Entisol.

L	P	K	B	Reps	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	Ca/Mn	Nod+
Coded levels				#	g/pot	%					ppm						
0	0	0	0	2	1.2	1.96	0.10	0.23	0.55	0.18	400	442	200	7.5	165	12	2.0
0	0	0	4	2	1.2	1.93	0.10	0.25	0.58	0.25	375	448	158	10.0	98	16	2.0
0	0	4	0	2	1.5	1.49	0.07	0.22	0.37	1.84	175	135	290	12.5	88	8	2.0
0	0	4	4	2	1.2	1.52	0.08	0.23	0.28	2.32	250	176	140	10.0	58	16	2.0
0	4	0	0	2	1.6	2.52	0.18	0.20	0.19	0.14	11625	438	112	10.0	73	18	3.0
0	4	0	4	2	1.3	2.11	0.16	0.22	0.20	0.15	11825	316	90	10.0	57	25	2.5
0	4	4	0	2	2.2	1.96	0.13	0.18	0.18	0.54	5075	312	218	17.5	60	8	4.5
0	4	4	4	2	2.2	1.96	0.13	0.18	0.18	0.46	4825	333	220	15.0	51	8	4.0
4	0	0	0	2	0.8	2.09	0.16	0.72	0.41	0.22	625	576	55	12.5	40	134	2.0
4	0	0	4	2	0.8	2.06	0.14	0.73	0.48	0.29	650	488	48	10.0	34	154	2.0
4	0	4	0	2	1.9	1.62	0.10	0.55	0.36	1.31	325	357	45	10.0	17	122	3.5
4	0	4	4	2	1.7	1.60	0.10	0.54	0.30	1.26	300	251	50	17.5	22	109	3.5
4	4	0	0	2	1.1	1.99	0.20	0.62	0.21	0.14	13575	504	49	22.5	34	130	3.0
4	4	0	4	2	0.9	2.06	0.20	0.55	0.22	0.18	12225	395	46	20.0	32	124	3.0
4	4	4	0	2	2.1	1.82	0.16	0.56	0.26	0.77	5975	439	63	17.5	23	94	4.5
4	4	4	4	2	1.9	1.88	0.16	0.50	0.22	0.75	5175	348	62	17.5	20	81	4.0
1	1	1	1	1	1.9	1.74	0.10	0.38	0.40	0.34	2500	562	110	15.0	80	34	3.0
1	1	1	3	1	1.7	1.64	0.09	0.38	0.44	0.40	2650	375	85	15.0	58	45	3.0
1	1	3	1	1	2.0	1.56	0.08	0.38	0.44	0.80	1550	388	165	15.0	55	23	3.0
1	1	3	3	1	1.6	1.61	0.08	0.37	0.44	1.06	1900	295	105	15.0	42	35	3.0
1	3	1	1	1	2.3	2.02	0.12	0.36	0.22	0.20	5050	550	105	15.0	42	34	4.0
1	3	1	3	1	2.3	1.99	0.12	0.32	0.22	0.21	5300	518	115	15.0	38	28	4.0
1	3	3	1	1	2.2	1.96	0.10	0.26	0.22	0.36	4350	396	135	15.0	32	19	5.0
1	3	3	3	1	2.3	1.81	0.11	0.30	0.28	0.42	4250	470	120	15.0	34	25	4.0
3	1	1	1	1	2.2	1.94	0.12	0.64	0.32	0.34	2450	510	90	15.0	29	71	4.0
3	1	1	3	1	2.0	1.80	0.12	0.62	0.36	0.36	2750	570	75	15.0	34	83	4.0
3	1	3	1	1	2.1	1.60	0.10	0.59	0.34	0.84	1950	392	60	15.0	19	98	4.0
3	1	3	3	1	2.0	1.67	0.10	0.54	0.36	1.03	2000	346	55	15.0	22	98	4.0
3	3	1	1	1	2.4	1.93	0.15	0.64	0.22	0.23	6000	636	85	15.0	30	75	4.0
3	3	1	3	1	1.9	1.99	0.15	0.58	0.19	0.24	5650	594	85	15.0	26	68	4.0
3	3	3	1	1	2.2	1.86	0.13	0.50	0.21	0.43	4300	392	80	10.0	24	62	5.0
3	3	3	3	1	2.5	1.90	0.14	0.52	0.23	0.51	5700	548	100	15.0	32	52	4.0
0	2	2	2	1	1.9	1.92	0.12	0.18	0.32	0.40	3700	354	210	15.0	102	9	4.0
4	2	2	2	1	1.8	1.92	0.17	0.64	0.26	0.56	5000	416	60	10.0	22	107	4.0
2	0	2	2	1	1.7	1.59	0.08	0.50	0.50	0.92	450	366	60	10.0	30	83	2.0
2	4	2	2	1	2.7	2.03	0.14	0.44	0.18	0.26	6550	612	130	10.0	38	34	4.0
2	2	0	2	1	1.1	2.06	0.17	0.50	0.35	0.19	4000	474	55	15.0	42	91	3.0
2	2	4	2	1	2.2	1.76	0.11	0.42	0.30	0.91	3100	506	135	10.0	36	31	5.0
2	2	2	0	1	2.1	1.83	0.11	0.43	0.26	0.37	3750	444	110	10.0	34	39	5.0
2	2	2	4	1	2.0	1.92	0.11	0.44	0.29	0.36	3500	426	90	15.0	40	49	4.0
2	2	2	2	6	2.1	1.90	0.11	0.47	0.25	0.37	3833	428	96	9.2	32	50	4.5

+ Visual evaluation of nodulation, 1 = none, 5 = excellent.

Appendix Table 18. Treatment combinations, and root-nodule yields and nutrient concentrations of *S. hamata* grown in a Florida Entisol.

L	P	K	B	Reps	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	Ca/Mn	Nod+
Coded levels				#	g/pot	---------- %				--------------	--------- ppm				------------		
0	0	0	0	2	0.7	1.96	0.10	0.24	0.34	0.26	1000	590	75	12.5	38	33	2.0
0	0	0	4	2	0.7	2.20	0.11	0.24	0.37	0.26	1106	751	96	11.0	40	30	2.0
0	0	4	0	2	0.7	2.07	0.10	0.21	0.14	1.46	675	420	175	12.5	31	13	3.0
0	0	4	4	2	0.7	1.82	0.10	0.24	0.14	1.46	800	469	165	10.0	38	15	3.0
0	4	0	0	2	0.8	2.42	0.20	0.25	0.23	0.20	6900	574	88	15.0	32	29	4.0
0	4	0	4	2	0.8	2.53	0.19	0.24	0.20	0.20	5900	660	82	12.5	30	29	4.0
0	4	4	0	2	1.1	2.44	0.15	0.19	0.12	1.14	5025	496	140	10.0	27	14	5.0
0	4	4	4	2	1.0	2.36	0.14	0.20	0.12	1.04	5300	678	160	12.5	33	12	4.5
4	0	0	0	2	0.8	2.53	0.16	0.52	0.26	0.24	825	690	40	17.5	28	133	2.0
4	0	0	4	2	0.6	2.32	0.16	0.50	0.27	0.22	775	675	48	11.0	24	103	3.0
4	0	4	0	2	0.8	2.25	0.16	0.41	0.14	1.64	450	451	58	7.5	18	73	3.5
4	0	4	4	2	0.8	2.25	0.14	0.44	0.12	1.39	375	509	52	10.0	22	88	4.0
4	4	0	0	2	0.7	2.87	0.36	0.48	0.22	0.23	8275	470	41	12.5	25	118	4.0
4	4	0	4	2	0.7	2.56	0.28	0.50	0.18	0.20	7419	545	40	11.0	20	124	4.0
4	4	4	0	2	0.9	2.63	0.24	0.40	0.12	1.20	3325	356	39	10.0	20	103	4.5
4	4	4	4	2	0.8	2.54	0.24	0.41	0.13	1.05	3425	452	39	10.0	20	110	4.5
1	1	1	1	1	0.7	1.77	0.10	0.33	0.34	0.50	4450	506	70	10.0	38	47	3.0
1	1	1	3	1	0.8	2.03	0.10	0.38	0.28	0.50	3750	558	55	10.0	26	69	3.0
1	1	3	1	1	0.8	1.86	0.10	0.32	0.13	1.26	1200	492	70	10.0	26	46	4.0
1	1	3	3	1	0.9	1.75	0.10	0.30	0.16	1.17	1300	480	55	10.0	28	54	4.0
1	3	1	1	1	1.0	2.20	0.15	0.39	0.16	0.23	4400	728	40	10.0	26	98	4.0
1	3	1	3	1	1.0	2.12	0.13	0.30	0.19	0.26	6700	584	55	11.0	22	55	4.0
1	3	3	1	1	0.9	2.10	0.13	0.33	0.14	0.98	3900	516	85	10.0	24	39	4.0
1	3	3	3	1	0.8	2.09	0.13	0.32	0.12	0.96	4100	466	60	5.0	24	53	4.0
3	1	1	1	1	1.0	2.14	0.15	0.46	0.27	0.30	4000	598	60	10.0	24	77	4.0
3	1	1	3	1	0.8	2.07	0.13	0.41	0.28	0.38	4100	410	55	5.0	23	75	4.0
3	1	3	1	1	0.8	2.01	0.11	0.38	0.14	1.09	1500	342	48	5.0	18	79	4.0
3	1	3	3	1	0.9	2.12	0.12	0.45	0.12	0.88	950	674	34	10.0	31	132	4.0
3	3	1	1	1	0.9	2.18	0.18	0.44	0.14	0.20	6450	575	38	5.0	15	116	4.0
3	3	1	3	1	0.8	2.21	0.18	0.38	0.17	0.26	7400	472	46	5.0	18	83	4.0
3	3	3	1	1	0.8	2.17	0.18	0.38	0.14	1.00	4300	404	45	10.0	20	84	4.0
3	3	3	3	1	0.9	2.14	0.14	0.38	0.12	0.59	3650	492	32	5.0	17	119	5.0
0	2	2	2	1	1.0	1.97	0.10	0.23	0.16	0.54	3350	588	70	5.0	28	33	4.0
4	2	2	2	1	1.0	2.26	0.17	0.47	0.15	0.44	4200	670	42	5.0	26	112	5.0
2	0	2	2	1	0.8	1.85	0.09	0.40	0.17	0.71	650	476	32	5.0	23	125	3.0
2	4	2	2	1	1.1	2.37	0.19	0.39	0.14	0.33	6550	562	50	5.0	29	78	5.0
2	2	0	2	1	0.8	2.18	0.16	0.43	0.26	0.18	5750	480	42	15.0	32	102	3.0
2	2	4	2	1	1.0	2.19	0.11	0.40	0.12	0.79	1950	422	36	10.0	24	111	5.0
2	2	2	0	1	1.0	2.25	0.16	0.36	0.23	0.64	5300	544	50	10.0	32	72	4.0
2	2	2	4	1	1.0	2.07	0.11	0.38	0.19	0.58	4500	409	46	10.0	26	83	4.0
2	2	2	2	6	1.0	2.09	0.13	0.41	0.17	0.48	3450	595	43	8.3	26	99	3.8

+ Visual evaluation of nodulation, 1 = none, 5 = excellent.

Appendix Table 19. Levels of significance for sources of variation affecting response variables from an Ultisol following the removal of a crop of two *Stylosanthes* species.

Source of variation	Response variables										
	pH(H_2O)	pH(KCl)	P	Ca	Mg	K	Fe	Mn	Cu	Zn	Ca/Mn
Stylosanthes hamata											
L	**p	**p	**p	**p	**p	NS	**p	**p	NS	**p	**p
LxL	NS	**n	NS	NS	**n	**n	**n	**n	**p	NS	NS
P	**p	NS	**p	*p	NS	NS	NS	*p	NS	**p	NS
PxP	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
K	NS	**n	*n	NS	*n	**n	NS	NS	NS	NS	**p
KxK	NS	*p	NS	NS	NS	*p	NS	NS	NS	NS	NS
B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxP	*n	NS	**p	NS	NS	NS	NS	NS	NS	NS	NS
LxK	NS	*p	NS	NS	NS	NS	NS	NS	NS	NS	*p
LxB	NS	NS	*p	NS	NS	NS	NS	NS	NS	NS	NS
PxK	NS	NS	*p	NS	NS	NS	*p	*p	NS	NS	**n
PxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*n
LxPxK	*n	*n	NS	NS	NS	NS	NS	NS	NS	NS	**n
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxKxB	NS	NS	NS	NS	NS	NS	**p	NS	NS	NS	NS
PxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxKxB	NS	NS	NS	NS	NS	NS	*p	NS	NS	NS	NS
Stylosanthes guianensis											
L	**p	**p	**p	**p	**p	**p	**n	**n	NS	**p	**p
LxL	**n	NS	NS	NS	**n	NS	NS	*p	NS	NS	NS
P	**p	**n	**p	**p	NS	NS	**p	**p	NS	*p	**n
PxP	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
K	NS	NS	NS	NS	**p	**p	**n	*n	NS	NS	NS
KxK	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B	NS	*p	NS	*n	*n	NS	NS	NS	*n	NS	*p
BxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxP	**n	**n	**p	**p	*p	NS	NS	NS	NS	NS	NS
LxK	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxB	NS	NS	NS	NS	NS	NS	*p	NS	NS	NS	NS
PxK	**n	NS	NS	NS	NS	NS	**p	**p	**p	NS	**n
PxB	NS	NS	*n	**n	*p	NS	NS	*p	NS	NS	NS
KxB	NS	*n	NS	*p	NS	*p	NS	NS	*p	NS	*n
LxPxK	NS	NS	NS	NS	NS	NS	NS	NS	*n	*n	*n
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxKxB	NS	NS	NS	*n	NS	NS	NS	NS	NS	NS	NS
PxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxKxB	NS	NS	NS	**p	NS	NS	NS	**p	NS	NS	NS

** - ($P < 0.01$). *- ($P < 0.05$). NS - Not significant at the 5% level of probability. Response to the source of variation is positive (p) or negative (n).

Appendix Table 20. Levels of significance for sources of variation affecting response variables from a Spodosol following the removal of a crop of two *Stylosanthes* species.

Source of	Response variables										
variation	pH(H_2O)	pH(KCl)	P	Ca	Mg	K	Fe	Mn	Cu	Zn	Ca/Mn
	Stylosanthes hamata										
L	**p	**p	**p	**p	**p	NS	**p	NS	**p	NS	**p
LxL	**p	**p	**n	**p	**n	**p	**n	*n	*n	*n	**p
P	NS	**n	**p	NS	NS	*n	**n	NS	NS	NS	NS
PxP	*p	*p	NS	NS	NS	NS	NS	NS	NS	NS	NS
K	**n	NS	NS	NS	NS	**p	NS	NS	NS	NS	NS
KxK	NS	NS	NS	NS	**p	NS	NS	NS	NS	NS	NS
B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxP	NS	NS	**p	NS	NS	NS	**p	NS	NS	NS	NS
LxK	*p	NS	NS	NS	NS	NS	NS	NS	*p	NS	NS
LxB	NS	NS	NS	NS	*n	NS	NS	NS	NS	NS	NS
PxK	NS	NS	NS	NS	**n	*n	NS	NS	NS	NS	*n
PxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxK	NS	NS	NS	NS	NS	NS	NS	NS	*n	NS	*p
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Stylosanthes guianensis										
L	**p	**p	**n	**p	**n	**n	**p	NS	**p	NS	**p
LxL	**p	**p	**p	**p	**p	**p	**n	NS	NS	NS	**p
P	**p	**n	**n	NS	NS	*n	NS	NS	NS	NS	*p
PxP	NS	NS	*p	NS	NS	NS	NS	NS	NS	*p	NS
K	**n	**n	NS	NS	NS	**p	NS	NS	NS	NS	NS
KxK	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B	NS	NS	*p	NS	NS	NS	NS	NS	NS	NS	NS
BxB	NS	**n	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxP	*n	NS	**p	NS	*p	NS	NS	*p	NS	*p	*n
LxK	NS	*n	NS	NS	NS	**n	NS	NS	NS	NS	NS
LxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxK	**n	**n	NS	NS	*n	*n	NS	NS	NS	NS	*p
PxB	NS	NS	*p	NS	NS	NS	NS	NS	NS	NS	NS
KxB	NS	NS	*n	NS	NS	NS	NS	NS	NS	NS	NS
LxPxK	NS	**n	NS	NS	NS	NS	NS	NS	NS	NS	*p
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	*n	*n	NS
LxKxB	NS	NS	**p	NS	*n	NS	NS	NS	NS	NS	NS
PxKxB	NS	NS	**p	*p	NS	NS	NS	*p	NS	NS	NS
LxPxKxB	NS	NS	**p	*p	*p	NS	NS	NS	NS	NS	NS

** - ($P<0.01$). * - ($P<0.05$). NS - Not significant at 5% level of probability.
Response to source of variation is positive (p) or negative (n).

Appendix Table 21. Levels of significance for sources of variation affecting response variables from an Entisol following the removal of a crop of two *Stylosanthes* species.

Source of	Response variables										
variation	pH(H_2O)	pH(KCl)	P	Ca	Mg	K	Fe	Mn	Cu	Zn	Ca/Mn
					Stylosanthes hamata						
L	**p	**p	**p	**p	**p	**n	**n	**n	*p	NS	**p
LxL	NS	**p	**p	**p	NS	**p	*n	*p	NS	NS	**n
P	**p	**p	**p	NS	**p	NS	NS	**p	NS	NS	**p
PxP	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
K	NS	*n	NS	**n	NS	**p	NS	NS	NS	NS	**n
KxK	NS	NS	NS	*p	NS	*p	NS	NS	NS	NS	*p
B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BxB	NS	NS	NS	*p	NS	NS	NS	NS	NS	NS	NS
LxP	**p	**n	**p	NS	NS	NS	NS	NS	NS	NS	**n
LxK	NS	NS	NS	**p	**p	**p	NS	NS	NS	NS	*p
LxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxK	*n	*n	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KxB	NS	NS	NS	*p	NS	NS	NS	NS	NS	NS	NS
LxPxK	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxB	**n	NS	NS	*n	NS	NS	NS	NS	NS	NS	NS
LxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
					Stylosanthes guianensis						
L	**p	**p	**p	**p	**p	NS	NS	**p	NS	NS	**p
LxL	**p	**p	**p	**p	NS	NS	NS	**n	**n	NS	**p
P	**p	*n	**p	NS	NS	**n	NS	*p	NS	**p	NS
PxP	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
K	**n	**n	NS	NS	NS	**p	NS	**p	NS	NS	*n
KxK	*p	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B	NS	NS	NS	NS	*p	NS	NS	NS	NS	NS	NS
BxB	NS	NS	NS	NS	NS	NS	**n	NS	NS	NS	NS
LxP	NS	NS	**p	NS	NS	NS	NS	NS	NS	NS	NS
LxK	NS	**n	NS	NS	*p	NS	NS	NS	NS	NS	*n
LxB	NS	NS	*p	NS	NS	NS	NS	NS	NS	NS	NS
PxK	**n	NS	NS	NS	NS	**n	NS	NS	NS	NS	NS
PxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	**p	NS
LxPxK	NS	NS	NS	NS	NS	*p	NS	NS	NS	NS	NS
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxKxB	NS	NS	NS	NS	NS	NS	NS	NS	*p	**p	*n
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*n

** - ($P < 0.01$). * - ($P < 0.05$). NS - Not significant at 5% level of probability. Response to source of variation is positive (p) or negative (n).

Appendix Table 22. Levels of significance for sources of variation affecting response variables measured in herbage of two *Stylosanthes* species grown in a Florida Ultisol.

Source of variation	Response variables												
	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	B	Ca/Mn
	------- *Stylosanthes hamata* -------												
L	**p	*p	**p	**p	**n	*n	NS	NS	**n	**n	**n	**n	**p
LxL	**n	**n	NS	NS	**p	*p	**n	**n	**p	NS	NS	NS	**p
P	**n	**p	**p	**n	NS	**n	**p	NS	**p	NS	NS	**n	**n
PxP	NS	NS	NS	NS	*p	NS	NS	NS	NS	NS	NS	NS	NS
K	*n	*n	*n	**p	**n	**p	**n	*p	**p	NS	**n	**p	**n
KxK	NS	NS	NS	NS	NS	*n	**p	NS	NS	NS	NS	NS	NS
B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**p	NS
BxB	NS	*n	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxP	NS	*n	*p	NS	NS	NS	NS	NS	*n	NS	*p	*p	NS
LxK	*p	NS	**n	**n	NS	NS	*n	NS	**n	*n	NS	NS	**n
LxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**n	NS
PxK	NS	NS	NS	**p	**p	NS	**p	NS	NS	NS	NS	**p	**p
PxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	*n	*n	**n	NS
KxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*p	**n	NS
LxPxK	NS	NS	*n	NS	*n	NS	*n	NS	NS	NS	NS	*n	NS
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**p	NS
LxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	*p	NS	*p	NS
PxKxB	NS	*p	NS	NS	NS	NS	NS	NS	NS	NS	NS	**p	NS
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	------- *Stylosanthes guianensis* -------												
L	**p	**p	**n	**p	**n	NS	*p	NS	**n	**n	**n	**n	**p
LxL	**n	**n	**p	**n	**n	**p	NS	NS	**p	**p	**p	**n	**p
P	**p	**p	**p	**n	**p	**n	**p	NS	**p	NS	NS	*n	**n
PxP	**n	*p	*p	**n	NS	*p	NS	*p	NS	*p	NS	NS	**p
K	**p	**n	**n	**n	**n	**p	NS	NS	**n	**n	**n	**n	NS
KxK	NS	*p	**p	**p	**p	NS	NS	NS	**p	**p	*p	NS	NS
B	**n	NS	NS	NS	NS	*p	NS	NS	**n	NS	NS	**p	*n
BxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxP	NS	NS	**p	**p	*p	*p	NS	*p	*p	*p	NS	**p	**n
LxK	**n	NS	NS	NS	**p	NS	NS	*p	**p	**p	NS	*n	NS
LxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*p	**n	NS
PxK	NS	*p	**n	**p	NS	*n	**n	NS	NS	NS	NS	*p	NS
PxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KxB	NS	NS	NS	NS	NS	NS	NS	NS	*p	NS	NS	**n	*n
LxPxK	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*p	NS
PxKxB	NS	NS	NS	NS	NS	NS	NS	NS	*n	NS	NS	NS	*p
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

** - ($P < 0.01$). * - ($P < 0.05$). NS - Not significant at 5% level of probability. Response to source of variation is positive (p) or negative (n).

Appendix Table 23. Levels of significance for sources of variation affecting response variables measured in herbage of two *Stylosanthes* species grown in a Florida Spodosol.

Source of	Response variables												
variation	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	B	Ca/Mn
	Stylosanthes hamata												
L	**p	**p	**n	**p	**n	**n	NS	**p	**n	**n	**n	**n	**p
LxL	**n	NS	**p	**n	**p	**p	**n	NS	**p	**p	**p	**p	**p
P	**p	NS	**p	**p	**n	*n	**p	NS	**n	**n	**n	**p	NS
PxP	NS	NS	NS	NS	NS	NS	**p	NS	NS	NS	NS	NS	NS
K	**p	**n	**n	**n	**n	**p	**n	NS	NS	NS	NS	**n	NS
KxK	NS	NS	NS	NS	NS	*n	**p	NS	NS	NS	NS	**p	NS
B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**p	NS
BxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxP	**p	*p	**n	NS	NS	NS	NS	NS	**p	**p	**p	NS	NS
LxK	NS	**p	NS	NS	**p	NS	NS	NS	NS	NS	NS	NS	NS
LxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*p	**n	NS
PxK	NS	NS	*n	**p	**p	NS	**n	NS	NS	**p	NS	NS	*p
PxB	NS	NS	NS	NS	*p	NS	NS	*p	NS	NS	NS	NS	NS
KxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxK	NS	NS	NS	NS	NS	NS	NS	NS	NS	*n	NS	**n	*n
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*n
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*n	*p
	Stylosanthes guianensis												
L	**p	**p	**n	**p	**n	**n	NS	NS	**n	**n	**n	**n	**n
LxL	**n	**n	**p	**n	**p	**p	**p	**p	**p	**p	**p	**p	**p
P	**p	**p	**p	*p	**p	*n	**p	NS	NS	**n	*p	*n	**p
PxP	*n	NS	NS	NS	NS	NS	*p	NS	NS	NS	NS	NS	NS
K	**p	**n	**n	**n	**n	**p	**n	**n	**n	**n	**n	**n	NS
KxK	NS	**p	*p	NS	**p	*n	NS	NS	NS	NS	NS	NS	NS
B	*n	NS	NS	NS	NS	**p	*n	NS	NS	NS	NS	**p	NS
BxB	*p	**p	NS	NS	NS	*n	NS	NS	NS	NS	NS	NS	NS
LxP	**p	*n	**n	**n	**n	*n	**n	*n	NS	**p	NS	**n	**n
LxK	**p	*n	**n	**n	**p	NS	NS	NS	**p	NS	**p	NS	NS
LxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxK	**p	NS	**n	**n	NS	NS	**n	*n	NS	**p	NS	**n	NS
PxB	NS	NS	NS	NS	NS	NS	NS	NS	*n	NS	NS	NS	NS
KxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxK	*p	*p	**p	**p	**p	*n	NS	NS	NS	NS	NS	NS	NS
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	*p	NS	NS	**n	NS
LxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxKxB	NS	NS	NS	NS	NS	NS	NS	NS	**p	NS	*p	NS	NS
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	NS	*n	NS	*n	NS	NS

** - ($P<0.01$). * - ($P<0.05$). NS - Not significant at 5% level of probability. Response to source of variation is positive (p) or negative (n).

Appendix Table 24. Levels of significance for sources of variation affecting response variables measured in herbage of two <u>Stylosanthes</u> species grown in a Florida Entisol.

Source of	Response variables												
variation	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	B	Ca/Mn
	---------- <u>Stylosanthes</u> <u>hamata</u> ----------												
L	**p	**p	**p	**p	**n	*n	**p	**p	**n	**n	**p	NS	**p
LxL	**n	NS	**p	*n	**p	**p	**n	NS	**p	**p	**p	NS	**n
P	**p	**p	**p	**n	**n	**n	**p	**n	**n	*n	**p	NS	**n
PxP	**n	NS	**p	NS	NS	**p	**p	NS	NS	**p	NS	NS	NS
K	**p	NS	**n	**n	**n	**p	**n	**p	**p	**n	NS	**n	**n
KxK	*n	NS	**p	NS	**p	**n	**p	NS	NS	**p	NS	NS	NS
B	NS	NS	NS	*p	NS	NS	NS	**p	NS	NS	NS	**p	NS
BxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxP	**n	**n	**p	NS	**p	**p	**n	*n	**p	**n	**p	NS	**n
LxK	NS	NS	**n	**n	*p	*n	NS	**n	**n	**n	NS	NS	**n
LxB	NS	NS	NS	NS	NS	NS	NS	**p	NS	NS	NS	**p	NS
PxK	**p	NS	**n	**p	**p	NS	**n	*n	*n	**n	NS	**n	*p
PxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**n	NS
LxPxK	**p	NS	**p	**p	NS	NS	NS	**p	**p	**p	NS	NS	NS
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**n	NS
LxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxKxB	NS	NS	NS	NS	NS	NS	NS	*p	NS	NS	NS	**p	NS
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	*p	NS	NS	NS	NS	NS
	---------- <u>Stylosanthes</u> <u>guianensis</u> ----------												
L	**p	NS	**p	**p	**n	**n	**p	NS	**n	**n	**n	NS	**p
LxL	**n	**n	**p	**n	**p	**p	NS	**p	**p	**p	**p	**p	**p
P	**p	**p	**p	**n	NS	**n	**p	**n	**n	**n	**n	**n	**n
PxP	**n	**n	**p	**p	**n	**p	NS	NS	NS	NS	NS	NS	NS
K	**p	**n	**n	**n	**n	**p	**p	**n	*n	**n	**n	**n	**n
KxK	**n	**p	**p	**p	**p	NS	NS	*p	NS	**p	*p	NS	NS
B	**n	*n	NS	NS	NS	**p	**n	NS	*n	*n	**n	**p	NS
BxB	NS	**p	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxP	**n	**n	NS	NS	NS	**p	**p	*n	**p	**p	**p	NS	**n
LxK	**p	NS	**n	**n	NS	**n	**n	NS	**n	NS	**p	NS	**n
LxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	*p	**p	*p	NS
PxK	**p	**n	**n	**p	**p	*p	**p	NS	NS	*p	NS	NS	NS
PxB	NS	NS	NS	NS	NS	NS	**p	NS	NS	NS	NS	NS	NS
KxB	NS	NS	NS	NS	NS	NS	**n	NS	NS	**p	**p	**n	NS
LxPxK	*n	*p	NS	**p	NS	*p	**n	*p	NS	NS	NS	NS	NS
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	*n	NS	NS	NS
LxKxB	NS	NS	NS	NS	NS	NS	*n	NS	NS	NS	**n	NS	NS
PxKxB	NS	NS	NS	NS	NS	NS	*n	NS	NS	NS	NS	NS	NS
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	*p	NS	*p	NS	NS	NS

** - ($P < 0.01$). * - ($P < 0.05$). NS - Not significant at 5% levels of probability. Response to source of variation is positive (p) or negative (n).

Appendix Table 25. Levels of significance for sources of variation affecting response variables measured in roots + nodules of two *Stylosanthes* species grown in a Florida Ultisol.

Source of variation	Response variables												
	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	Nod.	Ca/Mn
	----------- *Stylosanthes hamata* -----------												
L	**n	NS	**p	**p	*p	**p	NS	**n	NS	**n	NS	NS	**p
LxL	NS	NS	NS	NS	**n	**n	**p	NS	**p	NS	NS	**n	*n
P	*n	**p	**p	**n	**n	**n	**p	NS	*n	NS	NS	**p	**n
PxP	NS	NS	NS	NS	**p	**p	*n	NS	NS	NS	NS	NS	NS
K	NS	**p	NS	NS	**n	**p	**n	*n	**p	NS	NS	**p	**n
KxK	NS	NS	NS	NS	NS	*p	NS	NS	NS	**n	NS	NS	NS
B	NS	NS	NS	NS	NS	NS	NS	NS	*p	NS	NS	NS	**n
BxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	**n	NS	NS	NS
LxP	NS	NS	**p	*p	NS	**p	NS	*p	**p	NS	*n	NS	**n
LxK	*p	NS	NS	*n	NS	**p	*n	NS	**n	NS	NS	NS	NS
LxB	NS	NS	NS	*p	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxK	NS	*p	NS	NS	**p	**n	NS	NS	NS	NS	NS	NS	NS
PxB	NS	NS	NS	**p	NS	NS	NS	NS	NS	NS	NS	NS	NS
KxB	NS	**n	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxK	*p	*p	NS	NS	NS	*p	NS	NS	NS	NS	NS	*p	NS
LxPxB	NS	NS	NS	**n	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxKxB	NS	*n	NS	NS	NS	NS	NS	NS	NS	**n	*n	NS	NS
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	----------- *Stylosanthes guianensis* -----------												
L	**n	NS	**p	**p	**n	**p	NS	**n	**n	**n	**p	NS	**p
LxL	**n	NS	NS	NS	**p	**n	**p	**n	**p	NS	NS	**n	NS
P	**p	**p	**p	**n	**n	**n	**p	**p	NS	**p	**p	**p	**n
PxP	NS	NS	NS	NS	*p	**p	**n	NS	NS	NS	NS	NS	NS
K	**p	**n	**n	**n	NS	**p	**n	**p	**n	**n	**n	**p	NS
KxK	NS	NS	*p	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B	*n	NS	NS	NS	NS	**p	NS	NS	*n	NS	NS	NS	NS
BxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*p	NS	NS
LxP	NS	**p	NS	NS	NS	*n	NS	NS	NS	NS	NS	NS	NS
LxK	NS	NS	NS	NS	NS	**p	NS	*p	**p	NS	NS	NS	NS
LxB	NS	NS	NS	NS	NS	NS	NS	NS	*p	NS	NS	NS	NS
PxK	NS	**p	NS	*p	**p	**n	**n	NS	*p	*n	NS	**p	NS
PxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KxB	NS	*n	NS	NS	*n	*p	NS	NS	*p	NS	NS	NS	NS
LxPxK	NS	NS	NS	NS	**n	NS	NS	NS	**n	NS	NS	NS	NS
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxKxB	NS	NS	NS	NS	*p	NS	NS	NS	NS	NS	NS	NS	NS
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

** - ($P < 0.01$). * - ($P < 0.05$). NS - Not significant at 5% level of probability. Response to source of variation is positive (p) or negative (n).

Appendix Table 26. Levels of significance for sources of variation affecting response variables measured in roots + nodules of two *Stylosanthes* species grown in a Florida Spodosol.

Source of	Response variables												
variation	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	Nod.	Ca/Mn
	---------- *Stylosanthes hamata* ----------												
L	NS	**p	**n	**p	**p	**n	NS	*p	**n	**n	**n	**p	**p
LxL	**n	**n	**p	**n	**n	**p	**n	**p	NS	**p	**p	**n	**p
P	NS	NS	**p	NS	**n	NS	**p	NS	**n	NS	**n	**p	NS
PxP	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
K	*p	*n	**n	**n	**n	**p	**n	NS	NS	NS	**n	*p	NS
KxK	NS	*p	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxP	NS	NS	**n	NS	NS	NS	NS	NS	**p	**p	**p	**p	NS
LxK	NS	NS	*p	**n	NS	NS	NS	*p	NS	NS	NS	*n	NS
LxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxK	NS	NS	NS	NS	**p	NS	**n	NS	*p	NS	*p	NS	**n
PxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxK	NS	NS	**n	NS	NS	NS	NS	NS	NS	NS	NS	NS	**n
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	---------- *Stylosanthes guianensis* ----------												
L	NS	NS	**n	**p	NS	NS	**p	NS	**p	**n	**n	**p	**p
LxL	**n	*n	**p	**n	NS	**p	NS	NS	**n	NS	NS	**n	**p
P	**p	*p	**p	*p	**n	**n	**p	**n	*n	NS	**p	**p	NS
PxP	NS	NS	**n	NS	NS	NS	NS	NS	NS	NS	*n	NS	NS
K	**p	**n	NS	**p	**n	**p	**n	**p	**n	NS	**n	**p	NS
KxK	*n	NS	NS	NS	NS	NS	NS	NS	NS	NS	*p	NS	NS
B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BxB	*p	NS	NS	*p	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxP	*p	**p	**n	NS	NS	**p	**p	NS	NS	NS	**p	**p	NS
LxK	**p	**p	NS	**n	NS	NS	NS	NS	*p	NS	**p	**n	NS
LxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxK	**p	NS	NS	NS	**p	**n	**p	**n	NS	NS	**p	**p	NS
PxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxK	*p	NS	NS	**p	NS	**n	NS	NS	NS	NS	**n	**p	NS
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

** - ($P < 0.01$). * - ($P < 0.05$). NS - Not significant at 5% level of probability. Response to source of variation is positive (p) or negative (n).

Appendix Table 27. Levels of significance for sources of variation affecting response variables measured in roots + nodules of two *Stylosanthes* species grown in a Florida Entisol.

Source of	Response variables												
variation	Yield	N	P	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	Nod.	Ca/Mn
	------------ *Stylosanthes hamata* ------------												
L	NS	**p	**p	**p	*n	NS	NS	NS	**n	NS	**n	**n	**p
LxL	**p	**p	**p	**n	NS	**p	*n	NS	**p	**n	NS	**p	**n
P	**p	**p	**p	NS	**n	**n	**p	NS	NS	NS	**n	**p	NS
PxP	*n	*p	**p	NS	NS	NS	NS	NS	NS	NS	NS	*n	NS
K	**p	**n	**n	**n	**n	**p	**p	**p	**p	**n	*n	**p	**n
KxK	NS	*p	*p	NS	NS	NS	NS	NS	NS	**p	NS	NS	NS
B	NS	NS	**n	NS	NS	NS	NS	**p	NS	NS	NS	NS	NS
BxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxP	**n	NS	**p	NS	NS	NS	NS	*n	NS	NS	NS	**n	NS
LxK	NS	NS	*p	*n	NS	NS	**n	NS	**n	NS	NS	NS	NS
LxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxK	*p	NS	**n	NS	**n	**n	**n	NS	NS	NS	NS	NS	NS
PxB	NS	NS	*n	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*p	NS	NS
LxPxK	*n	NS	NS	NS	NS	NS	*n	NS	NS	NS	NS	NS	NS
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxKxB	NS	**P	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxKxB	NS	NS	*n	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxKxB	NS	NS	*p	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	------------ *Stylosanthes guianensis* ------------												
L	NS	NS	**n	**p	NS	*n	*n	**p	**n	**n	**n	**p	**p
LxL	**n	NS	**p	**n	NS	**p	**p	**n	**p	NS	**p	**n	**p
P	**p	**p	**p	**n	**n	**n	**p	*n	NS	**p	**n	**p	**n
PxP	NS	NS	NS	NS	NS	**p	NS	NS	NS	NS	NS	**n	NS
K	**p	**n	**n	**n	**n	**p	**n	**n	**p	NS	**n	**p	**n
KxK	**n	NS	**p	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B	*p	NS	NS	NS	NS	*p	NS	*p	**n	NS	**n	NS	NS
BxB	NS	NS	*n	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxP	*n	**n	NS	NS	**p	**n	NS	NS	**p	NS	**p	*n	**n
LxK	**p	NS	**n	**n	*p	**n	NS	NS	**n	*n	**p	*p	**n
LxB	NS	NS	NS	NS	NS	NS	NS	NS	**p	NS	**p	NS	NS
PxK	NS	*n	NS	*n	**p	**n	**n	**p	**p	NS	**p	*p	NS
PxB	NS	NS	NS	NS	NS	*n	NS	NS	**p	NS	**p	NS	NS
KxB	NS	NS	NS	NS	*p	NS	NS	NS	NS	NS	*p	NS	NS
LxPxK	NS	NS	**n	**p	NS	**p	NS	NS	*p	*p	**n	**n	NS
LxPxB	NS	NS	NS	NS	NS	*p	NS	NS	**n	NS	*n	NS	NS
LxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	*p	NS	NS	NS
PxKxB	NS	NS	NS	NS	NS	NS	NS	NS	*p	NS	NS	NS	NS
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

** - ($P<0.01$). * - ($P<0.05$). NS - Not significant at 5% level of probability.
Response to source of variation is positive (p) or negative (n).

Appendix Table 28. Effects of lime and P levels on herbage yields of two Stylosanthes species grown in three Florida soils.

Entisol - *S. guianensis*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
	g/pot				
0	4.8		6.9		7.6
1		8.9		10.4	
2	10.4		12.3		10.6
3		12.5		13.0	
4	9.2		14.5		9.2

Entisol - *S. hamata*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
	g/pot				
0	3.6		5.1		5.2
1		4.8		5.7	
2	6.1		6.7		7.6
3		6.3		6.3	
4	5.4		7.9		5.8

Spodosol - *S. guianensis*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
	g/pot				
0	2.2		4.2		2.6
1		6.4		7.6	
2	2.4		9.7		5.8
3		6.9		9.9	
4	2.6		10.4		5.8

Spodosol - *S. hamata*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
	g/pot				
0	1.7		5.0		1.9
1		5.5		6.7	
2	2.1		8.8		6.2
3		6.8		7.1	
4	1.5		11.0		4.4

Ultisol - *S. guianensis*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
	g/pot				
0	10.6		10.3		9.3
1		12.2		12.8	
2	14.3		13.5		12.3
3		14.5		13.6	
4	14.0		13.9		12.1

Ultisol - *S. hamata*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
	g/pot				
0	6.9		6.9		6.2
1		6.7		6.9	
2	7.5		7.6		7.3
3		8.2		7.7	
4	8.2		9.8		7.1

Note: Means are averages over K and B combinations.

Appendix Table 29. Effects of K and B levels on herbage yields of two Stylosanthes species grown in three Florida soils.

Entisol - S. guianensis

B	K levels				
levels	0	1	2	3	4
	g/pot				
0	5.5		13.3		10.9
1		10.8		13.0	
2	5.6		12.1		13.3
3		9.6		11.3	
4	4.7		12.3		9.9

Entisol - S. hamata

B	K levels				
levels	0	1	2	3	4
	g/pot				
0	4.3		6.7		6.1
1		5.8		6.1	
2	4.4		6.9		7.9
3		5.4		6.0	
4	4.0		6.5		5.9

Spodosol - S. guianensis

B	K levels				
levels	0	1	2	3	4
	g/pot				
0	2.4		12.2		4.9
1		6.8		9.1	
2	3.7		8.4		11.4
3		6.5		8.3	
4	2.2		8.6		3.7

Spodosol - S. hamata

B	K levels				
levels	0	1	2	3	4
	g/pot				
0	1.9		8.5		2.6
1		7.2		6.6	
2	3.9		8.0		11.3
3		6.9		6.3	
4	2.0		7.7		3.1

Ultisol - S. guianensis

B	K levels				
levels	0	1	2	3	4
	g/pot				
0	10.9		14.2		13.2
1		13.0		14.7	
2	11.5		13.1		14.4
3		11.2		14.2	
4	9.5		14.5		12.3

Ultisol - S. hamata

B	K levels				
levels	0	1	2	3	4
	g/pot				
0	7.2		7.2		7.2
1		6.8		8.2	
2	6.4		7.8		8.3
3		7.2		7.3	
4	6.7		7.8		7.2

Note: Means are averages over Lime and P combinations.

Appendix Table 30. Effects of lime and P levels on root-nodule weights of two *Stylosanthes* species grown in three Florida soils.

Entisol - *S. guianensis*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	-------- g/pot ---------				
0	1.3		1.7		1.3
1		1.8		2.1	
2	1.9		2.0		1.8
3		2.2		2.3	
4	1.8		2.7		1.5

Entisol - *S. hamata*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	-------- g/pot --------				
0	0.7		0.8		0.7
1		0.8		0.9	
2	1.0		1.0		1.0
3		0.9		0.8	
4	0.9		1.1		0.8

Spodosol - *S. guianensis*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	-------- g/pot ---------				
0	0.7		1.0		0.6
1		1.4		1.3	
2	0.6		1.8		1.2
3		1.6		1.8	
4	0.7		2.2		1.0

Spodosol - *S. hamata*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	------- g/pot ---------				
0	0.5		1.0		0.5
1		1.0		1.2	
2	0.6		1.3		0.9
3		1.3		1.1	
4	0.5		1.4		0.7

Ultisol - *S. guianensis*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	-------- g/pot ---------				
0	1.8		1.8		1.4
1		1.9		1.7	
2	2.3		2.0		1.6
3		1.9		1.8	
4	2.0		2.0		1.6

Ultisol - *S. hamata*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	------- g/pot --------				
0	1.0		0.9		0.8
1		1.0		0.8	
2	1.0		1.0		0.9
3		1.1		0.9	
4	1.0		1.2		0.9

Note: Means are averages over K and B combinations.

Appendix Table 31. Herbage N concentrations of two *Stylosanthes* species as affected by levels of P and K.

Entisol - *S. guianensis*

K	P levels				
levels	0	1	2	3	4
			%		
0	2.26		2.60		2.92
1		1.70		2.00	
2	1.55		1.78		1.91
3		1.62		1.80	
4	1.67		1.68		1.95

Entisol - *S. hamata*

K	P levels				
levels	0	1	2	3	4
			%		
0	1.95		2.07		2.29
1		2.06		2.12	
2	1.83		1.94		2.12
3		2.05		2.04	
4	1.91		1.94		2.15

Spodosol - *S. guianensis*

K	P levels				
levels	0	1	2	3	4
			%		
0	2.02		2.85		2.61
1		2.05		2.29	
2	1.61		2.11		2.29
3		1.93		2.03	
4	1.60		2.17		1.95

Spodosol - *S. hamata*

K	P levels				
levels	0	1	2	3	4
			%		
0	2.38		2.77		2.58
1		2.11		2.36	
2	1.94		2.31		2.41
3		2.24		2.36	
4	2.00		2.56		2.04

Ultisol - *S. guianensis*

K	P levels				
levels	0	1	2	3	4
			%		
0	1.95		2.19		2.32
1		1.82		2.10	
2	1.84		1.92		2.19
3		1.82		2.11	
4	1.89		2.04		2.14

Ultisol - *S. hamata*

K	P levels				
levels	0	1	2	3	4
			%		
0	2.50		2.77		2.70
1		2.68		2.65	
2	2.70		2.74		2.93
3		2.78		2.64	
4	2.52		3.22		2.82

Note: Means are averages over lime and B combinations.

Appendix Table 32. Total N in biomass from two Stylosanthes species as affected by levels of P and K.

Entisol - S. guianensis

K	P levels				
levels	0	1	2	3	4
	--------		mg/pot		---------
0	121		168		194
1		191		269	
2	134		260		332
3		195		299	
4	158		263		287

Entisol - S. hamata

K	P levels				
levels	0	1	2	3	4
	--------		mg/pot		---------
0	89		108		123
1		123		147	
2	108		153		193
3		127		153	
4	113		175		172

Spodosol - S. guianensis

K	P levels				
levels	0	1	2	3	4
	--------		mg/pot		---------
0	53		119		76
1		155		191	
2	84		233		283
3		177		244	
4	55		286		153

Spodosol - S. hamata

K	P levels				
levels	0	1	2	3	4
	--------		mg/pot		--------
0	47		159		71
1		162		198	
2	117		224		317
3		156		191	
4	50		327		104

Ultisol - S. guianensis

K	P levels				
levels	0	1	2	3	4
	--------		mg/pot		--------
0	205		290		305
1		243		306	
2	223		302		348
3		279		367	
4	237		333		355

Ultisol - S. hamata

K	P levels				
levels	0	1	2	3	4
	--------		mg/pot		--------
0	182		197		225
1		192		225	
2	208		233		318
3		223		244	
4	187		293		245

Note: Means are averages over lime and B combinations.

Appendix Table 33. Herbage N concentrations of two *Stylosanthes* species as affected by levels of lime and B.

Entisol - *S. guianensis*

B	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	2.18		1.74		2.16
1		1.71		1.78	
2	1.76		1.80		1.72
3		1.83		1.80	
4	2.24		2.32		2.20

Entisol - *S. hamata*

B	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	2.02		2.00		2.10
1		1.94		2.12	
2	1.92		1.94		2.02
3		1.93		2.28	
4	2.04		1.96		2.14

Spodosol - *S. guianensis*

B	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	1.56		2.36		2.47
1		1.82		2.39	
2	0.86		2.22		1.97
3		1.66		2.42	
4	1.72		2.56		2.42

Spodosol - *S. hamata*

B	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	1.79		2.64		2.70
1		2.00		2.55	
2	1.10		2.41		2.87
3		1.91		2.62	
4	1.92		2.12		2.60

Ultisol - *S. guianensis*

B	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	2.08		1.93		2.04
1		1.92		1.94	
2	1.89		1.99		1.87
3		2.10		1.90	
4	2.15		1.89		2.02

Ultisol - *S. hamata*

B	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	2.60		2.72		2.69
1		2.57		2.74	
2	2.82		2.80		2.80
3		2.68		2.78	
4	2.59		2.67		2.66

Note: Means are averages over P and K levels.

Appendix Table 34. Total N in biomass from two *Stylosanthes* species as affected by levels of lime and B.

Entisol - *S. guianensis*

B	$CaCO_3$ levels				
levels	0	1	2	3	4
	--------		mg/pot		--------
0	192		271		207
1		239		258	
2	219		247		216
3		215		241	
4	175		323		187

Entisol - *S. hamata*

B	$CaCO_3$ levels				
levels	0	1	2	3	4
	--------		mg/pot		--------
0	117		157		138
1		126		150	
2	136		149		177
3		124		149	
4	110		147		132

Spodosol - *S. guianensis*

B	$CaCO_3$ levels				
levels	0	1	2	3	4
	--------		mg/pot		--------
0	51		335		134
1		152		245	
2	29		235		137
3		135		235	
4	51		256		102

Spodosol - *S. hamata*

B	$CaCO_3$ levels				
levels	0	1	2	3	4
	--------		mg/pot		--------
0	36		255		93
1		162		215	
2	32		248		203
3		134		197	
4	37		194		106

Ultisol - *S. guianensis*

B	$CaCO_3$ levels				
levels	0	1	2	3	4
	--------		mg/pot		--------
0	312		315		260
1		323		297	
2	313		300		261
3		289		286	
4	287		319		242

Ultisol - *S. hamata*

B	$CaCO_3$ levels				
levels	0	1	2	3	4
	--------		mg/pot		--------
0	220		216		207
1		221		224	
2	235		244		228
3		218		221	
4	221		231		191

Note: Means are averages over P and K combinations.

Appendix Table 35. Levels of significance for sources of variation affecting the contents of some elements in biomass from two *Stylosanthes* species grown in three Florida soils.

Sources of	Ultisol				Spodosol				Entisol			
variation	N	P	Ca	K	N	P	Ca	K	N	P	Ca	K
	------------	------------	------------	------------	*Stylosanthes*	*hamata*	------------	------------	------------	------------	------------	------------
L	**p	NS	**p	NS	**p	NS	**p	**p	**p	**p	**p	**p
LxL	**n	*n	**n	**n	**n	**n	**n	**n	**p	**p	**n	**n
P	**p	**p	* n	* n	**p	**p	**p	**p	**p	**p	NS	**p
PxP	NS	NS	NS	NS	NS	NS	*n	*n	NS	NS	*n	**n
K	**p	NS	NS	**p	NS	NS	*p	**p	**p	NS	NS	**p
KxK	NS	NS	NS	**n	NS	NS	NS	NS	NS	NS	NS	**n
B	NS	NS	NS	NS	NS	NS	NS	NS	NS	*n	NS	*n
BxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxP	*n	NS	NS	NS	**p	NS	**p	**p	**n	NS	NS	**p
LxK	NS	NS	NS	NS	NS	NS	NS	*n	NS	NS	NS	NS
LxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxK	NS	NS	**p	**p	NS	NS	*p	**n	*p	NS	**p	**p
PxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxK	NS	NS	NS	NS	NS	NS	NS	**p	NS	NS	NS	**n
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	------------	------------	------------	------------	*Stylosanthes*	*guianensis*	------------	------------	------------	------------	------------	------------
L	**p	NS	**p	**n	**p	NS	**p	**p	*p	**p	**p	**n
LxL	**n	NS	*n	*p	**n	**n	**n	**n	**n	NS	**n	NS
P	**p	**p	**p	**p	**p	**p	**p	**p	**p	**p	**p	**p
PxP	NS	NS	NS	NS	NS	NS	**n	*n	*n	NS	*n	NS
K	**p	**n	**n	**p	**p	*p	**p	**p	**p	NS	**p	**p
KxK	NS	*p	**p	NS	NS	NS	NS	NS	*n	NS	NS	NS
B	**n	**n	**n	NS	NS	*n	*n	NS	*n	**p	*n	NS
BxB	NS	NS	NS	NS	**p	NS	*p	NS	*p	NS	NS	NS
LxP	NS	**p	**p	NS	**p	NS	**p	**p	**n	NS	NS	*p
LxK	*n	NS	NS	**p	**p	*n	**n	**n	*p	NS	**p	*p
LxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxK	NS	**n	**p	**p	**n	NS	**p	**p	**p	NS	**p	**p
PxB	NS	*n	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KxB	NS	*p	*p	*n	NS	NS	NS	NS	NS	NS	NS	NS
LxPxK	NS	NS	NS	NS	**p	*p	**p	**p	NS	*p	*p	**n
LxPxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LxPxKxB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

** - ($P < 0.01$). * - ($P < 0.05$). NS - Not significant at 5% level of probability. Response to source of variation is positive (p) or negative (n).

Appendix Table 36. Phosphorus contents in biomass from two *Stylosanthes* species as affected by levels of lime and P.

Entisol - *S. guianensis*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	-------- mg/pot --------				
0	4.1		5.5		9.5
1		7.8		10.6	
2	10.6		13.6		15.7
3		15.2		20.6	
4	18.0		22.7		24.2

Entisol - *S. hamata*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	-------- mg/pot --------				
0	3.2		4.3		6.8
1		4.0		6.0	
2	5.2		7.0		9.4
3		6.8		8.0	
4	7.6		11.5		12.3

Spodosol - *S. guianensis*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	-------- mg/pot --------				
0	2.2		4.0		2.9
1		11.9		11.4	
2	11.2		19.5		12.1
3		27.3		27.9	
4	20.7		35.2		18.9

Spodosol - *S. hamata*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	-------- mg/pot --------				
0	2.2		4.4		2.2
1		9.4		9.1	
2	8.2		14.4		11.3
3		17.4		13.8	
4	8.0		23.2		10.7

Ultisol - *S. guianensis*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	-------- mg/pot --------				
0	9.7		8.9		8.6
1		11.6		12.2	
2	13.7		16.3		17.0
3		21.1		20.3	
4	23.3		22.7		25.6

Ultisol - *S. hamata*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
	-------- mg/pot --------				
0	8.9		9.7		8.8
1		9.7		11.0	
2	12.2		12.6		12.5
3		13.8		13.8	
4	14.7		19.0		15.3

Note: Means are averages over K and B combinations.

Appendix Table 37. Calcium concentrations in roots + nodules of two *Stylosanthes* species as affected by levels of lime and P.

Entisol - *S. guianensis*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	0.23		0.50		0.64
1		0.38		0.60	
2	0.18		0.46		0.64
3		0.31		0.56	
4	0.20		0.44		0.56

Entisol - *S. hamata*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	0.23		0.40		0.47
1		0.33		0.42	
2	0.23		0.40		0.47
3		0.34		0.40	
4	0.23		0.39		0.44

Spodosol - *S. guianensis*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	0.14		0.49		0.58
1		0.33		0.60	
2	0.16		0.49		0.54
3		0.32		0.63	
4	0.17		0.44		0.62

Spodosol - *S. hamata*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	0.14		0.40		0.53
1		0.28		0.42	
2	0.18		0.39		0.44
3		0.28		0.50	
4	0.16		0.36		0.53

Ultisol - *S. guianensis*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	0.46		0.54		0.58
1		0.44		0.50	
2	0.36		0.50		0.57
3		0.45		0.50	
4	0.38		0.50		0.53

Ultisol - *S. hamata*

P	CaCO$_3$ levels				
levels	0	1	2	3	4
			%		
0	0.45		0.54		0.72
1		0.48		0.54	
2	0.40		0.55		0.67
3		0.46		0.63	
4	0.43		0.55		0.62

Note: Means are averages over K and B combinations.

Appendix Table 38. Potassium contents in biomass from two *Stylosanthes* species as affected by levels of P and K.

Entisol - *S. guianensis*

K	P levels				
levels	0	1	2	3	4
			mg/pot		
0	21		19		23
1		49		49	
2	76		87		84
3		116		116	
4	125		145		160

Entisol - *S. hamata*

K	P levels				
levels	0	1	2	3	4
			mg/pot		
0	19		20		19
1		52		50	
2	72		81		87
3		82		95	
4	82		114		106

Spodosol - *S. guianensis*

K	P levels				
levels	0	1	2	3	4
			mg/pot		
0	10		11		11
1		39		40	
2	64		70		67
3		101		104	
4	65		130		108

Spodosol - *S. hamata*

K	P levels				
levels	0	1	2	3	4
			mg/pot		
0	9		10		9
1		44		42	
2	67		73		75
3		99		107	
4	48		144		80

Ultisol - *S. guianensis*

K	P levels				
levels	0	1	2	3	4
			mg/pot		
0	42		47		49
1		74		75	
2	102		106		108
3		134		143	
4	164		175		182

Ultisol - *S. hamata*

K	P levels				
levels	0	1	2	3	4
			mg/pot		
0	52		42		52
1		74		77	
2	99		105		116
3		119		130	
4	126		143		142

Note: Means are averages over lime and B combinations.

Appendix Table 39. Potassium contents in biomass from two *Stylosanthes* species as affected by levels of lime and K.

Entisol - *S. guianensis*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
	mg/pot				
0	21		19		23
1		52		47	
2	86		87		80
3		115		116	
4	136		145		149

Entisol - *S. hamata*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
	mg/pot				
0	18		20		21
1		49		53	
2	77		80		93
3		86		91	
4	89		114		99

Spodosol - *S. guianensis*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
	mg/pot				
0	10		11		11
1		39		40	
2	52		71		74
3		97		107	
4	68		130		106

Spodosol - *S. hamata*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
	mg/pot				
0	8		10		10
1		42		43	
2	43		75		78
3		100		106	
4	50		144		78

Ultisol - *S. guianensis*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
	mg/pot				
0	46		47		45
1		77		73	
2	107		105		105
3		144		134	
4	183		175		163

Ultisol - *S. hamata*

K	CaCO$_3$ levels				
levels	0	1	2	3	4
	mg/pot				
0	53		42		50
1		80		71	
2	102		106		100
3		127		122	
4	135		142		132

Note: Means are averages over P and B combinations.

Appendix Table 40. Sodium concentrations in herbage of two *Stylosanthes* species as affected by levels of NaH_2PO_4 and K.

Entisol - *S. guianensis*

K	NaH_2PO_4 levels				
levels	0	1	2	3	4
	----------		ppm		----------
0	43		72		100
1		54		75	
2	52		58		75
3		57		69	
4	50		60		69

Entisol - *S. hamata*

K	NaH_2PO_4 levels				
levels	0	1	2	3	4
	----------		ppm		----------
0	112		2035		3163
1		230		738	
2	88		187		620
3		141		252	
4	107		180		464

Spodosol - *S. guianensis*

K	NaH_2PO_4 levels				
levels	0	1	2	3	4
	----------		ppm		----------
0	41		75		254
1		40		61	
2	50		46		70
3		51		68	
4	73		50		111

Spodosol - *S. hamata*

K	NaH_2PO_4 levels				
levels	0	1	2	3	4
	----------		ppm		----------
0	592		2715		5018
1		689		1656	
2	70		702		1275
3		180		526	
4	146		330		501

Ultisol - *S. guianensis*

K	NaH_2PO_4 levels				
levels	0	1	2	3	4
	----------		ppm		----------
0	76		168		170
1		115		178	
2	88		112		142
3		132		152	
4	91		132		116

Ultisol - *S. hamata*

K	NaH_2PO_4 levels				
levels	0	1	2	3	4
	----------		ppm		---------
0	218		1768		2115
1		485		1163	
2	122		496		1000
3		192		351	
4	100		215		392

Note: Means are averages over lime and B combinations.

Appendix Table 41. Sodium concentrations in roots + nodules of two *Stylosanthes* species as affected by levels of NaH_2PO_4 and K.

Entisol - *S. guianensis*

K	NaH_2PO_4 levels				
levels	0	1	2	3	4
			%		
0	0.05		0.40		1.23
1		0.26		0.55	
2	0.04		0.39		0.66
3		0.18		0.46	
4	0.03		0.31		0.53

Entisol - *S. hamata*

K	NaH_2PO_4 levels				
levels	0	1	2	3	4
			%		
0	0.09		0.58		0.71
1		0.41		0.62	
2	0.07		0.38		0.66
3		0.12		0.40	
4	0.06		0.20		0.43

Spodosol - *S. guianensis*

K	NaH_2PO_4 levels				
levels	0	1	2	3	4
			%		
0	0.17		---		0.15
1		0.46		0.96	
2	0.14		0.50		0.80
2		0.34		0.62	
4	0.32		0.33		0.59

Spodosol - *S. hamata*

K	NaH_2PO_4 levels				
levels	0	1	2	3	4
			%		
0	0.32		0.70		1.02
1		0.51		0.94	
2	0.10		0.56		0.72
3		0.31		0.86	
4	0.05		0.72		0.29

Ultisol - *S. guianensis*

K	NaH_2PO_4 levels				
levels	0	1	2	3	4
			%		
0	0.12		0.81		1.03
1		0.45		0.80	
2	0.08		0.62		0.98
3		0.34		0.71	
4	0.06		0.47		0.78

Ultisol - *S. hamata*

K	NaH_2PO_4 levels				
levels	0	1	2	3	4
			%		
0	0.16		0.57		0.82
1		0.62		0.73	
2	0.14		0.53		0.72
3		0.36		0.60	
4	0.08		0.32		0.71

Note: Means are averages over lime and B combinations.

Appendix Table 42. Boron concentrations in herbage of two *Stylosanthes* species as affected by levels of lime and B.

Entisol - *S. guianensis*

B	$CaCO_3$ levels				
levels	0	1	2	3	4
			ppm		
0	18		7		9
1		29		28	
2	47		42		46
3		64		54	
4	99		63		107

Entisol - *S. hamata*

B	$CaCO_3$ levels				
levels	0	1	2	3	4
			ppm		
0	15		11		9
1		25		26	
2	40		38		40
3		47		48	
4	61		60		64

Spodosol - *S. guianensis*

B	$CaCO_3$ levels				
levels	0	1	2	3	4
			ppm		
0	46		16		17
1		50		37	
2	92		54		57
3		86		70	
4	146		86		123

Spodosol - *S. hamata*

B	$CaCO_3$ levels				
levels	0	1	2	3	4
			ppm		
0	34		15		19
1		31		30	
2	55		41		37
3		56		48	
4	90		60		62

Ultisol - *S. guianensis*

B	$CaCO_3$ levels				
levels	0	1	2	3	4
			ppm		
0	31		25		24
1		38		40	
2	47		46		44
3		60		52	
4	70		64		49

Ultisol - *S. hamata*

B	$CaCO_3$ levels				
levels	0	1	2	3	4
			ppm		
0	27		28		23
1		25		25	
2	38		38		37
3		40		35	
4	49		45		39

Note: Means are averages over P and K combinations.

Appendix Table 43. Calcium to Mn ratio in herbage of two *Stylosanthes* species as affected by levels of lime and P.

Entisol - *S. guianensis*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
0	45		383		620
1		197		384	
2	36		245		481
3		131		309	
4	41		176		447

Entisol - *S. hamata*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
0	70		431		618
1		275		472	
2	54		370		511
3		229		404	
4	62		278		498

Spodosol - *S. guianensis*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
0	12		293		1202
1		114		506	
2	16		229		1390
3		122		516	
4	14		227		953

Spodosol - *S. hamata*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
0	11		280		1028
1		113		537	
2	11		297		978
3		146		680	
4	13		241		990

Ultisol - *S. guianensis*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
0	205		371		599
1		250		373	
2	139		281		425
3		211		311	
4	134		245		425

Ultisol - *S. hamata*

P	$CaCO_3$ levels				
levels	0	1	2	3	4
0	160		261		391
1		206		283	
2	150		229		338
3		189		299	
4	124		217		331

Note: Means are averages over K and B combinations.

Appendix Table 44. Analysis of variance procedure for soil data before planting.

Source of variation	Degrees of Freedom
Soils	2
Lime levels	4
Soil x lime levels	8
Leaching	1
Leaching x soil	2
Leaching x lime levels	4
Soil x leaching x lime levels	8
Total	29

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BIOGRAPHICAL SKETCH

Joaquim Carlos Werner was born March 5, 1937, at Presidente Soares, Minas Gerais, Brazil.

In March 1958, he entered the Universidade Federal Rural do Rio de Janeiro and received the degree of Engenheiro Agronomo in December 1961.

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From March 1968 to December 1969 he attended a Graduate Course in Soils and Plant Nutrition at Escola Superior de Agricultura 'Luiz de Queiroz,' Piracicaba, São Paulo, Brazil, and in June 1971, he received the Degree of Doutor em Agronomia from that same college.

From January 1970 to September 1975, he continued developing research programs on pasture management at the Instituto de Zootecnia of São Paulo, where he published approximately 30 papers on pasture management and forage plant fertilization.

In September 1975, he was granted a scholarship from the Projeto Ciencia e Tecnologia do Conselho de Tecnologia do Estado de São Paulo to pursue graduate studies at the University of Florida. At present he is a candidate for the degree of Doctor of Philosophy in the Agronomy Department.

He is a member of the Sociedade Brasileira de Zootecnia, American Society of Agronomy, Soil Science Society of America, Soil and Crop Science Society of Florida, and Gamma Sigma Delta Honor Society of Agriculture.

He is married to Mercia Itamar G. Werner, and they have two children, Carlos Arthur, and Ana Lidia.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Gerald O. Mott

Gerald O. Mott, Chairman
Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

C B Ammerman

C. B. Ammerman
Professor of Animal Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

W. G. Blue

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Professor of Soil Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

D. H. Hubbell

D. H. Hubbell
Professor of Soil Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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