AN INTEGRATED OVERVIEW

OF THE

FINAL PROJECT REPORTS

GREENHOUSE AND FIELD EVALUATIONS OF LIMESTONE AND GYPSUM FOR REDUCING PHOSPHORUS LEACHING AND RUNOFF FROM BEEF CATTLE PASTURES

South Florida Water Management District
Contract No. C-10201

Prepared by

University of Florida
Institute of Food and Agricultural Services
Range Cattle Research and Education Center
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Submitted by

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October 15, 2002

Original

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October 17, 2002

Ms. Steffany Gornak
Senior Environmental Analyst &
Project Supervisor
South Florida Water Management District
Okeechobee, Fl 34973

Dear Ms. Gornak:

We are pleased to submit the corrected "An Integrated Overview of the Final Project Reports" under SFWMD Contract No. C-10201 and our comments to your and the SFWMD staff's suggestions.

Dr. Alcordo had attempted to effect a better integration between the greenhouse results and the field experiments, hopefully, to your satisfaction..

Should you still see some needs to correct certain statements, do not hesitate to call me or Drs. Alcordo and/or Bottcher.

Sincerely,

Jack E. Rechcigl
Principal Investigator & Director, Gulf Coast Research and Education Center

Responses to the SFWMD Staff Comments on Contract C-10201 Final Report dated August 13, 2002.

- Individual study conclusions and recommendations are given in the Project Summary, Conclusions and Recommendations as suggested. The yield data in the two greenhouse studies and the field experiment are consistent; in all studies there was no response to P fertilization in terms of forage yield. With regards to Ca amendments, the results are also consistent between GS1 and the field experiment. The field experiment showed slightly elevated P levels in runoff with gypsum and slightly reduced P levels with Ca carbonate. In terms of leachate P concentrations, GS1 showed very strongly increased P levels with gypsum and reduced P levels with lime, whether calcium carbonate or dolomite. We already made the strongest recommendation for IFAS to reconsider its P recommendation for stargrass and similar improved gras species. The greenhouse and the field experiments indicated that regrowth forage containing 0.19 % P or possibly down to 16 % would not benefit from P fertlization.
- We understand that corrections were already made by Dr. Adjie.
- See attached CD containing the requested data.
- Editorial corrections were made as suggested.
- All greenhouse studies used SI units except for conductivity (umho/cm instead of mS/m) and % (instead of g/100g) for better comprehension by non-technical people. All fertilizer elements are now consistently expressed as elements as usual and all rates are in kg/ha. Dr. Bottcher, who prepared his own report, used ft instead of m or cm, °F instead of °C probably because of the his program.
- Re: Rainfall. See p.xxiv, par. 4.
- The lime amendment is not mobile and it would be very unlikely that the lime particles were washed off the plots; gypsum is highly soluble and it could be washed off the plots but gypsum is not a P immobilizer.
- Table GS1-4 cannot be reformatted without reformatting the rest of the tables which could not also be done because of the complexity of the headings.
- Overall means in tables cited were analyzed for overall comparison between horizons P(H) and the letters are correct.
- Values for mg P/kg in the case of 0 P (Table GS1-12) are the soil P which were deducted from the P-treated values to get the fertilizer P components.
- For GS1 study, there was some pre-treatment leaching so that we will have to run 3 P fractionations to achieve the suggested comparions. But no sample was taken after pre-treatment leaching. There was not a single leaching but a series of 8 leachings so we would have to run 8 multiple regression analysis for each of the 15 treatments. The suggestion is simply impractical.
- Individual study recommendations were removed and integrated into the project recommendations. See comments on the first bullet.
- Title changed to “Influence of Soil Horizons ....”, p.39.
- Tables in GS2 studies were analyzed by Lubos using Duncan, so LSDs are not appropriate.
- Chemical speciation modeling may be done for publication in the future. It will not, however explain the constant amounts of P leached from the Bh, thus, the suggested theory of intrinsic chemical equilibrium between precipitated P and adsorbed P and between adsorbed P and

mobile or leachable P.

- pp 55. This would be another speculation.
- p 60. Recommendation was revised and moved to project recommendations as suggested.
- R^2 values, although small or negligible at least give us some measure of the relations, hence are meaningful. Multiple regression may be done in the future for publication.
- Sentence in former p. 76 has been removed.
- Grinding was done by Lubos without clearing it with Dr. Rechcigl or Alcordo.
- Monthly values are now given as suggested.
- Berm breach is now discussed on p 137, par.3.

SOIL & WATER ENGINEERING TECHNOLOGY, INC.

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November 21, 2002

Ms. Steffany Gornak
South Florida Water Management District
Okeechobee Service Center
205 North Parrott Ave, Suite 201
Okeechobee, FL 34972

RE: EAAMOD Flow Prediction

Dear Steffany:

As we discussed, the estimates of flow off the fields were made by using EAAMOD. This was done because the paddlewheel samplers flow estimates were quite variable between the plots during storm events. The variability was caused by partial clogging of samplers and the gradient across the plots that caused the northern plots to have greater flow than the southern plots. The paddle wheel data were, however very useful in verifying the EAAMOD predictions as to the occurrence and relative magnitudes between events.

The flow estimates within EAAMOD are determined by the calculation of a continuous water balance which accurately tracks the position of the watertable. When the watertable reaches the surface runoff is initiated. The watertable predictions by EAAMOD were very good as verified by comparison to the measured watertable at the site. The accuracy of the watertable predictions provided a high confidence level in the use of EAAMOD for providing the flow at the site.

If you have any questions, just let me know.

Sincerely,

Del Bottcher, Ph.D., P.E.

CC: Jack Rechcigl

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PROJECT EXECUTIVE SUMMARY

The project consisted of (a) agronomic and (b) water quality field experiments with the following objectives: (1) to evaluate the effectiveness of Ca amendments in improving the retention capacity of soils for fertilizer P applied to stargrass pastures, (2) to reevaluate the current IFAS (Institute of Food and Agricultural Sciences) P fertilizer rate recommendations for improved pasture grasses using stargrass as the test crop, (3) to use the data collected to calibrate the EAAMOD (Everglades Agricultural Area Model) computer model and (4) to use the calibrated computer model to extend the field results to other field conditions and untested forages.

Agronomic Field Study (AGFS). The treatments consisted of 0, 12.5. 25, and 50 kg P ha^{-1} applied annually (April to May) for three years (1999, 2000, and 2001) to established stargrass (Cynodon sp.) pasture in Okeechobee Co. at the Williamson Cattle Ranch. Soil was Immokalee fine sand (sandy, siliceous, hyperthermic Arenic Alaquods). Calcium amendments were calcium carbonate and mined gypsum applied once at the start of the study (1999) at 0, 2, and 4 Mg ha^{-1}, pure basis, to plots that received 50 kg P ha^{-1}. Treatments were replicated four times using 32 plots each measuring 15 m x 30 m. Forage samples were collected once every 30-35 days for yield and for forage quality analysis. Forage quality measures analyzed were crude protein (CP), *in vitro* organic matter digestibility (IVOMD), and macro and micro nutrients. Soils were analyzed for Mehlich I extractable nutrients and for the various P fractions.

Water Quality Field Study (WQFS). For use in modeling, a fully automated weather station (Campbell Scientific, Inc.) was installed in the middle of the agronomic study area on April 26, 1999 to record weather data. Wells (PVC pipes) were also set up to monitor depth of water table at the station. Data collected consisted of the following:

Rainfall
Solar radiation
Air temperature
Soil temperature at 45 cm
Watertable above the spodic horizon (hardpan)
Watertable below the spodic horizon (hardpan)

The station was provided with a cellular phone communications package that allows for remote access for data downloads and station program maintenance. It also had a voice synthesizer and software that allowed it to call the field staff at the Range Cattle Research and Experiment Station (RCREC) to alert them to a rainfall event so that a sampling trip can be scheduled. The station can also call Soil and Water Engineering Technology, Inc. (SWET, Inc.) in Gainesville if a transducer error has occurred. SWET also does a daily download of data to keep track of the station's performance.

A 15-30 cm deep perimeter ditch around each agronomic plot was constructed and a flow integrating sampling device to collect runoff sample (paddlewheel-type) was set in place at each plot. The runoff from the plots flows out into the experimental block drainage ditches and into a main drainage ditch. The sampling devices were inspected every time there was a significant rainfall event; total sample volumes were recorded and small volumes of samples were collected and prepared for storage according to a sampling protocol.

Subsurface or ground water samples were collected at two depths from two wells consisting of 5-cm inside diameter PVC pipes installed at the center of each plot set 0.5 m apart. The "shallow" well pipes have their lower ends down to about 0.5 m (at the E horizon) and those of the "deep" well pipes down to about 1.0 m (at or below the Bh horizon) from the surface of the soil. Water samples were collected at least once each month or after every major rainfall event and prepared for storage according to the sampling protocol. Watertable levels were also measured and recorded every collection time.

Water samples were analyzed for P (ortho-P and total P) using a colorimetric method at a detection limit of 5 ppb, and also by inductively coupled argon plasma (ICAP) spectroscopy at a detection limit of 0.1 ppm. Specific conductivity and pH were also determined.

To help explain and/or confirm field results, three greenhouses studies were conducted during the first year (1999) using similar field treatments at the RCREC. Greenhouse study 1 (GS1) used potted individual soil horizons of Immokalee fine sand, with no stargrass planted, and leached over a 220-day period eight times sequentially, the Ap horizon using deionized water, the E horizon using Ap leachates, and the Bh horizon using E leachates. Greenhouse study 2, part I (GS2-I) also used potted individual soil horizons and pure sand planted to stargrass to determine the influence of individual horizons to fertilizer P applied twice at 50 kg P ha^{-1} each time and to determine the capacity of stargrass to utilize fertilizer P. And greenhouse study 2, part 2 (GS2-II), the greenhouse duplicate of the field experiment, used reconstructed soil profile of Immokalee fine sand planted to stargrass and the complete field treatments. Studies GS2-I and GS2-II were watered regularly, and water samples were collected ten times over a 24-week period.

Field and Greenhouse Agronomic Results. The field study showed that P fertilizer did not increase forage yields nor improve forage quality measures such as crude protein (CP) contents and *in vitro* organic matter digestibility (IVOMD). Forage from plots where no fertilizer P was applied for three crop years did not show any deterioration in forage yield and in quality on the third year; forage yields were influenced more by crop year, which had distinctly different rainfall levels during the growing season, than by P fertilization. Rainfall, though not an experimental variable, was recorded year-round during the three-year period of the study. Forage yields in greenhouse studies GS2-I and GS2-II also failed to increase with increasing amounts of P indicating that Immokalee fine sand has sufficient soil P to meet the needs of stargrass for maximum yield.

Greenhouse study GS2-II and the field study showed that P fertilization increased P contents significantly and linearly with P rates. With no differences in forage yields within each study, P contents in regrowth forage ranged from 0.27 to 0.29 for GS2-I, 0.22 to 0.30 for GS2-II, and 0.19 to 0.34 % for the field study. These data would indicate that stargrass pastures on Immokalee fine sand with regrowth forage containing 0.19 % P do not need any P fertilizer for maximum yield. Evaluation of P uptake by stargrass indicated that P fertilization only helped to build up soil P at the rate of at least 0.70 kg P for each kg of fertilizer P applied per ha per year with no agronomic benefits. Such build up increased the potential loss of soil P through runoff and leaching. Soil P fractionation using greenhouse and field soil samples indicates that the Ap, E, and Bh horizons of Immokalee fine sand have already high levels of P even in the unfertilized samples.

Calcium in forage in the field study only increased slightly relative to the increases in P with P rates resulting in the deterioration of the Ca:P ratio to levels that could be detrimental to feed efficiency and to animal growth and development. Phosphorus fertilization as low as 12.5 kg ha^{-1} reduced Ca:P ratio close to the acceptable lower limit of 1:1 just after three years of application. The highest rate of 50 kg ha^{-1} reduced Ca:P ratio to less than 1 by the second year of application. One time application of calcium carbonate or gypsum at 4 Mg ha^{-1} at the beginning of the study proved ineffective in preventing the deterioration of the Ca:P ratio to below the lower acceptable limit after three years of high P fertilization. Regrowth forage from greenhouse study GS2-II had Ca:P ratios ranging from 2.2:1 for the highest P rate to 3.1:1 for the control indicating no deterioration in this ratio with P fertilization. These acceptable Ca:P ratios could be attributed to the leaching of P, but not of Ca, out of the root zone upon continuous watering reducing P uptake with Ca uptake remaining relatively unaffected.

Field and Greenhouse Water Quality Results. The field water quality analysis indicated that the P fertility response for the stargrass was similar to what the previous bahiagrass study showed, that increased P application rates appear to exponentially increase soil-water P levels as fertilizer rates exceeded grass uptake rates. The runoff TP concentrations also increased with P fertilizer rate, but more linearly. The study also showed that the soil amendment Ca lime slightly decreased TP concentration in runoff while the gypsum amendment appeared to have slightly increased TP concentrations. Similar effects of P rates, lime, and gypsum in terms of leachate P concentrations were noted in greenhouse study GS1 but more strongly than these field observations had shown. Greenhouse study GS2-II which used Ca amendments that were ground to powder showed no effect of Ca lime on P levels in soil water or leachates sampled at various depths.

The data also indicated that the field was probably not fully equilibrated to the treatment trials, which meant that the treatment effects observed could possibly become even greater over more time. The dry conditions during the first two years of the study increased the equilibration time resulting in only the third year of data being useful for assessing the treatment effects. In spite of the equilibrium issue, the results clearly show that over fertilization will result in higher P losses. Though promising, the long term benefits of the Ca lime amendment are not clear from this study due to the equilibrium effect, and should be further investigated using higher application rates. Gypsum is clearly not a beneficial amendment for reducing P losses from pastureland.

After calibration, the EAAMOD model was able to accurately simulate the P fertilizer treatment effects observed at the site. The simulated and observed values for 2001 were highly correlated for the various phosphorous treatments. Regressing the simulated and observed TP outflow concentrations gave a slope of 1.01 and an R2 of 0.76 indicating a good trend and correlation between simulated and observed values. The model simulated the TP discharge concentration changes as influenced by P fertilizer rates, and therefore should be a useful tool for investigating other potential fertility BMPs on other soils and crops in the area.

Recommendations. Considering the major agronomic findings, it is concluded that stargrass on Immokalee fine sand does not need any P fertilization. Hence, it is strongly suggested that IFAS re-evaluate its recommendation on P fertilization of stargrass and other similar improved pastures species on Immokalee fine sand.

With an Ap soil pH of 4.4, forage yield data indicated that stargrass in the area may benefit from liming using calcium carbonate which showed some tendencies to increase forage yields. Greenhouse study GS1 demonstrated very strongly the ability of calcium carbonate or dolomite to reduce P losses through leaching and, therefore, would certainly be an added benefit to the use of lime on these soils. The greenhouse studies indicated that the use of the slowly soluble granular lime materials would be more effective to retain P in the soil than highly soluble fine-ground ones.

The economic justification of applying lime solely to retain P in the soil profile in Spodosols may not appear to be warranted because, as long as P is not permitted to be lost through runoff and/or lateral flow through the E horizon into drainage ditches, 95 % of Ap soil P and at least 99 % of fertilizer P are eventually screened out from the percolating water or leachates and retained. However, ranchers should be encouraged to apply lime to achieve soil pH for optimum forage yield which should also help retain soil P in the Ap horizon (root zone).

The greenhouse studies with stargrass also demonstrated pasture cropping as a major method or practice to prevent P losses through leaching and, possibly, also runoff.

Finally, in order to minimize soil and/or fertilizer P losses from agricultural lands, the following should be considered: (1) do not apply fertilizer P to spodic soils unless necessary or when % P in regrowth forage has fallen far below 0.19 %, (2) increase the capacity of the Ap horizon to retain soil P by use of appropriate soil amendments like limestone or dolomite at rates higher than 4 Mg ha^{-1}, (3) prevent P-loaded water atop the Bh horizon, that is in the E horizon, from reaching open ditches that drains into open bodies of waters or lakes, hence, construction of drainage ditches should be discouraged or when necessary must not cut through the E horizon, (4) allowing surface water time to leach through the Bh horizon by confining excess water in wetlands, and (4) leaving no significant portion of land left uncovered or unplanted to pasture grasses.

PROJECT INTRODUCTION

The paper is an overview of the key results of a project conducted by the University of Florida for the South Florida Water Management District under Contract No C-10201. The project consisted of two field and three greenhouse studies. The field studies, agronomic and water quality, were conducted on Immokalee fine sand (sandy, siliceous, hyperthermic Arenic Alaquod), a Spodosol, to evaluate the effects of P fertilizer, limestone, and gypsum rates on stargrass (Cynodon sp.) forage yield and quality and on P losses through runoff and leaching. Three greenhouse studies were conducted to evaluate the fate of P fertilizers and the effects of limestone and gypsum on P losses through leaching using soil samples from Ap, E, and Bh horizons of Immokalee fine sand where the field studies were conducted. Results from the greenhouse studies were expected to help explain and/or lend support to field results and to provide soil and Ca amendment parameters which could be of great value in modeling P losses under field conditions.

Only the key results of the greenhouse studies related to the field agronomic and water quality studies are presented. These then are used in the discussions of the field results. Detailed final reports of the various studies may be obtained from the South Florida Water Management District (SFWMD).

The major elements responsible for the growth of aquatic biota, hence to possible eutrophication of fresh water bodies, are N, C, and P. Because atmospheric N and C are also available to fresh water bodies or lakes through exchange between water and the atmosphere making their control difficult, attention has been focused on controlling P input to make P a limiting nutrient to aquatic biota. Phosphorus has been regarded as the primary factor controlling the eutrophication of Lake Okeechobee (Federico et al., 1981) and other receiving water bodies in south Florida. To help control the proliferation of algal blooms in Lake Okeechobee, management and research efforts of the SFWMD have been directed toward reducing P in the watershed from external and internal sources (SFWMD SWIM Plan, 1997). It was recognized very early on that the major sources of P getting into Lake Okeechobee via water surface runoff were fertilizer P on highly fertilized pastures and dairy animal wastes (Allen, Jr., L.H., 1988; Gunsalus et al., 1992). However, watershed management for water quality improvement in the Lake Okeechobee watershed has been primarily focused on animal waste management. Less attention was given to over-fertilization of improved pastures as a possible major contributor to P levels in water runoff.

The question of over P fertilization of pastures was earlier raised in the case of bahiagrass (Paspalum notatum). In the 1980's, little was known of the P requirements of bahiagrass for optimum forage production and quality despite the fact that nearly one million hectares of pasture land in Florida were cropped to bahiagrass. Some results of field studies, however, appeared to indicate that the then recommended rates of P fertilization of bahiagrass (48 kg P ha^{-1} for high production, low fertility soils) can be reduced substantially without forage production losses. Not only would lower P fertilization recommendations reduce fertilizer expenses of ranchers, they could also help reduce the pace of eutrophication of lakes, such as Lake Okeechobee, being brought about by P sources other than the P fertilizers. A 1990 P fertilizer rate and water quality study funded by the SFWMD (Rechcigl et al., 1990; Rechcigl and Bottcher, 1995), demonstrated that P fertilization rates can be reduced substantially without adverse effects on bahiagrass forage yield and quality. They also reported that P levels in surface water runoff were reduced by 33 to 60% as P fertilization rates decreased from 48 to 12 kg P ha^{-1}. This study in conjunction with other studies eventually led to the present recommendation of zero P for bahiagrass pastures grown in South Florida (Kidder et al., 1998; UP/IFAS Extension Circular 817 - Soil, Container Media, and Water Testing Interpretations and Standardized Fertilization Recommendations).

The recommended P rate for improved pasture grasses, other than bahiagrass, including stargrass (Cynodon sp.) is about 19 to 20 kg P ha^{-1} per year. Depending on soil P levels, P rates could range from zero for high P soils to 20 kg P ha^{-1} for low P soils (Kidder et al., 1998; UP/IFAS Extension Circular 817 - Soil, Container Media, and Water Testing Interpretations and IFAS Standardized Fertilization Recommendation). Relative to the control, the study of Rechcigl and Bottcher (1995), however, indicated that substantial amount of P were still being lost through surface runoff even at the low rate of 12 kg P ha^{-1}. Obviously, fertilization even at optimum rates can cause elevation of P levels in surface runoff. Thus, in addition to establishing the optimum rates of P fertilization for improved pasture grasses, certain soil amendments capable of tying up dissolved P from applied fertilizers also need to be studied to determine their effectiveness in reducing losses of fertilizer P from agricultural lands through runoff and leaching.

Phosphorus reactions and transport in soils have been widely studied by many investigators in relation to plant nutrition as well as to water quality. Mansell et al. (1995) summarized the general characteristics of the chemical reactions of P affecting P transport in acid, sandy soils in terms of (1) multiple processes and heterogeneous sorption micro-sites, (2) convex nonlinear sorption, (3) partial irreversibility, (4) multiple rate (fast and slow) reaction kinetics, and (5) competitive sorption with other anions (both organic and inorganic). Various techniques for reducing P leaching and runoff from acid soils to surface waters have been suggested. One way is the use of BMPs (best management practices) which, in the case of beef cattle pastures, mean mainly grazing management, drainage control of high-intensity areas, fencing animals from ditches and streams, reasonable and accurate application of fertilizers, etc. (Bottcher et al., 1999). Another way is the application of different amendments that should ensure P binding and retention in soil. The amendments most often used are limestone, dolomite, and gypsum; their beneficial effects being attributed mainly to changes in pH and calcium supply (Anderson et al., 1995, He et al., 1996). These amendments, however, are not efficient in all soils and with all P sources. Probert et al. (1991) showed only a small effect of liming on P sorption and P concentration in solution in their pot experiment with three Australian soils. Holford et al. (1994) observed even a decrease in soil sorptivity for P and an increase in soluble P during three years after lime application to some Australian soils. The authors attributed this effect mainly to pH-induced increase in surface negative charges and dissolution of soil Fe and Al phosphates. Increase of available P after liming was shown also by Barade and Chavan (1998) and Mongia et al. (1998) in acid soils of India. Lindsay (1981) explained that liming acid soils containing Fe and Al phosphates can be expected to increase phosphate solubility; however, if the soils are limed to pH > 6.5, Ca phosphates can precipitate and lower phosphate solubility.

Iron and Al materials represent another group of amendments for reducing P leaching (Ward and Summers, 1993, Robertson et al., 1997, Phillips, 1998). A major laboratory study on P retention in Florida soils using these amendments, Al (as alum: $Al_2(SO_4)_3.18H_2O$) and Fe ($FeSO_4.7H_2O$), together with calcium carbonate and gypsum was conducted by Anderson et al. (1995). The study indicated that, in general, the various soil amendments can significantly reduce the amounts of soluble P (PO_4-P) leached from Florida soils. Calcium carbonate was found effective when used to raise and maintain soil pH in the range of 7.0 - 7.5, while gypsum was effective at all pH ranges under anaerobic and at varying degrees under aerobic condition. It was also highly effective in Spodosols with high loads of manure. Alum and ferrous sulfate were also found effective. Some limitations of the applicability of the study should be considered. As pointed out by the authors themselves, the use of alum and ferrous sulfate may be limited due to Al's potential toxicity to plants, in the case of alum, and to costs for both. In the case of calcium carbonate, raising and maintaining the soil pH between 7.0 and 7.5 may not be suitable for crops needing a slightly acidic pH (5.0 - 5.5 optimum pH for most forage crops) for optimum production. Whether their results will hold true under field or even greenhouse conditions has not been determined. Hence, the need to determine the effects, under field conditions, preferably supported by data from controlled greenhouse studies, of the more acceptable amendments (lime and gypsum) not only on surficial ground water (surface runoff and shallow well water) quality but also on forage yield and quality at various levels of P fertilization.

Pot leaching experiments to study P losses in soils may have limited applicability, but they are valuable to help explain data obtained from field experiments or to test potential treatments for field application. The main advantages of greenhouse pot experiments compared to field trials are the relatively low initial variability among the individual units and easier control of the influencing factors and conditions. In comparison with laboratory experiments, greenhouse studies provide better simulation of natural conditions, especially when complete soil profile is used and plants are included. However, pot experiments also present some limitations. The simulated soil profile can never be absolutely identical with the natural one since the soil was disturbed and could not settle down naturally; it represents relatively small volume of soil; new plants cannot behave in the same way as in a well-established pasture; and occurrence of some preferential pathways is inevitable, especially along the pot walls, etc. Ibrikci (1993) used simulated profiles for studying P availability on a Spodosol (Myakka fine sand). She showed the spodic horizon to be a source of P for plants. Coutinho et al. (1997) carried out incubation and pot experiments to evaluate the effects of composted sewage sludge on P and N availability. Application of this sludge led to a decrease in Ca-bound P and increase in more firmly held forms, especially non-extractable fractions of P and P bound on Fe and Al. Wang et al. (1995) conducted experiments with small pots packed with individual soil horizons without plants to study the forms of P in leachates. They showed that in the leachates from the Ap horizon the phosphates and hydroxyphosphates associated with Ca and Mg were the most abundant; species of Al-P and Fe-P were not found in those leachates. Bolan et al. (1994) showed in their greenhouse and laboratory experiment that P sorption in soil was decreased by low molecular weight organic acids. Ghani and Rajan (1996) used pot experiment for determination of the influence of pH on dissolution and uptake by ryegrass of different P fertilizers.

PROJECT OBJECTIVES

The three main objectives of the project were:

(1) to evaluate the effectiveness of limestone and gypsum in improving the retention capacity of soils for fertilizer P applied to stargrass pastures;

(2) to reevaluate the current P fertilizer rate recommendations for improved pasture grasses using stargrass as the test crop; and

(3) to use the data collected to calibrate the EAAMOD (Everglades Agricultural Area Model) computer model and to use the calibrated computer model to extend the field results to other field conditions and untested forages.

PROJECT MATERIALS AND METHODS

In order to achieve the project objectives, both field and greenhouse experiments were conducted simultaneously. Field experiments on stargrass fertilization and water quality monitoring were carried out to provide data to help formulate conclusions and recommendations using EAAMOD-Field Program called for in the project objectives. Greenhouse experiments were conducted to provide data to help explain and/or support field experiment results and to provide soil and Ca amendment parameters which could be used in modeling P losses under field conditions.

The field experiments were conducted on Immokalee fine sand (sandy, siliceous, hyperthermic Arenic Alaquods), a Spodosol, at the Williamson Cattle Company beef cattle stargrass pasture field, Okeechobee Co. Samples from Ap, E, and Bh horizons from the said pasture field were used for the greenhouse studies.

Greenhouse Study 1 (GS1): Individual Soil Horizons with No Stargrass Planted

Objectives, treatments, and experimental design. The objectives of the study were to (a) evaluate the effects of surface-applied lime and gypsum materials on the leachability of soil and fertilizer P in potted Ap, E, and Bh horizons of Immokalee fine sand with no stargrass planted and (b) determine the various leachate properties associated with leachate P concentrations, hence with P mobility. Treatments (Table GS1-1) were factorial combinations of P rates using triple superphosphate (TSP) applied twice and Ca amendments MG (mined gypsum - 77% $CaSO_4.2H_2O$), PG (phosphogypsum - 91% $CaSO_4.2H_2O$), CL (calcium carbonate - 97% $CaCO_3$), and DL (dolomite - 54% $CaCO_3$ + 42% $MgCO_3$) applied once at the start of the study (Table GS1-2). Treatments were replicated three times, and the 45 pots for each soil horizon were arranged in the greenhouse in a randomized complete block design.

Table GS1-1. Factorial combinations of P rates (0, 50, 100 kg ha^{-1} equally split and applied 140 days apart) and Ca amendments - 0 Ca , MG, PG, CC, and DL at 800 kg Ca ha^{-1} - as treatments.

Treatment no.	Corresponding P (kg ha^{-1}) + Ca amendment (800 kg Ca ha^{-1})				
T1, T2, T3, T4, T5	0P + 0Ca	0P + MG	0P + PG	0P + CC	0P + DL
T6, T7, T8, T9, T10	50P + 0Ca	50P + MG	50P + PG	50P + CC	50P + DL
T11, T12, T13, T14, T15	100P + 0Ca	100P + MG	100P + PG	100P + CC	100P + DL

Table GS1-2. pH and total chemical analysis of phosphogypsum (PG) and mined gypsum (MG).

Amendment	pH	P	K	Ca	Mg	Al	Fe	Mn	Cu	Zn
		mg kg^{-1}								
Phosphogypsum	5.5	3000	74	250000	10	1100	575	1.9	1.3	6.0
Mined gypsum	6.3	80	14800	222000	12700	700	800	ND†	ND	ND

†Not determined.

Soil potting, pre-treatment, and treatment application. Plastic pots 14-cm tall tapering from an 11.4-cm top to a 10.2-cm dia bottom were used. The pots had eight drainage holes around the side close to the bottom separated 1 cm apart each measuring 2.5 cm long and 0.3 cm wide. Plastic strips placed inside the pots were used to cover the holes to prevent the sandy soil from running out with the water. Each soil horizon bulk sample (Table GS1-3) was air-dried, mixed thoroughly, and packed into the designated pots to within 1.2 cm from the top. The potted Ap, E, and Bh soil columns measured 12.8 cm long with a midpoint diameter of 10.7 cm and weighed, on the average, 1545, 1680, and 1795 g yielding typical Immokalee fine sand bulk densities (USDA-SCS-DACS, 1984) of 1.3, 1.5, and 1.6 g cm^{-3}, respectively. The mean water holding capacities (WHC), from saturation at air dry state to drainage overnight, were 0.36, 0.24, and 0.24 mL g^{-1} for the potted Ap, E, and Bh soils, respectively. These were determined using three replicates of each soil horizon samples which were similarly packed as the experimental ones but not used in the study.

Two WHC-volumes of deionized water were applied to each of the experimental Ap, E, and Bh pots. Leachates were collected into plastic cups overnight and bulked into Ap, E, and Bh leachates.

Table GS1-3. Pre-treatment pH and Mehlich I extractable elements and organic matter (OM) in the top 15-cm layer of Ap, E, and Bh horizons of Immokalee fine sand used in the study.

Horizon	pH	P	K	Ca	Mg	Fe	Mn	Cu	Zn	Al	OM
			---------------------------------- mg kg^{-1}							-------------------------------	%
Ap	4.4	5.93	22.8	482.6	27.5	8.02	0.434	0.049	0.779	42.1	3.23
E	5.1	1.34	0.7	77.7	3.3	1.93	0.035	0.022	0.263	6.6	0.20
Bh	4.6	49.13	2.2	263.7	19.3	3.62	0.038	0.019	0.294	1169.0	3.03

Equal volumes of the bulked leachates were applied to each of the corresponding potted soil horizons. This procedure was done to narrow down wide variations in soil variables within each soil horizon. Immediately after this pre-treatment, the moist potted E and Bh soils were covered at all times with heavy black plastic sheets, except during leaching, to keep sunlight out and the soil moist to simulate subsoil conditions.

Half of the P fertilizer rates (with the other half applied 140 days after) and the Ca amendments were applied together to the surface of the potted Ap soils. Also applied with the treatments were, on ha-basis, were 90 kg N (NH_4NO_3), 75 kg K (KCl), and 30 kg commercial micro nutrient mix (2.4% B, 2.4% Cu, 14.40% Fe, 6.0% Mn, 0.06% Mo, and 5.6% Zn). All the materials were computed based on the area (90.6 cm^2) at the midpoint of the tapering pots used in the study.

After treatment application and thereafter, the exposed potted Ap soils were watered with 100 mL or about 1-cm depth of water once a week between leachings.

Sequential leaching. Sequential leaching of the potted soil horizons was done as follows: 1000 mL of deionized water (about twice the WHC of the potted Ap soils which corresponded to about 11-cm depth of water or rainfall) was applied to each of the potted Ap soils, the leachate collected overnight into 1000-mL plastic cups, the volumes of the leachates recorded the next day, and about 90 mL of the Ap leachate from each pot set aside for the various chemical analyses; the procedure was repeated on the E soils by applying measured volumes of Ap leachates to the corresponding potted E soils and setting aside 60 ml of the E leachates; and finally on the Bh soils by applying measured volumes of E leachates to the corresponding Bh pots. Leaching was done 15, 30, 60, 90, and 120 d after the first P application and 25, 50, and 80 d after the second P application for a total of eight leaching events over a 220-d period.

Soil sampling and sample preparation. After the study, the potted soils were sampled for the various chemical analyses. Samples were air-dried, pulverized, and passed through a 2-mm sieve.

Greenhouse Study 2, Part I (GS2-I): Individual Soil Horizons Planted to Stargrass

Objectives, treatments, and experimental design. The study was conducted to (a) determine the impact of stargrass on the leachability of fertilizer P (TSP) applied to the surface of potted Ap, E, and Bh horizon samples from Immokalee fine sand, (b) determine the utilization of P fertilizer by stargrass in the individual soil horizons and in pure sand, and (c) compare the leachability of fine-ground and granular TSP in the Ap horizon and their effects on stargrass forage yield and quality. Commercial granular TSP fertilizer was ground manually to produce the fine-ground materials. The potted soil horizons as treatments are given in Table GS2-I-1. They were replicated three times and arranged in the greenhouse in a randomized complete block design.

Table GS2-I-1. Treatments (horizons and pure sand) and P fertilizer (TSP) used.

Treatment	Horizon	50 kg P ha^{-1} applied twice (100 kg P ha^{-1})
T1	Ap	Fine-ground TSP
T2	Ap(granular)	Granular TSP (unground commercial TSP)
T3	E	Fine-ground TSP
T4	Bh	Fine-ground TSP
T5	Pure sand	Commercial pure sand, fine-ground TSP

Soil potting, planting of stargrass, and treatment application. Certain major elements in soils used for the study are given in Table GS2-I-2.

Polyvinyl chloride (PVC) tubes with inside diameter of 20 cm and measuring 37 cm long, including the caps at the bottom, were used for pots. Each pot was provided with a drainage hole at the bottom. Over the drainage hole were laid, one on top of the other, two layers of rough screen, a layer of fiber glass, a Whatman micro-fiber filter with a pore size of 1 μm, and a layer of fine sand in order to obtain relatively clear bottom leachates and to prevent loss of soil. The Bh, E, and Ap horizon samples were then packed into their respective tubes to a depth of 26 cm and bulk densities of 1.3 g cm^{-3} for the Ap and 1.5 g cm^{-3} for the E, Bh, and pure sand. The commercial pure sand served as a check.

The pots were wetted to saturation with deionized water and drained overnight to WHC. These were then planted to swards of stargrass or sods, collected earlier from the field experimental plots, and cut down to a stubble height of 5 cm. Just enough planting materials were used to cover the soil surface in the PVC tubes. The plants were watered three times a week When the plants became well established, about three weeks after planting, a single rate of P was surface-applied (May 5, 1999)

Table GS2-I-2. Pre-treatment pH and Mehlich I extractable elements in Immokalee fine sand used in Greenhouse Study 2, Part I and Part II.

Horizon	pH	P	K	Ca	Mg	Fe
		----------------------------------	----------------------------------	mg kg^{-1}	------------------------------	
Ap	4.7	2.0	7.6	344	8.0	11.2
E	4.9	1.2	4.4	60	4.0	4.4
Bh	5.4	102.8	21.4	566	88.0	3.4
Pure sand	-	-	-	-	-	-

to all pots to initiate the study together with blanket application of 90 kg N ha^{-1} (NH_4NO_3), 75 kg K ha^{-1} (KCl), and 50 kg KBr ha^{-1} (as tracer). A second application of TSP was made 98 days (14th week) after the first application, again with blanket application of 90 kg N ha^{-1} (NH_4NO_3), 75 kg K ha^{-1} (KCl), and 50 kg KBr ha^{-1} (as tracer).

Watering and leachate sampling. Two days after the first fertilizer application, the soil columns were watered with the bottom drainage holes closed. The applied water was allowed to stand overnight. The first post-treatment leachates were collected the next morning by allowing the water to drain out through the drainage holes. The second sampling was made one week and the third sampling three weeks after treatment application. Thereafter, sampling was done every three weeks until the second TSP application made on the 14th week after the first application. Water sampling was resumed one week after the second TSP application and then every three weeks thereafter. In all instances, sampling was done one day after watering to allow the system to attain a level of equilibrium. About 75 ml from each pot was collected each time whenever that amount of free water was available.

Water application during the period of study averaged 3.8 mm day^{-1} which corresponds to a daily average of 3.7 mm day^{-1} over several years' period at the experiment station at Ona.

Forage sampling and sample preparation. The top growth of the plants was cut for samples down to a stubble height of 8 cm every 30 days except the first harvest which was done three weeks after treatment application due to a very vigorous growth. Plant samples were oven-dried for 4-6 days at 60°C and ground to pass an 0.84 mm sieve prior to analysis.

Soil sampling and sample preparation. After the study, the potted soils and the pure sand were sampled and samples were air-dried and passed through a 2-mm sieve for the various analyses.

Greenhouse Study 2, Part II (GS2-II): Reconstructed Soil Profile Planted to Stargrass

Objectives, treatments, and experimental design. The two objectives of this study were similar to the project objectives with the experiment conducted in the greenhouse for better control of the experimental variables. These were (a) to evaluate the effectiveness of surface-applied Ca amendments calcium carbonate (CL), dolomite (DL), and mined gypsum (MG) in improving the retention capacity of Spodosols planted to stargrass for fertilizer P and (2) to reevaluate the P fertilizer needs of stargrass on Immokalee fine sand in terms of forage yield and quality. Treatments (Table GS2-II-1) were replicated four times and arranged in the greenhouse in a randomized complete block design.

Table GS2-II-1. Experimental treatments (P applied twice for a total of 0, 25, 50, 100 kg P ha^{-1}).

Treatment	P (TSP)	MG	CL	DL
	--- kg ha^{-1} ---		--- Mg ha^{-1} ---	
T1	0.0	0	0	0
T2	12.5	0	0	0
T3	25.0	0	0	0
T4	50.0	0	0	0
T5	50.0	2	0	0
T6	50.0	4	0	0
T7	50.0	0	2	0
T8	50.0	0	4	0
T9	50.0	0	0	2
T10	50.0	0	0	4

Rates in Table GS2-II-1 for each Ca amendment were based on 100% content. The materials were obtained from the same bulk sources as those used in Greenhouse Study 1 (Table GS1-2). Both Ca amendments and TSP were ground to powder as in GS2-I.

Soil potting, planting of stargrass, and treatment application. Polyvinyl chloride (PVC) tubes with inside diameter of 20 cm and 100 cm long and capped at the bottom were used for pots. Each pot was provided with a drainage hole at the bottom over which were laid, one on top of the other, two layers of rough screen, a layer of fiber glass, a Whatman micro-fiber filter with a pore size of 1 µm, and a layer of pure sand in order to obtain relatively clear leachates and to prevent loss of soil particles. A transparent tubing connected to a water outlet drilled through the side of the tube served as a water level indicator.

The individual bulk soil horizon sample was mixed thoroughly before potting. The Ap samples were passed through 2-mm mesh sieve to remove organic debris. The reconstructed soil profile from naturally moist soil horizon samples packed into the tube consisted of 5 cm of C horizon, 20 cm of spodic horizon (Bh), 40 cm of E horizon, and 20 cm of Ap horizon including sod. The bulk density of the reconstructed Ap horizons was approximately 1.3 g cm^{-3}; the other horizons had bulk density of about 1.5 g cm^{-3}. During potting two 2-cm inside diameter PVC pipes set two inches apart were installed at the center of each tube to serve as sampling wells. The lower tips of the pipes were covered with two layers of rough screen, a layer of fiber glass, and a Whatman micro-fiber filter (pore size: 1 μm) in order to obtain relatively clear water samples. The lower tip of the "shallow well" rested at the bottom of the E horizon (60 cm); that of the "deep well" at the bottom of the spodic horizon (80 cm).

The soil columns or profiles were saturated initially with deionized water and then drained until the water levels in the columns settled to approximately 7 cm above the spodic horizon. Stargrass sods or swards from the Williamson pasture, with the debris removed and stubble height cut to 5 cm, were planted in each tube. Three weeks after planting, the various treatments were applied to the corresponding pots. Rates of 90 kg N ha^{-1} (NH_4NO_3), 75 kg K ha^{-1} (KCl), and 50 kg KBr ha^{-1} (as tracer) were applied to all pots. A second application of TSP treatments was made on the 14th week after the first application, again with blanket application of 90 kg N ha^{-1} (NH_4NO_3), 75 kg K ha^{-1} (KCl), and 50 kg KBr ha^{-1}.

Watering and soil water sampling. Pre-treatment (day zero) samples were collected from all pots two weeks after planting. Two days after treatment applications, soil columns were watered to keep water levels in the range of 5 to 15 cm above the spodic horizon in order to simulate ground water level and to enable water collection from the shallow wells and the first post-treatment (3rd day) water samples were collected the following day but only from the shallow wells. The second sampling was made one week and the third sampling three weeks after treatment application. Thereafter, sampling was done every three weeks until the second P fertilizer application. Sampling was then resumed one week after and every three weeks thereafter. In all instances, sampling was done one day after watering to allow the system to attain a level of equilibrium taking out sample volumes of about 75 mL from the shallow wells, the deep wells, and the bottom leachates in that sequence.

Water application during the period of study averaged 3.8 mm day^{-1} which corresponds to a daily average of 3.7 mm day^{-1} over several years' period at the experiment station in Ona.

Forage sampling and sample preparation. The top growth of the plants were cut for samples down to a stubble height of 8 cm every 30 days except the first harvest which was done three weeks after treatment application due to a very vigorous growth. Plant samples were oven-dried for 4-6 days at 60°C and ground to pass an 0.84 mm sieve for the various analyses.

Soil sampling and sample preparation. Samples from the different horizons of the reconstructed soil profile were collected after the study. Samples were air-dried and passed through a 2-mm sieve for the various analyses.

Field Study 1, Agronomic (AGFS): Phosphorus Fertilization and Effects of Calcium Amendments on Stargrass Forage Yield and Quality and on Soil

Objectives, treatments, and experimental design. The objectives of the study are listed in the Project Objectives. Treatments are given in Table AGFS-1. The plots used measured 15 m x 30 m and the treatments, replicated four times, were laid out in a randomized complete block design (Figure AGFS-1).

Table AGFS-1. Phosphorus fertilizer and Ca amendment rates based on 100% $CaCO_3$ or $CaSO_4.2H_2O$ content; P fertilizers applied annually and Ca amendments applied once at the start of the study.

Treatment	P rates	Calcium carbonate (CL)	Mined Gypsum (DL)
	---- kg P ha^{-1} -----	------------------ Mg ha^{-1}	-------------
T1	0.0	0	0
T2	12.5	0	0
T3	25.0	0	0
T4	50.0	0	0
T5	50.0	2	0
T6	50.0	4	0
T7	50.0	0	2
T8	50.0	0	4

Application of treatments. Granular triple superphosphate (TSP), used as source of P, was applied annually, in March of 1999 and 2000 and in April of 2001, to the designated plots. Commercial calcium carbonate (CL) and mined gypsum (MG), computed based on 100% $CaCO_3$ or $CaSO_4.2H_2O$ content, respectively, were applied together with P to the designated plots only once in March of 1999. Nitrogen and K at 90 kg N ha^{-1} using NH_4NO_3 and 75 kg K ha^{-1} using KCl were also applied to all plots during treatment application. A second blanket application of 90 kg N ha^{-1}, also using NH_4NO_3, was applied during the last week of August in 1999, 2000, and 2001. Treatments and other fertilizers were applied without staging the pasture.

Forage sampling and sample preparation. For forage yield sampling, the grass in a small area inside each plot was mowed down to a stubble height of 8 cm and a rectangular wire cage was set over the cut area to keep cattle from grazing on it. Forage from this caged area was harvested using a push lawn mower with a cutting width of 0.48 m pushed along the length of 2.23 m (0.48 m x 2.23

Treatment Legend

Tmt	Phos (kg/ha)	Ca Lime (Mg/ha)	Gypsum (Mg/ha)
T1	0	0	0
T2	12.5	0	0
T3	25	0	0
T4	50	0	0
T5	50	2	0
T6	50	4	0
T7	50	0	2
T8	50	0	4

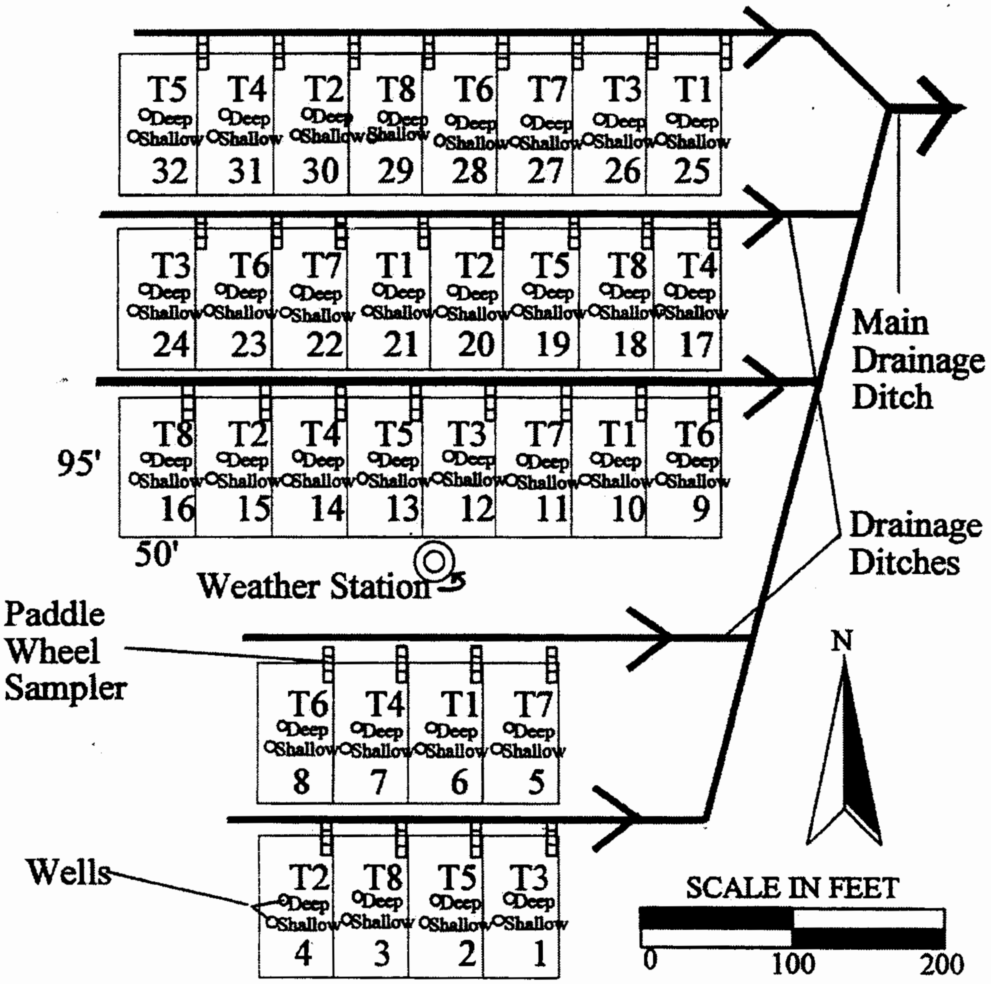

Figure 1. Plot Layout for Williamson Ranch Stargrass Study

m plot size) leaving also an 8-cm stubble. Forage harvest was done 30-35 days after the application of the treatments and the same interval of days thereafter for the subsequent harvest. After each harvest, a new uncut location within each plot was staged down to 8 cm and the wire cage set over it for the next harvest. Forage samples were oven-dried at 60°C for 5-6 days and ground to pass a 0.84 mm sieve for the various analyses. Experimental plots were sampled seven times in 1999 and six times each in 2000 and 2001.

Soil sampling and sample preparation. Pre-treatment soil samples were collected from two plots in each replication block from the surface down to the spodic layer at 15-cm depth interval in March 1999. Post-treatment soil samples were collected in duplicate from each experimental plot from the surface down to the spodic layer at 15-cm depth interval in August 1999, March 2000, October 2000, March 2001, and December 2001. Soils were air-dried and sieved through a 2-mm sieve for the various analyses. The pre-treatment soil analyses are given in Table FS1-2.

Table AGFS-2. Pre-treatment pH and Mehlich I extractable elements and organic matter (OM) in the top 15-cm layer of Ap, E, and Bh horizons of Immokalee fine sand used in the study.

Horizon	pH	P	K	Ca	Mg	Fe	Mn	Cu	Zn	Al	OM
			----------------	----------------	----------------	----------------	mg kg^{-1}	----------------	----------------	----------------	%
Ap	4.4	5.93	22.8	482.6	27.5	8.02	0.434	0.049	0.779	42.1	3.23
E	5.1	1.34	0.7	77.7	3.3	1.93	0.035	0.022	0.263	6.6	0.20
Bh	4.6	49.13	2.2	263.7	19.3	3.62	0.038	0.019	0.294	1169.0	3.03

Field Study 2, Water Quality (WQFS): Phosphorus Fertilization and Calcium Amendments, Phosphorus in Runoff and Ground Water, Weather Data Collection, and Use of Everglades Agricultural Area Model (EAAMOD)

EAAMOD Description

EAAMOD-FIELD is a field-scale model that was originally developed by Soil and Water Engineering Technology, Inc. (SWET) to simulate the effect of management strategies on the water and phosphorus (P) losses from muck fields found in the Everglades Agricultural Area (EAA). The tool is ideal for evaluating the impact of Best Management Practices (BMPs) on P losses.

The model was developed for the unique characteristics of the EAA, but has been updated for use in flatwood soil conditions throughout Florida. In the EAA, there is an organic topsoil covering a marl bedrock that is often separated by an impeding cap rock layer. However, the same layer structure is applicable to Flatwoods soils where the impeding layer is the Spodic horizon and the marl layer becomes the zone below the Spodic horizon. EAAMOD simulates a single field as a function of the soil type, crop type, weather, and the management practices that occur during the season (planting, harvest, phosphorus application, and water management). This manual reflects updates to EAAMOD and its interface to specifically handle the conditions and crops found in the northern Lake Okeechobee basins.

The graphical user interface permits the user to easily change model inputs, run EAAMOD, and then view the results. The user selects the field dimensions, soil, crop type and rotation, management practices, weather files, and water control by answering a few questions on each category. EAAMOD creates the appropriate input files using the user inputs and default values for many of the file parameters.

The management calendar greatly simplifies modifications to management events during the simulation period. The user can easily see the events, change the dates, or change the type of events. Default values are supplied for each parameter to aid the less experienced users. The user can modify the details for any event if more appropriate values are known.

Using these data, EAAMOD simulates the water flow and phosphorus transport from the field. By running several different long-term scenarios, the effects of these BMPs can be evaluated without being influenced by short-term weather effects. EAAMOD provides results as monthly or yearly averages and daily time-series data that can be viewed in tables or graphs.

Weather data collection. A Campbell Scientific, Inc. fully automated weather station was installed in the middle of the study area (Figure AGFS-1) on April 26, 1999, and data has been recorded since that time except for a couple short periods that data were inadvertently lost due to startup testing problems.

The following data were collected by the weather station recorded on a hourly basis:

Rainfall
Solar Radiation
Air temperature
Soil Temperature at 45 cm
Water Table above the Spodic Horizon (hardpan)
Water Table below the Spodic Horizon (hardpan

The station had a cellular phone communications package that allowed for remote access for data downloads and station program maintenance. It also had a voice synthesizer and software that allowed it to call field staff at the Ona Experiment Station to alert them to a rainfall event so that a sampling trip could be scheduled. The station was also able to call Soil and Water Engineering Technology, Inc. (SWET) in Gainesville to report errors in the transducer. SWET also did a daily download of data to keep track of the station's performance during the duration of the study.

Runoff water sampling. A 15-30 cm deep perimeter ditch around each plot was constructed and a flow integrating sampling device to collect runoff sample (Bottcher and Miller, 1991) was set in place at each plot (Figure FS1-1). Runoff from the plots flows out into the experimental block drainage ditches and into a main drainage ditch (Figure FS1-1). The sampling devices were inspected every time there was a significant rainfall event, total sample volumes were recorded, and small volumes of samples were collected and prepared for storage according to the sampling protocol (Appendix A).

Ground water sampling. Subsurface water samples were collected at two depths from two pipe wells consisting of 5-cm inside diameter PVC pipes installed at the center of each plot set 0.5 m apart. The "shallow" well pipes have their lower ends down to about 0.5 m (at the E horizon) and those of the "deep" well pipes down to about 1.0 m (at or below the Bh horizon) from the surface of the soil. The wells were checked for water at least once each month or after every major rainfall event, and samples were collected when water was present. The samples were prepared for storage according to the sampling protocol (Appendix A). All water samples were kept frozen until they were analyzed for the various nutrients. Water table levels were also measured and recorded every collection time.

Leachates and Soil Water Preparation and Chemical Analyses

Phosphorus quality assurance/quality control (QA/QC). Quality assurance and control for P were started from water collection (Appendix A) to chemical analysis (Appendix B). Quality assurance checks were used to ensure analytical data quality for water sample analysis. Since the main object of the study was P and its forms, special attention was paid to P determination using the method of Murphy and Riley (1962) on the ALPKEM automated analyzer at the detection limit of 0.005 ppm (5 ppb) and determination limit of 0.01 ppm (10 ppb). The values obtained were then compared to P values using inductively-coupled argon plasma (ICAP) spectroscopy with a detection limit of 0.1 ppm (100 ppb).

On the ALPKEM automated analyzer, sample reruns, external standards, and spike samples were run every 20 samples. Detection and determination limits of the method were calculated from standard deviation results of a set of blank samples. For detection limit, the standard deviation was multiplied by 3 and for determination limit by 10. Values obtained were 2.5 and 8.3 $\mu g \, P \, L^{-1}$ or ppb for orthophosphate P (OP) and 2.7 and 9.2 ppb for total phosphate (TP). For both OP and TP, values obtained from 100 ppb P standard were in the range 10 % of expected value which meant good accuracy. Data obtained from 10 ppb P standard in several cases dropped to about 80 % of expected value. This concentration was already close to the determination limit of 10 ppb P of the method, and achieving 80 % of the expected values were considered quite accurate. See Appendix B for details.

Because the analytical QA/QC indicated 0.1 ppm to be the most accurate lower limit for P, and most of the greenhouse and the field water samples happened to contain 0.1 ppm P or higher, only the ICAP-analyzed P values, which approximate TP, are presented in this integrated overview. This method, as used by the UF/IFAS Analytical Research Laboratory (ARL), is also certified by the Florida Department of Environmental Protection (DEP) for analysis of P in water. The relationships between OP and TP, as analyzed using Murphy and Riley (1962) colorimetric method, and P using inductively coupled argon plasma (ICAP) spectroscopy are given in Appendix C.

Greenhouse studies. Sub-samples from the main samples from the three greenhouse studies were analyzed for pH and electrical conductivity (EC) without filtration within hours after collection at the Range Cattle Research and Education Center (RCREC) laboratory at Ona using an Orion pH meter and a Fisher conductivity meter, respectively. The remainder of the samples from GS1 were filtered using Fisherbrand Q2 (fine and slow) and acidified to < pH 2 using HNO_3 (Weast, 1980-81). They were then stored in a freezer until analyzed for dissolved metals. The remainder of the samples from GS2-I and GS2-II were not filtered since these came out clear after passing through the 1 μm filters at the bottom of the PVC tubes nor were they treated with acid before storing them in a freezer. All analyses for P, K, Ca, Mg, Fe, Mn, Cu, and Zn were done at the Analytical Research Laboratory (ARL), Institute of Food and Agricultural Services (IFAS), Gainesville using inductively coupled argon plasma (ICAP) spectroscopy at a detection limit of 0.1 mg L^{-1} for P.

Field studies. All water samples from runoff samplers and monitoring wells were immediately placed in ice upon collection. They were brought to the RCREC laboratory, allowed to attain room temperature and immediately analyzed for pH and EC using subsamples. Two sets of the runoff samples were prepared, the first for ortho-P (OP) analysis which was filtered through 0.45 μm filters but not acidified and the second for total P (TP) which was acidified to pH < 2.0 with H_2SO_4 (Appendix A) but not filtered. Samples from the wells were filtered within a day after collection using 0.45 μm filters because of the dirt in the water. All samples were also analyzed for P using ICAP spectroscopy at a detection limit for P at 0.1 mg L^{-1}. Except for pH and EC, all other analyses were done at the ARL, IFAS in Gainesville. There was a very strong correlation between OP and ICAP-P values so that only the ICAP-P are presented in this overview for simplicity and clarity.

Stargrass Forage Analyses

The ground forage tissues from greenhouse and field harvests were ashed in a muffle furnace at 550°C for 6 hours. The ashes were dissolved in 0.3025 M HCl, and the HCl solutions were then filtered using a FisherBrand Q5 filter paper. The solutions were analyzed at the ARL in Gainesville for P, Ca, Mg, K, Cu, Fe, Mn, and Zn.

Forage samples from the field experiments were also analyzed for crude protein and IVOMD (*in vitro* organic matter digestibility) at the Forage Laboratory (FL), IFAS in Gainesville.

Soil Analyses

All soil samples were air-dried and passed through a 2- mm sieve before analysis. Soil pH and electrical conductivity (EC) were determined in water (1:2 ratio; w:v) using an Orion pH meter and a Fisher conductivity meter, respectively. Macro and micro nutrients were extracted using Mehlich I solution (0.05 N HCl in 0.025 N H_2SO_4; Mehlich, 1953), and P, Ca, Mg, K, Cu, Fe, Mn, Zn, and

Al were analyzed using ICAP spectroscopy. Organic matter was analyzed using the method of Walkley and Black (1934). All analyses were done at the ARL, IFAS in Gainesville.

Soil P fractionation was done by sequential extraction. Soil P was first extracted with 1 M KCl (Reddy et al., 1998 for AGFS) or NH_4Cl (Nair et al., 1995 for GS1) for labile P, then with 0.1 M NaOH for Al/Fe-P (NaOH-$P_{inorganic}$), a portion of which was digested with 11 N H_2SO_4 and ammonium peroxydisulfate to obtain NaOH-$P_{inorganic+organic}$ (hence, NaOH-$P_{inorganic+organic}$ less NaOH-$P_{inorganic}$ = NaOH-$P_{organic}$) and, finally with 0.5 M HCl for Ca/Mg-P. The mixtures were centrifuged at 3000 rpm (3620 x g) and the supernatant liquid filtered through Fisherbrand Q2 (fine and slow) filter papers. The residual soils were combusted in a muffle furnace at 550 °C for 4 hours and the residues were dissolved in 6 M HCl for residual P analysis. Fresh soil samples were similarly combusted and digested for total P analysis. Phosphorus in the various solutions was analyzed using a Hitachi Spectrophotometer Model 100-20 at a wavelength of 882 nm.

Statistical Analysis

Whenever appropriate, experimental data were analyzed statistically (SAS, 1985) using analysis of variance (ANOVA) using Tukey's Studentized Range Test (GS1 and AGFS) or Duncan's Multiple Range Test (GS2-I and GS2-II) for comparison of means. Regression equations were also determined and presented to define important relationships between variables.

PROJECT RESULTS AND DISCUSSIONS

The greenhouse studies were conducted only to help explain and/or confirm field results, hence only the key results directly related to the agronomic and water quality field experiments are presented in this overview. The field agronomic and water quality results, however, are presented in greater detail as possible. Complete reports for all studies are available at the SFWMD.

Greenhouse Study 1 (GS1): Individual Soil Horizons with No Stargrass Planted

Flow Volumes and Number of Hours for Matrix Flow

The volumes of water or leachate applied, A, the corresponding volumes leached, L, and the leached:applied ratios L/A, averaged over eight leaching events over a 220-d period, were not different between treatments within horizon (Table GS1-4). However, A, L, and the L/A ratios of 0.54, 0.86, and 0.71 for Ap, E, and Bh horizons, respectively, indicated different water-response characteristics between horizons. The applied volumes of 1.0, 0.45, and 0.33 L took about 4, 2, and 4 h to be poured out continuously in 1-cm depth increments into potted Ap, E, and Bh soils, respectively, or 4, 4, and 12 h on liter-basis. This indicated similar hydraulic conductivities between Ap and E but marked difference between the Ap-E and the Bh horizons. Field measurements of permeability of Immokalee fine sand indicated the Bh to be ten times less permeable than the Ap or the E horizons (USDA-SCS-DACS, 1984). Such soil profile hydraulic conductivity characteristics

Table GS1-4. Leachate volume during sequential leaching of potted soil horizons of a Spodosol using deionized water for Ap, Ap leachates for E, and E leachates for Bh, average of fifteen treatments and eight leaching events over a 220-d period, with no differences between treatments noted within horizon.

Horizon (H)[†]								
Ap			E			Bh		
A[‡]	L[§]	L/A[¶]	A	L	L/A	A	L	L/A
------- L pot^{-1} -------		Ratio	------ L pot^{-1} --------		Ratio	------ L pot^{-1} ------		Ratio
1.00a	0.54a	0.54c	0.45b	0.39b	0.86a	0.33c	0.24c	0.71b

[†] Means of the same variable between horizons having the same letter code are not different at P(H) ≤ 0.05; [‡] Applied volume, [§] Leached volume, [¶] Leached:Applied ratio.

would make lateral flow along the E horizon in Spodosols likely to occur under sustained rainfall even if it does not result in flooding or before the water table could rise to the top of the Bh horizon. This would make surface and sub-surface runoff above the Bh horizon the major pathway in Spodosols by which nutrient pollutants could reach into drainage ditches, streams, and bodies of water.

Calcium Amendments and Associated Key Leachate Properties

Besides Ca concentration, the key properties of leachates expected to be affected by the various Ca amendments are pH and EC. It is for these effects that Ca materials are considered possible amendments to reduce P losses through leaching and runoff for certain soils (Tunesi et al., 1999; Phillips, 1998; Anderson et al., 1995, Diaz et al., 1994; Zhu and Alva, 1994; Lindsay, 1979).

Leachate Ca concentration. Compared to the 0 Ca controls, MG and PG increased Ca concentrations in Ap leachates at all rates of fertilizer P but not CL or DL (Table GS1-5) due to differences in solubility between the lime and the gypsum materials. The solubilities of CL, DL, MG, and PG are 0.015, 0.32, 2.41, and 2.61 g L^{-1} (Weast, 1980-81; Alcordo and Rechcigl, 1992), respectively. Treatment differences were unchanged as the Ap leachates flowed through the potted E soils and as the ensuing E leachates passed through the Bh soils (Table GS1-5). In both E and Bh leachates, the L/A ratios for all treatments were > 1.0 but minimum values near 1.0 were not statistically different from values as high as 1.9 for the E soils or 1.6 for the Bh soils. This would indicate the E horizon's relatively low CECs (Calhoun and Carlisle, 1974) and the Bh horizon's Ca-saturated soil exchange complex (Table GS1-3).

Leachate EC. Closely associated with Ca concentration is leachate EC which is a gross measure of the amounts of dissolved charged particles. Compared to the 0 Ca controls, CL, or DL at all rates of fertilizer P., MG increased the EC of Ap leachates; PG slightly increased Ap leachate EC but the values were not statistically different from those of the controls, CL, DL, or MG (Table GS1-6). The L/A ratios followed similar differences noted in the case of the leachate EC. In general, differences in EC noted in Ap leachates were carried over to the E and then to the Bh leachates. The L/A ratios in both E and Bh leachates were not different between any two treatments and were all consistently > 1.0 indicating some contributions of charged particles by the E and the Bh soils to the flowing water.

Leachate pH. The effects of Ca amendments on Ap leachate pH unaffected by the acidic TSP fertilizer were indicated by treatments T1 through T5 (Table GS1-7). Lime materials CC and DL increased Ap leachate pH compared to the control. On the other hand, MG and PG reduced leachate pH to less than that of the control with MG reducing leachate pH further to below that of PG. The reduction in leachate pH with gypsum, a neutral salt, is due to the so-called "salting effect." The solubility of gypsum in water is very high as noted earlier. The high concentrations of Ca from dissolved gypsum could replace H and Al ions adsorbed in the soil exchange complex and bring them into solution. Trivalent Al ions in solution are readily hydrolyzed (Alcordo and Rechcigl, 1993) releasing more H ions into solution reducing further the pH of the Ap leachates.

Table GS1-5. Calcium in leachates from potted Ap, E, and Bh horizons of a Spodosol, average of eight leaching events over a 220-d period, without or with fertilizer P (kg P ha^{-1}) or Ca amendments MG (mined gypsum), PG (phosphogypsum), CL (calcium carbonate), and DL (dolomite) applied to Ap at 800 kg Ca ha^{-1}.

		Horizon (H)						
		Ap			E		Bh	
No.	Treatment (T)	A[†]	L[§]	L/A[¶]	L	L/A[#]	L	L/A[††]
		---- mg Ca L^{-1} ----		Ratio	mg Ca L^{-1}	Ratio	mg Ca L^{-1}	Ratio
T1	0P + 0Ca	-	56.2b[‡‡]	-	61.8b	1.73a	90.4b	1.50a
T2	0P + MG	-	182.4a	-	190.6a	1.49a	230.8a	1.31a
T3	0P + PG	-	166.2a	-	209.7a	1.92a	200.5a	1.33a
T4	0P + CL	-	60.4b	-	57.8b	1.44a	65.1b	1.30a
T5	0P + DL	-	64.7b	-	58.7b	1.33a	88.8b	1.49a
T6	50P + 0Ca	-	61.3b	-	59.1b	1.63a	65.4b	1.38a
T7	50P + MG	-	172.7a	-	173.7a	1.41a	194.4a	1.22a
T8	50P + PG	-	165.9a	-	203.5a	1.55a	186.1a	1.04a
T9	50P + CL	-	58.4b	-	51.1b	1.22a	61.6b	1.28a
T10	50P + DL	-	56.4b	-	58.6b	1.47a	76.4b	1.39a
T11	100P + 0Ca	-	59.3b	-	62.7b	1.63a	70.9b	1.23a
T12	100P + MG	-	180.9a	-	170.2a	1.27a	233.6a	1.53a
T13	100P + PG	-	189.2a	-	189.0a	1.44a	196.3a	1.23a
T14	100P + CL	-	63.3b	-	53.4b	1.25a	59.1b	1.64a
T15	100P + DL	-	60.1b	-	54.0b	1.44a	66.5b	1.28a
Overall means (H)[‡‡]		-	106.5b	-	110.4ab	1.48a	125.5a	1.34a

[†] Applied Ca not in solution form, [§] Leachate Ca, [¶] L/A (leached:applied ratios) not given since there was no A. [#] See Ap leachate Ca conc. for A. [††] See E leachate Ca conc. for A. [‡‡] Means having the same letter code are not different at P(T) or P(H) ≤ 0.05 based on Tukey' Studentized Range Test.

Table GS1-6. Electrical conductivity (EC) of leachates from potted Ap, E, and Bh horizons of a Spodosol, average of eight leaching events over a 220-d period, without or with fertilizer P (kg P ha^{-1}) or Ca amendments MG (mined gypsum), PG (phosphogypsum), CL (calcium carbonate), and DL (dolomitic limestone) applied to Ap at 800 kg Ca ha^{-1}.

No.	Treatment	Horizon (H)						
		Ap			E		Bh	
		A[†]	L[§]	L/A[¶]	L	L/A[#]	L	L/A[††]
		µmho cm^{-1}						
T1	0P + 0Ca	3.7a[‡‡]	391b	118.2b	517bc	1.77a	669bcde	1.64a
T2	0P + MG	3.7a	959a	302.2a	1100a	1.36a	1144a	1.24a
T3	0P + PG	3.7a	768ab	227.4ab	877abc	1.47a	909abcd	1.40a
T4	0P + CL	3.7a	397b	122.5b	471bc	1.62a	604de	1.51a
T5	0P + DL	3.7a	410b	125.7b	496bc	1.48a	939cde	1.51a
T6	50P + 0Ca	3.7a	415b	124.4b	498bc	1.58a	631cde	1.57a
T7	50P + MG	3.7a	933a	300.2a	1042a	1.32a	1082a	1.20a
T8	50P + PG	3.7a	797ab	244.6a	899abc	1.37a	947abc	1.21a
T9	50P + CL	3.7a	399b	119.7b	473bc	1.51a	590de	1.51a
T10	50P + DL	3.7a	385b	119.7b	452c	1.43a	566e	1.51a
T11	100P + 0Ca	3.7a	430b	131.3b	504bc	1.46a	587de	1.41a
T12	100P + MG	3.7a	983a	321.0a	1113a	1.35a	1188a	1.24a
T13	100P + PG	3.7a	803ab	255.2a	916ab	1.33a	980ab	1.23a
T14	100P + CL	3.7a	402b	128.2b	489bc	1.52a	580de	1.41a
T15	100P + DL	3.7a	413b	132.3b	474bc	1.43a	560e	1.39a
Overall means (H)[‡‡]		3.7	591c	184.7a	688b	1.46b	778a	1.40b

[†] Applied EC of deionized water, [§] Leachate EC, [¶] L/A (leached:applied ratios). [#] See Ap leachate EC for A. [††] See E leachate EC for A. [‡‡] Means having the same letter code are not different at P(T) or P(H) ≤ 0.05 based on Tukey' Studentized Range Test.

Table GS1-7. pH of leachates from potted Ap, E, and Bh horizons of a Spodosol, average of eight leaching events over a 220-d period, without or with fertilizer P (kg P ha^{-1}) or Ca amendments MG (mined gypsum), PG (phosphogypsum), CL (calcium carbonate), and DL (dolomitic limestone) applied to Ap at 800 kg Ca ha^{-1}.

No.	Treatment	Horizon (H)						
		Ap			E		Bh	
		A[†]	L[§]	L/A[¶]	L	L/A[#]	L	L/A[††]
T1	0P + 0Ca	5.20a[‡‡]	5.78d	1.05abcd	4.77abc	0.83abc	5.05ab	1.07bc
T2	0P + MG	5.20a	5.05g	0.92f	4.24ef	0.84ab	4.79cd	1.14ab
T3	0P + PG	5.20a	5.41e	0.98cdef	4.36def	0.80abc	4.90abcd	1.13ab
T4	0P + CL	5.20a	6.09ab	1.11a	4.77abc	0.79bc	5.03ab	1.07bc
T5	0P + DL	5.20a	6.15a	1.12a	4.68bc	0.76c	5.00ab	1.08abc
T6	50P + 0Ca	5.20a	5.76d	1.05abcde	5.01a	0.87a	5.05a	1.02c
T7	50P + MG	5.20a	5.22efg	0.95ef	4.24ef	0.82abc	4.85bcd	1.14ab
T8	50P + PG	5.20a	5.43e	0.99bcdef	4.32def	0.80bc	4.91abcd	1.14ab
T9	50P + CL	5.20a	5.97abcd	1.09ab	4.92ab	0.82abc	4.98abc	1.02c
T10	50P + DL	5.20a	6.03abc	1.10a	4.76abc	0.79bc	5.05a	1.07bc
T11	100P + 0Ca	5.20a	5.81cd	1.06abcd	4.51cde	0.78bc	5.00ab	1.11ab
T12	100P + MG	5.20a	5.13fg	0.94f	4.19f	0.82abc	4.76d	1.14ab
T13	100P + PG	5.20a	5.31ef	0.97def	4.23ef	0.80bc	4.85abcd	1.15a
T14	100P + CL	5.20a	5.85cd	1.06abcd	4.70abc	0.81abc	5.05a	1.08abc
T15	100P + DL	5.20a	5.87bcd	1.07abc	4.57cd	0.78bc	5.04ab	1.11ab
Overall means (H)[‡‡]		5.20	5.66a	1.03b	4.55c	0.81c	4.95b	1.10a

[†] pH of deionized water applied, [§] pH of Ap leachates, [¶] L/A (leached:applied ratios). [#] See Ap leachate pH for A. [††] See E leachate pH for A. [‡‡] Means having the same letter code are not different at P(T) or P(H) ≤ 0.05 based on Tukey' Studentized Range Test.

Compared to the control, MG and PG had greater acidifying effect on Ap leachates than TSP at the two rates of fertilizer P. On the other hand, the liming effects of CL and DL were effectively neutralized by TSP at the highest rate of fertilizer P (Table GS1-7). The L/A ratios clustered around 1.0 and differences were noted between treatments reflecting increases (>1.0 for CL and DL) or reductions (< 1.0 for MG and PG) in leachate pH.

Despite a wide Ap leachate pH range of from 5.05 to 6.15, the ensuing E leachates yielded a narrow pH range of from 4.19 to 5.01 indicating a strong buffering capacity toward this range (Table GS1-7). The higher the applied pH the lower the L/A ratios because of this buffering. Release of H ions into solution to keep the pH within this range may be responsible for the increase in EC L/A ratios in E leachates noted earlier. At this buffered pH range, Ca amendments applied to the surface of the soil would have little or no effect on P mobility in the E horizon of Immokalee fine sand.

The pH values of Bh leachates were intermediate between those of the Ap and the E and ranged from 4.76 to 5.05, again, indicating a strong buffering capacity toward this range (Table GS1-7). The L/A ratios were all > 1.0 due to this buffering, and the lower the applied pH the higher the L/A ratio. Again, because of this very narrow buffered pH range, Ca amendments applied to the soil surface are not likely to influence P mobility in the Bh horizon of Immokalee fine sand.

Calcium Amendments and P Concentrations in Leachates

Ap leachates. Phosphorus in leachates showed significant interactions with Ca amendments and fertilizer P rates unlike Ca concentrations, EC, and pH. The effects of the various Ca amendments became more defined as fertilizer P rates increased (Table GS1-8). For this and for practical reasons, the statistics for P concentrations as influenced by the amendments are presented at each rate of P rather than comparing all fifteen treatments at once in a single statistical analysis.

With no fertilizer P applied, MG increased soil P concentration in Ap leachates over that of the 0 Ca control, hence its leachability (Table GS1-8). At 50 and 100 kg P ha^{-1}, P concentrations in leachates from gypsum-treated soils were not different from those of the control. These results differed from those of Zhu and Alva (1994) who reported reductions in leaching losses of P from sandy soils with gypsum due to the formation of calcium phosphates. The studies of Diaz et al. (1994), however, showed that pH is the more critical factor than Ca concentration in P precipitation. Using stream waters with total P ranging from 0.10 to 3.55 mg L^{-1}, they reported that P solubility in stream waters with low Ca (20 and 50 mg L^{-1}) was not affected by pH in the range of 6 to 9. It was not until pH increased to 10 did 30 and 60% of the P precipitated out. Even at high Ca levels (100 and 200 mg L^{-1}), precipitation of P in appreciable amounts occurred only at pH 9.

The ability of the lime materials to immobilize P is demonstrated in Table GS1-8. With no fertilizer P, CL and DL tended to give lower P concentrations in Ap leachates than the 0 Ca control. At 50 and 100 kg P ha^{-1}, CL and DL significantly reduced P concentrations in Ap leachates relative to corresponding 0 Ca control. Comparing all fifteen treatments together (statistics not shown), Ap

Table GS1-8. Phosphorus in matrix flow from potted Ap, E, and Bh horizons of a Spodosol, average of eight leaching events over a 220-d period, without or with fertilizer P (kg P ha^{-1}) or Ca amendments MG (mined gypsum), PG (phosphogypsum), CL (calcium carbonate), and DL (dolomite) applied to Ap at 800 kg Ca ha^{-1}.

No.	Treatment (T)	Horizon (H)						
		Ap			E		Bh	
		A[†]	L[§]	L/A[¶]	L	L/A[#]	L	L/A[††]
Set 1:		---- mg P L^{-1} ----		Ratio	mg P L^{-1}	Ratio	mg P L^{-1}	Ratio
T1	0P + 0Ca	-	4.79b[‡‡]	-	4.69ab	1.67a	0.40a	0.15a
T2	0P + MG	-	7.40a	-	6.22a	1.15a	0.39a	0.08a
T3	0P + PG	-	4.22b	-	4.25ab	1.33a	0.45a	0.12a
T4	0P + CL	-	4.18b	-	3.31b	1.16a	0.44a	0.16a
T5	0P + DL	-	3.87b	-	2.98b	1.26a	0.27a	0.12a
P(T):		-	0.0003	-	0.0008	0.4831	0.9665	0.7038
Set 2:								
T6	50P + 0Ca	-	10.59a	-	9.36a	1.32a	0.54a	0.09a
T7	50P + MG	-	11.09a	-	8.94a	0.97a	0.61a	0.07a
T8	50P + PG	-	10.49a	-	9.27a	1.03a	0.33a	0.04a
T9	50P + CL	-	6.45b	-	5.56b	1.00a	0.38a	0.11a
T10	50P + DL	-	7.04b	-	6.25ab	1.12a	0.55a	0.10a
P(T):		-	0.0001	-	0.0010	0.5874	0.9168	0.6452
Set 3:								
T11	100P + 0Ca	-	16.60a	-	15.81a	1.47a	0.57a	0.07a
T12	100P + MG	-	17.98a	-	14.58a	1.09a	0.55a	0.04a
T13	100P + PG	-	17.56a	-	14.67a	1.18a	0.35a	0.06a
T14	100P + CL	-	10.36b	-	8.94b	1.07a	0.54a	0.10a
T15	100P + DL	-	10.41b	-	9.44b	1.20a	0.44a	0.05a
P(T):		-	0.0001	-	0.0001	0.5737	0.9281	0.5263
Overall means (H)[‡‡]		-	9.54a	-	8.28b	1.20a	0.45c	0.09b

[†] Applied P not in solution form, [§] Leachate P, [¶] L/A (leached:applied ratios) not given since there was no A. [#] See Ap leachate P concentrations for A. [††] See E leachate P concentrations for A. [‡‡] Means having the same letter code are not different at P(T) or P(H) ≤ 0.05 based on Tukey' Studentized Range Test.

leachate P concentrations for CL (T9) and DL (T10) at 50 kg P ha^{-1} were not different from that for 0 P + 0 Ca (T1) indicating the capacity of CL and DL to immobilize fertilizer P at moderate levels of application. Since dissolved Ca in CL- or DL-affected Ap leachates were much lower than in MG- or PG-affected leachates (Table GS1-5) and the pH of the leachates for CL or DL (Table GS1-7) were not that high to cause P in water to precipitate (Diaz et al., 1994), it could be concluded that precipitation occurred at the surface of the undissolved lime particles. This would mean that for lime materials to be effective in immobilizing P in soils, they must be in less soluble granular form. Greenhouse studies GS2-I and GS2-II, included in this report, which used CL and DL from the same bulk sources but ground to powder applied to individual soil horizons and reconstructed soil profile samples of Immokalee fine sand, respectively, planted to stargrass failed to show any immobilizing effects of the ground lime materials on fertilizer P applied up to 100 kg P ha^{-1}.

E leachates. The trends in differences in P concentrations between amendments in Ap leachates applied to the E soils were clearly reflected in the ensuing E leachates at all rates of fertilizer P (Table GS1-8). The L/A ratios were all close to 1.0 and were not different indicating no retention capacity of the E horizon of Immokalee fine sand for P. Since lime amendments applied to the surface of the soil had no effect on the highly-buffered acidic pH of soil water in the E horizon, studies such as injecting lime slurries into the E horizon may be worth exploring.

Bh leachates. Regardless of how high (15.81 mg P L^{-1}) or low (2.98 mg P L^{-1}) P concentrations were in the applied E leachates which showed some differences between treatments, the ensuing Bh leachate P concentrations were reduced to a narrow range of fractional values, 0.27 to 0.61 mg P L^{-1}, which were not statistically different (Table GS1-8). This meant that no matter how much P there was in the applied leachates, as much P as the system required was being retained by the soil solids and in water enveloping these solids. This could be explained by equilibrium reactions (1) between precipitated P and adsorbed P defined as ionic P in the non-leachable water around the soil solids and (2) between adsorbed P and mobile P in the moving leachates. Because of so much free Ca in the leachates, P would be strongly associated with Ca (Wang et al., 1995), most probably, as Ca -- H_2 PO_4, Ca -- HPO_4, Ca-- PO_4 ion pairs or as a kind of dipoles. Aluminum and Ca ions, being the dominant extractable ions in the Bh exchange complex (Table GS1-3), would exert strong attraction on the negative ends of the flowing ion-pairs. This would slow them down until they are eventually adsorbed as ion-pairs, possibly replacing loosely held hydroxyl ions (Parfitt, 1978), with the --PO_4, -- HPO_4, and -- PO_4 ends oriented towards the solid surface and the complementary Ca ions sticking out creating a new cloud or layer of positive charges around the solid particles. The 0 P fertilizer equilibrium between leachate, adsorbed, and precipitated P would be definitive for Immokalee fine sand. Removal of portions of adsorbed P through leaching would cause some precipitated P to dissolve to restore the equilibrium adsorbed P concentration. With total P of about 800 mg kg^{-1} (See P fractionation data in the Section on Soils), this equilibrium reaction could go on indefinitely. On the other hand, any increase in P concentrations in water flowing through the Bh horizon, as would result from fertilizer P application, would shift the reaction toward greater adsorbed P resulting, in turn, to increased P precipitation with Al (Borggaard, et al., 1990) and/or Ca to restore its definitive equilibrium. Thus, the relatively constant leachate P concentrations and L/A ratios at the three rates of fertilizer P (Table GS1-8).

Phosphorus Mobility and Associated Leachate Properties and Elements

The key leachate properties associated with the various Ca amendments are Ca concentrations, EC, and pH (Tables GS1-5, GS1-6, and GS1-7). The EC, as a gross measure of the amounts of dissolved charge particles, is strongly influenced not only by dissolved Ca but also by other macro and micro elements in leachates. Any or all of these variables could influence P mobility in the soil horizons. The linear regression equations quantifying the associations between P concentrations and these variables, within their respective range of values, are given in Table GS1-9.

Within the range of 4.8 to 6.7, Ap leachate pH was negatively associated with P concentrations (Table GS1-9), hence with P mobility in the Ap horizon. Whether significantly or not, EC and individual cations, except Cu, were positively associated with P concentrations. Dissolved Ca, Mg, K, Al, and Mn, which were significantly related to P concentrations most probably acted as ion pairs to P anions to neutralize their negative charges without precipitating under acid conditions.

Within the pH range of 4.0 to 5.5, E leachate pH and Cu were negatively while Ca, Al, and Mn were positively related to P concentrations all significantly (Table GS1-9). Aluminum, an important element in subsoil acidity (Alcordo and Rechcigl, 1993), was the most highly significant cation related to P concentrations in E leachates, hence in P mobility in the E horizon. Increased H ions, responsible for the buffered acidic pH of the E leachates may also have played similar role as Al. In Bh leachates, the small amounts of P that leached through the Bh horizon were significantly associated with Mn rather than with Ca, Mg, K, or Al which were present in substantially high concentrations (Table GS1-9). The adsorption and precipitation of P -- cation pairs in Bh soils hypothesized earlier which depleted P and left major cation concentrations unchanged may have blurred any association in the ensuing Bh leachates.

Calcium Amendments and P Losses from Ap, E, and Bh Horizons

Linear equations quantifying P losses through leaching for the various treatments are given in Table GS1-10. For soil P (0 P), CL or DL lost 12.0 or 12.5 compared to losses of 15.0, 19.3, and 13.7 mg P kg^{-1} for No Ca, MG, and PG treatments, respectively, after eight leaching events using a total of 88 cm of water. Increasing the rates of CL or DL application would likely increase the lime's effectiveness to tie up soil P. The discussions following assumed that the same amounts of soil P (0 P) for each treatment were leached from the P-fertilized soils for the corresponding treatment. At a single application of 25 kg P ha^{-1} leached with 55 cm-depth of water, both CL and DL retained in Ap soils almost every mg of fertilizer P applied; at 50 kg P ha^{-1}, CL and DL retained 840 and 730 g kg^{-1}, respectively, of fertilizer P. At 100 kg P ha^{-1} split in two equal applications 140 d apart and leached with 88 cm-depth of water, CL and DL retained 620 and 560 g kg^{-1} of fertilizer P. Equations in Table GS1-10 and the data in Tables GS1-11 and GS1-12 could have some potentials for use in modeling P losses from Spodosols in relation to fertilizer P rates, Ca amendments, and rainfall.

The E horizon soils have been shown to have no retention capacity for P except, possibly, for dissolved P in water retained in the micro pores (Tables GS1-4, GS1-11 and GS1-12). Thus, P that

Table GS1-9. Regression equations for P concentration (Y)† and associated pH, EC, and elements (X)‡ in matrix flow through potted Ap, E, and Bh horizons of a Spodosol at all rates of fertilizer P and all Ca amendments; eight sequential leaching events over a 220-d period using 11 cm of deionized water each time applied to Ap with the Ap leachate applied to E, and E leachate applied to Bh soil.

	Horizon								
Variable	Ap			E			Bh		
pH	Range: 4.84 - 6.67	P-value	R^2	Range: 3.97 - 5.47	P-value	R^2	Range: 4.40 - 5.60	P-value	R^2
	Y = 35.12 - 4.66X;	**	0.08	Y = 33.27 - 5.51X;	***	0.12	Y = 2.06 - 0.322X;	ns	0.01
EC	Range:100-2500 μmho cm^{-1}			Range: 160 - 2500			Range: 270 - 1900		
	Y = 624 + 0.04X;	***	0.11	Y = 70.10 + 0.02X;	ns	0.03	Y = 4.5 + 0.00X;	ns	0.00
Ca	Range: 8 - 440 mg L^{-1}			Range: 10 - 370			Range: 10 - 325		
	Y = 7.35 + 0.014X;	*	0.04	Y = 6.62 + 0.014X;	**	0.07	Y = 0.40 + 0.001X;	ns	0.00
Mg	Range: 1 - 70 mg L^{-1}			Range: 1 - 60			Range: 5 - 110		
	Y = 7.51 + 0.086X;	*	0.03	Y = 7.18 + 0.063X;	ns	0.03	Y = 0.43 + 0.001X;	ns	0.00
K	Range: 0.5 - 140 mg L^{-1}			Range: 0.5 - 150			Range: 5 - 120		
	Y = 7.49 + 0.074X;	***	0.10	Y = 7.27 + 0.030X;	ns	0.03	Y = 0.43 + 0.001X;	ns	0.00
Al	Range: 0.03 - 3.38 mg L^{-1}			Range: 0.37 - 7.57			Range: 0.47 - 10.13		
	Y = 8.58 + 2.77X;	**	0.06	Y = 9.97 - 2.24X;	***	0.13	Y = 0.46 + 0.001X;	ns	0.00
Fe	Range: 0.04 - 0.17 mg L^{-1}			Range: 0.10 - 0.45			Range: 0.02 - 0.16		
	Y = 9.05 + 4.23X;	ns	0.00	Y = 9.61 - 6.84X;	ns	0.01	Y = 0.49 - 0.44X;	ns	0.00
Mn	Range: 0.01 - 0.21 mg L^{-1}			Range: 0.01 - 0.19			Range: 0.01 - 0.13		
	Y = 8.40 + 34.33X;	**	0.05	Y = 7.37 + 26.25X;	*	0.03	Y = 0.15 + 13.77X;	**	0.11
Zn	Range: 0.02 - 0.34 mg L^{-1}			Range: 0.04 - 0.35			Range: 0.03 - 0.54		
	Y = 9.01 + 4.76X;	ns	0.01	Y = 7.19 + 8.45X;	ns	0.01	Y = 0.50 - 0.33X;	ns	0.00
Cu	Range: 0.00 - 0.11 mg L^{-1}			Range: 0.00 - 0.02			Range: 0.00 - 0.02		
	Y = 10.70 - 46.70X;	ns	0.01	Y = 9.71- 196.4X;	*	0.04	Y = 0.30 + 25.88X;	ns	0.02

†Y = mg P L^{-1} per unit X; ‡X: pH; EC = μmho cm^{-1}; all elements = mg X L^{-1}.
ns = not significant; * = significant at 0.05; ** = significant at 0.01; and *** = significant at $\leq$ 0.001.

Table GS1-10. Regression equations for P leached (Y)† from potted Ap horizon of a Spodosol and cm of deionized water applied (X)‡; influence of Ca amendments MG (mined gypsum), PG (phosphogypsum), CL (calcium carbonate), and DL (dolomite) applied at 800 kg Ca ha^{-1} at three rates of P.

	Number of leaching events and P application					
Amendment	Leachings 1-5, 1st P application			Leachings 1-8, 1st + 2nd P application		
	0 P	P-value	R^2	0 P	P-value	R^2
No Ca	Y = 0.218X;	***	0.96	Y = 0.170X;	**	0.81
MG	Y = 0.221X;	***	0.99	Y = 0.219X;	***	0.99
PG	Y = 0.177X;	***	0.98	Y = 0.156X;	***	0.93
CL	Y = 0.156X;	***	0.99	Y = 0.136X;	***	0.92
DL	Y = 0.170X;	***	0.95	Y = 0.142X;	**	0.83
	25 kg P ha^{-1} (14.6 mg P kg^{-1})			50 kg P ha^{-1} (29.2 mg P kg^{-1})		
No Ca	Y = 0.310X;	***	0.97	Y = 0.364X;	***	0.98
MG	Y = 0.260X;	***	0.96	Y = 0.296X;	***	0.97
PG	Y = 0.222X;	***	0.93	Y = 0.283X;	***	0.94
CL	Y = 0.158X;	***	0.92	Y = 0.171X;	***	0.97
DL	Y = 0.179X;	***	0.96	Y = 0.195X;	***	0.98
	50 kg P ha^{-1} (29.2 mg P kg^{-1})			100 kg P ha^{-1} (58.4 mg P kg^{-1})		
No Ca	Y = 0.475X;	***	0.97	Y = 0.557X;	***	0.98
MG	Y = 0.475X;	***	0.97	Y = 0.517X;	***	0.98
PG	Y = 0.460X;	***	0.98	Y = 0.503X;	***	0.98
CL	Y = 0.240X;	***	0.97	Y = 0.272X;	***	0.97
DL	Y = 0.307X;	***	0.98	Y = 0.321X;	***	0.98

†Y = mg P kg^{-1} per cm of water applied at 11-cm depth at a time; ‡X = 0, 11, 22, 33, . . . 88 cm.
** significant at 0.01 and *** significant at $\leq$ 0.001.

Table GS1-11. Accounting for total[+] P leached (retained) from potted Ap horizon of a Florida Spodosol (Immokalee fine sand) fertilized at three rates of P (0, 50, and 100 kg ha^{-1}) and amended with Ca-amendments applied at 800 kg Ca ha^{-1} and from the E and the Bh horizons after 8 leachings, the Ap with 88 cm of water, the E with Ap leachates, and the Bh with E leachates, over a period of 220 days.

Soil amendment (P rates)	Ap horizon	E horizon	Bh horizon	All horizons	
	mg P kg^{-1}	mg P kg^{-1}	mg P kg^{-1}	mg P kg^{-1}	%
<u>No P:</u>					
No amendment	13.09	10.40 (2.69)	0.59 (9.81)	(12.50)	(95.5)[#]
Mined gypsum	17.13	13.32 (3.81)	0.60 (12.72)	(16.53)	(96.5)
Phosphogypsum	12.65	9.75 (2.90)	0.64 (9.11)	(12.01)	(94.9)
Calcium carbonate	10.89	7.58 (3.31)	0.56 (7.02)	(10.33)	(94.9)
Dolomite	10.01	6.97 (3.04)	0.38 (6.59)	(9.63)	(96.2)
<u>29.2 mg P kg^{-1}</u>					
No amendment	30.91 (11.38)	21.32 (9.59)	0.70 (20.62)	(41.59)	(98.3)[##]
Mined gypsum	32.66 (13.67)	23.99 (8.67)	0.94 (23.05)	(45.39)	(98.0)
Phosphogypsum	30.17 (11.68)	23.05 (7.12)	0.46 (22.59)	(41.39)	(98.9)
Calcium carbonate	21.76 (18.33)	15.64 (6.12)	0.57 (15.07)	(39.52)	(98.6)
Dolomite	20.76 (18.45)	14.21 (6.55)	0.81 (13.40)	(38.40)	(97.9)
<u>58.4 mg P kg^{-1}</u>					
No amendment	49.87 (21.62)	37.46 (12.41)	0.88 (36.58)	(70.61)	(98.8)[###]
Mined gypsum	50.46 (25.07)	36.99 (13.47)	0.75 (36.24)	(74.78)	(99.0)
Phosphogypsum	48.50 (22.55)	36.88 (11.62)	0.49 (36.39)	(70.56)	(99.3)
Calcium carbonate	30.49 (38.80)	22.63 (7.86)	0.90 (21.73)	(68.39)	(98.7)
Dolomite	32.30 (36.11)	23.26 (9.04)	0.93 (22.33)	(67.47)	(98.6)

[+] Corrected for amounts removed for analysis (See Appendix, Tables 65-66).

[#] As percent of total P leached from the Ap horizon or of 13.09, ... 10.01.

[##] As percent of 29.2 + 13.09, ... 29.2 + 10.01.

[###] As percent of 58.4 + 13.09, ... 58.4 + 10.01.

Table GS1-12. Accounting for fertilizer[+] P leached (retained) from potted Ap horizon of a Florida Spodosol (Immokalee fine sand) fertilized at three rates of P (0, 50, and 100 kg ha^{-1}) and amended with Ca-amendments applied at 800 kg Ca ha^{-1} and from the E and Bh horizons after 8 leachings, the Ap with 88 cm of water, the E with Ap leachates, and the Bh with E leachates, over a period of 220 days.

Soil amendment (P rates)	Ap horizon	E horizon	Bh horizon	All horizons	
	mg P kg^{-1}	mg P kg^{-1}	mg P kg^{-1}	mg P kg^{-1}	%
<u>No P:</u>					
No amendment	13.09	10.40(2.69)	0.59(9.81)	(12.50)	(95.5)[#]
Mined gypsum	17.13	13.32(3.81)	0.60(12.72)	(16.53)	(96.5)
Phosphogypsum	12.65	9.75(2.90)	0.64(9.11)	(12.01)	(94.9)
Calcium carbonate	10.89	7.58(3.31)	0.56(7.02)	(10.33)	(94.9)
Dolomite	10.01	6.97(3.04)	0.38(6.59)	(9.63)	(96.2)
<u>29.2 mg P kg^{-1}</u>					
No amendment	30.91 (11.38)	21.32 (6.90)	0.70 (10.81)	(29.09)	(99.6)[##]
Mined gypsum	32.66 (13.67)	23.99 (4.86)	0.94 (10.33)	(28.86)	(98.8)
Phosphogypsum	30.17 (11.68)	23.05 (4.22)	0.46 (13.48)	(29.38)	(100.6)
Calcium carbonate	21.76 (18.33)	15.64 (2.81)	0.57 (8.05)	(29.19)	(100.0)
Dolomite	20.76 (18.45)	14.21 (3.51)	0.81 (6.81)	(28.77)	(98.5)
<u>58.4 mg P kg^{-1}</u>					
No amendment	49.87 (21.62)	37.46 (9.72)	0.88 (26.77)	(58.11)	(99.5)[###]
Mined gypsum	50.46 (25.07)	36.99 (9.66)	0.75 (23.52)	(58.25)	(99.7)
Phosphogypsum	48.50 (22.55)	36.88 (8.72)	0.49 (27.28)	(58.55)	(100.3)
Calcium carbonate	30.49 (38.80)	22.63 (4.55)	0.90 (14.71)	(58.06)	(99.4)
Dolomite	32.30 (36.11)	23.26 (6.00)	0.93 (15.74)	(57.84)	(99.0)

[+] Corrected for amounts removed for analysis (See Appendix, Tables 119 - 120).

[#] As percent of total P leached from the Ap horizon or of 13.09, ... 10.01 retained.

[##] As percent of applied P fertilizer (29.2).

[###] As percent of applied P fertilizer (58.4).

could leach through the Ap horizon could be lost from the soil profile should there be substantial lateral flow along the E horizon. However, P in water flowing across the Ap and the E horizons could be effectively retained in the Bh horizon if lateral flow above the Bh could be prevented or minimize. Calculations to account for P retained in each of the potted soil horizons indicated that 950 to 970 g kg^{-1} of soil P leached from the potted Ap and 990 to 1000 g kg^{-1} of fertilizer P applied to Ap soils were eventually retained after the leachates passed through the Bh soils.

Effects of Ca Amendments at Three Fertilizer P Rates on Soil Properties and Elements

Like the leachates, the two major properties that define the gross characteristics of soils are soil pH and EC. In relation to P, soil pH is the main property controlling the inorganic form of P, while Ca, Al, Fe, and Mn concentrations determine the quantity of these forms (Sharpley, 2000). The role of soil EC on P leaching depends on the major ionic charged species controlling the levels of the EC. Where SO_4 predominates in high concentrations, soil PO_4^- could become displaced from the exchange complex and become mobile.

Ap horizon. The pH, EC, and the Mehlich I extractable elements in potted Ap soils after eight leachings using a total of 88 cm of water over a period of 220 days are given in Table GS1-13. Effects on soil pH especially at zero P remained to be the distinguishing characteristic between the gypsum and the lime materials. At 25 kg P ha^{-1}, CL increased the soil pH over that of MG or PG, and DL over that of MG; at 50 kg P ha^{-1}, CL and DL increased the soil pH over that of PG, and DL over that of MG and PG. At all rates of fertilizer P, Mehlich 1 extractable P tended to be higher in all amended soils than in the controls, with the lime-amended soils tending to have more extractable P than the gypsum at the highest rate of P probably the consequence of lower P losses through leaching. Calcium carbonate consistently increased extractable Ca while MG and PG reduced extractable Mg at the three rates of fertilizer P.

E horizon. The effects of the amendments on pH were more pronounced on the E soils (Table GS1-14) than on the Ap. At all rates of P, CL and DL showed higher pH than PG and MG or the controls at zero and 25 kg P ha^{-1}. Mined gypsum at zero P and both gypsums at 25 and 50 kg P ha^{-1} reduced soil pH levels relative to those of the controls. Mined gypsum showed higher soil EC than the controls or the limed soils at zero and 25 kg P ha^{-1}, and both MG and PG had higher EC than the control or the limed soils at 50 kg P ha^{-1}. Unlike in the Ap soils, Mehlich I extractable P tended to be higher in the gypsum-amended soils than in the controls or the lime-amended soils despite the higher P losses through leaching from the E soils. This could be attributed to the disproportionately high levels of P from the gypsum-affected Ap leachates applied to the E soils than were leached. Calcium amendments either had no effect or no consistent effects on the other measured soil variables.

Bh horizon. Mined gypsum at zero and 25 kg P ha^{-1} and both PG and MG at 50 kg P ha^{-1} showed the lowest pH and the highest soil EC (Table GS1-15). Extractable P tended to be much lower in the lime-amended Bh soils than in the controls or the gypsum-amended soils at all rates of P. This could be attributed to the lower levels of P in the E leachates applied to the potted Bh soils.

Table GS1-13. pH, EC, organic matter (OM), and Mehlich I extractable elements in potted Ap horizon of a Florida Spodosol (Immokalee fine sand) fertilized at three rates of P (0, 29.2, and 58.4 mg kg^{-1}) as influenced by Ca amendments (A) applied at 800 kg Ca ha^{-1} in the form of mined gypsum (MG), phosphogypsum (PG), calcium carbonate (CL), or dolomite (DL) after 8 leachings with 88 cm of water over a period of 220 days.

Treatment		pH	EC	P	Ca	Mg	K	Al	Fe	Mn	Cu	Zn	OM
No.	kg P ha^{-1} + A		µmho cm^{-1}	mg kg^{-1}									%
Pre-treatment:		5.50	170.0	14.20	1070.0	53.9	29.00	37.1	8.56	1.80	0.270	2.04	1.70
T1	0 + 0	5.57b[#]	60.2a	5.30b	1373.3b	59.6b	14.10a	34.23c	3.75b	1.75a	0.347a	3.85a	3.00a
T2	0 + MG	5.40b	89.4a	15.27a	1436.7b	30.3c	9.73a	42.13a	4.43a	1.80a	0.297a	6.43a	3.03a
T3	0 + PG	5.57b	64.6a	7.30b	1563.3b	22.4c	9.03a	40.57ab	3.63bc	1.53a	0.293a	3.86a	3.03a
T4	0 + Cl	6.03a	52.3a	8.37b	1963.3a	63.2b	14.80a	37.60bc	3.29c	1.66a	0.273a	3.52a	3.07a
T5	0 + DL	6.23a	55.6a	7.10b	1576.7b	168.7a	12.70a	37.40ab	3.67bc	2.44a	1.290a	11.78a	3.10a
Statistics:													
P(Amendment)		< 0.01	0.43	< 0.01	0.01	< 0.01	0.35	0.02	< 0.01	0.33	0.08	0.17	0.93
LSD		0.23	45.5	3.30	265.0	14.3	7.37	4.18	0.39	0.98	0.817	7.89	0.75
T6	50 + 0	5.60bc	66.9a	10.93b	1506.7bc	62.9b	19.63a	36.43a	3.74b	1.81a	0.300ab	4.23a	3.03a
T7	50 + MG	5.37c	66.7a	24.37a	1463.3c	31.1c	11.20b	44.67a	4.54a	1.76a	0.303a	4.17a	3.20a
T8	50 + PG	5.60bc	66.2a	13.73b	1610.0b	22.7c	6.63b	34.10a	3.91b	1.31b	0.260bc	4.12a	3.10a
T9	50 + CL	6.00a	60.1a	16.10b	1880.0a	56.3b	13.00ab	36.80a	3.45b	1.57ab	0.240c	3.78a	2.87a
T10	50 + DL	5.90ab	74.6a	25.60a	1600.0bc	161.3a	8.97b	42.43a	4.02ab	1.79a	0.260bc	3.50a	3.43a
Statistics:													
P(Amendment)		0.01	0.88	< 0.01	< 0.01	< 0.01	0.05	0.47	0.03	0.01	0.03	0.49	0.78
LSD		0.32	31.7	5.93	141.4	19.7	8.25	14.74	0.61	0.27	0.046	1.05	1.05
T11	100 + 0	5.60bc	58.7a	15.10a	1433.3c	59.2b	11.67a	39.03c	3.96ab	1.64a	0.293a	3.73a	3.40a
T12	100 + MG	5.60bc	72.3a	26.77a	1560.0bc	35.1c	17.63a	43.83ab	4.32a	1.69a	0.287a	3.98a	3.13a
T13	100 + PG	5.50c	71.6a	21.10a	1606.7b	21.7c	11.37a	45.87a	3.90ab	1.33a	0.267a	3.99a	3.03a
T14	100 + CL	5.87ab	58.6a	30.38a	1916.7a	59.8b	19.81a	39.17bc	3.65b	1.59a	0.270a	3.33a	3.47a
T15	100 + DL	6.07a	56.1a	31.20a	1583.3bc	161.7a	17.70a	38.50c	3.71b	1.59a	0.250a	3.46a	2.93a
Statistics:													
P(Amendment)		0.03	0.88	0.20	< 0.01	< 0.01	0.20	< 0.01	0.02	0.13	0.34	0.31	0.56
LSD		0.35	18.3	15.8	151.8	23.7	9.10	4.68	0.55	0.31	0.049	0.81	0.85

[#] Means within a set of treatments with same letter code(s) are not different at P=0.05.

Table GS1-14. pH, EC, organic matter (OM), and Mehlich I extractable elements in potted E horizon of a Florida Spodosol (Immokalee fine sand) after 8 leachings over a period of 220 days using Ap leachates from potted Ap horizon fertilized at three rates of P (0, 29.2, and 58.4 mg kg^{-1}) and amended with Ca amendments (A) applied at 800 kg Ca ha^{-1} in the form of mined gypsum (MG), phosphogypsum (PG), calcium carbonate (CL), or dolomite (DL) and leached with 88 cm of water 8 times over the same period.

Treatment		pH	EC	P	Ca	Mg	K	Al	Fe	Mn	Cu	Zn	OM
No.	kg P ha^{-1} + A		µmho cm^{-1}	----------	----------	----------	mg kg^{-1}	----------	----------	----------	----------	----------	%
Pre-treatment:		5.40	46.0	0.90	37.60	1.60	5.70	10.7	4.31	0.09	0.000	0.280	0.00
T1	0 + 0	5.27b[#]	48.5b	1.83a	42.03a	2.37a	1.300a	8.47a	3.180a	0.043ab	0.030a	0.380a	0.10a
T2	0 + MG	4.93c	75.6a	2.70a	47.70a	3.43a	0.533a	8.53a	3.497a	0.010b	0.013a	0.357a	0.10a
T3	0 + PG	5.27b	38.0b	2.20a	42.27a	1.67a	0.467a	9.13a	3.463a	0.013b	0.013a	0.373a	0.03a
T4	0 + Cl	5.60a	40.4b	2.33a	48.20a	2.80a	1.133a	9.57a	3.480a	0.043ab	0.020a	0.413a	0.07a
T5	0 + DL	5.60a	36.7b	2.03a	47.07a	3.03a	1.033a	8.93a	3.290a	0.060a	0.013a	0.280a	0.03a
Statistics:													
P(Amendment)		< 0.01	0.05	0.20	0.31	0.12	0.07	0.44	0.60	0.05	0.30	0.68	0.62
LSD		0.17	26.5	0.766	8.26	1.39	0.675	1.45	0.535	0.036	0.020	0.212	0.13
T6	50 + 0	5.47b	36.1b	3.90ab	43.60b	2.23b	1.10a	9.37a	3.27a	0.027a	0.010a	0.380a	0.03a
T7	50 + MG	4.90c	80.9a	4.07a	51.70a	3.73a	0.80a	9.30a	3.57a	0.030a	0.017a	0.397a	0.00a
T8	50 + PG	5.00c	52.4b	4.37a	46.03b	2.30b	0.63a	8.93a	3.63a	0.050a	0.010a	0.360a	0.07a
T9	50 + CL	5.60a	42.0b	3.13c	46.17b	2.67b	1.30a	9.10a	3.33a	0.057a	0.013a	0.477a	0.00a
T10	50 + DL	5.60a	36.4b	3.40bc	46.60b	2.90b	1.30a	8.87a	3.24a	0.050a	0.053a	0.530a	0.03a
Statistics:													
P(Amendment)		< 0.01	< 0.01	< 0.01	0.04	< 0.01	0.13	0.30	0.13	0.62	0.58	0.75	0.21
LSD		0.11	22.5	0.57	4.66	0.67	0.63	0.59	0.38	0.053	0.069	0.338	0.09
T11	100 + 0	5.40a	32.1c	4.70b	41.13b	2.27b	1.00bc	8.67a	3.31a	0.043a	0.013a	0.313a	0.00a
T12	100 + MG	4.83c	77.9a	5.17ab	47.13a	3.70a	0.63bc	8.77a	3.48a	0.020a	0.010a	0.467a	0.07a
T13	100 + PG	5.10b	55.8b	5.90a	48.17a	2.30b	0.43c	9.67a	3.71a	0.033a	0.007a	0.337a	0.00a
T14	100 + CL	5.37a	39.5c	4.60b	45.30ab	2.50b	1.67a	9.27a	3.38a	0.047a	0.030a	0.623a	0.03a
T15	100 + DL	5.37a	41.1c	4.67b	43.77ab	2.67b	1.13ab	9.30a	3.39a	0.057a	0.013a	0.300a	0.00a
Statistics:													
P(Amendment)		< 0.01	< 0.01	0.02	0.04	0.01	0.01	0.33	0.15	0.37	0.38	0.22	0.15
LSD		0.35	14.7	0.78	4.44	0.73	0.60	1.16	0.33	0.041	0.027	0.332	0.06

[#] Means within a set of treatments with same letter code(s) are not different at P=0.05.

Table GS1-15. pH, EC, organic matter (OM), and Mehlich I extractable elements in potted Bh horizon of a Florida Spodosol (Immokalee fine sand) after 8 leachings over a period of 220 days using E leachates from potted E horizon previously leached with Ap leachates from potted Ap horizon fertilized at three rates of P (0, 29.2, and 58.4 mg P kg^{-1}) and amended with Ca amendments (A) applied at 800 kg Ca ha^{-1} in the form of mined gypsum (MG), phosphogypsum (PG), calcium carbonate (CL), or dolomite (DL) and leached with 88 cm of water 8 times over the same period.

Treatment		pH	EC	P	Ca	Mg	K	Al	Fe	Mn	Cu	Zn	OM
No.	kg P ha^{-1} + A		µmho cm^{-1}	mg kg^{-1}									%
Pre-treatment:		5.50	63.0	45.00	1000.0	124.0	35.80	940.0	4.92	0.14	0.030	0.490	2.90
T1	0 + 0	5.37a[#]	62.3c	57.67a	1180.0a	123.3a	33.33a	1073.3a	4.15a	0.180a	0.023a	0.353a	2.90a
T2	0 + MG	5.17b	98.9a	61.30a	1146.7a	92.4b	29.90a	1060.0a	4.34a	0.013c	0.023a	0.410a	3.03a
T3	0 + PG	5.27ab	78.5b	57.40a	1140.0a	97.3b	20.13b	1083.3a	4.27a	0.090b	0.073a	0.387a	3.00a
T4	0 + Cl	5.30a	72.9bc	56.87a	1163.3a	123.7a	32.20a	1073.3a	4.22a	0.187a	0.020a	0.410a	2.83a
T5	0 + DL	5.37a	68.5bc	54.20a	1133.3a	129.7a	29.10a	1070.0a	4.17a	0.213a	0.023a	0.330a	3.03a
Statistics:													
P(Amendment)		0.01	< 0.01	0.35	0.74	< 0.01	< 0.01	0.95	0.63	< 0.01	0.08	0.3834	0.58
LSD		0.11	16.0	7.31	87.8	15.7	4.79	67.0	0.30	0.069	0.073	0.152	0.33
T6	50 + 0	5.60bc	64.0b	63.27ab	1113.3a	121.7a	31.07a	1036.7a	4.10a	0.207a	0.023a	0.390a	2.83a
T7	50 + MG	5.37c	111.5a	62.83ab	1170.0a	104.5bc	28.80a	1056.7a	3.74a	0.127b	0.023a	0.450a	2.97a
T8	50 + PG	5.60bc	82.4b	66.07a	1176.7a	91.4c	17.67b	1046.7a	4.28a	0.077b	0.027a	0.390a	2.90a
T9	50 + CL	6.00a	63.9b	57.13b	1120.0a	118.7ab	31.33a	1076.7a	4.14a	0.203a	0.017a	0.383a	3.10a
T10	50 + DL	5.90ab	58.1b	57.27b	1130.0a	126.3a	32.67a	1056.7a	4.04a	0.210a	0.023a	0.343a	3.10a
Statistics:													
P(Amendment)		< 0.01	< 0.01	0.04	0.34	< 0.01	< 0.01	0.60	0.08	< 0.01	0.34	0.91	0.21
LSD		0.32	24.4	6.40	82.75	16.21	3.96	56.80	0.37	0.057	0.010	0.023	0.28
T11	100 + 0	5.37a	62.1c	72.67ab	1116.7b	119.0a	33.33ab	1056.7a	4.13a	0.187a	0.020a	0.327a	2.80a
T12	100 + MG	5.17b	114.9a	71.17ab	1156.7ab	95.2b	33.87a	1050.0a	4.17a	0.067b	0.023a	1.087a	3.13a
T13	100 + PG	5.20b	93.6b	75.07a	1193.3a	95.9b	20.63d	1076.7a	4.09a	0.100b	0.020a	0.400a	2.87a
T14	100 + CL	5.37a	65.6c	60.90c	1100.0b	117.3a	31.13c	1063.3a	4.05a	0.197a	0.020a	0.463a	2.70a
T15	100 + DL	5.37a	67.1c	64.20bc	1110.0b	118.0ab	31.23bc	1060.0a	4.13a	0.210a	0.017a	0.580a	3.03a
Statistics:													
P(Amendment)		< 0.01	< 0.01	0.04	0.03	0.04	< 0.01	0.84	0.60	< 0.01	0.77	0.3510	0.33
LSD		0.11	13.5	9.54	56.9	18.30	2.20	55.2	0.19	0.062	0.011	0.8694	0.49

[#] Means within a set of treatments with same letter code(s) are not different at P=0.05.

Losses of P from the potted Bh soils through leaching were not different indicating that higher levels of P were retained from the control and the gypsum-amended soils which remained extractable by a double acid solution. No consistent or significant trends relating Ca amendments P to the other measured soil variables were noted.

Soil Phosphorus Fractionation

The analytical total P values (Tables GS1-16 to GS1-18), which were less subject to analytical errors than the arithmetic totals, were generally within plus or minus 20 % of the latter. For the Ap horizon, organic and residual P appeared to be the most important sources of P (Table GS1-16). For the Bh, the organic and the inorganic (Al, Fe, etc.) appeared to be the major sources of P

Ap horizon. Total P tended to be higher with increasing P rates of application in this horizon (Table GS1-16). Within P rate, no significant differences between the treatments were noted, but potential effects of the lime materials in retaining P were indicated at the highest rate of P.

E horizon. No differences in total P were noted in the E horizon within fertilizer P rates (Table GS1-17). Total P retained in the E horizon tended to increase with increasing P rates. The amounts of P retained were most likely those associated with water adsorbed around the soil particles. No indication of any effects of Ca amendments on P retained could be seen.

Bh horizon. Total P tended to be higher with the two rates of P relative to the control indicating that fertilizer P was being retained in this horizon (Table GS1-18). In his horizon, the gypsums tended to retain P more effectively than the lime materials, particularly at the zero and the low P rate. The amount retained by mined gypsum was significantly higher than those of the control and dolomite at zero P, and that of phosphogypsum higher than those of the control and the lime materials at 25 kg P ha^{-1}.

Table GS1-16. Phosphorus fractions in potted Ap horizon of a Florida Spodosol (Immokalee fine sand) fertilized at three rates of P (0, 50, and 100 kg ha^{-1}) and amended with Ca amendments (A) applied at 800 kg ha^{-1} in the form of mined gypsum (MG), phosphogypsum (PG), calcium carbonate (CL), or dolomite (DL) after 8 leachings with 88 cm of water over a period of 220 days.

Treatment		Total P	Residual P	NaOH$_{total}$-P	NaOH$_{in}$-P	NaOH$_{or}$-P[+]	HCl-P	AmCl-P	Melh-P
No.	mg P kg^{-1} + A	mg P kg^{-1}							
T1	0 + 0	380.3a[#]	96.8a	202.6b	3.6b	199.0	12.4a	14.5a	5.3b
T2	0 + MG	441.0a	142.3a	280.6a	11.2a	269.4	18.4a	22.6a	15.3a
T3	0 + PG	422.3a	203.5a	249.4ab	4.5b	244.9	15.2a	13.4a	7.3b
T4	0 + Cl	388.3a	85.2a	202.6b	4.8b	197.8	28.8a	12.4a	8.4b
T5	0 + DL	454.3a	147.5a	249.4ab	5.7b	243.7	23.3a	13.7a	7.1b
<u>Statistics:</u>									
P(Amendment)		0.23	0.54	0.05	< 0.01	-	0.41	0.38	< 0.01
LSD		79.4	194.2	50.2	2.81	-	20.1	12.2	3.3
T6	29.2 + 0	448.0a	101.5a	296.2a	5.3a	290.9	19.8a	24.1a	10.9b
T7	29.2 + MG	564.7a	145.1a	343.0a	15.4a	327.6	31.7a	32.8a	24.4a
T8	29.2 + PG	471.7a	120.2a	233.8a	10.0a	223.8	26.4a	21.5a	13.7b
T9	29.2 + CL	504.0a	172.7a	311.8a	7.4a	304.4	38.9a	24.7a	16.1b
T10	29.2 + DL	461.0a	141.2a	343.0a	10.6a	332.4	23.3a	40.3a	25.6a
<u>Statistics:</u>									
P(Amendment)		0.19	0.47	0.68	0.06	-	0.15	0.17	< 0.01
LSD		107.8	102.0	226.6	6.6	-	16.2	17.4	5.9
T11	58.4 + 0	514.3a	114.8a	358.6a	10.9a	347.7	26.3b	28.2a	15.1a
T12	58.4 + MG	576.7a	105.0a	374.2a	13.2a	361.0	31.1b	43.7a	26.8a
T13	58.4 + PG	478.3a	87.5a	311.8a	9.8a	302.0	27.5b	43.2a	21.1a
T14	58.4 + CL	562.3a	108.5a	265.0a	11.3a	253.7	145.8a	96.0a	30.4a
T15	58.4 + DL	605.7a	115.5a	296.2a	11.4a	284.8	33.4b	55.1a	31.2a
<u>Statistics:</u>									
P(Amendment)		0.27	0.54	0.21	0.93	-	< 0.01	0.33	0.20
LSD		131.3	47.3	114.6	9.2	-	39.4	72.2	15.8

[#] Means within a set of treatments with same letter code(s) are not different at P=0.05.

[+] Values were obtained by difference (NaOH$_{total}$-P - NaOH$_{in}$) using the means, hence no statistics are given.

Table GS1-17. Phosphorus fractions in potted E horizon of a Florida Spodosol (Immokalee fine sand) after 8 leachings over a period of 220 days using Ap leachates from potted Ap horizon fertilized at three rates of P (0, 50, and 100 kg ha^{-1}) and amended with Ca amendments (A) applied at 800 kg ha^{-1} in the form of mined gypsum (MG), phosphogypsum (PG), calcium carbonate (CL), or dolomite (DL) and leached 8 times with 88 cm of water over the same period.

Treatment		Total P	Residual P	NaOH$_{total}$	NaOH$_{in}$-P	NaOH$_{or}$-P[+]	HCl-P	AmCl-P	Mehl-P
No.	mg P kg^{-1} + A				mg P kg^{-1}				
T1	0 + 0	63.0a[#]	45.5a	15.6a	7.0a	8.6	5.4a	9.3ab	1.8a
T2	0 + MG	74.7a	42.0a	0.0a	6.6a	-	4.7a	11.5a	2.7a
T3	0 + PG	71.7a	101.5a	0.0a	6.1a	-	8.1a	8.7ab	2.2a
T4	0 + Cl	73.7a	28.0a	15.6a	6.3a	9.3	4.7a	7.2b	2.3a
T5	0 + DL	73.7a	42.0a	15.6a	7.4a	8.2	5.3a	8.7ab	2.0a
<u>Statistics:</u>									
P(Amendment)		0.22	0.50	0.50	0.53	-	0.44	0.22	0.20
LSD		11.6	121.8	33.6	1.9	-	4.5	3.8	0.8
T6	29.2 + 0	80.3a	19.1a	15.6a	7.3a	8.3	5.3a	11.0a	3.9ab
T7	29.2 + MG	80.3a	37.8a	31.2a	9.2a	22.0	6.8a	14.0a	4.1a
T8	29.2 + PG	86.7a	40.1a	15.6a	7.8a	7.8	7.5a	11.8a	7.4a
T9	29.2 + CL	80.7a	23.8a	31.2a	7.0a	24.2	5.0a	9.8a	3.1c
T10	29.2 + DL	78.7a	28.0a	31.2a	8.0a	23.2	5.3a	11.8a	3.4c
<u>Statistics:</u>									
P(Amendment)		0.30	0.50	0.68	0.41	-	0.46	0.37	< 0.01
LSD		8.4	35.2	43.2	2.6	-	3.6	4.5	0.6
T11	58.4 + 0	85.0a	42.0a	15.6a	10.4a	5.2	5.3a	14.0a	4.7b
T12	58.4 + MG	91.3a	21.5a	31.2a	10.0a	21.2	5.0a	18.0a	5.2ab
T13	58.4 + PG	93.7a	18.0a	31.2a	8.8a	22.4	5.0a	18.5a	5.9a
T14	58.4 + CL	80.3a	21.5a	31.2a	7.5a	23.7	5.0a	12.4a	4.6b
T15	58.4 + DL	92.0a	18.0a	31.2a	9.0a	22.2	5.0a	15.2a	4.7b
<u>Statistics:</u>									
P(Amendment)		0.11	0.49	0.62	0.13	-	0.46	0.06	0.02
LSD		11.2	39.1	38.4	2.7	-	0.5	4.5	0.8

[#] Means within a set of treatments with same letter code(s) are not different at P=0.05.

[+] Values were obtained by difference (NaOH$_{total}$-P - NaOH$_{in}$) using the means, hence no statistics are given.

Table GS1-18. Phosphorus fractions in potted Bh horizon of a Florida Spodosol (Immokalee fine sand) after 8 leachings over a period of 220 days using E leachates from potted E horizon previously leached with Ap leachates from potted Ap horizon fertilized at three rates of P (0, 50, and 100 ha^{-1}) and amended with Ca amendments (A) at 800 kg ha^{-1} in the form of mined gypsum (MG), phosphogypsum (PG), calcium carbonate (CL), or dolomite (DL) and leached 8 times with 88 cm of water over the same period.

Treatment		Total P	Residual P	NaOH$_{total}$	NaOH$_{in}$-P	NaOH$_{or}$-P^{+}	HCl-P	AmCl-P	Mehl-P
No.	mg P kg^{-1} + A	mg P kg^{-1}							
T1	0 + 0	744.3bc[#]	16.8a	810.6a	149.1a	661.5	13.8a	2.3a	64.3a
T2	0 + MG	795.7a	18.2a	841.8a	196.2a	645.6	12.0a	2.3a	61.3a
T3	0 + PG	772.3ab	17.7a	919.6a	189.0a	730.6	12.4a	2.3a	57.4a
T4	0 + Cl	746.7abc	20.3a	810.6a	186.0a	624.6	10.3a	1.6a	56.9a
T5	0 + DL	711.7c	22.6a	888.6a	161.7a	726.9	10.7a	1.6a	54.2a
Statistics									
P(Amendment)		0.04	0.81	0.24	0.03	-	0.10	0.46	0.55
LSD		50.9	14.8	129.8	5.0	-	2.8	1.4	14.5
T6	29.2 + 0	779.3c	19.1a	966.0a	221.7a	744.3	12.0a	2.3a	63.3ab
T7	29.2 + MG	823.7ab	17.3a	966.0a	199.7a	766.3	14.3a	1.6a	62.8ab
T8	29.2 + PG	840.0a	22.4a	966.4a	230.7a	735.7	5.9a	1.6a	66.1a
T9	29.2 + CL	795.7bc	14.0a	982.0a	208.3a	773.7	16.2a	1.6a	57.1b
T10	29.2 + DL	788.7bc	16.8a	1044.0a	171.0a	873.0	11.7a	1.6a	57.3b
Statistics:									
P(Amendment)		0.05	0.55	0.96	0.19	-	0.33	0.46	0.04
LSD		42.2	13.0	347.8	57.6	-	5.9	1.1	6.4
T11	58.4 + 0	849.3a	25.4a	1028.8a	215.1a	813.7	14.3a	1.6a	72.7ab
T12	58.4 + MG	842.3a	15.9a	826.2b	213.3a	612.9	12.8a	1.6a	71.2ab
T13	58.4 + PG	842.3a	17.7a	882.0a	224.7a	657.3	13.4a	2.3a	75.1a
T14	58.4 + CL	806.3a	16.8a	1013.2a	218.5a	794.7	15.6a	2.3a	60.9c
T15	58.4 + DL	800.3a	20.3a	997.6a	244.6a	753.0	11.7a	2.3a	64.2bc
Statistics:									
P(Amendment)		0.15	0.42	0.02	0.46	-	0.92	0.46	0.04
LSD		49.2	13.5	100.6	20.7	-	10.3	1.4	9.5

[#] Means within a set of treatments with same letter code(s) are not different at P=0.05.

[+] Values were obtained by difference (NaOH$_{total}$-P - NaOH$_{in}$) using the means, hence no statistics are given.

Greenhouse Study 2, Part I (GS2-I): Individual Soil Horizons Planted to Stargrass

The secondary objective of the study - to compare the leachability of fine-ground and granular TSP in the Ap horizon of Immokalee fine sand can be disregarded outright for the reason that no significant differences (Ap + fine-ground TSP versus Ap + granular TSP) in most of the variables in soils, leachates, and forage were noted. For all practical purposes, TSP applied in GS2, Part I and Part II might just as well had been granular commercial TSP.

Influence of Soil Horizons on Leachate Properties and Elements

Leachate pH. Excluding the pure sand, leachate pH values for the soil horizons ranged from 6.13 to 7.36 throughout the 24-week period of sampling (Table GS2-I-3). These high values and narrow pH range are not likely to show any effects of pH on P mobility in individual or over all soil horizons. The high pH values may have been brought about and maintained by reducing conditions that developed at the bottom of the tubes due to standing water and watering three times a week averaging 3 cm per week. Reducing conditions normally develop in water-saturated soils and tend to increase soil-water pH. The redox potential was not measured. The pH values of water passing through similar soil horizons within hours, but with no stargrass planted (GS1), at the same 50 kg P ha^{-1} rate averaged 5.87, 4.57, and 5.04 for Ap, E, and Bh, respectively. Also, unlike the results obtained in GS1, Table GS2-I-3 indicated little or no influence of horizons on leachate pH. In relation to GS1, it is suggested that cropping with stargrass and letting the applied water stand for weeks could have strong influence on water pH in the horizons of Immokalee fine sand.

Leachate EC. Table GS2-I-4 shows the Ap leachates with the highest EC values that differentiated them from the other soil horizons. The Ap leachate EC values remained higher than those of the E, the Bh, or the pure sand during the whole period. Cropping, watering, and removal of water samples eventually narrowed the differences in EC leachate of Ap, E, Bh, and pure sand from an initial of 325 - 2330 to 339 - 846 µmho cm^{-1} range after 24 weeks of plant growth and 64 cm of water applied.

Calcium. Calcium concentrations in leachates over time are given in Table GS2-I-5. The Ap soils showed much higher leachate Ca than the other media. Calcium concentrations in Ap leachates decreased linearly over time from a high average of about 600 initially down to 115 mg Ca L^{-1} by the 15th week after the start of the study and thereafter remained relatively stable. It is suggested that this depletion of Ca in the Ap horizon was brought about primarily by leaching of excess Ca upon removal of 75 mL for analysis. Interestingly, Ca in leachates from sandy E and Bh horizons and from pure sand remained relatively constant throughout the growing and leaching period at a narrow range of from 40 to 87 mg Ca L^{-1}. This would indicate that the said media had the capacity to provide a steady source of Ca to stargrass which were not readily leachable.

Magnesium. Except in magnitude, Mg concentrations in Ap horizons over time behaved just like Ca (Table GS2-I-6) decreasing linearly over time from an average of 130 initially down to 28 mg Mg L^{-1} by the 15th week after the start of the study. They then stabilized thereafter to values not much different from those of the sandy horizons and pure sand. The E soils appeared to have the

Table GS2-I-3. pH of leachates from potted horizons of Immokalee fine sand, a Spodosol, and from pure sand fertilized at 50 kg P ha^{-1} using fine-ground TSP, unless indicated otherwise, and planted to stargrass.

	Week from first (second) P application									
Horizon (Treatment)	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	pH									
Ap	6.85b[#]	7.29ab	6.85b	7.13a	7.36ab	7.40ab	7.25ab	6.90cb	7.04b	6.79ab
Ap (granular TSP)	6.96b	7.07abc	6.60b	6.88ab	6.96b	7.18abc	7.23ab	7.15ab	7.16ab	6.87ab
E	6.24b	6.36bc	6.93b	6.13b	6.83b	6.79c	7.00bc	7.25ab	7.05b	6.77ab
Bh	6.93b	6.20c	7.07b	6.78ab	7.11ab	7.00ab	6.61c	6.56c	6.19c	6.43b
Pure sand	7.82a	7.58a	7.68a	7.67a	7.69a	7.56a	7.61a	7.61a	7.64a	7.34a
Statistics:										
P(Horizons)	< 0.01	0.04	< 0.01	0.03	0.08	< 0.01	0.02	0.01	< 0.01	0.17

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.

Table GS2-I-4. Electrical conductivity (EC) of leachates from potted horizons of Immokalee fine sand, a Spodosol, and from pure sand fertilized at 50 kg P ha^{-1} using fine-ground TSP, unless indicated otherwise, and planted to stargrass.

	Week from first (second) P application									
Horizon (Treatment)	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	---------- µmho cm^{-1} ----------									
Ap	2330a[#]	1182a	1657a	1036a	861a	635ab	643ab	670ab	704ab	640b
Ap (granular TSP)	2217a	1324a	1935a	1115a	973a	790a	806a	886a	888a	846a
E	895b	500b	714b	440b	342b	429b	372c	338c	283c	339d
Bh	500c	503b	531b	489b	473b	472b	511bc	509bc	492bc	532bc
Pure sand	325d	456b	377b	486b	496b	477b	505bc	498bc	491bc	469cd
Statistics:										
P(Horizons)	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.

Table GS2-I-5. Ca concentrations in leachates from potted horizons of Immokalee fine sand, a Spodosol, and from pure sand fertilized at 50 kg P ha^{-1} using fine-ground TSP, unless indicated otherwise, and planted to stargrass.

	Week from first (second) P application									
Horizon (Treatment)	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	mg L^{-1}									
Ap	631.6a[#]	400.6a	319.3a	225.7a	177.5a	146.4a	113.7a	144.1a	136.3ab	120.1ab
Ap (granular TSP)	559.8a	479.2a	344.6a	257.6a	176.7a	173.4a	116.1a	142.8a	152.5a	157.5a
E	60.7b	53.9b	76.1b	66.5b	47.5b	77.2b	59.1b	54.1a	50.5c	49.8c
Bh	40.0b	52.0b	56.9b	53.1b	48.4b	52.5b	55.8b	73.1a	63.9bc	57.0bc
Pure sand	27.1b	57.6b	71.4b	51.8b	78.5b	86.8b	54.2b	53.6a	59.0c	64.5bc
Statistics:										
P(Horizons)	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.01	< 0.01	0.15	0.03	0.01

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.

Table GS2-I-6. Mg concentrations in leachates from potted horizons of Immokalee fine sand, a Spodosol, and from pure sand fertilized at 50 kg P ha^{-1} using fine-ground TSP, unless indicated otherwise, and planted to stargrass.

	Week from first (second) P application									
Horizon (Treatment)	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	mg L^{-1}									
Ap	141.8a[#]	72.2a	56.7a	44.2a	36.0a	27.5ab	24.4ab	31.0ab	29.4ab	29.1ab
Ap (granular TSP)	121.1a	86.9a	63.3a	52.1a	40.6a	36.1a	31.4a	37.6a	36.0a	37.3a
E	7.4b	5.4b	7.6b	5.6c	4.2c	5.9d	5.4c	5.3c	5.3c	5.6c
Bh	15.1b	22.5b	24.2b	22.6b	21.1b	22.8bc	23.8ab	25.2ab	27.8ab	28.2ab
Pure sand	5.9b	8.0b	13.4b	12.4bc	13.9bc	16.2cd	15.8b	16.2bc	16.4b	14.5bc
Statistics:										
P(Horizons)	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.01	< 0.04

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.

least CA. Like Ca, depletion of Mg could have been brought about primarily by leaching of excess Mg. Like Ca, Mg in leachates from sandy soil horizons and from pure sand remained relatively constant through the growing and leaching period at a narrow range of from 6 to 28 mg Mg L^{-1} indicating that the said media had the capacity to provide a steady source of Mg to stargrass.

Potassium. Potassium in Ap also decreased almost linearly over time from an average of 133 initially down to 21 mg K L^{-1} by the last sampling (Table GS2-I-7). There is, however, no logical reasons why such differences should be attributed to the differences in the particle size of TSP. The depletion of K in the Ap leachates could be primarily attributed to the leaching of excess K upon leachate withdrawal for analysis and to a lesser degree to crop removal. Potassium fertilizer was applied to all pots twice, the first at the beginning of the study and the second on the 14th week. The latter application appeared to have made no difference to K concentrations in leachates indicating that it was being utilized by the plant.

Aluminum. Table GS2-I-8 shows Al concentrations over time. The Al levels in Ap and in pure sand leachates were well defined, in Ap sharply decreasing over time up to the 12th week from an initial value of about 1.4 and stabilizing to 0.4 and 0.6 mg L^{-1} thereafter. This could be due primarily to leaching of excess Al upon removal of soil water for analysis. The lowest Al concentrations were in pure sand leachates which remained steady throughout at about 0.2 mg L^{-1}. Aluminum concentrations in Bh leachates varied widely throughout the sampling period as did Al levels in E leachates up to the 12th week. No explanation is suggested except analytical variability.

Iron. Iron concentrations were higher in E (initially, 1st, 3rd, and 9th week) and in Bh (1st, 9th and 12th week) leachates than in Ap or in pure sand (Table GS2-I-9). There was little to indicate what the effects of cropping and leaching were on Fe concentrations in leachates because of its very low concentrations.

Nitrate. Nitrogen was applied to the pots as ammonium nitrate fertilizer. The differences in NO_3 concentrations in leachates from the various potted horizons and pure sand shown in Table GS2-I-10 indicated that the applied amount represented but a small fraction of soil nitrate in the Ap horizon. This amount was barely detectable in the E, Bh, and in pure sand. Like the cationic nutrients, nitrate linearly decreased from an initial average value of 291 mg NO_3 L^{-1} down to zero or undetectable level by the 9th week of plant growth and watering. Nitrate values went up on the 21st and the 24th after the second N application made on the 14th week. Because of extreme analytical variability, however, values as high as 74 mg NO_3 L^{-1} were not differentiable statistically from zero (Table GS2-I-10).

Sulfate. No sulfate fertilizer was used in the study so that the amounts of SO_4 shown in Table GS2-I-11 can only be soil SO_4. Again, the analytical variability was extremely high so that values 3 and 216 mg L^{-1} (18th week) were not statistically differentiable. Like nitrate, SO_4 in Ap leachates also decreased over time from 883 initially down to 59 mg SO_4 L^{-1} by the 15th week. Sulfate concentration appeared to be stable in the sandy horizons and in pure sand throughout the period.

Table GS2-I-7. K concentrations in leachates from potted horizons of Immokalee fine sand, a Spodosol, and from pure sand fertilized at 50 kg P ha^{-1} using fine-ground TSP, unless indicated otherwise, and planted to stargrass.

	Week from first (second) P application									
Horizon (Treatment)	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	mg L^{-1}									
Ap	146.0a[#]	73.2a	54.7a	55.4a	39.3ab	28.5b	27.4b	26.9bc	20.0bc	13.1b
Ap (granular TSP)	118.5a	77.2a	60.0a	60.1a	51.9a	49.0a	52.8a	38.8b	39.0b	30.0a
E	47.1b	29.0b	20.7b	16.4b	10.4c	9.4ab	7.4bc	5.2bc	3.7c	2.6c
Bh	22.7bc	27.9b	25.3b	27.2b	25.6b	23.6b	22.0bc	26.9bc	11.8c	11.1bc
Pure sand	1.8c	1.7c	1.7c	0.6c	1.2c	1.2c	1.8c	2.0c	1.9c	1.3c
Statistics:										
P(Horizons)	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.04	< 0.03	0.13	0.01	0.04

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.

Table GS2-I-8. Al concentrations in leachates from potted horizons of Immokalee fine sand, a Spodosol, and from pure sand fertilized at 50 kg P ha^{-1} using fine-ground TSP, unless indicated otherwise, and planted to stargrass.

	Week from first (second) P application									
Horizon (Treatment)	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	mg L^{-1}									
Ap	1.46a[#]	1.03a	0.83a	0.64a	0.52a	0.49b	0.35b	0.44ab	0.45b	0.38bc
Ap (granular TSP)	1.34a	1.18a	0.94a	0.72a	0.52a	0.54ab	0.35b	0.59a	0.50b	0.50b
E	0.53b	0.55b	0.85a	0.69a	0.36ab	0.36b	0.24b	0.23ab	0.24b	0.23cd
Bh	0.32c	0.53b	1.28a	0.72a	0.49ab	0.84a	0.75a	0.63a	1.19a	0.92a
Pure sand	0.08c	0.20c	0.22b	0.19b	0.24b	0.28b	0.17b	0.18b	0.21b	0.14d
Statistics:										
P(Horizons)	< 0.01	< 0.01	0.04	0.08	0.13	0.02	< 0.01	0.08	< 0.01	< 0.01

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.

Table GS2-I-9. Fe concentrations in leachates from potted horizons of Immokalee fine sand, a Spodosol, and from pure sand fertilized at 50 kg P ha^{-1} using fine-ground TSP, unless indicated otherwise, and planted to stargrass.

	Week from first (second) P application									
Horizon (Treatment)	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	mg L^{-1}									
Ap	0.03b[#]	0.06c	0.06bc	0.07a	0.24bc	0.26b	0.23a	0.19a	0.17a	0.19a
Ap (granular TSP)	0.02b	0.02c	0.05bc	0.09a	0.19c	0.41ab	0.22a	0.21a	0.22a	0.17a
E	0.41a	0.43b	0.66a	2.53a	2.44a	0.34ab	0.61a	0.46a	0.28a	0.42a
Bh	0.06b	0.77a	0.21b	0.62a	1.14b	0.91a	0.45a	0.45a	0.32a	0.53a
Pure sand	0.00b	0.02c	0.01c	0.01a	0.02c	0.01b	0.03a	0.04a	0.03a	0.00a
Statistics:										
P(Horizons)	< 0.01	< 0.01	< 0.01	0.25	< 0.01	0.06	0.44	0.40	0.32	0.18

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.

Table GS2-I-10. Nitrate concentrations in leachates from potted horizons of Immokalee fine sand, a Spodosol, and from pure sand fertilized at 50 kg P ha^{-1} using fine-ground TSP, unless indicated otherwise, and planted to stargrass.

	Week from first (second) P application									
Horizon (Treatment)	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	mg L^{-1}									
Ap	355.45a[#]	86.27b	0.08a	10.48ab	0.16a	0.00a	0.52a	0.04b	47.00a	26.26a
Ap (granular TSP)	227.06a	177.82a	42.33a	20.92a	0.00a	0.00a	0.00a	0.00b	73.94a	48.69a
E	42.83b	13.60b	0.34a	9.63ab	0.16a	0.00a	0.16a	1.83a	0.87a	0.59a
Bh	0.32b	0.25b	0.08a	0.17b	0.00a	0.00a	0.00a	0.01b	0.29a	0.17a
Pure sand	0.21b	0.21b	0.00a	0.00b	0.00a	0.00a	0.00a	0.00b	0.00a	0.00a
Statistics:										
P(Horizons)	< 0.01	< 0.01	< 0.01	0.15	0.58	-	0.10	0.04	0.57	0.56

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.

Table GS2-I-11. Sulfate concentrations in leachates from potted horizons of Immokalee fine sand, a Spodosol, and from pure sand fertilized at 50 kg P ha^{-1} using fine-ground TSP, unless indicated otherwise, and planted to stargrass.

	Week from first (second) P application									
Horizon (Treatment)	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	mg L^{-1}									
Ap	953a[#]	857ab	737a	571a	275a	223a	101bc	121a	98ab	4a
Ap (granular TSP)	812a	1388a	833a	697a	290a	50a	16c	216a	142ab	109a
E	371b	240b	208b	212b	101a	249a	122ab	106a	98ab	94a
Bh	136c	186b	215b	192b	164a	199a	220a	149a	274a	163a
Pure sand	10c	28b	55b	55b	51a	29a	11c	3a	2b	2a
Statistics:										
P(Horizons)	< 0.01	0.02	< 0.01	< 0.01	0.55	0.19	< 0.01	0.30	0.06	0.27

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.

Chloride. Chloride was applied to the pots as KCl. From the values in pure sand, the applied Cl represented but a small fraction of Cl in the Ap horizon (Table GS2-I-12). Chloride in Ap leachates decreased very gradually over time down to the last sampling but appeared to be stable in the other soil horizons and in pure sand. The pure sand and the E horizon leachates had the least amounts of chloride.

Phosphorus in Leachates

Leachate P concentrations over time are given in Table GS2-I-13. Leachate P concentrations in both potted Ap soils differed only on the 9th and the 12th week of sampling. The results indicated that grinding the commercial granular TSP to powder made no difference in P solubility in soil.

Unlike the major cationic or anionic plant nutrients discussed earlier which decreased in concentrations with time, P in leachates remained relatively constant in each medium over time (Table GS2-I-13). Table GS2-I-13 also shows that P concentrations in the Ap leachates remained very much higher than those in E, Bh, or pure sand leachates, and these even increased after the second P fertilizer application particularly by the 24th week. These showed that the amounts of readily available soil P in the Ap horizon of Immokalee fine sand were simply far in excess of stargrass's needs for P. On the other hand, the very small amounts of P that leached through E, Bh, and pure sand would imply that stargrass utilized most of the fertilizer P and demonstrated pasture cropping as the major method or practice to prevent P losses through leaching and, possibly, also runoff. By the 24th week, almost nothing leached from Bh and pure sand.

Relations Between Phosphorus and Some Leachate Properties and Elements

Leachate pH and P. There was no relation (Table GS2-I-14) between leachate pH and P concentrations within the pH range 6.13 to 7.82. Labile inorganic P in soils is relatively high at this pH range or between pH 6.0 and 7.0 (Buckman and Brady, 1970; Sharpley, 2000).

Leachate EC and P. Leachate EC was strongly positively correlated with P concentrations in leachates (Table GS2-14). This would indicate that P tended to be highly mobile in soil-water high in salt concentrations as noted in GS1.

Leachate cations and P. Individually, all major cations were associated positively with P concentrations particularly Ca, Mg, and K (Table GS2-I-14; GS1). This would indicate that ion-pairing between the dissolved anionic P species such as PO_4^-, HPO_4, and H_2PO_4 and the cations give P its mobility in the soil.

No significant association between Al and Fe with P in leachates were noted (Table GS2-I-14). This was likely due to the low solubility of these materials in the pH range just noted. Although not significant, Fe tended to be negatively associated with P concentrations. This was also observed in GS1 using the same or similar soils with no stargrass planted. Low dissolved Fe in leachates would mean low Fe precipitates in equilibrium with dissolved Fe and low potential capacity to tie up P, thus the higher P concentrations at the lower Fe concentrations or the negative association.

Table GS2-I-12. Chloride concentrations in leachates from potted horizons of Immokalee fine sand, a Spodosol, and from pure sand fertilized at 50 kg P ha^{-1} using fine-ground TSP, unless indicated otherwise, and planted to stargrass.

	Week from first (second) P application									
Horizon (Treatment)	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	mg L^{-1}									
Ap	140a[#]	56ab	47a	39a	33a	30ab	33ab	29ab	21ab	14a
Ap (granular TSP)	112a	93a	55a	44a	40a	40a	47a	41a	33a	27a
E	23b	12b	11b	9b	9b	10b	12b	13b	9b	7a
Bh	36b	42ab	41a	38a	41a	38a	44a	40ab	23ab	22a
Pure sand	5b	5b	6b	7b	9b	9b	12b	13b	11ab	10a
Statistics:										
P(Horizons)	< 0.01	0.03	< 0.01	< 0.01	< 0.01	0.02	0.03	0.05	0.17	0.18

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.

Table GS2-I-13. Phosphorus concentrations in leachates from potted horizons of Immokalee fine sand, a Spodosol, and from pure sand fertilized at 50 kg P ha^{-1} using fine-ground TSP, unless indicated otherwise, and planted to stargrass.

	Week from first (second) P application									
Horizon (Treatment)	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	mg L^{-1}									
Ap	2.29a[#]	2.74a	2.13a	1.26a	2.32a	3.06b	2.88a	3.19a	3.07a	5.47a
Ap (granular TSP)	1.60a	2.59a	2.75a	1.56a	1.26b	5.42a	2.03a	1.96ab	3.24a	6.83a
E	0.22b	0.14b	0.23b	0.14b	0.19c	0.13c	0.18b	0.16b	0.15b	0.11b
Bh	0.18b	0.12b	0.18b	0.16b	0.15c	0.18c	0.18b	1.19ab	0.12b	0.08b
Pure sand	0.10b	0.10b	0.16b	0.07b	0.17c	0.15c	0.13b	0.12b	0.13b	0.00b
Statistics:										
P(Horizons)	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.05	< 0.01	< 0.01

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.

Table GS2-I-14. Relationships between P concentrations (Y = mg P/unit X) and pH, EC, cation, and anions (X) in leachates from all potted media (Ap, E, and Bh horizons of Immokalee fine sand and from pure sand) planted to stargrass and fertilized twice at 50 kg P ha^{-1}.

Leachate variable	Unit	Regression equation	R^2	P-level[#]
Gross property:				
pH	-	$Y = -0.043X + 1.56$	0.00	ns
EC	µmho cm^{-1}	$Y = 0.002X + 0.18$	0.18	**
Macro cations:	mg L^{-1}			
Calcium		$Y = 0.005X + 0.54$	0.20	***
Magnesium		$Y = 0.025X + 0.52$	0.19	**
Potassium		$Y = 0.022X + 0.62$	0.16	**
Micro cations:	mg L^{-1}			
Aluminum		$Y = 0.823X + 0.80$	0.03	ns
Fe		$Y = -0.698X + 1.50$	0.05	ns
Macro anions:	mg L^{-1}			
Sulfate (SO_4)		$Y = 0.001X + 0.98$	0.04	ns
Chloride (Cl)		$Y = 0.197X + 0.65$	0.10	*
Nitrate (NO_3)		$Y = 0.007X + 1.09$	0.08	*

[#] ns = not significant at P = 0.05, * significant at P = 0.05, ** significant at P = 0.01, *** significant at $P \leq 0.001$.

Leachate anions and P. Anions Cl and NO_3 were supplied to the potted soils as KCl and NH_4NO_3 but no SO_4. All the anions tended to be positively associated with P concentrations in leachates (Table GS2-I-14). These associations might be coincidental in the sense that these anions can remain in dissolved state in the soil water only when paired with the abundant major cations like Ca, Mg, or K.

Forage Yield, Phosphorus, and Other Nutrients in Forage

Forage Yield and Percent Dry Matter. Total yields and average % DM in Table GS2-I-15 were not different for all soil horizons. Pure sand gave the lowest yield which was significantly different only from the Ap with fine-ground TSP. The potted Ap yields of 41.9 for granular and 52.5 mg pot^{-1} for fine-ground TSP were not statistically different. On hectare-basis, forage DM yields would have ranged from 12.26 Mg for sand to and average of 15.03 Mg for the two Ap's.

Phosphorus and other nutrients in forage. The two applications of P fertilizers totaled 314.0 mg pot^{-1}. The P uptake values for the plants in the two Ap soils computed from dry matter yields, averaged 132.0 mg pot^{-1} or 42.0 % of the applied fertilizer P (Table GS2-I-15). The P uptake by plants in E, Bh, and pure sand averaged 34.7, 36.3, and 33.4 % of the applied P, respectively, which were not statistically different from one another and, most likely, are not different from the lower P uptake value of 34.7 % for Ap plants fertilized with granular TSP. Thus, despite the different amounts of available P among the various media (Tables GS2-I-2 and GS2-I-16), P uptake by stargrass was limited to a narrow range of 0.27 to 0.29 % P in the tissue. This would mean that soils planted to stargrass having 0.27 to 0.29 % P with no P fertilizer do not need any fertilizer P, and any application of P would just be a waste of money since it is not likely to increase forage yield but would most likely increase P losses through leaching and/or runoff (Table GS2-I-13).

Higher tissue K contents were not strongly associated with increased yields. Iron, Cu, Zn, and Mn uptakes were very similar for all soil horizons and for pure sand (Table GS2-I-15). Since pure sand was not supposed to have as much of these macro and micro nutrients as the soil horizons, their sources in the potted pure sand could have been the rich top soil in the sods or swards. It appeared then that there were enough Ca, Mg, and the micro nutrients in the top two inches of soil of Immokalee fine sand to meet the needs of stargrass.

Phosphorus and Other Nutrients in Soil

The pre-treatment analyses of Ap, E, and Bh horizons (Table GS2-I-1) indicated that the Bh horizon was much richer in plant nutrients than the Ap horizon except for Fe. The E horizon, being primarily sand, had the least amounts of plant nutrients among the three soil horizons. At the end of the study the soils were analyzed again to determine the changes that had occurred after cropping with stargrass. The sod was separated from the soil column, and the sod soil was analyzed separately.

Soil Column. Although no statistical analysis was done to compare pre- and post-treatment values, some notable changes appeared to have occurred (Table GS2-I-16). The pH values of potted Ap and E horizons, but not that of the Bh, appeared to have increased due, probably, to the loss of acidic substances from these horizons because of leaching. The almost unchanged pH of the Bh rules out the effect of submergence, which tended to increase soil pH, since the Bh tended to remain moist for longer periods than the Ap or the E due to the standing water. This then could be due to the strong buffering capacity of the Bh horizon at the pH range 4.8 - 5.0 as reported in GS1.

Phosphorus appeared to have build up in the Ap soils after P fertilization averaging 15.0 mg kg^{-1} compared to the pre-fertilization value of 2.0 mg kg^{-1}. It is possible, however, that the low pre-fertilization value for the Ap soil was simply an analytical anomaly. More will be said about these pre- and post-fertilization P values in accounting for fertilizer P. The E soils ended up with the same pre- and post fertilization P values of 1.2 (Table GS2-I-1) and 1.3 mg kg^{-1} (Table GS2-I-16). The applied P could be accounted for by P taken up by the plant, in leachates withdrawn for analysis, retained in the soil column, and in the sod soil (Table GS2-I-16). It was unfortunate that no pre-fertilization analysis of the sod soil was done or that no P control was included in the treatments at least for the Ap soil. The Bh continued to have the highest amount of extractable P.

Table GS2-I-15. Total dry matter (DM) yield, percent dry matter (%DM), and total elemental uptake by stargrass planted in potted Ap, E, and Bh horizons of Immokalee fine sand, a Spodosol, and in pure sand fertilized at 50 kg P ha^{-1} applied twice using fine-ground TSP, unless indicated otherwise.

			Elemental uptake								
Horizon (Treat.)	%DM	DM	P	K	Ca	Mg	Fe	Al	Cu	Zn	Mn
		g pot^{-1}	mg pot^{-1}								
Ap	27.4a	52.5a[#]	155a	479a	389a	143a	2.71a	266a	0.55a	2.35a	1.85a
Ap (granular TSP)	24.1a	41.9ab	109b	452a	248b	97b	2.12a	318a	0.40a	2.06a	1.13a
E	29.7a	40.2ab	109b	326b	324ab	113ab	3.05a	467a	0.45a	1.91a	1.45a
Bh	28.2a	42.6ab	114b	453a	292ab	118ab	2.66a	342a	0.45a	2.16a	1.44a
Pure sand	27.0a	38.5b	105b	333b	277ab	116ab	2.63a	410a	0.49a	2.02a	1.54a
Statistics:											
P(Horizons)	0.41	0.18	0.04	< 0.01	0.12	0.15	0.70	0.61	0.44	0.94	0.32

[#] Means with same letter are not different at P = 0.05 using Duncan's multiple range test.

Table GS2-I-16. Soil pH and certain Mehlich I extractable elements in potted soil horizons of Immokalee fine sand and in pure sand planted to stargrass and fertilized twice at 50 kg P ha^{-1} with the second P application made 14 weeks after the first.

Horizon	pH	P	K	Ca	Mg	Fe
		------------------------------ mg kg^{-1} ------------------------------				
Ap	6.1b[#]	12.9b	5.2ab	1195b	72.0b	7.9bc
Ap (granular)	6.0b	17.1b	8.8a	1323a	86.7a	8.7a
E	5.3c	1.3c	0.4c	36d	4.0c	4.4bc
Bh	5.0d	92.3a	4.0bc	573c	90.7a	3.7c
Pure sand	6.5a	2.4c	0.4c	28d	2.7c	4.3c
Statistics:						
P(horizon)	< 0.01	< 0.01	< 0.01	< 0.02	< 0.01	0.07
Sod soil:						
Ap	5.3a	28.3a	16.0a	1759a	256a	3.2a
Ap(granular)	5.3a	16.7a	21.9a	2076a	345a	3.5a
E	5.2a	31.9a	16.3a	1456a	257a	4.0a
Bh	4.8a	28.9a	18.8a	1245a	229a	4.5a
Pure sand	5.1a	24.9a	17.6a	1517a	285a	5.3a
Statistics:						
P(horizon)	0.61	0.64	0.75	0.80	0.91	0.68

[#] Means with same letter are not different at $P = 0.05$ using Duncan's multiple range test.

For the other nutrients, the E and the pure sand had the lowest amounts of K, Ca, and Mg (Table GS2-I-16). Between the pre- and the post-fertilization, K remained almost unchanged in the Ap and was substantially reduced in the E and the Bh soils. Extractable Ca and Mg were substantially increased in the Ap but remained almost unchanged in the Bh. Iron was unchanged in the Ap, E, or the Bh soils.

Sod Soil. Table GS2-I-16 shows no significant differences in sod soil pH or any of the plant nutrients between any two potted soil horizons of Immokalee fine sand and pure sand. This would indicate that similar amounts of any one particular nutrient analyzed were taken up by the plant and/or lost from the sod soil with leaching.

Accounting for Soil and Fertilizer Phosphorus

The summary for P in the above-ground plant tissue (roots and the stubble portions were not analyzed), in leachate withdrawn for analysis, and in soil column and in sod soil is given in Table GS2-I-17. Total P in leachates was the sum of the products of the volumes and concentrations for ten samplings done during the period of study.

Table GS2-I-17. Accounting for P in soil horizons of Immokalee fine sand and in pure sand planted to stargrass and fertilized twice at 50 kg P ha^{-1} with the second P application made 14 weeks after the first.

	Potted growing media			
P Source	Ap horizon	E horizon	Bh horizon	Pure sand
Fertilizer P + initial soil P:	Total mg P pot^{-1} (%)			
Fertilizer P applied	314.0 (90.60)	314.0 (91.12)	314.0 (19.78)	314.0 (96.17)
Initial soil P in column	21.2 (6.12)	14.7 (4.27)	1,258.9 (79.31)	0.0 (0.00)[#]
Sod soil [##]	11.3 (3.26)	15.9 (4.61)	14.5 (0.91)	12.5 (3.83)
Initial-Total	346.5 (100.0)	344.6 (100.0)	1,587.4 (100.0)	326.5 (100.0)
Post fertilization P sources:				
Plant tissue	132.0 (43.32)	109.0 (77.36)	114.0 (9.05)	105.0 (71.43)
Leachate withdrawn	2.2 (0.72)	0.1 (0.07)	0.2 (0.02)	0.1 (0.07)
Soil column	159.2 (52.25)	15.9 (11.28)	1,130.3 (89.78)	29.4 (20.00)
Sod soil	11.3 (3.62)	15.9 (11.28)	14.5 (1.15)	12.5 (8.50)
Post-Total	304.7 (100.0)	140.9 (100.0)	1,259.0 (100.00)	147.0 (100.0)
	post-P:pre-P ratio			
Soil: post-P:pre-P ratio	7.51 [1.05][###]	1.08	0.90	-
Total: post-P:pre-P ratio	0.88 [0.78][###]	0.41	1.26	0.45

[#] Zero P was assumed since no analysis of pure sand was done prior to planting and P fertilization.

[##] Values are those after the study using an amount of sod soil of about 500 g; no analysis of soil in sod was done prior to planting and P fertilization. Estimated values are intended to show the very high P concentrations in sod soil (Table GS1-I-15) in proper perspective.

[###] Using the value for Ap in Table GS1-3 as discussed in the text.

Fertilizer P applied to each pot ranged from about 20 % of the total P in Bh soils to 96 % in pure sand. The Ap and the E had almost similar initial P concentrations of 2.0 and 1.2 mg kg^{-1} (Table GS2-I-1), respectively. The value for Ap appeared unreasonable low. For portions of the same or similar soils, Table GS1-3 showed the Ap and the E horizons to have initial P concentrations of 14.2 and 0.9 mg P kg^{-1} . Using 14.2 mg P kg^{-1} for Ap for the present study would result to a total P of 150.7 mg pot^{-1} instead of just 24.5 mg pot^{-1} shown in Table GS2-I-17. Then the initial total and the post-fertilization total of 476.0 and 304.7 mg P pot^{-1}, respectively, would be more reasonable. Because the choice of value to use for Ap would affect the interpretation of the data, it is not unreasonable to use the value obtained in Table GS1-3 for the same or similar soil. Not to do otherwise would force us to conclude that the post-study soil P concentration increased 7.5 times that of pre-study P concentration which cannot be explained without resorting to claims of increased soil P mobilization in the Ap upon P fertilization.

Using the pre-fertilization P concentration value of Table GS1-I-3 for Ap soil suggested above, the data indicated that the potted Ap, E, and Bh soil horizons contained as much P after the study as was present initially, with soil pre-P:post-P ratios of 1.06, 1.08, and 0.90, respectively (Table GS2-I-17). This would indicate that the stargrass plant took up almost the same amount of P in each potted medium, and this was supported by the P uptake (Tables GS2-I-15). That this was indeed the case was supported also by the leachate P data which showed almost no loss of P for E, Bh, and pure sand. The greater loss of P from the Ap could be attributed to amounts of P in excess of plant needs because of the significant amounts of soil P. On percent basis, the Bh lost the least amount of P through leaching. Accounting for total P gave ratios less than 1.0 (Table GS2-I-17) due to the unaccounted P in roots and in stubbles and possible conversion of fertilizer P into non-Mehlich extractable P. Unaccounted P appeared to be highest for E horizon and for pure sand with total post-P:pre-P ratios of 0.41 and 0.45, respectively.

Greenhouse Study 2, Part II (GS2-II): Reconstructed Soil Profile Planted to Stargrass

Calcium Amendments and Associated Leachate Properties

In this study, shallow well water samples were obtained at the bottom of the E horizon while those of the deep well at the bottom of the spodic horizon. The bottom leachates were samples that drained at the bottom of the PVC tubes. For convenience, all samples are simply called leachates and, at time, soil water.

It may be important to note at this point that the granular mined gypsum, the calcium carbonate, and the dolomite were all ground into fine powder for use in this study. While it was shown in GS2-I that fine-ground TSP behaved no differently from the commercial granular TSP, this may not be true in the case of the Ca amendments. This should be kept in mind when evaluating the effects of the Ca amendments in this study.

Leachate Ca concentration. There were no statistical differences between any two Ca amendments due, most likely, to the grinding of the amendments into powder (Tables GS2-II-2, GS2-II-3, and GS2-II-4). Nor were any differences noted between any amendment and the control indicating a very well limed soil. In the shallow well leachates, Ca concentrations in the control tended to be lower than in the amended leachates, but the differences did not attain a level of significance. This would mean that the amendments did add some Ca to the Ap+E profile but not enough to make any significant difference to an already well-limed field.

Leachate EC. Tables GS2-II-5, GS2-II-6, and GS2-II-7 show the statistics for each collection for the shallow wells, the deep wells, and the bottom leachates, respectively. At no instance were there any differences between any two treatments although the control tended to have lower EC than the amended ones particularly for the shallow wells. For the amendments, this would indicate that grinding them into powder obliterated the distinctive difference in solubilities between the lime materials and the gypsum which, in water at 25 ^{0}C, are 0.014, 0.320, and 2.410 g L^{-1} for calcium carbonate, dolomite, and gypsum, respectively (Weast, 1980-81). No doubt, this would have consequence on their effects on P mobility in soils.

Leachate pH. The pH of shallow well leachates ranged from 6.87 to 7.09 at pre-amendment application and from 6.24 to 7.02 for the ten samplings during the 24-week period (Table GS2-II-8). These high values and narrow pH range are not likely to show any effects of pH on P mobility in individual or over all soil horizons. The high pH values may have been brought about and maintained by reducing conditions that developed in the tubes due to standing water. Reducing conditions normally develop in water-saturated soils and tend to increase soil-water pH. The redox potential was not measured. The lower post-treatment pH could be attributed to the influence of the acidic TSP. It is surprising to note that the pH values of leachates from the control, the lime-treated, and the gypsum-treated soils were not statistically different except at one sampling (21st week) during the 24-week period. Even at this one instance, only dolomite at 4 Mg ha^{-1} had pH higher than the control. Consistent with what was found in GS1, mined gypsum reduced the pH of leachates below that of the control in this one instance. In all instances, the pH values of the lime- and the

Table GS2-II-2. Ca concentrations in shallow well leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at 50 kg P ha^{-1} and amended with Ca amendments.

		Week from first (second) P application									
Treatment	Rate	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	Mg ha^{-1}	mg L^{-1}									
No amendment	0	125.3a[#]	98.0a	88.4a	82.5a	81.8a	65.8a	71.1a	67.3a	66.3a	62.7a
Gypsum	2	206.8a	157.7a	128.7a	104.1a	90.7a	74.4a	71.7a	69.5a	63.6a	59.0a
	4	159.3a	134.2a	87.4a	79.2a	76.3a	61.5a	20.2a	54.8a	53.7a	64.3a
Limestone	2	178.6a	149.8a	108.7a	92.9a	85.3a	72.2a	71.6a	63.6a	59.4a	56.5a
	4	182.7a	145.9a	134.7a	105.7a	92.4a	78.3a	76.7a	69.4a	59.5a	59.3a
Dolomite	2	191.8a	137.7a	134.5a	111.5a	99.3a	83.5a	39.6a	77.1a	72.0a	67.1a
	4	161.1a	109.3a	128.0a	116.6a	99.9a	79.9a	78.4a	70.8a	63.5a	57.6a
REGRESSION:											
Gypsum											
Linear (R^2)		-[##]	ns[###]	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Limestone											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Dolomite											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns

[#] Means within collection having the same letter are not different at $P = 0.05$ using Duncan's multiple range test.

[##] Not determined; [###] Not significant at $P = 0.05$.

Table GS2-II-3. Ca concentrations in deep well leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at 50 kg P ha^{-1} and amended with Ca amendments.

Treatment	Rate	Week from first (second) P application									
		0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	Mg ha^{-1}	mg L^{-1}									
No amendment	0	66.1a[#]	56.2a	50.7a	42.1a	35.4a	37.1a	40.2a	35.4a	39.0a	37.5a
Gypsum	2	77.7a	57.1a	40.7a	36.2a	40.1a	42.7a	52.2a	42.1a	47.2a	44.9a
	4	72.2a	55.6a	52.0a	58.8a	49.9a	56.5a	56.9a	49.6a	49.3a	46.6a
Limestone	2	72.6a	51.9a	42.2a	47.4a	50.1a	46.1a	52.3a	46.2a	48.3a	46.7a
	4	78.6a	61.2a	44.5a	47.5a	48.3a	49.0a	53.0a	43.9a	51.0a	50.0a
Dolomite	2	74.0a	51.0a	60.8a	43.0a	41.1a	45.2a	50.2a	44.1a	46.1a	47.9a
	4	68.9a	58.2a	64.1a	44.7a	46.4a	46.4a	45.8a	44.4a	50.5a	50.0a
<u>REGRESSION:</u>											
Gypsum											
Linear (R^2)		-[##]	ns [###]	ns	ns	ns	ns	0.78[*]	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	0.79[*]	ns	ns	ns
<u>Limestone</u>											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
<u>Dolomite</u>											
Linear (R^2)		-	ns	ns	ns	0.77[*]	0.71[*]	ns	ns	0.88[*]	0.68[*]
Quadratic (R^2)		-	ns	ns	ns	0.79[*]	0.70[*]	ns	ns	0.89[*]	0.69[*]

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.
[##] Not determined; [###] Not significant at P = 0.05; [*] Significant at P = 0.05.

Table. GS2-II-4. Ca concentrations in bottom leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at 50 kg P ha^{-1} and amended with Ca amendments.

Treatment	Rate	Week from first (second) P application									
		0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	Mg ha^{-1}	----------------------	----------------------	----------------------	----------------------	mg L^{-1}	----------------------	----------------------	----------------------	----------------------	----------------------
No amendment	0	36.1a$^{\#}$	32.7a	31.8a	33.7a	31.2a	35.2a	41.0a	37.6a	41.5ab	39.8bc
Gypsum	2	28.1a	28.0a	24.6a	21.4a	23.2a	30.0a	44.2a	40.6a	42.0ab	46.3ab
	4	33.5a	27.4a	27.5a	27.1a	27.3a	32.0a	45.9a	35.4a	36.6b	37.7c
Limestone	2	30.4a	24.7a	22.3a	21.2a	21.6a	26.1a	39.8a	32.7a	35.3b	37.5c
	4	30.0a	27.1a	17.6a	18.1a	20.9a	26.2a	45.2a	34.9a	38.0ab	42.2abc
Dolomite	2	38.0a	32.4a	29.7a	27.5a	30.8a	36.2a	47.7a	41.7a	46.0a	47.6a
	4	34.7a	31.4a	22.3a	21.4a	23.4a	28.0a	38.3a	36.7a	40.1ab	44.3abc
REGRESSION:											
Gypsum											
Linear (R^2)		-$^{\#\#}$	ns$^{\#\#\#}$	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Limestone											
Linear (R^2)		-	ns	0.71^{*}	0.80^{**}	0.77^{*}	0.72^{*}	ns	ns	ns	ns
Quadratic (R^2)		-	ns	0.75^{*}	0.90^{**}	0.78^{*}	0.72^{*}	ns	ns	ns	ns
Dolomite											
Linear (R^2)		-	ns	ns	0.78^{*}	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	0.75^{*}	ns	ns	ns	ns	ns	ns

$^{\#}$Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.
$^{\#\#}$Not determined; $^{\#\#\#}$Not significant at P = 0.05; * Significant at P = 0.05; and ** Significant at P = 0.01.

Table GS2-II-5. EC of shallow well leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at 50 kg P ha^{-1} and amended with Ca amendments.

		Week from first (second) P application									
Treatment	Rate	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	Mg ha^{-1}	-----	-----	-----	-----	µmho cm^{-1}	-----	-----	-----	-----	-----
No amendment	0	758a[#]	584a	657a	520a	450a	397a	446a	445a	399a	413a
Gypsum	2	1100a	788a	925a	672a	553a	482a	490a	484a	439a	445a
	4	888a	689a	811a	604a	512a	432a	453a	409a	407a	404a
Limestone	2	1019a	756a	970a	640a	527a	450a	463a	453a	418a	430a
	4	958a	733a	863a	624a	520a	433a	439a	450a	391a	402a
Dolomite	2	1031a	743a	861a	630a	515a	462a	495a	485a	426a	454a
	4	898a	666a	871a	588a	488a	436a	443a	463a	389a	411a
<u>REGRESSION:</u>											
Gypsum											
Linear (R^2)		-[##]	ns[###]	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
<u>Limestone</u>											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
<u>Dolomite</u>											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns

[#]Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.
[##]Not determined; [###]Not significant at P = 0.05.

Table GS2-II-6. EC of deep well leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at 50 kg P ha^{-1} and amended with Ca amendments.

Treatment	Rate	Week from first (second) P application									
		0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	Mg ha^{-1}	µmho cm^{-1}									
No amendment	0	575a[#]	544a	598a	523a	463a	433a	464a	457a	467a	476a
Gypsum	2	605a	473a	563a	426a	414a	420a	469a	455a	470a	489a
	4	596a	507a	557a	482a	428a	406a	441a	453a	454a	482a
Limestone	2	564a	511a	539a	492a	459a	433a	465a	470a	488a	495a
	4	631a	497a	554a	476a	451a	422a	448a	448a	468a	492a
Dolomite	2	638a	517a	574a	493a	451a	426a	477a	472a	472a	505a
	4	592a	528a	573a	476a	426a	406a	431a	450a	451a	484a
<u>REGRESSION:</u>											
Gypsum											
Linear (R^2)		-[##]	ns [###]	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
<u>Limestone</u>											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
<u>Dolomite</u>											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.
[##] Not determined; [###] Not significant at P = 0.05.

Table. GS2-II-7. EC of bottom leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at 50 kg P ha^{-1} and amended with Ca amendments.

		Week from first (second) P application									
Treatment	Rate	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	Mg ha^{-1}	μmho cm^{-1}									
No amendment	0	571a[#]	533a	548a	506a	468a	443a	458a	458a	467a	482a
Gypsum	2	574a	453a	492a	434a	403a	411a	464a	468a	467a	502a
	4	549a	439a	476a	420a	395a	401a	431a	442a	452a	468a
Limestone	2	540a	452a	473a	435a	413a	413a	440a	450a	477a	484a
	4	557a	459a	497a	430a	418a	412a	435a	448a	457a	477a
Dolomite	2	582a	502a	527a	478a	440a	435a	476a	485a	467a	509a
	4	729a	464a	512a	438a	410a	401a	443a	453a	439a	484a
<u>REGRESSION:</u>											
Gypsum											
Linear (R^2)		-[##]	ns [###]	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
<u>Limestone</u>											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
<u>Dolomite</u>											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns

[#] Means within collection having the same letter are not different at $P = 0.05$ using Duncan's multiple range test.
[##] Not determined; [###] Not significant at $P = 0.05$.

Table GS2-II-8. pH of shallow well leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at 50 kg P ha^{-1} and amended with Ca amendments.

		Week from first (second) P application									
Treatment	Rate	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	Mg ha^{-1}	pH									
No amendment	0	7.08a[#]	6.84a	6.80a	6.85a	6.73a	6.29a	6.58a	6.39a	6.90a	6.47a
Gypsum	2	6.91a	6.74a	6.55a	6.68a	6.66a	6.24a	6.49a	6.34a	6.54b	6.34a
	4	6.98a	6.72a	6.72a	6.65a	6.64a	6.49a	6.52a	6.64a	6.36b	6.45a
Limestone	2	7.05a	6.64a	6.48a	6.75a	6.68a	6.36a	6.53a	6.41a	6.66ab	6.29a
	4	6.93a	6.55a	6.63a	6.79a	6.53a	6.31a	6.45a	6.46a	6.70ab	6.37a
Dolomite	2	6.87a	6.59a	6.73a	6.81a	6.63a	6.25a	6.51a	6.33a	6.57ab	6.31a
	4	7.09a	6.71a	6.83a	6.91a	6.55a	6.26a	6.47a	6.37a	6.50b	6.39a
<u>REGRESSION:</u>											
Gypsum											
Linear (R^2)		-[##]	ns [###]	ns	ns	ns	ns	ns	ns	0.65[**]	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	0.66[**]	ns
<u>Limestone</u>											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
<u>Dolomite</u>											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.
[##] Not determined; [###] Not significant at P = 0.05; [**] Significant at P = 0.01.

gypsum-treated leachates were not different. In GS1 where no stargrass was planted to the potted soils, pH of leachates defined the difference between the gypsums and the lime materials. Unfortunately, the grinding of the amendments prevented us from attributing this unexpected non-effect solely to cropping.

For the deep wells, the statistics are given in Table GS2-II-9. Six out of nine post-treatment samplings indicated no effects of amendments on pH. Of the other three, no consistent differences on treatment effects were noted.

The bottom leachates were much more acidic than the shallow or the deep wells samples (Table GS2-II-10). No differences in pH between any two treatments were noted in eight samplings out of nine. The one collection with differences (18th week) showed gypsum at 2 Mg ha^{-1} having a pH lower than that of limestone at the same rate and no other. Again, cropping and the grinding of the amendments may have masked the distinctive difference between the gypsum and the lime materials.

Calcium Amendments and P Concentrations in Leachates

Phosphorus concentrations in leachates. Tables GS2-II-11, GS2-II-12, and GS2-II-13 for the shallow wells, deep wells, and bottom leachates, respectively, show the effects of the various Ca amendments on P in leachates. No logical significant post-application differences between treatments were noted in all samplings at all depths. This would mean that calcium carbonate or dolomite when ground to powder was not effective in reducing P losses through leaching. Study GS1demonstrated the effectiveness of granular commercial calcium carbonate and dolomite in reducing P losses through leaching. They attributed the beneficial effects of the lime materials to increased leachate pH, which was not observed in this study, and to precipitation of P unto the surfaces of the undissolved granular limestone and dolomite particles because of their low solubility.

Phosphorus concentrations in shallow wells appeared to indicate that limestone at 2 Mg ha^{-1} but not at 4 Mg ha^{-1} (Table GS2-II-11) enhanced the leaching of P. This effect would be more typical of gypsum than of lime (GS1). More noteworthy was the fact that P concentrations in leachates upon passing through the Bh horizon were reduced to less 0.5 mg L^{-1} regardless of how high the initial P concentrations were. The capacity of the Bh horizon to retain P was also undiminished over the whole period of study (Tables GS2-II-12 and GS2-II-13).

Phosphorus Concentrations and Leachate Properties and Elements

Leachate pH and P. The quantitative relationships between leachate pH and P concentrations are given in Table GS2-II-14. Phosphorus concentrations in leachates that passed through the Ap+E horizons (shallow wells) were positively associated with increasing pH in the pH range of 6.2 to 7.2. Such significant relationship was lost when the leachates passed through the Bh horizon (deep wells) due to the strong adsorption of P by the Bh horizon which reduced P concentrations in the ensuing leachates to a relatively close or uniform values of about one-tenth those of the Ap+E leachates. Further reduction in P concentrations upon crossing the C horizon (bottom leachates) and reduced leachate pH resulted to a negative relation between P and pH in the pH range of 5 to 6.5.

Table GS2-II-9. pH of deep well leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at 50 kg P ha^{-1} and amended with Ca amendments.

Treatment	Rate	Week from first (second) P application									
		0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	Mg ha^{-1}	pH									
No amendment	0	7.41ab[#]	6.75a	6.81a	6.81a	6.41a	6.12a	6.34a	5.59abc	6.16a	5.72ab
Gypsum	2	7.39ab	7.13a	7.21a	6.63a	6.14a	6.71a	6.10a	5.52bc	5.81a	5.99a
	4	7.31ab	7.01a	7.07a	6.94a	6.53a	6.19a	6.01a	6.23ab	6.12a	6.10a
Limestone	2	7.38ab	7.05a	7.32a	7.01a	6.57a	6.39a	6.44a	6.26ab	6.24a	6.17a
	4	7.38ab	7.13a	7.12a	6.88a	6.38a	6.17a	6.44a	6.10abc	6.33a	6.07a
Dolomite	2	7.53a	7.03a	7.14a	6.83a	6.20a	6.87a	6.40a	5.39c	5.82a	5.46b
	4	7.25b	7.02a	6.91a	6.98a	6.76a	6.34a	6.45a	6.30c	6.25a	6.14a
<u>REGRESSION:</u>											
Gypsum											
Linear (R^2)		-[##]	ns [###]	ns	ns	ns	ns	ns	ns	ns	0.42[*]
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	0.42[*]
<u>Limestone</u>											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
<u>Dolomite</u>											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.
[##] Not determined; [###] Not significant at P = 0.05; [*] Significant at P = 0.05.

Table GS2-II-10. pH of bottom leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at 50 kg P ha^{-1} and amended with Ca amendments.

Treatment	Rate	Week from first (second) P application									
		0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	Mg ha^{-1}	pH									
No amendment	0	6.06a[#]	6.40a	6.20a	6.15a	5.86a	5.60a	6.15a	5.59ab	5.54a	5.26a
Gypsum	2	6.19a	6.24a	6.09a	6.04a	5.56a	5.49a	5.93a	5.19b	5.16a	5.00a
	4	6.17a	6.57a	6.22a	6.11a	6.00a	5.63a	5.96a	5.25ab	5.33a	5.12a
Limestone	2	7.23a	6.48a	6.10a	6.20a	5.85a	5.77a	6.06a	5.69a	5.45a	5.20a
	4	6.54a	5.99a	5.77a	6.89a	5.50a	5.62a	6.13a	5.65ab	5.34a	5.29a
Dolomite	2	6.26a	6.11a	6.09a	6.06a	5.70a	5.58a	5.97a	5.39ab	5.20a	5.09a
	4	6.48a	6.27	5.97a	5.97a	5.76a	5.53a	5.85a	5.43ab	3.35a	5.17a
REGRESSION:											
Gypsum											
Linear (R^2)		-[##]	ns [###]	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Limestone											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Dolomite											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.
[##] Not determined; [###] Not significant at P = 0.05.

Table GS2-II-11. Phosphorus concentrations in shallow well leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at 50 kg P ha^{-1} and amended with Ca amendments.

Treatment	Rate	Week from first (second) P application									
		0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	Mg ha^{-1}	mg L^{-1}									
No amendment	0	2.90ab[#]	2.55a	2.08a	1.80a	1.72a	1.39a	1.34a	1.22a	1.10a	1.41a
Gypsum	2	2.81ab	2.46a	2.20a	1.83a	1.70a	1.53a	1.62a	1.40a	1.34a	1.43a
	4	3.15ab	2.26a	1.89a	1.35a	1.84a	1.31a	0.83a	1.16a	1.25a	1.32a
Limestone	2	3.60a	2.86a	3.03a	2.64a	2.50a	1.70a	1.56a	1.57a	1.46a	1.74a
	4	2.71ab	2.34a	2.62a	2.35a	2.21a	1.51a	1.41a	1.22a	1.09a	1.48a
Dolomite	2	2.66ab	2.32a	2.36a	1.92a	1.75a	1.55a	0.89a	1.34a	1.22a	1.18a
	4	2.05b	1.66a	1.88a	1.92a	1.76a	1.54a	1.53a	1.39a	1.39a	1.51a
REGRESSION:											
Gypsum											
Linear (R^2)		-[##]	ns[###]	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Limestone											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Dolomite											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.

[##] Not determined; [###] Not significant at P = 0.05.

Table GS2-II-12. Phosphorus concentrations in deep well leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at 50 kg P ha^{-1} and amended with Ca amendments.

Treatment	Rate	Week from first (second) P application									
		0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
	Mg ha^{-1}	mg L^{-1}									
No amendment	0	0.17a[#]	0.17a	0.13a	0.14a	0.16a	0.09a	0.09b	0.15a	0.17a	0.13a
Gypsum	2	0.22a	0.13a	0.14a	0.19a	0.28a	0.25a	0.17a	0.23a	0.20a	0.22a
	4	0.22a	0.18a	0.11a	0.19a	0.13a	0.18a	0.12ab	0.17a	0.23a	0.16a
Limestone	2	0.21a	0.18a	0.08a	0.20a	0.18a	0.19a	0.10ab	0.12a	0.18a	0.18a
	4	0.19a	0.16a	0.12a	0.19a	0.20a	0.14a	0.11ab	0.14a	0.17a	0.15a
Dolomite	2	0.18a	0.13a	0.13a	0.16a	0.14a	0.12a	0.13ab	0.15a	0.25a	0.13a
	4	0.19a	0.18a	0.13a	0.16a	0.17a	0.11a	0.11ab	0.16a	0.25a	0.15a
<u>REGRESSION:</u>											
Gypsum											
Linear (R^2)		-[##]	ns[###]	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
<u>Limestone</u>											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
<u>Dolomite</u>											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns

[#] Means within collection having the same letter are not different at $P = 0.05$ using Duncan's multiple range test.
[##] Not determined; [###] Not significant at $P = 0.05$.

Table. GS2-II-13. Phosphorus concentrations in bottom leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at 50 kg P ha^{-1} and amended with Ca amendments.

		Week from first (second) P application									
Treatment	Rate	0	1	3	6	9[+]	12[+]	15(1)	18(4)	21(7)	24(10)
	Mg ha^{-1}	mg L^{-1}									
No amendment	0	0.17a[#]	0.11a	0.07a	0.04a	0.11a	0.08a	0.15a	0.11a	0.15a	0.14a
Gypsum	2	0.15a	0.07a	0.11a	0.05a	0.11a	0.08a	0.10a	0.10a	0.11a	0.18a
	4	0.16a	0.09a	0.05a	0.13a	0.18a	0.08a	0.13a	0.09a	0.12a	0.14a
Limestone	2	0.15a	0.10a	0.01a	0.06a	0.10a	0.08a	0.12a	0.11a	0.14a	0.14a
	4	0.19a	0.09a	0.05a	0.07a	0.10a	0.07a	0.09a	0.14a	0.15a	0.14a
Dolomite	2	0.14a	0.09a	0.08a	0.10a	0.16a	0.07a	0.14a	0.16a	0.13a	0.13a
	4	0.15a	0.09a	0.09a	0.05a	0.12a	0.08a	0.09a	0.13a	0.12a	0.16a
REGRESSION:											
Gypsum											
Linear (R^2)		-[##]	ns[###]	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Limestone											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Dolomite											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns

[+] Values for 9th and 12th weeks were derived from the relation: ICAP-P = (0.8311)(OP) - 0.0551 from Figure II-11.
[#] Means within collection having the same letter are not different at $P = 0.05$ using Duncan's multiple range test.
[##] Not determined; [###] Not significant at $P = 0.05$.

Table GS2-II-14. Relationships between leachate P concentrations (Y) and pH (X) of leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized twice at 50 kg P ha^{-1} and amended with Ca amendments (all amendments).

Variable (range)	Unit	Regression equation	No. of obs.[#]	R^2	Probability
Shallow wells:					
pH (pH 6.2 to pH 7.2)	-	$Y = 1.543X - 8.317$	76	0.3002	1E-06
Deep wells:					
pH (pH 5.4 to pH 7.5)	-	$Y = 0.004X + 0.187$	70	0.0022	0.6985
Bottom leachates:					
pH (pH 5.0 to pH 6.5)	-	$Y = -0.039X + 0.339$	56	0.1849	0.0009
All depths:					
pH (pH5.0 to pH 7.5)	-	$Y = 0.700X - 3.646$	203	0.1634	2E-09

[#] Each observation is the average of four replicates.

Leachate EC and P. In practical terms, EC is a measure of the concentration of dissolved charged ions in the leachates. Table GS2-II-15 shows that P concentrations in shallow well leachates were significantly positively related to EC but not in deep well leachates. This would mean that ionic P species were as mobile as the non-P ionic species in the Ap+E horizons. But in the deep well leachates (Ap+E+Bh), because of the preferential adsorption of P by the Bh horizon, the significant positive relation was lost - meaning that the concentrations of the charged P species were no longer proportional to the overall concentration of all charged ions in the leachates. In the bottom leachates the positive significant relation between EC and P would indicate that P concentrations, although further reduced after the Ap+E+Bh leachates passed through the C horizon, represented a significant increasing portion of the EC in the 450 to 700 μmho cm^{-1} range.

Cations and P in leachates. This section presents the association between Ca and other cations with P concentrations in leachates over all treatments (control, mined gypsum, calcium carbonate, and dolomite). Values were from all pots that received 50 kg P ha^{-1}. Table GS2-II-16 shows that the Ca, Mg, K, Al, and Fe were all significantly and positively associated with P concentrations in the shallow well leachates. Only Al was significantly associated with P in deep well leachates and Ca, K, and Al in the bottom leachates. At all depths, P concentrations are significantly and positively associated with Ca, Mg. K. Al, and Fe.

Table GS2-II-15. Relationships between leachate P concentrations (Y) and EC (X) of leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized twice at 50 kg P ha^{-1} and amended with Ca amendments (all amendments).

Variable (range)	Unit	Regression equation	No. of obs.[#]	R^2	Probability
Shallow wells:					
EC (400 to 1100)	µmho cm^{-1}	Y = 0.0026X + 0.3315	70	0.6893	6E-19
Deep wells:					
EC (400 to 650)	µmho cm^{-1}	Y = 6E-06X + 0.1603	70	8E-05	0.9432
Bottom leachates:					
EC (425 to 750)	µmho cm^{-1}	Y = 0.0002X - 0.0053	56	0.1088	0.0131
All depths:					
EC (400 to 1100)	µmho cm^{-1}	Y = 0.0042X - 1.4214	196	0.3812	6E-22

[#] Each observation is the average of four replicates.

Anions and P in leachates. Table GS2-II-17 presents the quantitative relationships between the major anions and P concentrations over all treatments (control, mined gypsum, calcium carbonate, and dolomite). Values were from all pots that received 50 kg P ha^{-1}.

Nitrate was significantly and positively associated with P in the Ap+E (shallow wells) leachates and over all samples. This, however, may be more of the indirect effect of Ca on NO_3 and on anionic P species, keeping significant portions of these anions in solution, than on the direct effect of excess NO_3 displacing PO_4 in the exchange complex. But, no matter how remote, it could also mean that the high NO_3 concentrations kept proportionate amounts of anionic P in solution.

Sulfate and P concentrations were positively and significantly associated in the shallow wells (Ap+E), bottom leachates (Ap+E+Bh+C), and over all depths but not in deep wells or Ap+E+Bh profile. Again, the positive and significant association could be more of the indirect effect of Ca on SO_4 and on anionic P species, keeping significant portions of both in solution, than on the direct effect of excess SO_4 displacing anionic P species from the exchange complex. But because sulfate is divalent there is greater probability for SO_4 than for NO_3 doing just that. Also, by competing with anionic P for adsorption sites, SO_4 could have kept significant amounts of fertilizer P from being adsorbed unto the exchange complex of the soil solids.

Table GS2-II-16. Relationships between leachate P concentrations (Y) and cations (X) in leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized twice at 50 kg P ha^{-1} and amended with Ca amendments (all amendments).

Variable (range)	Unit	Regression equation	No. of obs.#	R^2	Probability
Shallow wells:					
Ca (20 to 200)	mg L^{-1}	Y = 0.013X + 0.630	77	0.7119	6E-22
Mg (4 to 33)	"	Y = 0.081X + 0.328	77	0.5010	6E-13
K (30 to 80)	"	Y = 0.038X + 0.075	77	0.5778	3E-13
Al (0.2 to 0.75)	"	Y = 4.228X - 0.144	77	0.6283	9E-18
Fe (0.1 to 1.4)	"	Y = -1.576X + 2.349	77	0.3590	9E-09
Deep wells:					
Ca (35 to 80)	mg L^{-1}	Y = 0.001X + 0.122	70	0.0384	0.1039
Mg (20 to 60)	"	Y = -0.001X + 0.187	70	0.0245	0.1954
K (22.5 to 34)	"	Y = 0.002X + 0.115	70	0.0081	0.4583
Al (0.2 to 1.3)	"	Y = 0.116X + 0.114	70	0.2229	4E-05
Fe (0.07 to 1.0)	"	Y = 0.005X + 0.162	70	0.0007	0.8284
Bottom leachates:					
Ca (18 to 50)	mg L^{-1}	Y = 0.003X + 0.016	56	0.3459	2E-06
Mg (20 to 50)	"	Y = -0.001X + 0.132	56	0.0090	0.4873
K (22 to 37)	"	Y = 0.006X - 0.059	56	0.2425	0.0001
Al (0.1 to 1.3)	"	Y = 0.049X + 0.088	56	0.2140	0.0003
Fe (0.02 to 4.5)	"	Y = 0.005X + 0.105	56	0.0262	0.2333
All depths:					
Ca (20 to 200)	mg L^{-1}	Y = 0.022X - 0.585	203	0.7729	1E-66
Mg (4 to 60)	"	Y = -0.051X + 2.148	203	0.2271	7E-13
K (22.5 to 80)	"	Y = 0.070X - 1.733	203	0.7762	3E-67
Al (0.1 to 1.3)	"	Y = 0.606X + 0.519	203	0.0222	0.0340
Fe (0.01 to 4.5)	"	Y = -0.381X + 1.036	203	0.1116	1E-06

Each observation is the average of four replicates.

Chloride was significantly positively associated with P only in shallow well leachates. The loss of the significant positive association in deep well and in bottom leachates could be due to the strong adsorption of P by the Bh horizon as well as the release of more Cl from the Bh horizon which remained relatively unchanged in the bottom leachates (Table GS2-II-17, range of values).

Table GS2-II-17. Relationships between leachate P concentrations (Y) and anions (X) in leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized twice at 50 kg P ha^{-1} and amended with Ca amendments (all amendments).

Variable (range)	Unit	Regression equation	No. of obs.[#]	R^2	Probability
Shallow wells:					
NO_3 (0 to 55)	mg L^{-1}	Y = 0.034X + 1.456	77	0.7193	2E-22
SO_4 (100 to 400)	"	Y = 0.005X + 0.650	77	0.3126	1E-07
Cl (9 to 27)	"	Y = 0.149X + 0.746	77	0.1491	0.0005
Deep wells:					
NO_3 (0 to 9)	mg L^{-1}	Y = 0.0020X + 0.1619	70	0.0061	0.5190
SO_4 (130 to 275)	"	Y = -0.0002X + 0.1957	70	0.0120	0.3657
Cl (20 to 47)	"	Y = 0.0008X + 0.1379	70	0.0155	0.3037
Bottom leachates:					
NO_3 (0)	mg L^{-1}	-	-	-	-
SO_4 (110 to 340)	"	Y = 0.0006X - 0.0152	56	0.4434	2E-08
Cl (20 to 55)	"	Y = 0.0001X + 0.1089	56	0.0006	0.8621
All depths:					
NO_3 (0 to 55)	mg L^{-1}	Y = 0.059X + 0.656	146	0.5753	8E-28
SO_4 (100 to 400)	"	Y = 0.007X - 0.906	203	0.1858	1E-10
Cl (9 to 55)	"	Y = -0.067X + 2.585	203	0.3902	2E-23

[#] Each observation is the average of four replicates.

Phosphorus Fertilizer and Some Leachate Properties

In this portion of the study, data were obtained from pots that received two applications of 0, 12.5, 25, and 50 kg P ha^{-1} as treatments and no Ca amendments.

Leachate Ca concentration. No effects of P rates were noted on Ca concentrations in leachates sampled at various depths (Table GS2-II-18). The Bh horizon, and to a lesser degree the C horizon, tended to strongly retain Ca especially during the early period of watering or leaching.

Leachate EC. No effects of P rates were noted on leachate EC at all depths indicating that leachate EC was primary dominated by the naturally occurring soluble salts in the soil and that even the highest TSP rate did not contribute to any measurable increase in EC (Table GS2-II-19). Leachate EC at Ap+E+Bh (deep wells) horizons and in bottom leachates tended to be much lower

Table GS2-II-18. Ca concentrations in leachates sampled at three depths from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at four rates of P, no Ca amendments.

Depth/Treat.	Rate	Week from first (second) P application									
		0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
Shallow wells:	kg P ha^{-1}	mg L^{-1}									
1	0.0	167.1a[#]	147.9a	99.3a	81.5a	78.7a	61.8a	22.4a	60.2a	61.0a	53.1a
2	12.5	193.7a	117.7a	91.5a	80.7a	79.3a	69.3a	72.2a	67.9a	63.3a	62.3a
3	25.0	152.5a	88.0a	104.0a	95.7a	88.4a	70.5a	31.0a	66.9a	64.5a	58.1a
4	50.0	125.3a	98.0a	88.4a	82.5a	81.8a	65.8a	71.1a	67.3a	66.3a	62.7a
REGRESSION:											
Linear (R^2)		-[##]	ns[###]	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Deep wells:											
1	0.0	74.8a	58.7a	51.7a	54.1a	50.4a	48.3a	45.7a	46.6a	44.9a	43.7a
2	12.5	69.5a	58.5a	63.3a	51.4a	54.6a	50.9a	52.7a	48.1a	52.7a	54.0a
3	25.0	73.7a	63.2a	54.5a	53.5a	48.4a	52.9a	49.9a	43.6a	52.5a	46.3a
4	50.0	66.1a	56.2a	50.7a	42.1a	35.4a	37.1a	40.2a	35.4a	39.0a	37.5a
REGRESSION:											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Bottom leachates:											
1	0.0	30.6a	27.0a	25.0a	24.7a	25.9a	28.4a	35.7a	35.5a	36.1a	38.8a
2	12.5	31.3a	26.8a	28.4a	27.0a	31.5a	38.4a	43.8a	41.7a	46.1a	46.0a
3	25.0	32.9a	42.2a	25.6a	23.0a	24.0a	31.0a	45.2a	34.8a	36.7a	37.9a
4	50.0	36.1a	32.7a	31.8a	33.7a	31.2a	35.2a	41.0a	37.6a	41.5a	39.8a
REGRESSION:											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.
[##] Not determined; [###] Not significant at P = 0.05.

than at the bottom of the Ap+E (shallow ells) horizons indicating strong adsorption of the dissolved salt components in the Bh horizon.

Leachate pH. Table GS2-II-20 shows no effects of P rates on pH of leachates sampled at the bottom of the Ap+E (shallow wells) and Ap+E+Bh (deep wells) horizons and in bottom leachates. The bottom leachates tended to have much lower pH values than the shallow or the deep well leachates. Thus, no effect of TSP rates on leachate pH were statistically differentiable.

Phosphorus Fertilizer and P Concentrations in Leachates

Phosphorus concentrations in leachates. Although P concentrations in leachates from the Ap-E horizons were not statistically different (Table GS2-II-21), P concentrations tended to be lower for the control than for the P-fertilized pots throughout the sampling period. Phosphorus concentrations in the Ap+E leachates were reduced very sharply within the 84-day period (12 weeks). This could be attributed to plant uptake and to adsorption in the Ap horizon. There were no indications in leachate P of the second fertilizer P applied on the 14th week from the first although P concentrations remained relatively high and steady on the 15 week and thereafter. From an averaged P concentration of 3.48 mg L^{-1} in shallow well leachates at day zero (Table GS2-II-21), P concentrations in deep well leachates averaged 0.19 mg L^{-1} for the same period indicating a P retention rate of about 95 % in the Bh horizon.

Factors Affecting P in Leachates in P-fertilized Soil

Fertilizer rates and P. Table GS2-II-21 indicated no effects of P rates on leachate P concentrations at various depths and over all samples. Study GS1, using similar soils and individual soil horizons with no stargrass planted to the potted soils, demonstrated significant relations between P application rates and P concentrations in leachates in the Ap horizon. Significant relations also were noted between the amounts of P in Ap leachates applied to E and amounts of P in E applied to Bh. Thus, the absence of any P rate effects on leachate P concentrations in the present study strongly indicated that stargrass pastures, or cropping with forage in general, could effectively reduce P loss through leaching and, possibly, runoff.

Leachate EC and P. Table GS2-II-22 shows that P concentrations in shallow well leachates were significantly positively related to EC but not in deep well leachates. This would mean that ionic P species were as mobile as the non-P ionic species in the Ap-E horizons. In the deep well leachates (Ap+E+Bh), due to the preferential adsorption of P by the Bh horizon, the significant relation was lost. In bottom leachates it would appear that the further reduced P concentrations remained a significant contributing portion to the EC increasing in concentrations as EC increased from 450 to 600 μmho cm^{-1}, hence the significant positive slope.

Leachate pH and P. Table GS2-II-23 shows that P concentrations in leachates were positively associated with pH within the pH range of 6.2 and 7.2 observed in shallow well leachates. Significant association between pH and P concentrations were not noted in deep well and in bottom leachates due to the selective adsorption of P by the Bh horizon.

Table GS2-II-19. EC of leachates sampled at three depths from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at four rates of P, no Ca amendments.

		Week from first (second) P application									
Depth/Treat.	Rate	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
Shallow wells:	kg P ha^{-1}	µmho cm^{-1}									
1	0.0	975a[#]	770a	911a	655a	553a	465a	498a	439a	441a	438a
2	12.5	1080a	656a	768a	570a	483a	435a	479a	459a	415a	430a
3	25.0	839a	533a	693a	493a	421a	392a	397a	432a	383a	403a
4	50.0	758a	584a	657a	520a	450a	397a	446a	445a	399a	413a
REGRESSION:											
Linear (R^2)		-[##]	ns[###]	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Deep wells:											
1	0.0	632a	543a	604a	526a	479a	445a	475a	476a	486a	505a
2	12.5	582a	553a	577a	528a	499a	464a	511a	485a	495a	517a
3	25.0	592a	554a	605a	517a	452a	418a	469a	438a	449a	462a
4	50.0	575a	544a	598a	523a	463a	433a	464a	457a	467a	476a
REGRESSION:											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Bottom leachates:											
1	0.0	569a	459a	501a	443a	422a	419a	445a	468a	480a	501a
2	12.5	545a	437a	472a	441a	433a	443a	478a	477a	485a	499a
3	25.0	563a	569a	606a	475a	418a	401a	432a	434a	420a	447a
4	50.0	571a	533a	548a	506a	468a	443a	458a	458a	467a	482a
REGRESSION:											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.

[##] Not determined; [###] Not significant at P = 0.05.

Table GS2-II-20. pH of leachates sampled at three depths from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at four rates of P, no Ca amendments.

		Week from first (second) P application									
Depth/Treat.	Rate	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
Shallow wells:	kg P ha^{-1}	pH									
1	0.0	7.04a$^{\#}$	6.70a	6.47a	6.86a	6.56a	6.34a	6.39a	6.23a	6.60a	6.32a
2	12.5	6.84a	6.78a	6.51a	6.69a	6.61a	6.23a	6.43a	6.31a	6.49a	6.28a
3	25.0	6.99a	6.81a	6.61a	6.80a	6.64a	6.23a	6.47a	6.41a	6.45a	6.36a
4	50.0	7.08a	6.84a	6.80a	6.85a	6.72a	6.29a	6.58a	6.39a	6.90a	6.47a
REGRESSION:											
Linear (R^2)		-$^{\#\#}$	ns$^{\#\#\#}$	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Deep wells:											
1	0.0	7.45a	6.99a	7.03a	6.74a	6.43a	6.25a	6.23a	6.21a	6.14b	6.02a
2	12.5	7.32a	6.92a	7.07a	6.78a	6.42a	6.19a	6.34a	6.34a	6.23a	6.17a
3	25.0	7.11a	7.06a	7.25a	6.67a	6.31a	6.24a	6.49a	6.18a	6.22a	6.01a
4	50.0	7.41a	6.75a	6.81a	6.81a	6.41a	6.12a	6.34a	5.59a	6.16a	5.72a
REGRESSION:											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	0.31*	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	0.32*	ns	ns
Bottom leachates:											
1	0.0	6.12a	6.46a	6.10a	6.00a	5.67a	5.65a	5.83b	5.37a	5.25a	5.05a
2	12.5	6.16a	6.37a	6.14a	6.07a	5.81a	5.49a	6.05ab	5.61a	5.44a	5.43a
3	25.0	6.13a	6.09a	5.88a	5.82a	5.67a	5.67a	6.16a	5.37a	5.38a	5.35a
4	50.0	7.06a	6.40a	6.20a	6.15a	5.86a	5.60a	6.15a	5.59a	5.54a	5.26a
REGRESSION:											
Linear (R^2)		-	ns	ns	ns	ns	ns	0.30*	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	0.30*	ns	ns	ns

[#] Means within collection having the same letter are not different at $P = 0.05$ using Duncan's multiple range test.

[##] Not determined; [###] Not significant at $P = 0.05$; [*] Significant at $P = 0.05$.

Table GS2-II-21. Phosphorus concentrations in leachates sampled at three depths from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at four rates of P, no Ca amendments.

		Week from first (second) P application									
Depth/Treat.	Rate	0	1	3	6	9	12	15(1)	18(4)	21(7)	24(10)
Shallow wells:	kg P ha^{-1}	mg L^{-1}									
1	0.0	3.14a[#]	2.11a	1.71a	1.01a	1.09a	0.73b	0.56a	0.83a	0.81b	0.84a
2	12.5	4.17a	3.05a	2.33a	1.84a	1.66a	1.36a	1.37a	1.32a	1.15ab	1.29a
3	25.0	3.75a	2.35a	2.20a	2.09a	1.69a	1.49a	0.79a	1.28a	1.30a	1.23a
4	50.0	2.90a	2.55a	2.08a	1.80a	1.72a	1.39a	1.34a	1.22a	1.10ab	1.41a
REGRESSION:											
Linear (R^2)		-[##]	ns[###]	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Deep wells:											
1	0.0	0.20a	0.18a	0.16a	0.20a	0.16a	0.14a	0.09a	0.13a	0.21a	0.22a
2	12.5	0.19b	0.16a	0.15a	0.14a	0.22a	0.14a	0.16a	0.15a	0.23a	0.14a
3	25.0	0.21a	0.18a	0.07a	0.18a	0.19a	0.22a	0.11a	0.17a	0.18a	0.17a
4	50.0	0.17ab	0.17a	0.13a	0.14a	0.16a	0.09a	0.09a	0.15a	0.17a	0.13a
REGRESSION:											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Bottom leachates:											
1	0.0	0.13a	0.10a	0.10a	0.13a	0.07a	0.07a	0.15a	0.16a	0.13a	0.15a
2	12.5	0.13a	0.10a	0.15a	0.08a	0.13a	0.11a	0.14a	0.12a	0.12a	0.13a
3	25.0	0.16a	0.13a	0.12a	0.02a	0.10a	0.05a	0.11a	0.11a	0.12a	0.14a
4	50.0	0.17a	0.11a	0.07a	0.04a	0.06a	0.08a	0.15a	0.11a	0.15a	0.14a
REGRESSION:											
Linear (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		-	ns	ns	ns	ns	ns	ns	ns	ns	ns

[#] Means within collection having the same letter are not different at P = 0.05 using Duncan's multiple range test.
[##] Not determined; [###] Not significant at P = 0.05.

Table GS2-II-22. Relationships between leachate P concentrations (Y) and EC (X) of leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized twice at 0, 12.5, 25, and 50 kg P ha^{-1}, no Ca amendments.

Variable (range)	Unit	Regression equation	No. of obs.[#]	R^2	Probability
Shallow wells:					
EC (400 to 1100)	μmho cm^{-1}	Y = 0.0037X - 0.3179	40	0.6177	2E-09
Deep wells:					
EC (400 to 650)	μmho cm^{-1}	Y = 6E-05X + 0.1327	40	0.0065	0.6203
Bottom leachates:					
EC (425 to 750)	μmho cm^{-1}	Y = 0.0002X + 0.0193	40	0.0804	0.0762
All depths:					
EC (400 to 1100)	μmho cm^{-1}	Y = 0.0045X - 1.6285	120	0.3331	5E-12

[#] Each observation is the average of four replicates.

Cations and P in leachates. The significant positive associations between Ca and P in leachates at various depths (Table GS2-II-24) indicated that Ca was the primary cation that served as ion-pair with the various anionic P species such as $H_2PO_4^-$, HPO_4^{--}, and PO_4^{---} that gave mobility to P in the whole soil profile even in the absence of Ca amendments.

The significant positive slope for Mg and P in shallow well leachates simply indicated the effect of Ca on Mg and on P in the Ap+E horizons. The more Ca in the Ap+E leachates the more Mg and P were brought into or kept in solution (Table GS2-II-24). No significant associations between Mg and P were noted in the deep wells due to the selective adsorption of P by the Bh horizon and the release of more Mg from the same horizon into the soil water. Both P and Mg appeared to have been similarly reduced as the Ap+E+Bh leachates crossed the C horizon thus keeping Mg and P concentration ratios unchanged.

The associations between P and K in leachates were very similar to those of Ca (Table GS2-II-24). Like Ca, K was strongly retained in the Bh horizon (deep wells). Unlike Ca, K was not retained in the C horizon (bottom leachates).

Phosphorus was significantly and positively associated with Al in shallow and deep wells and in bottom leachates (Table GS2-II-24). Because Al concentrations in leachates were extremely low, the slopes were relatively high. The significant positive slope in the deep well leachates, unlike the slopes for EC, Ca, Mg, or K, which were not significant or tended to be negative, would indicate that

Table GS2-II-23. Relationships between leachate P concentrations (Y) and pH (X) of leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized twice at 0, 12.5, 25, and 50 kg P ha^{-1}, no Ca amendments.

Variable (range)	Unit	Regression equation	No. of obs.#	R^2	Probability
Shallow wells:					
pH (pH 6.2 to pH 7.2)	-	Y = 2.476X - 14.520	44	0.4482	7E-07
Deep wells:					
pH (pH 5.4 to pH 7.5)	-	Y = 0.006X + 0.120	40	0.0057	0.6439
Bottom leachates:					
pH (pH 5.0 to pH 6.5)	-	Y = -0.014X + 0.193	40	0.0202	0.3812
All depths:					
pH (pH5.0 to pH 7.5)	-	Y = 0.867X - 4.746	124	0.2078	1E-07

Each observation is the average of four replicates.

Al moved through the Bh horizon with P anions tugging along. In this case, it may be said that Al and anionic P showed strong affinity for one another, probably as ion-pair, as they moved through the various horizons of Immokalee fine sand.

Iron was significantly associated with P in a negative way in shallow well leachates (Ap+E horizons) and when averaged overall depths (Table GS2-II-24). This trend was similar to that noted in Part I and on the amendment effects of this report and by Study GS1 in the E horizon leachates. Low dissolved Fe concentrations in leachates would mean low Fe precipitates in equilibrium with dissolved Fe and low potential capacity to tie up P, thus the higher P concentrations at the lower Fe concentrations or the negative association. In relation to Al which was positively associated with dissolved P, it is suggested that Fe at the observed concentrations effectively precipitated P out of the soil water but not Al at relatively lower concentrations than those of Fe. The negative slope could mean that dissolved P species at concentrations between 1.0 and 4.0 mg P L^{-1} could be effectively precipitated out to less than 0.5 mg P L^{-1} from leachates with Fe concentration of 1.5 mg L^{-1} or more in equilibrium with the precipitated Fe phase.

Anions and P in leachates. Nitrate was significantly and positively associated with P in the Ap+E (shallow wells) leachates and over all samples (Table GS2-II-25). This, however, may be more of the indirect effect of Ca on NO_3 and on anionic P species, keeping significant portions of these anions in solution, than on the direct effect of excess NO_3 displacing PO_4 in the exchange

Table GS2-II-24. Relationships between leachate P concentrations (Y) and cations (X) in leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized twice at 0, 12.5, 25, and 50 kg P ha^{-1}, no Ca amendments.

Variable (range)	Unit	Regression equation	No. of obs.[#]	R^2	Probability
Shallow wells:					
Ca (20 to 200)	mg L^{-1}	Y = 0.022X - 0.098	44	0.8038	2E-16
Mg (4 to 33)	"	Y = 0.126X - 0.386	44	0.3885	6E-06
K (30 to 80)	"	Y = 0.048X - 0.331	44	0.5707	3E-09
Al (0.2 to 0.75)	"	Y = 5.714X - 0.763	44	0.6314	1E-10
Fe (0.1 to 1.4)	"	Y = -2.577X + 2.517	44	0.2440	0.0007
Deep wells:					
Ca (35 to 80)	mg L^{-1}	Y = 0.001X + 0.084	40	0.1413	0.0168
Mg (20 to 60)	"	Y = -0.001X + 0.179	40	0.0133	0.4786
K (22.5 to 34)	"	Y = -0.002X + 0.222	40	0.0073	0.5990
Al (0.2 to 1.3)	"	Y = 0.101X + 0.120	40	0.0910	0.0585
Fe (0.07 to 1.0)	"	Y = -0.023X + 0.168	40	0.0106	0.5276
Bottom leachates:					
Ca (18 to 50)	mg L^{-1}	Y = 0.002X + 0.031	40	0.2027	0.0036
Mg (20 to 50)	"	Y = 6E-05X + 0.111	40	0.0002	0.9383
K (22 to 37)	"	Y = 0.005X - 0.018	32	0.1820	0.0149
Al (0.1 to 1.3)	"	Y = 0.004X + 0.112	40	0.0008	0.8637
Fe (0.02 to 4.5)	"	Y = 0.001X + 0.119	32	0.0015	0.8308
All depths:					
Ca (20 to 200)	mg L^{-1}	Y = 0.027X - 0.853	124	0.8187	5E-47
Mg (4 to 60)	"	Y = -0.051X + 2.122	124	0.2760	4E-10
K (22.5 to 80)	"	Y = 0.072X - 1.733	116	0.7455	1E-35
Al (0.1 to 1.3)	"	Y = 0.626X + 0.443	124	0.0156	0.1672
Fe (0.01 to 4.5)	"	Y = -0.375X + 1.015	116	0.1051	0.0004

[#] Each observation is the average of four replicates.

Table GS2-II-25. Relationships between leachate P concentrations (Y) and anions (X) in leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized twice at 0, 12.5, 25, and 50 kg P ha^{-1}, no Ca amendments.

Variable (range)	Unit	Regression equation	No. of obs.[#]	R^2	Probability
<u>Shallow wells:</u>					
NO_3 (0 to 55)	mg L^{-1}	Y = 0.047X + 1.230	44	0.7708	5E-15
SO_4 (100 to 400)	"	Y = 0.011X - 0.783	44	0.2961	0.0001
Cl (9 to 27)	"	Y = 0.059X + 0.788	44	0.0357	0.2195
<u>Deep wells:</u>					
NO_3 (0 to 9)	mg L^{-1}	Y = 0.0040X + 0.1570	40	0.0368	0.2354
SO_4 (130 to 275)	"	Y = -0.0003X + 0.2209	40	0.0195	0.3900
C) (20 to 47)	"	Y = 0.0009X + 0.1350	40	0.0213	0.3685
<u>Bottom leachates:</u>					
NO_3 (0)	mg L^{-1}	- -	-	-	
SO_4 (110 to 340)	"	Y = 0.0004X - 0.0231	40	0.1344	0.0200
Cl (20 to 55)	"	Y = 0.0005X + 0.0973	40	0.0104	0.5303
<u>All depths:</u>					
NO_3 (0 to 55)	mg L^{-1}	Y = 0.065X + 0.570	84	0.6737	1E-21
SO_4 (100 to 400)	"	Y = 0.006X - 0.560	124	0.0377	0.0308
Cl (9 to 55)	"	Y = -0.071X + 2.537	124	0.3566	2E-15

[#] Each observation is the average of four replicates.

complex. Again, no matter how remote, it could also mean that the high NO_3 concentrations kept proportionate amounts of anionic P in solution. The reduction in NO_3 concentrations in deep well leachates would indicate that this anion was relatively strongly adsorbed by the Bh horizon or that the roots were able to effectively utilize the nitrates for plant growth.

Sulfate and P concentrations were positively and significantly associated in the Ap+E (shallow wells) and in Ap+E+Bh+C (bottom) leachates but tended to be negatively associated in Ap+E+Bh (deep well) leachates (Table GS2-II-25). Again, the positive and significant association could be more of the indirect effect of Ca on SO_4 and on anionic P species, keeping significant portions of them in solution, than on the direct effect of excess SO_4 displacing anionic P species from the exchange complex. But because of the divalence of the sulfate there is greater probability for SO_4 than for NO_3 doing just that and also, by competing with anionic P for adsorption sites, keeping significant amounts of fertilizer P from being adsorbed unto the exchange complex of the soil solids. The slope for the deep well leachates, which tended to be negative, would indicate that the anionic P species were preferentially retained in the Bh horizon over the SO_4 anions.

Chloride was not significantly associated with P at all depths indicating poor ability of Cl to replace P in the exchange complex (Table GS2-II-25). The Bh horizon appeared to have augmented Cl concentration of the Ap+E+Bh while the C horizon appeared to have no retention capacity for Cl.

Effects of Calcium Amendments on Stargrass Forage Yield and Quality

This section presents the effects of the various Ca amendments on forage yield and quality of stargrass grown on reconstructed soil profile of Immokalee fine sand all fertilized at 50 kg P ha^{-1}.

Forage yield and percent dry matter. The various Ca amendments showed no effects on dry matter content of the forage or on forage dry matter yield. However, gypsum at 2 and 4 and dolomite at 4 Mg ha^{-1} tended to have higher yields than the control (TableGS2-II-26).

Phosphorus and other macro nutrients in forage. Limestone at 2 and 4 Mg ha^{-1} reduced P uptake by stargrass (Table GS2-II-26). This would indicate that despite the grinding of the material into powder, the effectiveness of limestone to render P less mobile hence less available to plant, due most probably to precipitation unto the surfaces of the particles, remained operative. Gypsum at 2 and 4 Mg ha^{-1} also tended to reduce P uptake. This could be due to the fast leaching of Ca from gypsum with Ca dragging the PO_4 into deeper horizons beyond the reach of the just-establishing plant roots during the early stage of growth.

Calcium in gypsum-treated pots, which were already very high in the control, appeared to have augmented Ca uptake but not in limestone- or dolomite-treated pots. This would indicate that Ca in these liming materials remained less available for plant use despite grinding them into powder.

Potassium uptake appeared to have been enhanced by gypsum but not by the liming materials. This tendency had been observed by the authors also in their phosphogypsum studies (Rechcigl et al., 1996).

Magnesium uptake tended to increase in gypsum-amended soils contrary to the just above-cited study with phosphogypsum which showed adverse effects of gypsum on Mg uptake, especially during the first year of gypsum application. This could be due to the presence of a steady source of Mg in the soil.

Micro nutrients in forage. All the Ca amendments showed no effects on Al or Fe uptake although Al in forage tended to be higher in amended plants than in the control plants, and even linearly increased with rates in the case of dolomite (Table GS2-II-26). Copper and Zn uptakes differed only between gypsum at 4 and limestone at 2 Mg ha^{-1} rates, while Mn uptake was significantly adversely affected by limestone and tended to be so adversely affected by dolomite. Gypsum, on the other hand, tended to increase Mn uptake.

Table GS2-II-26. Total dry matter yield (DMY), percent dry matter (%DM), and total elemental uptake by stargrass planted in reconstructed soil profile of Immokalee fine sand fertilized at 50 kg P ha^{-1} applied twice and amended with Ca amendments.

Amendment	Rate	%DM	DMY	P	K	Ca	Mg	Fe	Al	Cu	Zn	Mn
	Mg ha^{-1}	%	g pot^{-1}	mg pot^{-1}								
No amendment	0	25.6a[#]	46.5ab	138a	404bc	304bc	131ab	3.15a	314a	0.61ab	1.82ab	1.39ab
Gypsum	2	27.0a	51.7ab	124ab	479ab	359ab	131ab	3.43a	470a	0.68ab	1.78ab	1.55a
	4	26.1a	53.1a	122ab	539a	380a	137ab	3.25a	379a	0.81a	1.94a	1.53a
Limestone	2	24.7a	40.8b	90c	356c	250c	93a	2.91a	339a	0.52b	1.37b	0.93c
	4	26.9a	43.0ab	100bc	397bc	301bc	110bc	3.23a	421a	0.68ab	1.65ab	1.04c
Dolomite	2	24.1a	44.8ab	124ab	373c	263c	124ab	2.99a	404a	0.73ab	1.71ab	1.08bc
	4	27.3a	52.5a	139a	421bc	338ab	150a	3.95a	526a	0.64ab	1.94a	1.14bc
REGRESSION:												
Mined Gypsum												
Linear (R^2)		ns[##]	ns	ns	0.47*	0.35*	ns	ns	ns	0.37*	ns	ns
Quadratic (R^2)		ns	ns	ns	0.49*	0.35*	ns	ns	ns	0.38*	ns	ns
Ca carbonate												
Linear (R^2)		ns	ns	0.47*	ns	ns	ns	ns	ns	ns	ns	0.44*
Quadratic (R^2)		ns	ns	0.44*	ns	ns	ns	ns	ns	ns	ns	0.40*
Dolomite												
Linear (R^2)		ns	ns	ns	ns	ns	ns	ns	0.47*	ns	ns	0.42*
Quadratic (R^2)		ns	ns	ns	ns	ns	ns	ns	0.40*	ns	ns	0.41*

[#] Means within columns having the same letter are not different at $P \leq 0.05$ based on Duncan's multiple range test.
[##] ns = not significant; * Significant at ≤ 0.05.

Effects of Phosphorus Fertilizer on Stargrass Forage Yield and Quality

The results presented in this section were obtained from pots fertilized at four rates of P with no Ca amendments.

Forage yield and percent dry matter. Table GS2-II-27 shows that P fertilizer applied twice at 12.5, 25.0 and 50 kg P ha^{-1} to stargrass grown on reconstructed soil profile of Immokalee fine sand had no beneficial effects on forage dry matter yield or on dry matter content. This strongly indicated that P was readily available in sufficient amounts in these soils for optimum stargrass needs.

Phosphorus and other macro nutrients in forage. Fertilizer P increased P contents in forage from 0.20 to 0.30 % as P rates increased from 0 to 50 kg P ha^{-1} (Table GS2-II-27) but not forage yield as noted earlier. Thus, stargrass having P contents within the range would not benefit from P fertilization in terms of forage yield. Similar observations were noted earlier in the individual soil horizons study (GS2-I). Fertilizer P had no effects on Ca, K, or Mg contents in forage (Table GS2-II-27). A Ca:P ratio of 3.1:1 for the control and 2.2:1 for the highest for P fertilizer rate were well within the desirable Ca:P ratio range of not less than 1:1 to not more than 7:1 (Wise et al., 1963).

Micro nutrients in forage. The various P rates also had no effects on Fe, Cu, Mn, Zn, and Al. Iron and Al, however, tended to increase with rates while the concentrations of the other micro nutrients remained relatively similar (Table GS2-II-27).

Effects of Calcium Amendments on Soil

At the end of the study, representative samples from Ap, E, and Bh horizons of the reconstructed soil profile of Immokalee fine sand were obtained for the various analyses.

Ap horizon. Relative to the control, all Ca amendments had no effects on soil pH (Table GS2-II-28). Between the Ca amendments, gypsum at 4 Mg ha^{-1} showed lower pH than limestone at 2 but not at 4 Mg ha^{-1}. All Ca-amended soils tended to have lower extractable P than the control indicating possible reduced extractability of soil P. Limestone and dolomite at 4 Mg ha^{-1} tended to have the least Mehlich-extractable P. All Ca amendments had no effects on K, Ca, Mg, and Fe in the Ap horizon.

E horizon. Relative to the control no effects of the various Ca amendments were noted on E soil pH (Table GS2-II-29). Limestone at 2 but not at 4 Mg ha^{-1} indicated a higher soil pH than gypsum at 2 but not at 4 Mg ha^{-1}. Although not significantly different from any other treatment, limestone at 4 Mg ha^{-1} showed the lowest extractable P. No other effects of the Ca amendments were noted.

Bh horizon. Relative to the control no effects of the various Ca amendments on soil P or other soil variables were noted in the Bh horizon soils (Table GS2-II-30). Dolomite at 4 Mg ha^{-1} showed higher soil pH than gypsum also at 4 Mg ha^{-1} but not over the control. Limestone at 2 Mg ha^{-1} showed higher K than gypsum at 4 Mg ha^{-1} but not over the control.

Table GS2-II-27. Total dry matter yield (DMY), percent dry matter (%DM), and total elemental uptake by stargrass planted in reconstructed soil profile of Immokalee fine sand fertilized at four rates of P applied twice, no Ca amendments.

Treatment	Rate	%DM	DMY	P	K	Ca	Mg	Fe	Al	Cu	Zn	Mn
	kg ha^{-1}	%	g pot^{-1}	mg pot^{-1}								
1	0.0	25.6a[#]	45.5a	89b	380a	276a	115a	2.85a	294a	0.75a	1.78a	1.37a
2	12.5	27.0a	47.5a	103b	394a	296a	141a	3.05a	311a	0.86a	1.85a	1.43a
3	25.0	26.1a	45.4a	104b	365a	272a	121a	3.28a	454a	0.78a	1.77a	1.36a
4	50.0	24.7a	46.5a	138a	404a	304a	131a	3.15a	314a	0.61a	1.82a	1.39a
<u>REGRESSION:</u>												
Linear (R^2)		ns[##]	ns	0.64[*]	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic (R^2)		ns	ns	0.63[*]	ns	ns	ns	ns	ns	ns	ns	ns

[#] Means within columns having the same letter are not different at $P \leq 0.05$ based on Duncan's multiple range test.
[##] ns = not significant; [*] Significant at ≤ 0.05.

Table GS2-II-28. Soil pH and Mehlich I extractable elements in Ap horizon of reconstructed soil profile of Immokalee fine planted to stargrass fertilized twice at 50 kg ha^{-1}, with the second P application applied 14 weeks after the first, and amended with Ca amendments.

Amendment	Rate	pH	P	K	Ca	Mg	Fe
	Mg kg^{-1}		---------------------- mg kg^{-1}	----------	----------	----------	----------
No amendment	0	5.9ab[#]	9.2a	5.9a	1423a	90.0a	7.6a
Gypsum	2	5.9ab	6.2a	6.2a	1326a	77.0a	7.3a
	4	5.7b	5.8a	5.3a	1214a	71.0a	6.2a
Limestone	2	6.0a	5.8a	4.9a	1272a	77.0a	7.4a
	4	5.9ab	5.6a	5.1a	1329a	66.0a	7.1a
Dolomite	2	5.9ab	7.4a	6.1a	1313a	77.0a	6.7a
	4	5.9ab	5.6a	5.3a	1212a	76.0a	7.3a
<u>REGRESSION:</u>							
<u>Mined Gypsum</u>							
Linear (R^2)		0.25*	ns[##]	ns	ns	ns	ns
Quadratic (R^2)		0.25*	ns	147ns	ns	ns	ns
<u>Limestone</u>							
Linear (R^2)		ns	0.25*	ns	ns	ns	ns
Quadratic (R^2)		ns	0.29*	ns	ns	ns	ns
<u>Dolomite</u>							
Linear (R^2)		ns	ns	ns	ns	ns	ns
Quadratic (R^2)		ns	ns	ns	ns	ns	ns

[#] Means within columns having the same letter are not different at $P \leq 0.05$ based on Duncan's multiple range test.

[##] ns = not significant; * Significant at ≤ 0.05.

Table GS2-II-29. Soil pH and Mehlich I extractable elements in E horizon of reconstructed soil profile of Immokalee fine with the Ap horizon planted to stargrass fertilized twice at 50 kg ha^{-1}, with the second P application applied 14 weeks after the first, and amended with Ca amendments.

Amendment	Rate	pH	P	K	Ca	Mg	Fe
	Mg kg^{-1}			mg kg^{-1}			
No amendment	0	6.2ab	1.8a	1.8a	48a	4.0a	0.6a
Gypsum	2	6.1b	1.9a	1.9a	41a	4.0a	0.4a
	4	6.2ab	1.4a	2.1a	55a	8.0a	0.4a
Limestone	2	6.3a	1.6a	2.0a	43a	4.0a	0.5a
	4	6.2ab	1.1a	2.9a	39a	4.0a	0.3a
Dolomite	2	6.1b	1.9a	2.1a	37a	4.0a	0.9a
	4	6.1b	1.9a	1.7a	45a	4.0a	0.5a
REGRESSION:							
Mined Gypsum							
Linear (R^2)		ns	ns	ns	ns	ns	ns
Quadratic (R^2)		ns	ns	ns	ns	ns	ns
Limestone							
Linear (R^2)		ns	0.34^*	ns	0.37^*	ns	ns
Quadratic (R^2)		ns	0.36^*	ns	0.38^*	ns	ns
Dolomite							
Linear (R^2)		ns	ns	ns	ns	ns	ns
Quadratic (R^2)		ns	ns	ns	ns	ns	ns

[#] Means within columns having the same letter are not different at $P \leq 0.05$ based on Duncan's multiple range test.

[##] ns = not significant; * Significant at ≤ 0.05.

Table GS2-II-30. Soil pH and Mehlich I extractable elements in Bh horizon of reconstructed soil profile of Immokalee fine with the Ap horizon planted to stargrass fertilized twice at 50 kg ha^{-1}, with the second P application applied 14 weeks after the first, and amended with Ca amendments.

Amendment	Rate	pH	P	K	Ca	Mg	Fe
	Mg kg^{-1}		mg kg^{-1}				
No amendment	0	5.5ab	133.1a	37.7ab	962a	141a	6.6a
Gypsum	2	5.6ab	150.4a	33.4ab	897a	107a	7.2a
	4	5.4b	119.3a	32.9a	836a	118a	7.2a
Limestone	2	5.6ab	107.2a	40.8b	1130a	143a	7.6a
	4	5.5ab	128.8a	35.1ab	903a	113a	6.5a
Dolomite	2	5.7a	152.3a	34.1ab	968a	144a	6.7a
	4	5.6ab	127.9a	37.3ab	1010a	141a	7.0a
REGRESSION:							
Mined Gypsum							
Linear (R^2)		ns	ns	ns	ns	ns	ns
Quadratic (R^2)		ns	ns	ns	ns	ns	ns
Limestone							
Linear (R^2)		ns	ns	ns	ns	ns	ns
Quadratic (R^2)		ns	ns	ns	ns	ns	ns
Dolomite							
Linear (R^2)		ns	ns	ns	ns	ns	ns
Quadratic (R^2)		ns	ns	ns	ns	ns	ns

[#] Means within columns having the same letter are not different at $P \leq 0.05$ based on Duncan's multiple range test.
[##] ns = not significant.

Effects of Phosphorus Fertilizer on Soil

Ap horizon. Table GS2-II-31 shows that P fertilizers up to 100 kg ha^{-1} to a reconstructed soil profile of Immokalee fine sand planted to stargrass had no effects on soil pH or on the concentrations of K, Ca, Mg, or Fe. The highest P rate, however, increased extractable P in Ap over the lower P fertilizer rates including the control which had the lowest soil P.

Table GS2-II-31. Soil pH and Mehlich I extractable elements in Ap horizon of reconstructed soil profile of Immokalee fine planted to stargrass fertilized twice at four rates of P, with the second P application applied 14 weeks after the first, no Ca amendments.

Treatment	Rate	pH	P	K	Ca	Mg	Fe
	kg P ha^{-1}		---------------------- mg kg^{-1}	------------------------------			
1	0.0	5.9a[#]	4.6b	5.3a	1222a	78.0a	6.4a
2	12.5	5.9a	4.9b	5.4a	1249a	77.0a	5.9a
3	25.0	5.9a	5.2b	5.0a	1279a	65.0a	7.1a
4	50.0	5.9a	9.2a	5.9a	1423a	90.0a	7.6a
<u>REGRESSION:</u>							
Linear (R^2)		ns[##]	ns	ns	ns	ns	ns
Quadratic (R^2)		ns	ns	ns	ns	ns	ns

[#] Means within columns having the same letter are not different at $P \leq 0.05$ based on Duncan's multiple range test.
[##] ns = not significant.

E horizon. Phosphorus fertilizers reduced the pH of the E horizon when compared to that of the control (Table GS2-II-32). No other effects of P fertilizers applied to the surface of the Ap were noted in the E horizon.

Bh horizon. No effects of fertilizer P applied up to 100 kg ha^{-1} to the surface of the Ap horizon of reconstructed soil profile of Immokalee fine sand planted to stargrass were noted in the Bh horizon (Table GS2-II-33).

Accounting for Soil and Fertilizer Phosphorus in Ca-amended Soil

The summary for P in plant tissue (with the exception of the roots and the stubble portions), in leachate withdrawn for analysis, and in soil is given in Table GS2-II-34. Total P in leachates was the sum of the products of the volumes and the corresponding concentrations for ten samplings done during the period of study.

The P in above-ground plant tissue represented only from 7 to 9 percent of the post-study total P accounted for (Table GS2-II-34). Subtracting 89 mg P pot^{-1} extracted by the plants in the no P and no amendment treatments (Table GS2-II-26), stargrass plants utilized only 15.1, 10.8, 0.3, and 10.8 % of the 100 kg ha^{-1} fertilizer P in no amendment, gypsum-, limestone-, and dolomite-amended pots, respectively (Table GS2-II-34). This and the fact that there were no effects of P rates on yield indicated that stargrass pasture on Immokalee fine sand would not benefit from P fertilization.

Table GS2-II-32. Soil pH and Mehlich I extractable elements in E horizon of reconstructed soil profile of Immokalee fine sand with the Ap horizon planted to stargrass fertilized twice at four rates of P, with the second P application applied 14 weeks after the first, no Ca amendments.

Treatment	Rate	pH	P	K	Ca	Mg	Fe
	kg P ha^{-1}		---------------------- mg kg^{-1}	-----------------------------			
1	0.0	6.5a	1.5a	1.8a	50a	4.0a	0.4a
2	12.5	6.3b	1.3a	1.6a	39a	4.0a	0.4a
3	25.0	6.3b	1.8a	1.7a	48a	4.0a	0.6a
4	50.0	6.1b	1.8a	1.8a	48a	4.0a	0.6a
<u>REGRESSION:</u>							
Linear (R^2)		0.39*	ns	ns	ns	ns	ns
Quadratic (R^2)		0.39*	ns	ns	ns	ns	ns

Means within columns having the same letter are not different at $P \leq 0.05$ based on Duncan's multiple range test.

ns = not significant; * Significant at ≤ 0.05.

Table GS2-II-33. Soil pH and Mehlich I extractable elements in Bh horizon of reconstructed soil profile of Immokalee fine with the Ap horizon planted to stargrass fertilized twice at four rates of P, with the second P application applied 14 weeks after the first, no Ca amendments.

Treatment	Rate	pH	P	K	Ca	Mg	Fe
	kg P ha^{-1}		---------------------- mg kg^{-1}	-----------------------------			
1	0.0	5.4a	143a	37.1a	791a	129a	6.5a
2	12.5	5.6a	146a	34.8a	839a	123a	7.0a
3	25.0	5.5a	132a	36.6a	950a	114a	7.1a
4	50.0	5.5a	133a	37.7a	962a	141a	6.6a
<u>REGRESSION:</u>							
Linear (R^2)		ns	ns	ns	ns	ns	ns
Quadratic (R^2)		ns	ns	ns	ns	ns	ns

Means within columns having the same letter are not different at $P \leq 0.05$ based on Duncan's multiple range test.

Table GS2-II-34. Accounting for soil and fertilizer P in reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized twice at 50 kg P ha^{-1}, with second P application applied 14 weeks after the first, and amended with Ca amendments at 2 Mg ha^{-1}.

	Treatment			
P Source	No amendment	Gypsum	Limestone	Dolomite
Fertilizer P + initial soil P:	Total mg P pot^{-1} (%)			
Fertilizer P applied	314.0 (21.9)	314.0 (21.9)	314.0 (21.9)	314.0 (21.9)
P in soil column	1106.9 (77.3)	1106.9 (77.3)	1106.9 (77.3)	1106.9 (77.3)
Ap 8.16 kg	115.9 (10.5)	115.9 (10.5)	115.9 (10.5)	115.9 (10.5)
E 18.84 kg	22.6 (2.0)	22.6 (2.0)	22.6 (2.0)	22.6 (2.0)
Bh 9.42 kg	968.4 (87.5)	968.4 (87.5)	968.4 (87.5)	968.4 (87.5)
C[#] 2.35 kg	-	-	-	-
Sod soil[##]	11.3 (0.8)	11.3 (0.8)	11.3 (0.8)	11.3 (0.8)
Initial-Total	1432.2 (100)	1432.2 (100)	1432.2 (100)	1432.2 (100)
Post fertilization P sources:	Total mg P pot^{-1} (%)			
Plant tissue	138.00 (9.1)	124.00 (7.6)	90.00 (7.6)	124.00 (7.4)
Leachate withdrawn	1.71 (0.1)	1.79 (0.1)	2.13 (0.2)	1.65 (0.1)
Shallow wells	1.52	1.56	1.93	1.45
Deep wells	0.11	0.15	0.12	0.11
Bottom leachates	0.08	0.08	0.08	0.09
Soil column	1362.8 (90.0)	1503.2 (91.6)	1087.3 (91.3)	1530.9 (91.8)
Ap 8.16 kg	75.1 (5.5)	50.6 (3.4)	47.3 (4.4)	60.4 (3.9)
E 18.84 kg	33.9 (2.5)	35.8 (2.4)	30.2 (2.8)	35.8 (2.4)
Bh 9.42 kg	1253.8 (92.0)	1416.8 (94.2)	1009.8 (92.8)	1434.7 (93.7)
C[#] 2.35 kg	-	-	-	-
Sod soil[##]	11.3 (0.7)	11.3 (0.7)	11.3 (0.9)	11.3 (0.7)
Post-Total	1513.8 (100)	1640.3 (100)	1190.7 (100.)	1667.9 (100)
	post-P:pre-P ratio			
Soil: post-P:pre-P ratio	1.23[###]	1.36	0.98	1.38
Total: post-P:pre-P ratio	1.06[###]	1.14	0.83	1.17

[#] No analysis was done before and after the study.

[##] Values were those after the study using a sod soil of 500 g at 1.0 g cm^{-3} averaged over the two Ap soils (Tables GS2-I-16 and GS2-I-17); no analysis of soil in sod was done prior to planting and P fertilization. [###] Using the value for Ap from Table GS1-3.

In the soil profile, Mehlich-extractable P in the Ap horizon was reduced after the study in all treatments but increased in the Bh horizon with the least increase noted in limestone-treated pots (Table GS2-II-34). Total extractable P for the whole soil column or profile increased in the control (no amendment) and in gypsum- and dolomite-amended pots but not in limestone-amended ones as indicated by the post-P:pre-P ratios. This would indicate that the P retained in limestone-treated soils were not readily extracted by Mehlich I compared to those in pots that received other treatments. This was also noted in greenhouse study GS1, a leaching study using individual soil horizons with no stargrass planted. Thus, the two greenhouse studies demonstrated the immobilizing effects of calcium carbonate on soil and fertilizer P.

Accounting for Soil and Fertilizer Phosphorus in Soil with No Ca Amendments

The summary for P in plant tissue (with the exception of the roots and the stubble portions), in leachate withdrawn for analysis, and in soil fertilized at four rates of P with no Ca amendments is given in Table GS2-II-35. Total P in leachates was the sum of the products of the volumes and the corresponding concentrations for ten samplings done during the period of study.

The P in above-ground plant tissue represented only from 6 to 9 percent of the post-study total P accounted for. Subtracting 89 mg P pot^{-1} extracted by the plants in the no P and no amendment treatments (Table GS2-II-27), stargrass plants utilized only 17.3, 9.3, and 15.0 % of fertilizer P applied at 25, 50, and 100 kg P ha^{-1}, respectively (Table GS2-II-35). This and the fact that there was no effects of P rates on yield indicated strongly that stargrass pasture on Immokalee fine sand would not benefit from P fertilization.

In the soil profile, Mehlich-extractable P in the Ap horizon was also reduced after the study in all treatments but increased in the Bh horizon in similar magnitudes (Table GS2-II-35) for the four P rates. Total extractable P for the whole soil column or profile increased in the control (no P) and in P-fertilized pots as indicated by the total post-P:pre-P ratios but in decreasing ratios with increasing P rates. This would indicate that the non-readily extractable P increases, mostly in the Bh horizon, with increasing P rates. This was also noted by Alcordo et al. (2002) in their leaching study using similar soil but no stargrass planted.

Table GS2-II-35. Accounting for soil and fertilizer P in reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized twice at four rates of P, with the second P application applied 14 weeks after the first, no Ca amendments.

	kg P ha^{-1}			
P Source	No P	12.5	25.0	50.0
Fertilizer P + initial soil P:	------------ Total mg P pot^{-1} (%) ------------			
Fertilizer P applied	0.0 (0.0)	78.5 (6.6)	157.0 (12.3)	314.0 (21.9)
P in soil column	1106.9 (76.7)	1106.9 (76.7)	1106.9 (76.7)	1106.9 (76.7)
Ap 8.16 kg	115.9 (8.0)	115.9 (8.0)	115.9 (8.0)	115.9 (8.0)
E 18.84 kg	22.6 (1.6)	22.6 (1.6)	22.6 (1.6)	22.6 (1.6)
Bh 9.42 kg	968.4 (67.1)	968.4 (67.1)	968.4 (67.1)	968.4 (67.1)
C[#] 2.35 kg	-	-	-	-
Sod soil[##]	11.3 (0.8)	11.3 (0.8)	11.3 (0.8)	11.3 (0.8)
Initial-Total	1118.2 (100)	1196.7 (100)	1275.2 (100)	1432.2 (100)
Post fertilization P sources:	------------ Total mg P pot^{-1} (%) ------------			
Plant tissue	89.0 (5.9)	103.00 (6.6)	104.0 (7.2)	138.00 (0.9)
Leachate withdrawn	1.71 (0.1)	1.79 (0.1)	2.13 (0.1)	1.65
Shallow wells	1.14	1.73	1.68	1.52
Deep wells	0.13	0.13	0.13	0.11
Bottom leachates	0.09	0.08	0.08	0.08
Soil column	1412.9 (93.3)	1439.8 (92.5)	1319.7 (91.8)	1361.9 (90.0)
Ap 8.16 kg	37.5 (2.7)	40.0 (2.8)	42.4 (3.2)	75.1 (5.5)
E 18.84 kg	28.3 (2.0)	24.5 (1.7)	33.9 (2.6)	33.9 (2.5)
Bh 9.42 kg	1347.1 (95.3)	1375.3 (95.5)	1243.4 (94.2)	1252.9 (92.0)
C[#] 2.35 kg	-	-	-	-
Sod soil[##]	11.3 (0.7)	11.3 (0.7)	11.3 (0.8)	11.3 (0.7)
Post-Total	1514.0 (100)	1555.9 (100)	1437.1 (100.)	1512.9 (100)
	------------ post-P:pre-P ratio ------------			
Soil: post-P:pre-P ratio	1.28[###]	1.30	1.19	1.23
Total: post-P:pre-P ratio	1.35[###]	1.30	1.13	1.06

[#] No analysis was done before and after the study.

[##] Values were those after the study using a sod soil of 500 g at 1.0 g cm^{-3} averaged over the two Ap soils (Tables GS2-I-16 and GS2-I-17); no analysis of soil in sod was done prior to planting and P fertilization. [###] Using the value for Ap from Table GS1-3.

Field Study 1 (AGFS): Stargrass P Fertilization Experiment

Effects on Forage Yield and Quality

Forage Yield and Percent Dry Matter (% DM)

Effects of fertilizer P. The effects of all 8 treatments are given in Table AGFS-3 for % DM and total DM forage yields. Phosphorus fertilization of stargrass pasture on Immokalee fine sand up to 50 kg P ha^{-1} showed no beneficial effects on forage yield or dry matter content in 1999, 2000, 2001, or when averaged over the three-year period. Table AGFS-4, which analyzed the effects of fertilizer P rates only, also indicated no effects of P fertilization on stargrass nor any significant trends in forage yield with P rates. No differences in % DM with treatments were noted. The greenhouse study conducted concurrently with the field study using similar treatments also showed no effects of fertilizer P on forage yield of stargrass grown on potted reconstructed soil profile of Immokalee fine sand (Rechcigl et al., 2002).

Effects of lime. Table AGFS-3 showed that calcium carbonate at 4 Mg ha^{-1} (T6), but not at 2 Mg (T5), applied to plots that received 50 kg P ha^{-1} tended to increase forage yield in 1999, 2000, and 2001, and when averaged overall. But the differences between T6 and T4 (50 P, no lime) or between T6 and T1 (0 P, no lime) were not significant. Table AGFS-5, for the lime treatments only, although showing no significant differences between rates or any significant trends in forage yield with rates, tended to have consistently higher forage yield at 4 Mg ha^{-1} than at the lower rates. This would indicate that 4 Mg lime ha^{-1}, or possibly higher, can be used as soil amendment to tie up P (Alcordo et al., 2002) without adverse effects on forage yield of stargrass. The greenhouse study using reconstructed soil profile of Immokalee fine sand, dolomite at 4 Mg ha^{-1} also showed similar tendency to increase stargrass forage yield (Rechcigl et al., 2002). No differences in % DM with treatments were noted.

Effects of gypsum. There was a tendency for 2 and 4 Mg gypsum ha^{-1} to increase forage yield during the first year of application (1999) but not thereafter or when averaged over the three-year period (Tables AGFS-3 and AGFS-6). The one-year greenhouse study using reconstructed soil profile showed that gypsum at the said rates also tended to increase stargrass forage yield (Rechcigl et al., 2002). No differences in % DM with treatments were noted in both studies. However, since gypsum at the lower rate has been shown in a leaching study (Alcordo et al. 2002) to increase the mobility of soil or fertilizer P in matrix flow, it should not be recommended as a soil amendment, as some studies did suggest (Anderson et al., 1995), to tie up P in Spodosols.

Crude Protein (CP) and *in vitro* Organic Matter Digestibility (IVOMD)

The value of a forage as a source of amino acids is reflected on the amount of total N contents. Forages contain N in many forms other than amino acids which may be converted to amino acid by rumen microorganisms. All forms of N present in plants are included in the term crude protein (CP) which is obtained by multiplying total % N by 6.25. Protein contains 22 different amino acids and is necessary for the overall health and development of animal life.

Table AGFS-3. Effects of P fertilizer, calcium carbonate, and mined gypsum on percent dry matter (%DM) and total forage DM yield of stargrass pasture on Immokalee fine sand fertilized annually with P without or with Ca amendment applied once in 1999; 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Year/Treatment	P	$CaCO_3$	Gypsum	DM	Forage yield
1999:	kg ha^{-1}	---------- Mg ha^{-1}	---------	%	Mg DM ha^{-1}
T1	0.00	0.0	0.0	38.0a[†]	8.81b
T2	12.50	0.0	0.0	37.4a	8.29b
T3	25.00	0.0	0.0	33.8a	9.89ab
T4	50.00	0.0	0.0	35.8a	9.97ab
T5	50.00	2.0	0.0	35.2a	9.87ab
T6	50.00	4.0	0.0	35.7a	10.88ab
T7	50.00	0.0	2.0	33.6a	12.10a
T8	50.00	0.0	4.0	34.1a	11.93a
2000:					
T1	0.00	0.0	0.0	35.7a	9.28a
T2	12.50	0.0	0.0	36.1a	7.34a
T3	25.00	0.0	0.0	34.1a	7.63a
T4	50.00	0.0	0.0	34.4a	8.44a
T5	50.00	(2.0)[††]	0.0	34.7a	8.42a
T6	50.00	(4.0)	0.0	33.4a	9.53a
T7	50.00	0.0	(2.0)[††]	35.0a	8.44a
T8	50.00	0.0	(4.0)	35.6a	8.05a
2001:					
T1	0.00	0.0	0.0	32.5a	11.88a
T2	12.50	0.0	0.0	33.5a	11.12a
T3	25.00	0.0	0.0	32.1a	12.90a
T4	50.00	0.0	0.0	33.0a	11.87a
T5	50.00	(2.0)[††]	0.0	32.9a	11.80a
T6	50.00	(4.0)	0.0	33.7a	12.18a
T7	50.00	0.0	(2.0)[††]	33.5a	12.62a
T8	50.00	0.0	(4.0)	34.2a	11.31a
3-year Mean:					
T1	0.00	0.0	0.0	35.5a	9.99a
T2	12.50	0.0	0.0	35.8a	8.92a
T3	25.00	0.0	0.0	33.4a	10.14a
T4	50.00	0.0	0.0	34.5a	10.09a
T5	50.00	2.0[††]	0.0	34.3a	10.03a
T6	50.00	4.0	0.0	34.3a	10.88a
T7	50.00	0.0	2.0[††]	34.0a	11.05a
T8	50.00	0.0	4.0	34.6a	10.43a

[†] Means in column having the same letter are not different at the 5% level of significance using Tukey's Studentized Range (HSD) Test.

[††] Based on initial rate of application made in 1999.

Table AGFS-4. Effects of P fertilizer applied annually without Ca amendments on percent dry matter (%DM) and total forage DM yield of stargrass pasture on Immokalee fine sand; 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Year/Treatment	P	$CaCO_3$	Gypsum	DM	Forage yield
1999:	kg ha^{-1}	---------- Mg ha^{-1}	-----------	%	Mg DM ha^{-1}
T1	0.0	0.0	0.0	38.0a[†]	8.81a
T2	12.5	0.0	0.0	37.4a	8.29a
T3	25.0	0.0	0.0	33.8a	9.89a
T4	50.0	0.0	0.0	35.8a	9.97a
Statistics:					
P(treatment)	-	-	-	0.6099	0.2724
$LSD_{0.05}$	-	-	-	6.6	2.02
P(linear)	-	-	-	0.4349	0.1286
P(quadratic)	-	-	-	0.4059	0.9312
2000:					
T1	0.0	0.0	0.0	35.7a	9.28a
T2	12.5	0.0	0.0	36.1a	7.34a
T3	25.0	0.0	0.0	34.1a	7.63a
T4	50.0	0.0	0.0	34.4a	8.44a
Statistics:					
P(treatment)	-	-	-	0.8836	0.3737
$LSD_{0.05}$	-	-	-	5.8	2.3
P(linear)	-	-	-	0.5725	0.5537
P(quadratic)	-	-	-	0.8507	0.1388
2001:					
T1	0.0	0.0	0.0	32.5a	11.88a
T2	12.5	0.0	0.0	33.5a	11.12a
T3	25.0	0.0	0.0	32.1a	12.90a
T4	50.0	0.0	0.0	33.0a	11.87a
Statistics:					
P(treatment)	-	-	-	0.9813	0.7784
$LSD_{0.05}$	-	-	-	7.2	3.40
P(linear)	-	-	-	0.9841	0.8217
P(quadratic)	-	-	-	0.9581	0.7304
3-year mean:					
T1	0.0	0.0	0.0	35.5a	9.99a
T2	12.5	0.0	0.0	35.8a	8.92a
T3	25.0	0.0	0.0	33.4a	10.14a
T4	50.0	0.0	0.0	34.5a	10.09a
Statistics:					
P(treatment)	-	-	-	0.5747	0.4165
$LSD_{0.05}$	-	-	-	3.7	1.62
P(linear)	-	-	-	0.3994	0.6138
P(quadratic)	-	-	-	0.5929	0.6637

[†] Means in column having the same letter are not different at P(treatment) $\leq$ 0.05.

Table AGFS-5. Effects of calcium carbonate on percent dry matter (%DM) and total forage DM yield of stargrass pasture on Immokalee fine sand applied once in 1999 to plots fertilized annually at 50 kg P ha^{-1}; 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Treatment	P	$CaCO_3$	Gypsum	DM	Forage yield
1999:	kg ha^{-1}	---------- Mg ha^{-1} -----------		%	Mg DM ha^{-1}
T4	50.0	0.0	0.0	35.8a[†]	9.97a
T5	50.0	2.0	0.0	35.2a	9.87a
T6	50.0	4.0	0.0	35.7a	10.88a
Statistics:					
P(treatment)	-	-	-	0.9756	0.5956
LSD$_{0.05}$	-	-	-	5.6	2.25
P(linear)	-	-	-	0.7952	0.4067
P(quadratic)	-	-	-	0.8268	0.5581
2000:					
T4	50.0	0.0	0.0	34.4a	8.44a
T5	50.0	(2.0)[††]	0.0	34.7a	8.42a
T6	50.0	(4.0)	0.0	33.4a	9.53a
Statistics:					
P(treatment)	-	-	-	0.8677	0.6002
LSD$_{0.05}$	-	-	-	5.1	2.61
P(linear)	-	-	-	0.6880	0.3871
P(quadratic)	-	-	-	0.7283	0.6045
2001:					
T4	50.0	0.0	0.0	33.0a	11.87a
T5	50.0	(2.0)[††]	0.0	32.9a	11.80a
T6	50.0	(4.0)	0.0	33.7a	12.18a
Statistics:					
P(treatment)	-	-	-	0.9690	0.9709
LSD$_{0.05}$	-	-	-	6.7	3.35
P(linear)	-	-	-	0.8304	0.8550
P(quadratic)	-	-	-	0.8971	0.8739
3-year mean:					
T4	50.0	0.0	0.0	34.5a	10.09a
T5	50.0	2.0[††]	0.0	34.3a	10.03a
T6	50.0	4.0	0.0	34.3a	10.88a
Statistics:					
P(treatment)	-	-	-	0.9953	0.5059
LSD$_{0.05}$	-	-	-	3.3	1.63
P(linear)	-	-	-	0.9317	0.3332
P(quadratic)	-	-	-	0.9630	0.5142

[†] Means in column having the same letter are not different at P(treatment) $\leq$ 0.05.
[††] Based on initial rate of application made in 1999.

Table AGFS-6. Effects of mined gypsum on percent dry matter (%DM) and total forage DM yield of stargrass pasture on Immokalee fine sand applied once in 1999 to plots fertilized annually at 50 kg P ha^{-1}; 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Treatment	P	$CaCO_3$	Gypsum	DM	Forage yield
1999:	kg ha^{-1}	---------- Mg ha^{-1} -----------		%	Mg DM ha^{-1}
T4	50.0	0.0	0.0	35.8a[†]	9.97a
T7	50.0	0.0	2.0	33.6a	12.10a
T8	50.0	0.0	4.0	34.1a	11.93a
Statistics:					
P(treatment)	-	-	-	0.5381	0.2544
$LSD_{0.05}$	-	-	-	4.6	2.73
P(linear)	-	-	-	0.3210	0.1773
P(quadratic)	-	-	-	0.6171	0.3370
2000:					
T4	50.0	0.0	0.0	34.4a	8.44a
T7	50.0	0.0	(2.0)[††]	35.0a	8.44a
T8	50.0	0.0	(4.0)	35.6a	8.05a
Statistics:					
P(treatment)	-	-	-	0.9363	0.9292
$LSD_{0.05}$	-	-	-	6.1	2.29
P(linear)	-	-	-	0.7178	0.7409
P(quadratic)	-	-	-	0.9934	0.8487
2001:					
T4	50.0	0.0	0.0	33.0a	11.87a
T7	50.0	0.0	(2.0)[††]	33.5a	12.62a
T8	50.0	0.0	(4.0)	34.2a	11.31a
Statistics:					
P(treatment)	-	-	-	0.9204	0.7352
$LSD_{0.05}$	-	-	-	6.1	3.35
P(linear)	-	-	-	0.6857	0.7378
P(quadratic)	-	-	-	0.9761	0.4798
3-year mean:					
T4	50.0	0.0	0.0	34.5a	10.09a
T7	50.0	0.0	2.0[††]	34.0a	11.05a
T8	50.0	0.0	4.0	34.6a	10.43a
Statistics:					
P(treatment)	-	-	-	0.9515	0.5168
$LSD_{0.05}$	-	-	-	3.2	1.67
P(linear)	-	-	-	0.9298	0.7154
P(quadratic)	-	-	-	0.7624	0.2764

[†] Means in column having the same letter are not different at P(treatment) ≤ 0.05.

[††] Based on initial rate of application made in 1999.

In vitro organic matter digestibility (IVOMD) is another measure of forage quality. The apparent digestibility of forage is the proportional difference between the quantities consumed and those excreted in the feces. Digestibility is related to the energy value of forage.

Effects of fertilizer P. The effects of fertilizer P on CP or IVOMD in relation to the other seven treatments are given in Table AGFS-7. Table AGFS-7 showed no differences between any two treatments in 1999, 2000, and 2001 or when averaged over the three-year period. The analysis for P rates alone (Table AGFS-8) also showed no effects of or significant trends with rates on CP or IVOMD in 1999, 2000, and 2001 or when averaged over the three-year period. This is one more reason to re-evaluate the present P fertilizer recommendation for stargrass on Spodosols.

Effects of lime. Calcium carbonate applied to plots that received 50 kg P ha^{-1} showed no beneficial or adverse effects on CP or IVOMD of stargrass forage (Tables AGFS-7 and AGFS-9).

Effects of gypsum. Gypsum, also applied to plots that received 50 kg P ha^{-1}, showed no beneficial or adverse effects on CP or IVOMD of stargrass in 1999, 2000, and 2001 or when averaged over the three-year period (Tables AGFS-7 and AGFS-10).

Macro Nutrients P, K, Ca, Mg, and Ca:P Ratio

The following were obtained from McDowell et al. (1993) and may be referred to for more detailed information.

Eighty percent of P in the entire body of livestock is found in bones and teeth. The National Research Council (1984) indicated that for beef cattle 0.17 to 0.59 % P in feed or forage is adequate for growing and fattening steers and heifers.

Potassium is the principal cation of intercellular fluids. It is essential to animal life for a variety of body functions. For ruminant species, K in feed should be about 0.5 to 1.0 %.

Calcium together with P make up 70 % of the total mineral elements in the body of livestock. Like P, Ca is important in the development of the bones and teeth of animals 99% of which is Ca. The NRC (1984) requirements for beef cattle indicate that 0.17 to 1.53 % Ca in feed are adequate for growing and fattening steers and heifers. Calcium must be made available to livestock in proper quantities and ratios relative to P. A dietary Ca:P ratio between 1:1 and 2:1 is assumed to be ideal. Ruminants can tolerate a wider range of Ca:P ratios. A study by Wise et al. (1963) indicated that Ca:P ratios below 1:1 and over 7:1 could reduce growth and feed efficiency.

Magnesium is also important in skeletal development with some 70 % of total body Mg being present in bones. It is the second most plentiful cation of intercellular fluids after K. Minimum requirements for growth of cattle may be met by forage or diets containing 0.10 % Mg.

Effects of fertilizer P. The effects of fertilizer P on P contents of stargrass in relation to the other treatments are given in Table AGFS-11. For P rates alone, Table AGFS-12 showed that P in

Table AGFS-7. Effects of P fertilizer, calcium carbonate, and gypsum on percent crude protein (% CP) and *in vitro* organic matter digestibility (% IVOMD) of stargrass forage from pasture growing on Immokalee fine sand soil, 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Year/Treatment	P	$CaCO_3$	Gypsum	CP	IVOMD
1999:	kg ha^{-1}	---------- Mg ha^{-1}	-----------	---------------- %	--------------
T1	0.00	0.0	0.0	10.4a[†]	46.5a
T2	12.50	0.0	0.0	10.4a	46.9a
T3	25.00	0.0	0.0	11.0a	47.5a
T4	50.00	0.0	0.0	10.4a	47.1a
T5	50.00	2.0	0.0	10.2a	47.3a
T6	50.00	4.0	0.0	10.8a	48.0a
T7	50.00	0.0	2.0	11.4a	48.2a
T8	50.00	0.0	4.0	11.5a	48.4a
2000:					
T1	0.00	0.0	0.0	14.2a	54.6a
T2	12.50	0.0	0.0	13.8a	53.4a
T3	25.00	0.0	0.0	13.6a	54.8a
T4	50.00	0.0	0.0	13.8a	54.5a
T5	50.00	(2.0)[††]	0.0	13.9a	54.7a
T6	50.00	(4.0)	0.0	13.8a	54.5a
T7	50.00	0.0	(2.0)[††]	13.6a	53.8a
T8	50.00	0.0	(4.0)	12.6a	53.3a
2001:					
T1	0.00	0.0	0.0	12.8a	50.0a
T2	12.50	0.0	0.0	12.5a	49.6a
T3	25.00	0.0	0.0	13.0a	50.1a
T4	50.00	0.0	0.0	12.2a	49.8a
T5	50.00	(2.0)[††]	0.0	12.2a	49.3a
T6	50.00	(4.0)	0.0	12.6a	50.8a
T7	50.00	0.0	(2.0)[††]	12.5a	50.6a
T8	50.00	0.0	(4.0)	11.8a	49.1a
3-year mean:					
T1	0.00	0.0	0.0	12.3a	50.2a
T2	12.50	0.0	0.0	12.1a	49.8a
T3	25.00	0.0	0.0	12.5a	50.6a
T4	50.00	0.0	0.0	12.0a	50.3a
T5	50.00	2.0[††]	0.0	12.0a	50.3a
T6	50.00	4.0	0.0	12.4a	51.0a
T7	50.00	0.0	2.0[††]	12.4a	51.4a
T8	50.00	0.0	4.0	12.0a	50.1a

[†] Means in column having the same letter are not different at the 5% level of significance using Tukey's Studentized Range (HSD) Test.

[††] Based on initial rate of application made in 1999.

Table AGFS-8. Effects of P fertilizer without the amendments on percent crude protein (%CP) and *in vitro* matter digestibility (% IVOMD) of stargrass forage growing on Immokalee fine sand, 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Year/Treatment	P	$CaCO_3$	Gypsum	CP	IVOMD
1999:	kg ha^{-1}	---------- Mg ha^{-1}	-----------	--------------- %	----------------
T1	0.0	0.0	0.0	10.4a[†]	46.5a
T2	12.5	0.0	0.0	10.4a	46.9a
T3	25.0	0.0	0.0	11.0a	47.5a
T4	50.0	0.0	0.0	10.4a	47.1a
Statistics:					
P(treatment)	-	-	-	0.5992	0.9488
$LSD_{0.05}$	-	-	-	1.3	3.9
P(linear)	-	-	-	0.7513	0.7177
P(quadratic)	-	-	-	0.2582	0.6620
2000:					
T1	0.0	0.0	0.0	14.2a	54.6a
T2	12.5	0.0	0.0	13.8a	53.4a
T3	25.0	0.0	0.0	13.6a	54.8a
T4	50.0	0.0	0.0	13.8a	54.5a
Statistics:					
P(treatment)	-	-	-	0.9700	0.7021
$LSD_{0.05}$	-	-	-	2.29	2.6
P(linear)	-	-	-	0.7701	0.7994
P(quadratic)	-	-	-	0.6908	0.7807
2001:					
T1	0.0	0.0	0.0	12.8a	50.0a
T2	12.5	0.0	0.0	12.5a	49.6a
T3	25.0	0.0	0.0	13.0a	50.1a
T4	50.0	0.0	0.0	12.2a	49.8a
Statistics:					
P(treatment)	-	-	-	0.8448	0.9932
$LSD_{0.05}$	-	-	-	1.9	3.4
P(linear)	-	-	-	0.5704	0.9627
P(quadratic)	-	-	-	0.6673	0.9792
3-year mean:					
T1	0.0	0.0	0.0	12.3a	50.2a
T2	12.5	0.0	0.0	12.1a	49.8a
T3	25.0	0.0	0.0	12.5a	50.6a
T4	50.0	0.0	0.0	12.0a	50.3a
Statistics:					
P(treatment)	-	-	-	0.8604	0.8913
$LSD_{0.05}$	-	-	-	1.1	2.1
P(linear)	-	-	-	0.7282	0.7554
P(quadratic)	-	-	-	0.6330	0.8463

[†] Means in column having the same letter are not different at $P(treatment) \leq 0.05$.

Table AGFS-9. Effects of calcium carbonate at 50 kg P ha^{-1} on percent crude protein (%CP) and *in vitro* organic matter digestibility (% IVOMD) of stargrass forage growing on Immokalee fine sand, 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Year/Treatment	P	$CaCO_3$	Gypsum	CP	IVOMD
1990:	kg ha^{-1}	---------- Mg ha^{-1} -----------		-------------- % --------------	
T4	50.0	0.0	0.0	10.4a[†]	47.1a
T5	50.0	2.0	0.0	10.2a	47.3a
T6	50.0	4.0	0.0	10.8a	48.0a
Statistics:					
P(treatment)	-	-	-	0.6239	0.8709
$LSD_{0.05}$	-	-	-	1.2	3.5
P(linear)	-	-	-	0.4794	0.6293
P(quadratic)	-	-	-	0.5071	0.8380
2000:					
T4	50.0	0.0	0.0	13.8a	54.5a
T5	50.0	(2.0)[††]	0.0	13.9a	54.7a
T6	50.0	(4.0)	0.0	13.8a	54.5a
Statistics:					
P(treatment)	-	-	-	0.9960	0.9822
$LSD_{0.05}$	-	-	-	2.4	2.8
P(linear)	-	-	-	0.9745	0.9976
P(quadratic)	-	-	-	0.9334	0.8503
2001:					
T4	50.0	0.0	0.0	12.2a	49.8a
T5	50.0	(2.0)[††]	0.0	12.2a	49.3a
T6	50.0	(4.0)	0.0	12.6a	50.8a
Statistics:					
P(treatment)	-	-	-	0.8464	0.6063
$LSD_{0.05}$	-	-	-	1.9	3.1
P(linear)	-	-	-	0.6163	0.4976
P(quadratic)	-	-	-	0.7770	0.4637
3-year mean:					
T4	50.0	0.0	0.0	12.0a	50.3a
T5	50.0	2.0 [††]	0.0	12.0a	50.3a
T6	50.0	4.0	0.0	12.4a	51.0a
Statistics:					
P(treatment)	-	-	-	0.7603	0.7363
$LSD_{0.05}$	-	-	-	1.1	2.0
P(linear)	-	-	-	0.5297	0.5086
P(quadratic)	-	-	-	0.6967	0.6763

[†] Means column having the same letter are not different at $P(\text{treatment}) \leq 0.05$.

[††] Based on initial rate of application made in 1999.

Table AGFS-10. Effects of mined gypsum at 50 kg P ha^{-1} on percent crude protein (%CP) and IVOMD of stargrass forage from pasture growing on Immokalee fine sand, 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Year/Treatment	P	$CaCO_3$	Gypsum	CP	IVOMD
1999:	kg ha^{-1}	---------- Mg ha^{-1}	-----------	--------------- %	-----------------
T4	50.0	0.0	0.0	10.4a[†]	47.1a
T7	50.0	0.0	2.0	11.4a	48.2a
T8	50.0	0.0	4.0	11.5a	48.4a
Statistics:					
P(treatment)	-	-	-	0.2738	0.8609
$LSD_{0.05}$	-	-	-	1.5	4.8
P(linear)	-	-	-	0.1480	0.6239
P(quadratic)	-	-	-	0.4818	0.8108
2000:					
T4	50.0	0.0	0.0	13.8a	54.5a
T7	50.0	0.0	(2.0)[††]	13.6a	53.8a
T8	50.0	0.0	(4.0)	12.6a	53.3a
Statistics:					
P(treatment)	-	-	-	0.5305	0.7083
$LSD_{0.05}$	-	-	-	2.2	2.9
P(linear)	-	-	-	0.2950	0.4088
P(quadratic)	-	-	-	0.6853	0.9612
2001:					
T4	50.0	0.0	0.0	12.2a	49.8a
T7	50.0	0.0	(2.0)[††]	12.5a	50.6a
T8	50.0	0.0	(4.0)	11.8a	49.1a
Statistics:					
P(treatment)	-	-	-	0.7816	0.6750
$LSD_{0.05}$	-	-	-	1.8	3.3
P(linear)	-	-	-	0.7217	0.6820
P(quadratic)	-	-	-	0.5469	0.4334
3-year mean:					
T4	50.0	0.0	0.0	12.0a	50.3a
T7	50.0	0.0	2.0 [††]	12.4a	51.4a
T8	50.0	0.0	4.0	12.0a	50.1a
Statistics:					
P(treatment)	-	-	-	0.6252	0.8797
$LSD_{0.05}$	-	-	-	1.1	2.3
P(linear)	-	-	-	0.9204	0.9218
P(quadratic)	-	-	-	0.3356	0.6198

[†] Means in column having the same letter are not different at P(treatment) $\leq$ 0.05.
[††] Based on initial rate of application made in 1999.

Table AGFS-11. Effects of P fertilizer, calcium carbonate, and gypsum on macro nutrients in stargrass forage from pasture growing on Immokalee fine sand, 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Year/Treatment	P	$CaCO_3$	Gypsum	P	K	Ca	Mg	Ca:P
1999:	kg ha^{-1}	------ Mg ha^{-1} ------		------------------	%	---------------------		Ratio
T1	0.0	0.0	0.0	0.16d†	0.88a	0.27b	0.17a	1.83a
T2	12.5	0.0	0.0	0.19cd	0.82a	0.29ab	0.19a	1.63ab
T3	25.0	0.0	0.0	0.23bc	0.99a	0.31ab	0.19a	1.35bc
T4	50.0	0.0	0.0	0.28a	0.92a	0.32ab	0.19a	1.16c
T5	50.0	2.0	0.0	0.27a	0.89a	0.34ab	0.17a	1.23c
T6	50.0	4.0	0.0	0.26ab	0.85a	0.33ab	0.16a	1.29bc
T7	50.0	0.0	2.0	0.27ab	1.00a	0.33ab	0.15a	1.22c
T8	50.0	0.0	4.0	0.27a	1.07a	0.35a	0.15a	1.29bc
2000:								
T1	0.0	0.0	0.0	0.19c	1.20a	0.33a	0.18a	1.77a
T2	12.5	0.0	0.0	0.24c	1.03a	0.31a	0.16a	1.41b
T3	25.0	0.0	0.0	0.31b	1.22a	0.35a	0.18a	1.16bc
T4	50.0	0.0	0.0	0.39a	1.18a	0.35a	0.18a	0.92c
T5	50.0	(2.0)††	0.0	0.37ab	1.15a	0.37a	0.16a	1.07c
T6	50.0	(4.0)	0.0	0.38ab	1.26a	0.38a	0.17a	1.03c
T7	50.0	0.0	(2.0)††	0.38ab	1.14a	0.37a	0.17a	1.01c
T8	50.0	0.0	(4.0)	0.39a	1.18a	0.37a	0.17a	1.00c
2001:								
T1	0.0	0.0	0.0	0.21b	1.21a	0.29a	0.21a	1.39a
T2	12.5	0.0	0.0	0.26b	1.15a	0.31a	0.21a	1.17b
T3	25.0	0.0	0.0	0.35a	1.39a	0.33a	0.22a	0.96c
T4	50.0	0.0	0.0	0.36a	1.17a	0.31a	0.18a	0.87c
T5	50.0	(2.0)††	0.0	0.36a	1.18a	0.36a	0.19a	0.99bc
T6	50.0	(4.0)	0.0	0.36a	1.13a	0.34a	0.22a	0.97bc
T7	50.0	0.0	(2.0)††	0.38a	1.11a	0.35a	0.19a	0.94c
T8	50.0	0.0	(4.0)	0.36a	1.05a	0.39a	0.16a	1.07bc
3-year mean:								
T1	0.0	0.0	0.0	0.19c	1.09a	0.29d	0.19a	1.67a
T2	12.5	0.0	0.0	0.23c	0.99a	0.30cd	0.19a	1.42b
T3	25.0	0.0	0.0	0.29b	1.19a	0.33abcd	0.19a	1.17c
T4	50.0	0.0	0.0	0.34a	1.08a	0.32bcd	0.19a	0.99c
T5	50.0	2.0††	0.0	0.33ab	1.06a	0.35ab	0.17a	1.11c
T6	50.0	4.0	0.0	0.33ab	1.07a	0.35abc	0.19a	1.10c
T7	50.0	0.0	2.0††	0.34a	1.08a	0.35abc	0.17a	1.07c
T8	50.0	0.0	4.0	0.34ab	1.10a	0.37a	0.16a	1.13c

[†] Means in column having the same letter are not different at the 5% level of significance using Tukey's Studentized Range (HSD) Test.

[††] Based on initial rate of application made in 1999.

Table AGFS-12. Effects of P fertilizer on macro nutrients in stargrass forage from pasture growing on Immokalee fine sand, 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Year/Treatment	P	$CaCO_3$	Gypsum	P	K	Ca	Mg	Ca:P
1999:	kg ha^{-1}	---- Mg ha^{-1} ----		---------------------- % ----------------------				Ratio
T1	0.0	0.0	0.0	0.156d[†]	0.878a	0.272a	0.167a	1.83a
T2	12.5	0.0	0.0	0.189c	0.822a	0.295a	0.189a	1.63ab
T3	25.0	0.0	0.0	0.229b	0.992a	0.307a	0.192a	1.35bc
T4	50.0	0.0	0.0	0.280a	0.923a	0.318a	0.191a	1.16c
Statistics:								
P(treatment)	-	-	-	0.0001	0.4264	0.2108	0.5964	0.0001
$LSD_{0.05}$	-	-	-	0.027	0.208	0.045	0.042	0.29
P(linear)	-	-	-	0.0001	0.4375	0.0446	0.3089	0.0001
P(quadratic)	-	-	-	0.3805	0.6244	0.4849	0.3879	0.2926
Intercept	-	-	-	0.159	-	0.279	-	1.789
$Slope_{linear}$	-	-	-	0.0025	-	0.0009	-	-0.014
2000:								
T1	0.0	0.0	0.0	0.191d	1.202a	0.326a	0.179a	1.77a
T2	12.5	0.0	0.0	0.237c	1.028a	0.314a	0.164a	1.41b
T3	25.0	0.0	0.0	0.314b	1.220a	0.349a	0.178a	1.16c
T4	50.0	0.0	0.0	0.394a	1.184a	0.345a	0.183a	0.92c
Statistics:								
P(treatment)	-	-	-	0.0001	0.1905	0.3452	0.3555	0.0001
$LSD_{0.05}$	-	-	-	0.042	0.195	0.044	0.021	0.24
P(linear)	-	-	-	0.0001	0.6516	0.2177	0.3909	0.0001
P(quadratic)	-	-	-	0.4125	0.6048	0.8241	0.3723	0.0486
Intercept	-	-	-	0.193	-	-	-	1.676
$Slope_{linear}$	-	-	-	0.0042	-	-	-	-0.016
2001:								
T1	0.0	0.0	0.0	0.214c	1.208a	0.290a	0.215a	1.39a
T2	12.5	0.0	0.0	0.263b	1.149a	0.305a	0.209a	1.17b
T3	25.0	0.0	0.0	0.351a	1.387a	0.333a	0.216a	0.96c
T4	50.0	0.0	0.0	0.362a	1.172a	0.310a	0.181a	0.87c
Statistics:								
P(treatment)	-	-	-	0.0001	0.2182	0.3403	0.4085	0.0001
$LSD_{0.05}$	-	-	-	0.045	0.246	0.045	0.046	0.14
P(linear)	-	-	-	0.0001	0.9712	0.4159	0.1551	0.0001
P(quadratic)	-	-	-	0.0073	0.2410	0.1480	0.4176	0.0038
Intercept	-	-	-	0.232	-	-	-	1.321
$Slope_{linear}$	-	-	-	0.003	-	-	-	-0.010
3-year mean:								
T1	0.0	0.0	0.0	0.185d	1.085ab	0.295b	0.186a	1.67a
T2	12.5	0.0	0.0	0.227c	0.990b	0.304ab	0.188a	1.42b
T3	25.0	0.0	0.0	0.295b	1.189a	0.329a	0.195a	1.17c
T4	50.0	0.0	0.0	0.342a	1.084ab	0.324a	0.185a	0.99d
Statistics:								
P(treatment)	-	-	-	0.0001	0.0316	0.0344	0.8115	0.0001
$LSD_{0.05}$	-	-	-	0.025	0.131	0.026	0.022	0.15
P(linear)	-	-	-	0.0001	0.5212	0.0168	0.9745	0.0001
P(quadratic)	-	-	-	0.0203	0.4629	0.1762	0.3914	0.0079
Intercept	-	-	-	0.193	-	0.300	-	1.606
$Slope_{linear}$	-	-	-	0.003	-	0.001	-	-0.013

[†] Means column having the same letter are not different at P(treatment) ≤ 0.05.

forage increased linearly with P rates in 1999, 2000, 2001, and the rate of increase averaged 0.003

Table AGFS-11 indicated some effects of fertilizer P on Ca in forage. Analyzed for P rates alone (Table AGFS-12), Ca contents in forage fertilized at 25 and 50 kg P ha^{-1} were significantly higher than in the control forage when averaged over the three-year period. The increase in Ca was significantly linear with P rates with a slope of 0.001 % per kg P applied. This could be attributed to the dissolution of Ca materials in the soil due to the strong acidity of phosphoric acid in triple superphosphate making it much more readily available for plant uptake.

Tables AGFS-11 and AGFS-12 showed that fertilizer P had no effects on Mg uptake by stargrass growing on Immokalee fine sand.

The deterioration of the Ca:P ratios with fertilizer P was strongly indicated in Table 11. In the absence of any Ca amendments, the deterioration started immediately in the first year (1999) of P fertilizer application (Table AGFS-12). By the third year (2001), the application of 25 kg P ha^{-1} reduced Ca:P ratio to less than 1:1. Averaged over the three-year period, Ca:P ratio decreased by 0.013 unit for each kg of P applied per ha (Table AGFS-12).

Effects of lime. Tables AGFS-11 and AGFS-13 showed that P in forage from limed plots (T5 and T6) were not different from the unlimed control (T4) in all years or when averaged overall. These meant that at the highest rate of 50 kg P ha^{-1}, lime application of up to 4 Mg ha^{-1} was not sufficient to effectively tie up P which remained readily available, hence highly mobile, for plant uptake.

Table AGFS-13 showed that calcium carbonate had no influence on K, Ca, and Mg uptake by stargrass. The higher Ca in lime-amended forages (T5 and T6) compared to that in 0 P, 0 lime forages (T1) shown in Table AGFS-11 could be attributed to soil Ca solubilized by phosphoric acid applied at the rate of 50 kg P ha^{-1} rather than to the applied lime. Table AGFS-13 indicated that Ca from the applied lime was not readily available for plant uptake or that soil Ca was more than sufficient to meet the optimal needs of the crop.

Effects of gypsum. As with the lime-amended forages, P contents in forages from gypsum-amended plots (T7 and T8) were not different from the no gypsum control (T4) in all years or when averaged overall (Tables AGFS-11 and AGFS-14). This meant that at the highest rate of 50 kg P ha^{-1}, gypsum application of up to 4 Mg ha^{-1} was not effective in tying up P which remained readily available for plant uptake, hence highly mobile.

Tables AGFS-11 and AGFS-14 showed that gypsum had no influence on K uptake by stargrass. Averaged over the three-year period, gypsum linearly increased Ca by 0.012 % but reduced Mg by 0.007 % in stargrass forage fertilized at 50 kg P ha^{-1} (Table AGFS-14).

As with the lime-amended forages, Ca:P ratio in stargrass was not strongly increased by gypsum when applied to plots that were fertilized at high rates of P (Tables AGFS-11 and AGFS-14). From a high of 1.67:1 for the 0 P, 0 gypsum treatment (T1), Ca:P ratio decreased to 0.99:1 for the 50 P,

Table AGFS-13. Effects of calcium carbonate on macro nutrients in stargrass forage from pasture growing on Immokalee fine sand, 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Year/Treatment	P	$CaCO_3$	Gypsum	P	K	Ca	Mg	Ca:P
<u>1999:</u>	kg ha^{-1}	------ Mg ha^{-1} ------		------------------	%	------------------		Ratio
T4	50.0	0.0	0.0	0.280a[†]	0.923a	0.318a	0.191a	1.16a
T5	50.0	2.0	0.0	0.272a	0.885a	0.339a	0.165a	1.23a
T6	50.0	4.0	0.0	0.259a	0.848a	0.327a	0.161a	1.29a
<u>Statistics:</u>								
P(treatment)	-	-	-	0.4031	0.7331	0.6745	0.1789	0.2284
$LSD_{0.05}$	-	-	-	0.034	0.199	0.047	0.035	0.16
P(linear)	-	-	-	0.1855	0.4324	0.7087	0.0862	0.1048
P(quadratic)	-	-	-	0.8162	0.9819	0.4223	0.4824	0.5751
<u>2000:</u>								
T4	50.0	0.0	0.0	0.394a	1.184a	0.345a	0.183a	0.92a
T5	50.0	(2.0)[††]	0.0	0.369a	1.145a	0.371a	0.163a	1.07a
T6	50.0	(4.0)	0.0	0.384a	1.259a	0.377a	0.172a	1.03a
<u>Statistics:</u>								
P(treatment)	-	-	-	0.6727	0.5443	0.3485	0.1363	0.2147
$LSD_{0.05}$	-	-	-	0.057	0.209	0.047	0.019	0.17
P(linear)	-	-	-	0.7258	0.4743	0.1724	0.2817	0.2111
P(quadratic)	-	-	-	0.4147	0.4025	0.6259	0.0916	0.2167
<u>2001:</u>								
T4	50.0	0.0	0.0	0.362a	1.172a	0.310a	0.181a	0.87b
T5	50.0	(2.0)[††]	0.0	0.364a	1.180a	0.357a	0.185a	0.99a
T6	50.0	(4.0)	0.0	0.356a	1.128a	0.339a	0.224a	0.97a
<u>Statistics:</u>								
P(treatment)	-	-	-	0.9675	0.9159	0.2768	0.6004	0.0373
$LSD_{0.05}$	-	-	-	0.065	0.264	0.060	0.095	0.10
P(linear)	-	-	-	0.8573	0.7398	0.3312	0.3637	0.0396
P(quadratic)	-	-	-	0.8553	0.8001	0.2020	0.6631	0.1180
Intercept	-	-	-	-	-	-	-	0.891
$Slope_{linear}$	-	-	-	-	-	-	-	0.025
<u>3-year mean:</u>								
T4	50.0	0.0	0.0	0.342a	1.084a	0.324a	0.185a	0.99b
T5	50.0	2.0[††]	0.0	0.332a	1.060a	0.355a	0.171a	1.11a
T6	50.0	4.0	0.0	0.330a	1.069a	0.347a	0.185a	1.10a
<u>Statistics:</u>								
P(treatment)	-	-	-	0.7369	0.9373	0.0928	0.6115	0.0181
$LSD_{0.05}$	-	-	-	0.033	0.134	0.029	0.033	0.09
P(linear)	-	-	-	0.4675	0.8127	0.1200	0.9774	0.0193
P(quadratic)	-	-	-	0.7753	0.7870	0.1250	0.3220	0.1073
Intercept	-	-	-	-	-	-	-	1.014
$Slope_{linear}$	-	-	-	-	-	-	-	0.028

[†] Means in column having the same letter are not different at P(treatment) ≤ 0.05.

[††] Based on initial rate of application made in 1999.

Table AGFS-14. Effects of gypsum on macro nutrients in stargrass forage from pasture growing on Immokalee fine sand, 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Year/Treatment	P	$CaCO_3$	Gypsum	P	K	Ca	Mg	Ca:P
1999:	kg ha^{-1}	---- Mg ha^{-1} -----		----------------------	------ %	------	----------------------	Ratio
T4	50.0	0.0	0.0	0.280a[†]	0.923a	0.318a	0.191a	1.16a
T7	50.0	0.0	2.0	0.269a	1.004a	0.326a	0.147b	1.22a
T8	50.0	0.0	4.0	0.274a	1.071a	0.353a	0.148b	1.29a
Statistics:								
P(treatment)	-	-	-	0.7598	0.6589	0.3332	0.0084	0.2301
LSD$_{0.05}$	-	-	-	0.030	0.232	0.048	0.031	0.15
P(linear)	-	-	-	0.7028	0.4055	0.1584	0.0080	0.0876
P(quadratic)	-	-	-	0.5265	0.7100	0.6549	0.1015	0.9568
Intercept	-	-	-	-	-	-	0.184	-
Slope$_{linear}$	-	-	-	-	-	-	-0.011	-
2000:								
T4	50.0	0.0	0.0	0.394a	1.184a	0.345a	0.183a	0.92a
T7	50.0	0.0	(2.0)[††]	0.383a	1.142a	0.369a	0.170a	1.01a
T8	50.0	0.0	(4.0)	0.392a	1.177a	0.374a	0.166a	1.00a
Statistics:								
P(treatment)	-	-	-	0.9217	0.9107	0.4677	0.2310	0.4576
LSD$_{0.05}$	-	-	-	0.059	0.206	0.049	0.020	0.16
P(linear)	-	-	-	0.9327	0.9454	0.2561	0.1034	0.3001
P(quadratic)	-	-	-	0.6941	0.6705	0.6364	0.6052	0.4858
2001:								
T4	50.0	0.0	0.0	0.362a	1.172a	0.310a	0.181a	0.87b
T7	50.0	0.0	(2.0)[††]	0.377a	1.106a	0.352a	0.187a	0.94ab
T8	50.0	0.0	(4.0)	0.359a	1.049a	0.392a	0.157a	1.07a
Statistics:								
P(treatment)	-	-	-	0.8281	0.5874	0.1869	0.1901	0.0132
LSD$_{0.05}$	-	-	-	0.063	0.238	0.089	0.034	0.13
P(linear)	-	-	-	0.9272	0.3046	0.0681	0.1676	0.0037
P(quadratic)	-	-	-	0.5451	0.9615	0.9750	0.2315	0.6534
Intercept	-	-	-	-	-	-	-	0.861
Slope$_{linear}$	-	-	-	-	-	-	-	0.050
3-year mean:								
T4	50.0	0.0	0.0	0.342a	1.084a	0.324b	0.185a	0.99b
T7	50.0	0.0	2.0[††]	0.340a	1.081a	0.348ab	0.167b	1.07ab
T8	50.0	0.0	4.0	0.338a	1.098a	0.372a	0.157b	1.13a
Statistics:								
P(treatment)	-	-	-	0.9744	0.9966	0.0341	0.0039	0.0142
LSD$_{0.05}$	-	-	-	0.033	0.131	0.036	0.017	0.09
P(linear)	-	-	-	0.8199	0.9346	0.0094	0.0010	0.0036
P(quadratic)	-	-	-	0.9973	0.9926	0.9823	0.5950	0.9325
Intercept	-	-	-	-	-	0.324	0.184	0.994
Slope$_{linear}$	-	-	-	-	-	0.012	-0.007	0.034

[†] Means in column having the same letter are not different at P(treatment) ≤ 0.05.

[††] Based on initial rate of application made in 1999.

0 gypsum (T4) and to 1.13:1 for the 50 P, 4 Mg gypsum ha^{-1} (T8) treatments. Table AGFS-14 showed that the rate of increase in Ca:P ratio was 0.034 unit for each Mg or 0.14 unit for 4 Mg gypsum ha^{-1}.

Micro Nutrients Cu, Fe, Mn, and Zn

Effects of fertilizer P. Averaged over the three-year period, fertilizer P showed no effects on Cu, Fe, Mn, or Zn in forage (Tables AGFS-15 and AGFS-16).

Effects of lime. Averaged over the three-year period, calcium carbonate at 2 or 4 Mg ha^{-1} reduced Mn in stargrass forage linearly with a slope of -1.68 mg Mn per kg forage per Mg lime ha^{-1} applied (Table AGFS-17). It had no effects on Cu, Fe, or Zn (Tables AGFS-15 and AGFS-17).

Effects of gypsum. Again, averaged over the three-year period, gypsum showed no effects on Cu, Fe, or Zn but increased Mn in plant tissue at the rate of 0.77 mg Mn per kg forage per Mg gypsum ha^{-1} applied (Tables AGFS-15 and AGFS-18).

Time Effects on Forage Yield and Quality

It has been shown for three crop years that stargrass pasture on Immokalee fine sand does not seem to need fertilizer P to maintain the existing optimum yield and quality. Whether forage yield and quality without P fertilization is sustainable in longer terms cannot be answered with certainty. Using the three crop years as treatments, we could check whether or not some deteriorations in forage yield and quality have occurred during the period. This may also give us some idea what to expect if no P fertilizer is applied during the next few years. While the main interest for this time effect evaluation is on the overall control (0 P, 0 amendment) or simply 0 P, all eight treatments are included for completeness.

Forage Yield and Percent Dry Matter (%DM)

Table AGFS-19 showed that without applying fertilizer P for three crop years, %DM remained the same throughout the three-year period, while DM forage yield was significantly higher in 2001 than in 1999 or 2000 due, most likely, to the abundant rainfall in 2001.

Crude Protein (CP) and *in vitro* Organic Matter Digestibility (IVOMD)

The overall control or 0 P forage showed significantly higher CP content in 2000 and 2001 than in 1999 indicating no deterioration in this quality with crop year (Table AGFS-19). Digestibility also indicated no deterioration with crop year with the IVOMD of the 1999 and the 2001 forages not significantly different (Table AGFS-19).

Table AGFS-15. Effects of P fertilizer, calcium carbonate, and gypsum on micro nutrients in stargrass forage from pasture growing on Immokalee fine sand, 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Year/Treatment	P	$CaCO_3$	Gypsum	Cu	Fe	Mn	Zn
1999:	kg ha^{-1}	------ Mg ha^{-1} ------		---------------------- mg kg^{-1} ----------------------			
T1	0.0	0.0	0.0	9.1a[†]	38.8a	18.9b	59.5a
T2	12.5	0.0	0.0	9.0a	39.9a	21.6b	60.4a
T3	25.0	0.0	0.0	9.0a	42.8a	23.1b	54.3a
T4	50.0	0.0	0.0	8.9a	40.4a	22.4b	55.9a
T5	50.0	2.0	0.0	8.7a	37.7a	19.5b	54.0a
T6	50.0	4.0	0.0	8.0a	37.9a	18.4b	48.6a
T7	50.0	0.0	2.0	8.4a	39.3a	22.7b	52.2a
T8	50.0	0.0	4.0	9.0a	42.4a	30.3a	51.2a
2000:							
T1	0.0	0.0	0.0	7.4a	50.4a	19.7ab	60.2a
T2	12.5	0.0	0.0	6.3a	47.0a	18.5ab	57.2a
T3	25.0	0.0	0.0	6.7a	49.2a	21.6a	61.9a
T4	50.0	0.0	0.0	6.5a	50.9a	19.4ab	60.7a
T5	50.0	(2.0)[††]	0.0	6.1a	49.5a	15.3b	53.8a
T6	50.0	(4.0)	0.0	6.1a	51.5a	16.0b	57.3a
T7	50.0	0.0	(2.0)[††]	5.8a	51.7a	22.9a	61.5a
T8	50.0	0.0	(4.0)	6.4a	48.0a	22.9a	58.9a
2001:							
T1	0.0	0.0	0.0	8.0a	61.6a	34.2ab	61.1a
T2	12.5	0.0	0.0	7.5a	64.9a	34.2ab	73.5a
T3	25.0	0.0	0.0	8.1a	67.3a	38.6a	72.4a
T4	50.0	0.0	0.0	6.9a	62.7a	33.8ab	63.6a
T5	50.0	(2.0)[††]	0.0	6.4a	69.1a	25.3bc	62.2a
T6	50.0	(4.0)	0.0	8.8a	55.7a	20.6c	61.2a
T7	50.0	0.0	(2.0)[††]	7.1a	64.0a	29.5abc	64.9a
T8	50.0	0.0	(4.0)	7.0a	62.4a	33.9ab	65.9a
3-year mean:							
T1	0.0	0.0	0.0	8.2a	49.7a	24.0bc	60.2a
T2	12.5	0.0	0.0	7.7a	50.0a	24.6abc	63.5a
T3	25.0	0.0	0.0	8.0a	52.6a	27.5ab	62.4a
T4	50.0	0.0	0.0	7.5a	50.8a	25.0abc	59.9a
T5	50.0	2.0 [††]	0.0	7.1a	51.3a	20.0cd	56.6a
T6	50.0	4.0	0.0	7.6a	48.0a	18.3d	55.4a
T7	50.0	0.0	2.0 [††]	7.1a	51.2a	25.0abc	59.3a
T8	50.0	0.0	4.0	7.5a	50.5a	29.1a	58.3a

[†] Means in column having the same letter are not different at the 5% level of significance using Tukey's Studentized Range (HSD) Test.

[††] Based on initial rate of application made in 1999.

Table AGFS-16. Effects of P fertilizer on micro nutrients in stargrass forage from pasture growing on Immokalee fine sand, 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Year/Treatment	P	$CaCO_3$	Gypsum	Cu	Fe	Mn	Zn
1999:	kg ha^{-1}	------ Mg ha^{-1} ------		---------------------- mg kg^{-1} ----------------------			
T1	0.0	0.0	0.0	9.1a[†]	38.8a	18.9a	59.4a
T2	12.5	0.0	0.0	9.0a	39.9a	21.6a	60.4a
T3	25.0	0.0	0.0	9.0a	42.8a	23.1a	54.3a
T4	50.0	0.0	0.0	8.9a	40.4a	22.4a	55.9a
Statistics:							
P(treatment)	-	-	-	0.9986	0.6203	0.1418	0.5612
$LSD_{0.05}$	-	-	-	3.3	6.2	3.8	9.8
P(linear)	-	-	-	0.8672	0.5748	0.0852	0.3350
P(quadratic)	-	-	-	0.9841	0.2947	0.1099	0.6506
2000:							
T1	0.0	0.0	0.0	7.4a	50.4a	19.7a	60.2a
T2	12.5	0.0	0.0	6.3a	47.0a	18.5a	57.2a
T3	25.0	0.0	0.0	6.7a	49.2a	21.6a	61.9a
T4	50.0	0.0	0.0	6.5a	50.9a	19.4a	60.7a
Statistics:							
P(treatment)	-	-	-	0.7097	0.6691	0.2429	0.6466
$LSD_{0.05}$	-	-	-	2.0	6.8	3.1	7.5
P(linear)	-	-	-	0.5339	0.6281	0.8657	0.6256
P(quadratic)	-	-	-	0.4891	0.3956	0.3957	0.9671
2001:							
T1	0.0	0.0	0.0	8.0a	61.6a	34.2a	61.1b
T2	12.5	0.0	0.0	7.5a	64.9a	34.2a	73.5a
T3	25.0	0.0	0.0	8.1a	67.3a	38.6a	72.4a
T4	50.0	0.0	0.0	6.9a	62.7a	33.8a	63.6ab
Statistics:							
P(treatment)	-	-	-	0.5571	0.8670	0.4586	0.0255
$LSD_{0.05}$	-	-	-	1.9	14.4	7.5	10.1
P(linear)	-	-	-	0.3007	0.9187	0.7965	0.9773
P(quadratic)	-	-	-	0.6043	0.4022	0.1773	0.0038
Intercept	-	-	-	-	-	-	61.39
$Slope_{linear}$	-	-	-	-	-	-	1.00
$Slope_{quadratic}$	-	-	-	-	-	-	- 0.02
3-year mean:							
T1	0.0	0.0	0.0	8.2a	49.7a	24.0a	60.2a
T2	12.5	0.0	0.0	7.7a	50.0a	24.6a	63.5a
T3	25.0	0.0	0.0	8.0a	52.6a	27.5a	62.4a
T4	50.0	0.0	0.0	7.5a	50.8a	25.0a	59.9a
Statistics:							
P(treatment)	-	-	-	0.7606	0.8035	0.1727	0.4858
$LSD_{0.05}$	-	-	-	1.5	6.3	3.6	5.6
P(linear)	-	-	-	0.4107	0.6595	0.3719	0.6926
P(quadratic)	-	-	-	0.9217	0.4907	0.0802	0.1726

[†] Means in column having the same letter are not different at P(treatment) ≤ 0.05.

Table AGFS-17. Effects of calcium carbonate on micro nutrients in stargrass forage from pasture growing on Immokalee fine sand, 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Year/Treatment	P	$CaCO_3$	Gypsum	Cu	Fe	Mn	Zn
1999:	kg ha^{-1}	------ Mg ha^{-1} ------		-------------------- mg kg^{-1} --------------------			
T4	50.0	0.0	0.0	8.9a[†]	40.4a	22.4a	55.9a
T5	50.0	2.0	0.0	8.7a	37.7a	19.5ab	54.0a
T6	50.0	4.0	0.0	8.0a	37.9a	18.4b	48.6a
Statistics:							
P(treatment)	-	-	-	0.8282	0.6207	0.0546	0.2251
$LSD_{0.05}$	-	-	-	3.2	6.0	3.4	8.9
P(linear)	-	-	-	0.5645	0.4072	0.0196	0.0981
P(quadratic)	-	-	-	0.8359	0.6081	0.5522	0.6277
Intercept	-	-	-	-	-	22.10	-
$Slope_{linear}$	-	-	-	-	-	-1.01	-
2000:							
T4	50.0	0.0	0.0	6.5a	50.9a	19.4a	60.7a
T5	50.0	(2.0)[††]	0.0	6.1a	49.5a	15.3b	53.8a
T6	50.0	(4.0)	0.0	6.1a	51.5a	16.0b	57.3a
Statistics:							
P(treatment)	-	-	-	0.8945	0.8743	0.0011	0.2348
$LSD_{0.05}$	-	-	-	2.2	8.1	2.2	8.0
P(linear)	-	-	-	0.6836	0.8860	0.0034	0.3869
P(quadratic)	-	-	-	0.8139	0.6198	0.0174	0.1424
Intercept	-	-	-	-	-	19.37	-
$Slope_{linear}$	-	-	-	-	-	-3.23	-
$Slope_{quadratic}$	-	-	-	-	-	0.59	-
2001:							
T4	50.0	0.0	0.0	6.9a	62.7a	33.8a	63.6a
T5	50.0	(2.0)[††]	0.0	6.4a	69.1a	25.3b	62.2a
T6	50.0	(4.0)	0.0	8.8a	55.7a	20.6b	61.2a
Statistics:							
P(treatment)	-	-	-	0.5060	0.3074	0.0001	0.8711
$LSD_{0.05}$	-	-	-	4.3	17.3	5.3	10.5
P(linear)	-	-	-	0.3699	0.4194	0.0001	0.6589
P(quadratic)	-	-	-	0.4563	0.1915	0.4137	0.7785
Intercept	-	-	-	-	-	33.17	-
$Slope_{linear}$	-	-	-	-	-	- 3.29	-
3-year mean:							
T4	50.0	0.0	0.0	7.5a	50.8a	25.0a	59.9a
T5	50.0	2.0[††]	0.0	7.1a	51.3a	20.0b	56.6a
T6	50.0	4.0	0.0	7.6a	48.0a	18.3b	55.4a
Statistics:							
P(treatment)	-	-	-	0.8787	0.5904	0.0001	0.2149
$LSD_{0.05}$	-	-	-	1.9	7.1	2.6	5.4
P(linear)	-	-	-	0.8958	0.4277	0.0001	0.0993
P(quadratic)	-	-	-	0.6235	0.5151	0.1399	0.5505
Intercept	-	-	-	-	-	24.49	-
$Slope_{linear}$	-	-	-	-	-	-1.68	-

[†] Means in column having the same letter are not different at $P(treatment) \leq 0.05$.
[††] Based on initial rate of application made in 1999.

Table AGFS-18. Effects of gypsum on micro nutrients in stargrass forage from pasture growing on Immokalee fine sand, 1999 (7 harvests), 2000 (6 harvests), and 2001 (6 harvests) seasons.

Year/Treatment	P	CaCO$_3$	Gypsum	Cu	Fe	Mn	Zn
1999:	kg ha^{-1}	------ Mg ha^{-1} ------		---------------------- mg kg^{-1} ----------------------			
T4	50.0	0.0	0.0	8.9a[†]	40.4a	22.4b	55.9a
T7	50.0	0.0	2.0	8.4a	39.3a	22.7b	52.2a
T8	50.0	0.0	4.0	9.0a	42.4a	30.3a	51.2a
Statistics:							
P(treatment)	-	-	-	0.9294	0.7729	0.0016	0.5212
LSD$_{0.05}$	-	-	-	3.3	8.4	4.7	8.6
P(linear)	-	-	-	0.9964	0.7434	0.0071	0.2552
P(quadratic)	-	-	-	0.7029	0.5244	0.0138	0.9979
Intercept	-	-	-	-	-	21.21	-
Slope$_{linear}$	-	-	-	-	-	1.97	-
2000:							
T4	50.0	0.0	0.0	6.5a	50.9a	19.4a	60.7a
T7	50.0	0.0	(2.0)[††]	5.8a	51.7a	22.9a	61.5a
T8	50.0	0.0	(4.0)	6.4a	48.0a	22.9a	58.9a
Statistics:							
P(treatment)	-	-	-	0.7668	0.6061	0.1331	0.8409
LSD$_{0.05}$	-	-	-	2.2	7.7	4.0	9.1
P(linear)	-	-	-	0.7301	0.5957	0.0519	0.7913
P(quadratic)	-	-	-	0.5225	0.3977	0.6259	0.6006
Intercept	-	-	-	-	-	19.97	-
Slope$_{linear}$	-	-	-	-	-	0.89	-
2001:							
T4	50.0	0.0	0.0	6.9a	62.7a	33.8a	63.6a
T7	50.0	0.0	(2.0)[††]	7.1a	64.0a	29.5a	64.9a
T8	50.0	0.0	(4.0)	7.0a	62.4a	33.9a	65.9a
Statistics:							
P(treatment)	-	-	-	0.9805	0.9776	0.3665	0.9073
LSD$_{0.05}$	-	-	-	1.9	15.4	6.9	10.6
P(linear)	-	-	-	0.8727	0.9832	0.7087	0.6666
P(quadratic)	-	-	-	0.9078	0.8330	0.1730	0.9315
3-year mean:							
T4	50.0	0.0	0.0	7.5a	50.8a	25.0b	59.9a
T7	50.0	0.0	2.0[††]	7.1a	51.2a	25.0b	59.3a
T8	50.0	0.0	4.0	7.5a	50.5a	29.1a	58.3a
Statistics:							
P(treatment)	-	-	-	0.8445	0.9776	0.0235	0.8460
LSD$_{0.05}$	-	-	-	1.5	6.7	3.4	5.5
P(linear)	-	-	-	0.9236	0.9909	0.0473	0.6013
P(quadratic)	-	-	-	0.5669	0.8318	0.0573	0.8054
Intercept	-	-	-	-	-	21.47	-
Slope$_{linear}$	-	-	-	-	-	0.77	-

[†] Means in column having the same letter are not different at P(treatment) ≤ 0.05.

[††] Based on initial rate of application made in 1999.

Table AGFS-19. Percent dry matter (%DM), forage DM yields, crude protein (CP), and *in vitro* organic matter digestibility (IVOMD) of stargrass (harvests 1- 6) pasture on Immokalee fine sand at various P (kg ha^{-1}) rates applied annually without or with Ca amendments (Mg ha^{-1}) mined gypsum (MG) or calcium carbonate (CC) applied once in 1999 with Crop Year as treatments.

	P fertilization and amendment rates							
Crop Year	0 P	12.5 P	25 P	50 P	50P+2CC	50P+4CC	50P+2MG	50P+4MG
	% DM							
1999	38.6a[†]	38.0a	34.2a	36.3a	35.7a	36.2a	33.2a	34.0a
2000	35.7a	36.1a	34.1a	34.4a	34.7a	33.4a	35.0a	35.6a
2001	32.5a	33.5a	32.1a	33.0a	32.9a	33.7a	33.5a	34.2a
Statistics:								
P(Year)	0.2831	0.4753	0.7720	0.6059	0.6175	0.6046	0.7701	0.8445
LSD$_{0.05}$	7.6	7.3	6.6	6.6	5.6	6.3	5.5	5.8
	Mg DM ha^{-1}							
1999	8.09b	7.73b	9.35b	9.37ab	9.21b	10.13a	11.33a	11.29a
2000	9.28ab	7.34b	7.63b	8.44b	8.42b	9.53a	8.44b	8.05b
2001	11.88a	11.12a	12.90a	11.87a	11.80a	12.18a	12.62a	11.31a
Statistics:								
P(Year)	0.0160	0.0059	0.0004	0.0321	0.0114	0.1932	0.0097	0.0245
LSD$_{0.05}$	2.61	2.49	2.56	2.64	2.28	3.03	2.73	2.67
	% CP							
1999	10.5b	10.6b	11.2b	10.5b	10.2b	10.8b	11.6a	11.9a
2000	14.2a	13.8a	13.6a	13.8a	13.9a	13.8a	13.6a	12.6a
2001	12.8a	12.5ab	13.0ab	12.2ab	12.2a	12.6ab	12.5a	11.8a
Statistics:								
P(Year)	0.0008	0.0080	0.0476	0.0043	0.0011	0.0149	0.1630	0.6580
LSD$_{0.05}$	1.9	2.0	2.0	1.9	1.9	2.0	2.0	1.8
	% IVOMD							
1999	47.5b	47.9b	48.4b	48.4b	48.1b	48.9b	52.2a	50.0b
2000	54.6a	53.4a	54.8a	54.5a	54.7a	54.5a	53.8a	53.3a
2001	50.0b	49.6b	50.1b	49.8b	49.3b	50.8b	50.6a	49.1b
Statistics:								
P(Year)	0.0010	0.0117	0.0005	0.0015	0.0001	0.0035	0.0978	0.0278
LSD$_{0.05}$	3.7	3.6	3.2	3.6	3.1	3.2	2.9	3.2

[†] Means in column for each variable having the same letter are not different at P(treatment) $\le$ 0.05.

Macro Nutrients P, K, Ca, Mg, and Ca:P Ratio

The withholding of fertilizer P (0 P) for three crop years showed no adverse effects on P, K, Ca, and Mg contents in forage (Table AGFS-20). Phosphorus, K, and Mg even tended to increase somewhat linearly over the years with the 2001 harvests having significantly higher P, K, and Mg contents than the 1999 harvests due to the abundant rainfall.

The impacts of the other treatments are best assessed by the Ca:P ratios (Table AGFS-20). With increasing rates of P without Ca amendments, Ca:P ratios deteriorated sharply with crop year. By the third year (2001) of fertilizer P application, even the lowest P rate of 12.5 kg ha^{-1} brought the Ca:P level down to 1.17:1, which was close to the lower limit of 1:1, and the next higher rates brought the Ca:P ratios further down to unacceptable levels (Table AGFS-20).

Calcium amendments applied in 1999 to plots that received 50 kg P ha^{-1} were not able to prevent the deterioration of the Ca:P ratios with crop year (Table AGFS-20). Relative to the treatment of 50 kg P ha^{-1} without Ca amendment, calcium carbonate or gypsum did raise the Ca:P ratios in 1999, 2000, and 2001 harvests but values remained close to the lower limit of 1:1 and well below the unfertilized and un-amended forages.

Thus, fertilizer P application to stargrass pasture on Immokalee fine sand not only failed to increase forage yield, crude protein content, and digestibility but could reduce Ca:P ratio to levels detrimental to animal growth and development and to feed efficiency. A single application of calcium carbonate or gypsum over a three-year period failed to prevent the deterioration of Ca:P ratios in pasture fertilized annually at 50 kg P ha^{-1}. This could be due to the strong "luxury consumption" by stargrass for P but not as strong for Ca.

Micro Nutrients Cu, Fe, Mn, and Zn

The absence of fertilizer P (0 P) showed no adverse effects on Cu, Fe, Mn, and Zn contents in forage over the years (Table AGFS-21). Iron and Mn tended to increase somewhat linearly over the years with the 2001 harvests having significantly higher Fe and Mn contents than the 1999 harvests due to the abundant rainfall.

It is concluded that stargrass pastures on Immokalee fine sand used in the study do not need any P fertilizer to maintain their present optimum forage yield and quality. As little as 12.5 kg P ha^{-1} applied annually could have adverse effects on the Ca:P ratio in forage on the long term if no Ca source is applied. But Ca amendments up to 4 Mg ha^{-1} applied once in three crop years may not be effective in raising Ca:P ratios in pastures receiving high rates of fertilizer P annually.

Effects on Soil pH, Macro and Micro Nutrients, and Aluminum

Soil samples were collected twice each crop year - 1999 through 2001 - before treatment application and near the end of the growing season at 15-cm interval down to the spodic horizon. Table AGFS-22 gives the after-treatment averages of five samplings.

Table AGFS-20. Macro nutrients in stargrass forage (harvests 1-6) from pasture on Immokalee fine sand at various P (kg ha^{-1}) rates applied annually without or with Ca amendments (Mg ha^{-1}) mined gypsum (MG) or calcium carbonate (CC) applied once in 1999 with Crop Year as treatments.

	P fertilization and amendment rates							
Crop Year	0 P	12.5 P	25 P	50 P	50P+2CC	50P+4CC	50P+2MG	50P+4MG
	% P							
1999	0.160b[†]	0.190b	0.225b	0.280b	0.269b	0.256b	0.269b	0.271b
2000	0.191b	0.237a	0.314a	0.394a	0.369a	0.384a	0.383a	0.392a
2001	0.214a	0.263a	0.351a	0.362a	0.364a	0.356a	0.377a	0.359a
Statistics:								
P(Year)	0.0001	0.0003	0.0001	0.0013	0.0003	0.0001	0.0002	0.0001
LSD$_{0.05}$	0.024	0.034	0.037	0.057	0.053	0.052	0.056	0.047
	% K							
1999	0.937b	0.885b	1.071b	1.002b	0.939b	0.902b	1.091a	1.150a
2000	1.202a	1.028ab	1.220ab	1.184a	1.145a	1.259a	1.142a	1.177a
2001	1.208a	1.149a	1.387a	1.172a	1.180a	1.128ab	1.106a	1.049a
Statistics:								
P(Year)	0.0377	0.0184	0.0150	0.2398	0.0474	0.0097	0.9084	0.4453
LSD$_{0.05}$	0.235	0.181	0.211	0.238	0.206	0.231	0.229	0.210
	% Ca							
1999	0.270b	0.295a	0.311a	0.319a	0.336a	0.329b	0.329a	0.347a
2000	0.326a	0.314a	0.349a	0.345a	0.371a	0.377a	0.369a	0.374a
2001	0.290ab	0.305a	0.333a	0.310a	0.357a	0.339ab	0.352a	0.392a
Statistics:								
P(Year)	0.0304	0.7783	0.1060	0.3301	0.2808	0.0223	0.2325	0.4404
LSD$_{0.05}$	0.042	0.049	0.046	0.049	0.058	0.049	0.058	0.086
	% Mg							
1999	0.172b	0.197ab	0.197a	0.199a	0.168b	0.163a	0.151b	0.153a
2000	0.179b	0.164b	0.178a	0.183a	0.163b	0.172a	0.170b	0.166a
2001	0.215a	0.234a	0.211a	0.200a	0.217a	0.251a	0.213a	0.187a
Statistics:								
P(Year)	0.0075	0.0265	0.1666	0.5564	0.0236	0.1007	0.0011	0.0640
LSD$_{0.05}$	0.028	0.043	0.035	0.036	0.042	0.090	0.033	0.029
	Ca:P ratio							
1999	1.83a	1.63	1.35a	1.16a	1.23a	1.29a	1.22a	1.29a
2000	1.77a	1.41ab	1.16b	0.92b	1.07b	1.03b	1.01b	1.00b
2001	1.39b	1.17a	0.96c	0.87b	0.99b	0.97b	0.94b	1.07b
Statistics:								
P(Year)	0.0053	0.0163	0.0001	0.0008	0.0066	0.0042	0.0018	0.0170
LSD$_{0.05}$	0.31	0.32	0.17	0.14	0.16	0.16	0.14	0.17

[†] Means in column for each variable having the same letter are not different at P(treatment) ≤ 0.05.

Table AGFS-21. Micro nutrients in stargrass forage (harvests 1-6) from pasture on Immokalee fine sand at various P (kg ha^{-1}) rates applied annually without or with Ca amendments (Mg ha^{-1}) mined gypsum (MG) or calcium carbonate (CC) applied once in 1999 with Crop Year as treatments.

	P fertilization and amendment rates							
Crop Year	0 P	12.5 P	25 P	50 P	50P+2CC	50P+4CC	50P+2MG	50P+4MG
	mg Cu kg^{-1}							
1999	9.92a[†]	9.79a	9.67a	9.58a	9.29a	8.52a	9.04a	9.71a
2000	7.42a	6.29a	6.67a	6.54b	6.08b	6.08a	5.79a	6.37b
2001	8.00a	7.45a	8.11a	6.86b	6.43b	8.83a	7.05a	6.98ab
Statistics:								
P(Year)	0.1372	0.0325	0.1035	0.0470	0.0425	0.4568	0.0576	0.0429
LSD$_{0.05}$	2.58	2.65	2.76	2.64	2.73	4.72	2.69	2.76
	mg Fe kg^{-1}							
1999	36.71c	38.79b	40.83b	39.17b	36.00c	35.48b	37.04c	40.92b
2000	50.37b	46.96b	49.21b	50.92ab	49.46b	51.50a	51.71b	48.04b
2001	61.50a	64.91a	67.29a	62.73a	69.10a	55.70a	63.98a	62.44a
Statistics:								
P(Year)	0.0001	0.0001	0.0001	0.0037	0.0001	0.0001	0.0001	0.0004
LSD$_{0.05}$	6.93	9.53	8.95	13.49	12.81	7.53	9.28	10.35
	mg Mn kg^{-1}							
1999	18.00b	21.92b	22.75b	22.63b	19.42b	17.83ab	22.30b	28.87a
2000	19.75b	18.50b	21.63b	19.37b	15.29c	15.96b	22.92b	22.92b
2001	34.19a	34.23a	38.62a	33.80a	25.33a	20.62a	29.55a	33.87a
Statistics:								
P(Year)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0362	0.0085	0.0004
LSD$_{0.05}$	5.01	6.52	5.29	5.01	3.04	3.57	4.98	5.24
	mg Zn kg^{-1}							
1999	60.58a	60.83a	54.21b	56.50a	54.63a	48.96b	52.96b	51.25a
2000	60.21a	57.21a	61.87b	60.75a	53.83a	57.25ab	61.54ab	58.92a
2001	61.05a	73.49a	72.35a	63.57a	62.24a	61.23a	64.91a	65.91a
Statistics:								
P(Year)	0.9830	0.0095	0.0002	0.3997	0.1452	0.0439	0.0442	0.0104
LSD$_{0.05}$	9.13	10.79	8.30	10.43	9.30	9.71	9.59	9.35

[†] Means in column for each variable having the same letter are not different at $P(\text{treatment}) \leq 0.05$.

Table AGFS-22. Three-year mean soil pH and Mehlich 1 extractable elements in Immokalee fine sand profile as influenced by P fertilization (kg ha^{-1}) applied annually and soil amendments (A) calcium carbonate (CL) or mined gypsum (MG) in A Mg ha^{-1}applied once in 1999.

Depth/Treatment	pH	P	K	Ca	Mg	Fe	Mn	Cu	Zn	Al
Ap (0 - 15 cm):	mg kg^{-1}									
T1 0P+0A	4.9ab[†]	4.13b	40.0a	447b	60.7a	8.3ab	0.49a	0.039a	1.07a	45.3b
T2 12.5P+0A	4.7ab	3.61b	33.9a	393b	50.8a	7.7ab	0.32a	0.062a	0.83a	43.9b
T3 25P+0A	4.7ab	4.33b	28.2a	439b	48.4a	7.5ab	0.37a	0.089a	0.96a	43.2b
T4 50P+0A	4.8ab	5.23b	25.1a	412b	49.9a	7.9ab	0.37a	0.051a	0.96a	44.2b
T5 50P+2CL[††]	4.7ab	6.09b	23.3a	531ab	50.8a	7.5ab	0.44a	0.049a	1.16a	44.1b
T6 50P+4CL	4.7ab	6.11b	31.1a	562ab	53.6a	6.6b	0.45a	0.051a	0.88a	39.8b
T7 50P+2MG[††]	5.0a	6.99ab	40.7a	893a	53.1a	7.6ab	0.42a	0.055a	0.89a	46.1ab
T8 50P+4MG	4.5b	10.63a	31.6a	580ab	43.4a	10.6a	0.47a	0.043a	0.88a	58.5a
Ap (15 - 30 cm):										
T1 0P+0A	5.0a	1.06a	8.6a	169a	9.8a	4.2a	0.14a	0.021ab	0.36a	16.9a
T2 12.5P+0A	4.9a	1.20a	8.4a	123a	10.7a	4.5a	0.12a	0.019b	0.49a	18.4a
T3 25P+0A	4.7a	1.52a	9.9a	145a	8.7a	4.7a	0.15a	0.061a	0.53a	18.5a
T4 50P+0A	5.0a	2.37a	7.6a	182a	10.0a	5.0a	0.15a	0.026ab	0.67a	18.9a
T5 50P+2CL[††]	4.9a	1.93a	5.4a	166a	8.6a	5.0a	0.13a	0.023ab	0.45a	16.6a
T6 50P+4CL	4.9a	2.39a	6.8a	207a	11.5a	4.1a	0.15a	0.031ab	0.49a	15.2a
T7 50P+2MG[††]	5.0a	2.27a	6.7a	202a	9.6a	4.4a	0.14a	0.023ab	0.49a	21.3a
T8 50P+4MG	4.6a	2.57a	6.1a	124a	7.3a	5.6a	0.08a	0.020b	0.43a	19.3a
E (30 - 75 cm):										
T1 0P+0A	5.4a	0.45c	3.5a	49ab	2.25a	2.1a	0.06a	0.019a	0.30a	6.7a
T2 12.5P+0A	5.1bcd	0.49bc	3.0a	29b	1.46a	2.4a	0.06a	0.018a	0.24a	7.6a
T3 25P+0A	4.9cd	0.93abc	3.5a	45ab	2.09a	2.6a	0.06a	0.032a	0.33a	10.4a
T4 50P+0A	5.2abc	1.28a	3.0a	42ab	1.92a	2.3a	0.07a	0.022a	0.49a	8.2a
T5 50P+2CL[††]	5.3ab	1.01abc	2.7a	47ab	1.95a	2.5a	0.08a	0.020a	0.41a	10.0a
T6 50P+4CL	5.2abc	0.80abc	2.6a	44ab	1.84a	2.0a	0.06a	0.020a	0.28a	5.8a
T7 50P+2MG[††]	5.2abc	1.06ab	3.3a	64a	2.35a	2.2a	0.06a	0.026a	0.34a	7.8a
T8 50P+4MG	4.8d	1.23a	3.5a	39b	2.39a	2.4a	0.06a	0.016a	0.41a	11.7a
Bh (75 - 90 cm):										
T1 0P+0A	4.9a	26.2ab	8.1a	543ab	34.4ab	9.1a	0.10a	0.015a	0.28a	918a
T2 12.5P+0A	4.5a	28.0ab	9.0a	421ab	29.3b	11.7a	0.11a	0.016a	0.37a	1033a
T3 25P+0A	4.7a	21.3ab	8.2a	394ab	13.4b	11.3a	0.16a	0.017a	0.33a	808a
T4 50P+0A	4.5a	26.4ab	5.9a	427ab	30.4b	10.2a	0.12a	0.014a	0.30a	940a
T5 50P+2CL[††]	4.8a	19.4b	5.7a	466ab	26.0b	9.9a	0.09a	0.014a	0.38a	963a
T6 50P+4CL	4.4a	21.9ab	8.1a	470ab	62.5a	12.7a	0.12a	0.016a	0.29a	987a
T7 50P+2MG[††]	4.7a	20.2ab	7.3a	590a	31.3b	10.9a	0.13a	0.016a	0.30a	940a
T8 50P+4MG	4.4a	32.3a	9.8a	345b	21.2b	10.1a	0.18a	0.016a	0.43a	1073a

[†] Means in column having the same letter are not different at the 5% level of significance using Tukey's Studentized Range (HSD) Test.

[††] Based on initial rate of application made in 1999.

In general, gypsum at 4 Mg ha^{-1} (T8) tended to impart lower pH at all depths than the other treatments (Table AGFS-22). The lime (T5 and T6), on the other hand, was not able to raise soil pH beyond that of the general control (T1) probably because it was applied to plots that received the highest rate of phosphoric acid fertilizer.

Except for the highest fertilizer P application without Ca amendments (T4), the highest rate of gypsum applied to plots that received the highest rate of P (T8) was also associated with the highest Mehlich I extractable P at all depths (Table AGFS-22). This indicated the high solubility of gypsum-associated P in the soil making gypsum an unlikely candidate for soil amendment to help reduce P losses through runoff or leaching (Greenhouse Study GS1). Similar effects of gypsum on Fe and Al were notable in the Ap horizon but not at the lower depths.

No effects of treatments on K were noted at all depths. Calcium carbonate and gypsum appeared to have affected Ca levels only in the Ap horizon (0-15 cm). Calcium levels were generally higher for the Ca-amended plots (T5 through T8) than the un-amended ones (T1 through T4). Differences noted for Mg at the lowest depth only (Bh horizon) could be due to natural variability rather than the effects of treatments.

No effects of treatments on Mn and Zn were noted at all depths. Because of the extremely small levels Cu in the soil, statistical differences noted between treatments could be due more to chance than to real effects of treatments. For this reason, no further analysis of the micro nutrients isolating the effects of fertilizer P and Ca amendments will be done.

The separate analysis for fertilizer P rates without Ca amendments, and of lime or gypsum applied to plots that received 50 kg P ha^{-1} should help isolate the effects of fertilizer P and Ca amendments on soil pH, macro nutrients, and Al.

Effects of Fertilizer P

No consistent effects of pH were noted (Table AGFS-23). Fertilizer P linearly increased Mehlich I extractable P levels down to 75 cm with slopes of 0.030, 0.027, and 0.018 mg P per kg soil for each kg of fertilizer P applied per ha at 0-15, 15-30, and 30-75 cm depths, respectively. This supports the observation given earlier that the stargrass pasture took up only 0.30 kg P per forage for each kg of fertilizer P applied per ha with 0.70 kg of the applied P being retained in the soil.

No differences between fertilizer P rates were noted for K, Ca, Mg, or Al at the top three depths. Differences between P rates in the case of Mg in the Bh horizon could be due to natural variability rather than to treatments (Table AGFS-23).

Effects of lime

Calcium carbonate applied to plots that received 50 kg P ha^{-1} failed to reduce soil P levels down to the depth of 30 cm. Beyond 30 cm, lime appeared to have reduced extractable P. The reduction was significant at 30-75 cm depth with a slope of 0.12 mg P per kg soil for Mg of lime applied per

Table AGFS-23. Three-year mean effects of P fertilizer applied annually on soil pH and Mehlich 1 extractable macro nutrients and Al in Immokalee fine sand profile.

Depth/Treatment	P	$CaCO_3$	Gypsum	pH	P	K	Ca	Mg	Al
Ap (0-15 cm):	kg ha^{-1}	----- Mg ha^{-1} -----			-------------------- mg kg^{-1} --------------------				
T1	0.0	0.0	0.0	4.89a†	4.13ab	40.0a	447a	60.7a	45.3a
T2	12.5	0.0	0.0	4.75a	3.61b	33.9a	393a	50.8a	43.9a
T3	25.0	0.0	0.0	4.75a	4.33ab	28.2a	439a	48.4a	43.2a
T4	50.0	0.0	0.0	4.78a	5.23a	25.1a	412a	49.9a	44.2a
Statistics:									
P(treatment)	-	-	-	0.5545	0.0491	0.3327	0.5118	0.3940	0.9281
LSD$_{0.05}$	-	-	-	0.22	1.14	17.2	78.5	15.7	6.3
P(linear)	-	-	-	0.4594	0.0183	0.0798	0.6270	0.2297	0.7560
P(quadratic)	-	-	-	0.2483	0.2386	0.5576	0.7697	0.2221	0.5478
Intercept	-	-	-	-	3.75	-	-	-	-
Slope$_{linear}$	-	-	-	-	0.030	-	-	-	-
Ap (15-30 cm):									
T1	0.0	0.0	0.0	4.98a	1.06b	8.6a	169a	9.8a	16.9a
T2	12.5	0.0	0.0	4.87a	1.20b	8.4a	123a	10.7a	18.4a
T3	25.0	0.0	0.0	4.73a	1.52b	9.9a	145a	8.7a	18.5a
T4	50.0	0.0	0.0	5.02a	2.37a	7.6a	182a	10.0a	18.9a
Statistics:									
P(treatment)	-	-	-	0.1246	0.0062	0.8768	0.2493	0.9479	0.8133
LSD$_{0.05}$	-	-	-	0.26	0.78	5.6	62.3	6.5	4.4
P(linear)	-	-	-	0.7067	0.0005	0.7664	0.3786	0.9333	0.4123
P(quadratic)	-	-	-	0.1239	0.5023	0.5479	0.1126	0.8366	0.6479
Intercept	-	-	-	-	0.946	-	-	-	-
Slope$_{linear}$	-	-	-	-	0.027	-	-	-	-
E (30-75 cm):									
T1	0.0	0.0	0.0	5.37a	0.45b	3.48a	49.4a	2.25a	6.7a
T2	12.5	0.0	0.0	5.07bc	0.49b	3.03a	29.3b	1.46a	7.6a
T3	25.0	0.0	0.0	4.95c	0.93a	3.50a	45.2a	2.09a	10.4a
T4	50.0	0.0	0.0	5.22ab	1.28a	3.04a	41.7a	1.92a	8.2a
Statistics:									
P(treatment)	-	-	-	0.0001	0.0001	0.8499	0.0027	0.1725	0.4203
LSD$_{0.05}$	-	-	-	0.18	0.35	1.41	11.4	0.78	4.5
P(linear)	-	-	-	0.2546	0.0001	0.6073	0.7625	0.8040	0.4695
P(quadratic)	-	-	-	0.0001	0.8659	0.9554	0.1446	0.4519	0.2160
Intercept	-	-	-	5.37	0.395	-	-	-	-
Slope$_{linear}$	-	-	-	-0.03	0.018	-	-	-	-
Slope$_{quadratic}$	-	-	-	0.001	-	-	-	-	-

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Table AGFS-23. (Continuation): Three-year mean effects of P fertilizer applied annually on soil pH and Mehlich 1 extractable macro nutrients and Al in Immokalee fine sand profile.

Depth/Treatment	P	$CaCO_3$	Gypsum	pH	P	K	Ca	Mg	Al
Bh (75-90 cm):	kg ha^{-1}	----- Mg ha^{-1}	-----		--------------------	------------ mg kg^{-1}	------------	--------------------	
T1	0.0	0.0	0.0	4.85a	26.2a	8.06a	543a	34.4a	918a
T2	12.5	0.0	0.0	4.51a	28.0a	9.01a	421a	29.3a	1033a
T3	25.0	0.0	0.0	4.71a	21.3a	8.24a	394a	13.4b	808a
T4	50.0	0.0	0.0	4.49a	26.4a	5.89a	427a	30.4a	940a
Statistics:									
P(treatment)	-	-	-	0.1018	0.4491	0.3357	0.0630	0.0415	0.2435
$LSD_{0.05}$	-	-	-	0.33	8.6	3.49	117	15.5	216
P(linear)	-	-	-	0.0875	0.8176	0.1331	0.0903	0.5164	0.7956
P(quadratic)	-	-	-	0.6487	0.3755	0.3012	0.05362	0.0161	0.5612
Intercept	-	-	-	-	-	-	-	35.57	-
$Slope_{linear}$	-	-	-	-	-	-	-	-1.37	-
$Slope_{quadratic}$	-	-	-	-	-	-	-	0.02	-

†Means in column having the same letter are not different at P(treatment) $\leq$ 0.05.

ha (Table AGFS-24).

Extractable Ca at 0-15 cm depth increased with lime rates but not at the deeper horizons. Lime treatments showed no effects on K or Al at all depths (Table AGFS-24). The differences noted between treatments for pH and Mg in the Bh horizon could be chance events.

Effects of gypsum

Gypsum showed stronger effects on the soil than calcium carbonate. Table AGFS-25 showed it affected soil pH, P, K, Ca, and Al.

At all depths, gypsum reduced soil pH either linearly (0-15 cm and 15-30 cm) or quadratically (30-75 cm and 75-90 cm).

It increased extractable P in the top soil layer linearly with a slope of 1.35 mg P per kg soil for each Mg of gypsum applied per ha. Gypsum at the high rate of 4 Mg ha^{-1} also increased extractable P in the Bh horizon indicating the movement of P, most probably in the form of Ca and Mg ion pairs (Alcordo et al., 2002; Wang et al., 1995), where it eventually precipitated in the Bh horizon in still soluble forms.

Gypsum also brought some K down to the Bh layer where extractable K increased linearly with gypsum rates with a slope of 0.98 mg K per kg soil for each Mg of gypsum applied per ha.

Table AGFS-24. Three-year mean effects of calcium carbonate applied once in 1999 to plots that received 50 kg P ha^{-1} applied annually on soil pH and Mehlich 1 extractable macro nutrients and Al in Immokalee fine sand profile.

Depth/Treatment	P	$CaCO_3$	Gypsum	pH	P	K	Ca	Mg	Al
Ap (0-15 cm):	kg ha^{-1}	----- Mg ha^{-1}	-----		--------------------		mg kg^{-1}	--------------------	
T4	50.0	0.0	0.0	4.78a†	5.23a	25.1a	412b	49.9a	44.2a
T5	50.0	2.0††	0.0	4.72a	6.09a	23.3a	531a	50.8a	44.1a
T6	50.0	4.0	0.0	4.66a	6.11a	31.1a	562a	53.6a	39.8a
Statistics:									
P(treatment)	-	-	-	0.6628	0.3328	0.7313	0.0563	0.8553	0.2014
$LSD_{0.05}$	-	-	-	0.26	1.34	20.7	112	13.8	5.5
P(linear)	-	-	-	0.3675	0.1949	0.5653	0.0094	0.5964	0.1173
P(quadratic)	-	-	-	0.9780	0.4726	0.5895	0.3686	0.8639	0.3845
Intercept	-	-	-	-	-	-	426	-	-
$Slope_{linear}$	-	-	-	-	-	-	38	-	-
Ap (15-30 cm):									
T4	50.0	0.0	0.0	5.02a	2.37a	7.6a	182a	10.0a	18.9a
T5	50.0	2.0††	0.0	4.93a	1.93a	5.4a	166a	8.6a	16.6a
T6	50.0	4.0	0.0	4.91a	2.39a	6.8a	207a	11.5a	15.2a
Statistics:									
P(treatment)	-	-	-	0.6550	0.6154	0.4309	0.5271	0.4741	0.0828
$LSD_{0.05}$	-	-	-	0.26	1.04	3.4	72	4.8	3.2
P(linear)	-	-	-	0.3836	0.9769	0.6458	0.4888	0.5249	0.0277
P(quadratic)	-	-	-	0.7790	0.3269	0.2265	0.3720	0.2980	0.7536
Intercept	-	-	-	-	-	-	-	-	18.7
$Slope_{linear}$	-	-	-	-	-	-	-	-	-0.9
E (30-75 cm):									
T4	50.0	0.0	0.0	5.22a	1.28a	3.04a	41.7a	1.92a	8.2a
T5	50.0	2.0††	0.0	5.32a	1.01ab	2.68a	46.6a	1.95a	10.0a
T6	50.0	4.0	0.0	5.20a	0.80b	2.60a	43.6a	1.84a	5.8a
Statistics:									
P(treatment)	-	-	-	0.3197	0.0195	0.7838	0.6002	0.9319	0.3167
$LSD_{0.05}$	-	-	-	0.17	0.35	1.33	9.9	0.72	5.7
P(linear)	-	-	-	0.8136	0.0051	0.4967	0.8627	0.7863	0.3628
P(quadratic)	-	-	-	0.1365	0.9337	0.8774	0.3202	0.7956	0.2224
Intercept	-	-	-	-	1.27	-	-	-	-
$Slope_{linear}$	-	-	-	-	-0.12	-	-	-	-

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Table AGFS-24. (Continuation). Three-year mean effects of calcium carbonate applied once in 1999 to plots that received 50 kg P ha^{-1} applied annually on soil pH and Mehlich 1 extractable macro nutrients and Al in Immokalee fine sand profile.

Depth/Treatment	P	$CaCO_3$	Gypsum	pH	P	K	Ca	Mg	Al
Bh (75-90 cm):	kg ha^{-1}	----- Mg ha^{-1} -----			--------------------	mg kg^{-1}	--------------------		
T4	50.0	0.0	0.0	4.49a	26.4a	5.89a	427a	30.4b	940a
T5	50.0	2.0[††]	0.0	4.76a	19.4a	5.67a	466a	26.0b	963a
T6	50.0	4.0	0.0	4.43a	21.9a	8.07a	470a	62.5a	987a
Statistics:									
P(treatment)	-	-	-	0.0544	0.1218	0.1206	0.7114	0.0362	0.8703
$\text{LSD}_{0.05}$	-	-	-	0.38	6.9	2.58	109	28.9	191
P(linear)	-	-	-	0.5892	0.1954	0.0982	0.4775	0.0345	0.6043
P(quadratic)	-	-	-	0.1151	0.1000	0.2158	0.6786	0.1305	0.9340
Intercept	-	-	-	4.49	-	-	-	22.8	-
$\text{Slope}_{\text{linear}}$	-	-	-	0.29	-	-	-	8.0	-
$\text{Slope}_{\text{quadratic}}$	-	-	-	-0.08	-	-	-	-	-

[†] Means in column having the same letter are not different at P(treatment) ≤ 0.05.
[††] Based on initial rate of application made in 1999.

For some reason, extractable Ca increased quadratically with gypsum rates with the 2 Mg gypsum ha^{-1} treated soil tending to have more extractable Ca than the 4 Mg gypsum ha^{-1} rate at all depths (Table AGFS-25).

Finally, gypsum appeared to be associated with extractable Al in the top soil (0-15 cm) increasing it linearly with a slope of 0.36 mg Al per kg soil for each Mg of gypsum applied per ha.

Contrary to most findings on the leaching effects of gypsum on Mg (Alcordo et al., 1998), the present study showed no association between gypsum rate and extractable Mg in the soil profile. It could be that Mg was so easily leached out even through the Bh horizon so that no trace of its movement could be found (Greenhouse Study GS1).

Soil Phosphorus Fractionation

The highest P fraction in all horizons was the NaOH-P or the so-call Al/Fe-associated P (Table AGFS-26). Only in the E soils were total NaOH-P (digested NaOH extract) values higher than the NaOH-$P_{\text{inorganic}}$ (undigested NaOH extract) giving positive values for NaOH-P_{organic}. This problem, due to losses during digestion, led to low sums of the P fractions which averaged 67 and 90 % of the independently determined total P for Ap and Bh soils, respectively. Separately determined total P values within ± 10 % of the sum of the various P fractions or vice versa are considered acceptable for this type of analysis (Nair et al., 1995).

Table AGFS-25. Three-year effects of gypsum applied once in 1999 to plots that received 50 kg P ha^{-1} applied annually on soil pH and Mehlich 1 extractable macro nutrients and Al in Immokalee fine sand profile.

Depth/Treatment	P	CaCO$_3$	Gypsum	pH	P	K	Ca	Mg	Al
Ap (0-15 cm):	kg ha^{-1}	----- Mg ha^{-1}-----			--------------------		mg kg^{-1}	--------------------	
T4	50.0	0.0	0.0	4.78a[†]	5.23b	25.1a	412a	49.9a	44.2b
T7	50.0	0.0	2.0[††]	4.97a	6.99ab	40.7a	893a	53.1a	46.1b
T8	50.0	0.0	4.0	4.47b	10.63a	31.6a	580a	43.4a	58.5a
Statistics:									
P(treatment)	-	-	-	0.0038	0.0152	0.4826	0.0589	0.5883	0.0059
LSD$_{0.05}$	-	-	-	0.28	3.67	25.8	401	19.2	9.3
P(linear)	-	-	-	0.0357	0.0047	0.6193	0.4030	0.4986	0.0031
P(quadratic)	-	-	-	0.0070	0.5597	0.2728	0.0257	0.4392	0.1958
Intercept	-	-	-	4.78	4.91	-	412	-	42.4
Slope$_{linear}$	-	-	-	0.27	1.35	-	439	-	3.6
Slope$_{quadratic}$	-	-	-	-0.09	-	-	-99	-	-
Ap (15-30 cm):									
T4	50.0	0.0	0.0	5.02a	2.37a	7.6a	182a	10.0a	18.9a
T7	50.0	0.0	2.0[††]	4.97a	2.27a	6.7a	202a	9.6a	21.3a
T8	50.0	0.0	4.0	4.58b	2.57a	6.1a	124a	7.3a	19.3a
Statistics:									
P(treatment)	-	-	-	0.0356	0.8880	0.7028	0.0942	0.4267	0.6618
LSD$_{0.05}$	-	-	-	0.36	1.23	3.7	73	4.4	5.7
P(linear)	-	-	-	0.0183	0.7524	0.4042	0.1165	0.2281	0.8739
P(quadratic)	-	-	-	0.2803	0.7122	0.9550	0.1278	0.6228	0.3731
Intercept	-	-	-	5.07	-	-		-	--
Slope$_{linear}$	-	-	-	-0.11	-	-		-	--
E (30-75 cm):									
T4	50.0	0.0	0.0	5.22a	1.28a	3.04a	41.7b	1.92a	8.2a
T7	50.0	0.0	2.0[††]	5.17a	1.06a	3.29a	63.7a	2.35a	7.8a
T8	50.0	0.0	4.0	4.80b	1.23a	3.50a	39.2b	2.39a	11.7a
Statistics:									
P(treatment)	-	-	-	0.0005	0.4025	0.8014	0.0365	0.4297	0.5853
LSD$_{0.05}$	-	-	-	0.22	0.45	1.58	18.9	0.81	8.9
P(linear)	-	-	-	0.0003	0.9859	0.5110	0.8883	0.2017	0.3959
P(quadratic)	-	-	-	0.1095	0.1781	0.9227	0.0103	0.8159	0.5549
Intercept	-	-	-	5.27	-	-	41.7	-	-
Slope$_{linear}$	-	-	-	-0.10	-	-	22.6	-	-
Slope$_{quadratic}$	-	-	-	-	-	-	-5.8	-	-

Continue to next page.

Table AGFS-25. (Continuation). Three-year effects of gypsum applied once in 1999 to plots that received 50 kg P ha^{-1} applied annually on soil pH and Mehlich 1 extractable macro nutrients and Al in Immokalee fine sand profile.

Depth/Treatment	P	$CaCO_3$	Gypsum	pH	P	K	Ca	Mg	Al
Bh (75-90 cm):	kg ha^{-1}	----- Mg ha^{-1}-----			-------------------- mg kg^{-1} --------------------				
T4	50.0	0.0	0.0	4.49a	26.4ab	5.89b	427ab	30.4a	940a
T7	50.0	0.0	(2.0)††	4.69a	20.2b	7.34ab	590a	31.3a	940a
T8	50.0	0.0	(4.0)	4.37a	32.3a	9.78a	345b	21.2a	1073a
Statistics:									
P(treatment)	-	-	-	0.0945	0.0403	0.0860	0.0290	0.2294	0.3607
$LSD_{0.05}$	-	-	-	0.30	8.8	3.45	187	13.5	216
P(linear)	-	-	-	0.4068	0.210	90.0284	0.3777	0.1586	0.2173
P(quadratic)	-	-	-	0.0445	0.026	40.7915	0.0119	0.3260	0.4737
Intercept	-	-	-	4.49	26.4	5.71	427	-	-
$Slope_{linear}$	-	-	-	0.23	-7.6	0.98	185	-	-
$Slope_{quadratic}$	-	-	-	-0.07	2.3	-	-51	-	-

† Means in column having the same letter are not different at P(treatment) ≤ 0.05.
††Based on initial rate of application made in 1999.

The most reliable values in soil P fractionation would probably be total P and residual P because of their straight-forward extraction by combustion. Even considering only the lowest total P values in each soil horizon, it appeared that Immokalee fine sand has a large reservoir of soil P for plant use.

No effects of fertilizer P rates were noted in Table AGFS-26. Mined gypsum at 4 Mg ha^{-1}, however, significantly increased P concentrations in the Bh soils relative to the 2 Mg MG and the 4 Mg CL ha^{-1}. This is consistent with the results of the greenhouse study GS1 which demonstrated increased mobility of P with gypsum even at the lower rate of 2 Mg ha^{-1}.

Table AGFS-26. Phosphorus fractions in Immokalee fine sand profile as influenced by P fertilization and soil amendments (A) calcium carbonate (CL) or mined gypsum (MG), average of 1999 - 2001 samplings.

	P fractions in Immokalee fine sand						
Horizon/Treatment	Total	Residual	NaOHtot[1]	NaOHin[2]	NaOHor[3]	HCl[4]	KCl
kg P ha^{-1}+Mg A ha^{-1}	-------------------------			mg kg^{-1}	-------------------------		
Ap horizon:							
T1 0.0 + 0A	446.8a[†]	37.5a	247.5a	230.6a	16.4	2.10a	5.31ab
2 12.5 + 0A	378.6a	31.8a	233.7a	236.8a	-	1.73a	4.20b
T3 25.0 + 0A	406.4a	41.0a	207.9a	228.5a	-	2.35a	4.71b
T4 50.0 + 0A	383.0a	31.3a	228.9a	212.8a	15.2	1.54a	7.39ab
T5 50.0 + 2CL	433.5a	31.8a	239.2a	233.6a	5.6	2.90a	6.48ab
T6 50.0 + 4CL	417.0a	35.7a	213.4a	225.2a	-	2.54a	5.96ab
T7 50.0 + 2MG	450.4a	34.8a	239.3a	219.1a	20.2	5.41a	5.63ab
T8 50.0 + 4MG	501.5a	34.5a	341.3a	270.3a	71.0	5.06a	9.16a
P(Treatment)	0.33	0.98	0.12	0.83	-	0.39	0.01
E horizon:							
T1 0.0 + 0A	45.1a	4.6a	27.8a	19.0a	8.8	0.12a	0.49a
T2 12.5 + 0A	24.4a	5.2a	31.2a	19.6a	11.6	0.07a	0.99a
T3 25.0 + 0A	39.6a	4.1a	43.6a	22.4a	21.2	0.13a	0.87a
T4 50.0 + 0A	44.2a	4.9a	42.1a	22.1a	20.0	0.12a	1.60a
T5 50.0 + 2CL	44.2a	3.9a	37.2a	22.0a	15.2	0.08a	1.25a
T6 50.0 + 4CL	44.4a	5.3a	33.3a	18.4a	14.9	0.38a	0.81a
T7 50.0 + 2MG	42.0a	3.9a	38.5a	22.1a	16.4	0.09a	1.12a
T8 50.0 + 4MG	39.7a	7.9a	33.6a	20.6a	13.0	0.32a	1.79a
P(Treatment)	0.58	0.56	0.81	0.99	-	0.45	0.10
Bh horizon:							
T1 0.0 + 0A	698.4ab	27.3a	591.0a	615.5a	-	6.79a	0.59a
T2 12.5 + 0A	763.9ab	22.6a	644.7a	832.0a	-	7.37a	0.67a
T3 25.0 + 0A	530.9b	17.9a	541.0a	541.9a	-	4.43a	0.99a
T4 50.0 + 0A	674.5ab	29.6a	643.3a	557.8a	85.5	5.97a	0.89a
T5 50.0 + 2CL	679.7ab	21.8a	553.7a	562.2a	-	5.38a	0.64a
T6 50.0 + 4CL	653.1b	25.3a	506.5a	714.6a	-	3.63a	0.34a
T7 50.0 + 2MG	647.9b	18.2a	567.0a	598.6a	-	3.70a	0.88a
T8 50.0 + 4MG	996.0a	44.8a	725.4a	720.3a	5.1	9.64a	0.91a
P(Treatment)	0.01	0.12	0.33	0.08	-	0.22	0.50

[1] Al/Fe-P plus organic-P released upon digestion; [2] Al/Fe-P fraction only; [3] Organic fraction obtained as difference between Al/Fe-P + organic-P and Al/Fe-P; [4] Ca/Mg-P; [5] labile P.

[†] Means in column having the same letter are not different at P(treatment) ≤ 0.05.

Field Study 2, Water Quality (WQFS): Phosphorus Fertilization and Calcium Amendments, Phosphorus in Runoff and Ground Water, Weather Data Collection, and Use of Everglades Agricultural Area Model (EAAMOD)

This report is a summary of the water quality and weather data and the EAAMOD modeling work for the project. The complete results together with all the appendices of raw data may be obtained from the SFWMD.

The paddlewheel samplers for runoff and the shallow PVC wells for ground water sampling were set up on the thirty-two field plots used for the agronomic study (Figure AGFS-1) during February, March, and April of 1999. An automated weather station was also installed in late April 1999 and has provided data continuously during the period of study except for a five-day period during May 1999.

Surface and ground water samples had been collected since March 17, 1999. However, due to dry conditions during potions of 1999 and most of 2000, very few surface runoff and shallow ground water samples were collected during this period. One of the paddlewheel samplers was connected to the CR10 data logger on June 27, 2000 to provide rotation counts during flow events. Year 2001 did have about three short periods of high rainfall that did trigger significant runoff.

The last samples for the project were collected in November 2001. The weather station has been left in service for additional weather data.

The field data were used to calibrate and verify the use of the EAAMOD model. The model was successfully applied to the fertility treatments. Only these treatments were simulated because the model currently does not handle soil amendments. The modeling setup and the results are presented in this report.

Weather Data and Other Observations

A Campbell Scientific, Inc. fully automated weather station was installed in the middle of the study area (Figure AGFS-1) on April 26, 1999 and data has been recorded since that time except for a five day period that data were inadvertently lost due to startup testing problems in early May 1999. The following data were collected by the weather station recorded on an hourly basis: (a) Rainfall rainfall, (b) solar radiation, (c) air temperature, (d) soil Temperature at 1.5 feet depth, until October 16, 2001 at which time it was inadvertently raised to 0.5 inches, (e) water table above and below the spodic horizon (hardpan).

The station had a cellular phone communications package that allowed for remote access for data downloads and station program maintenance. It also had a voice synthesizer and software that allowed it to alert field staff at the Ona Experiment Station of rainfall events so that sampling trips could be scheduled. The station also called Soil and Water Engineering Technology, Inc. (SWET) in Gainesville, FL when transducer errors occurred. The only error detected was a low battery alarm twice. On the first occasion, the voltage regulator had to be replaced and the second time the battery had to be replaced. In neither case were data lost. SWET also did daily downloads of data to keep track of the station(s performance and data retrieval.

Rainfall. The rainfall data collected between April 26, 1999 and January 30, 2002 for the station are presented in Table WQFS-1 as monthly averages. Rainfall during year 2000 was well below normal but came at regular enough intervals to maintain good pasture grass growth.

Watertable. The watertable levels were extremely low for most of 2000 (Table WQFS-1) which resulted in very little runoff. Water levels were more normal during 2001. The quick response of the watertable to every rainfall event observed during the first year, 1999, which continued during the next two years, 2000 and 2001, provided excellent hydraulic response data for model calibration. Watertable levels above and below the spodic horizon during each year are shown in Figures WQFS-1 through WQFS-3.

Solar radiation. Table WQFS-1 provides the solar radiation data which are clearly correlated with the rainfall data, i.e. high rainfall days had low solar radiation.

Air and soil temperature. Table WQFS-1 shows the air and soil temperature. Soil temperatures were consistently higher than the air temperatures throughout the period of study.

Water Quality Data and Quality Assurance

Three types of water quality samples were collected in each of the plots. They were shallow well (above spodic layer), deep ground well (below spodic layer), and surface runoff samples (paddlewheel) collected by the paddlewheel samplers (Bottcher and Miller, 1991). The sampling procedures/protocols in Appendix A were strictly observed. Sampling frequency of surface and ground water samples was monthly, if available, with the timing of collection controlled by the occurrence of rainfall. Surface water samples were collected immediately after the first significant event of a month. A second surface sampling was scheduled during a month if another major runoff event occurred. Ground water samples were collected once a month after the first significant event, particularly if the water table was above the spodic.

All samples were analyzed for pH and electrical conductivity (EC) or specific conductance. Ortho-P (OP) and total P (TP) were analyzed using the colorimetric method of Murphy and Riley (1962). Water quality QA/QC discussed in the section on "Leachates and Soil Water Preparation and Chemical Analyses" (p. 15 of this overview report) was observed. Another QA/QC adopted for this study was the use of duplicate samples (Appendix D) and equipment blanks.

Perusal of Appendix D shows the variation that occurred between duplicate samples and the equipment blanks. In general, the duplicates showed a consistence of results; however, some variations were noted particularly for TP, which would be expected because of highly variable total suspended solids (TSS) influences and the additional process of digesting the samples. As anticipated, the highest variations occurred for the lowest concentrations where relative error

Table WQFS-1. Monthly averages of rainfall, depth of watertable, solar radiation, and air and soil temperature at Williamson Ranch, Okeechobee, 1999 to 2002.

Year/Month	Rainfall (in)	Depth of watertable (ft below surface)	Solar radiation (W/sq m)	Air temperature (^{O}F)	Soil temperature (^{O}F)
1999					
April	0.36	4.31	171.61	80.12	81.08
May	1.29	4.77	183.45	73.06	77.43
June	0.03	5.51	160.67	66.43	71.93
July	0.10	5.91	129.52	62.52	68.48
August	0.75	6.10	140.42	55.10	63.05
September	0.03	6.20	173.33	63.62	65.85
October	1.58	6.35	194.77	67.77	69.67
November	2.38	5.81	211.70	69.90	72.21
December	2.09	6.29	239.06	71.84	75.00
2000					
January	9.30	5.53	218.72	76.99	79.42
February	13.92	2.54	190.86	77.73	79.66
March	5.46	1.24	211.33	79.51	80.72
April	9.54	1.20	198.70	77.91	79.62
May	4.12	1.73	160.12	74.99	76.71
June	3.62	1.41	137.86	67.73	68.82
July	0.53	3.15	136.83	68.03	68.51
August	2.65	3.99	134.04	61.14	64.75
September	4.77	4.69	198.00	78.68	80.31
October	1.21	4.95	176.76	70.74	75.66
November	0.04	5.67	146.48	65.07	70.73
December	0.22	5.97	129.56	60.67	67.54
2001					
January	0.59	6.13	151.77	55.32	61.84
February	0.03	6.22	178.04	67.29	68.43
March	3.96	6.37	193.66	67.06	69.46
April	0.42	5.75	211.46	69.87	72.93
May	3.75	6.37	248.12	73.65	76.11
June	8.19	5.14	213.59	77.03	79.64
July	13.93	1.85	196.48	78.30	79.84
August	5.84	1.59	218.78	79.54	80.83
September	9.60	0.88	170.06	76.78	78.98
October	4.89	1.61	157.56	73.08	74.64
November	1.44	1.98	143.70	67.92	68.51
December	0.76	3.31	127.63	65.72	67.21
2002					
January (1-17)	1.08	3.53	124.41	54.70	58.86

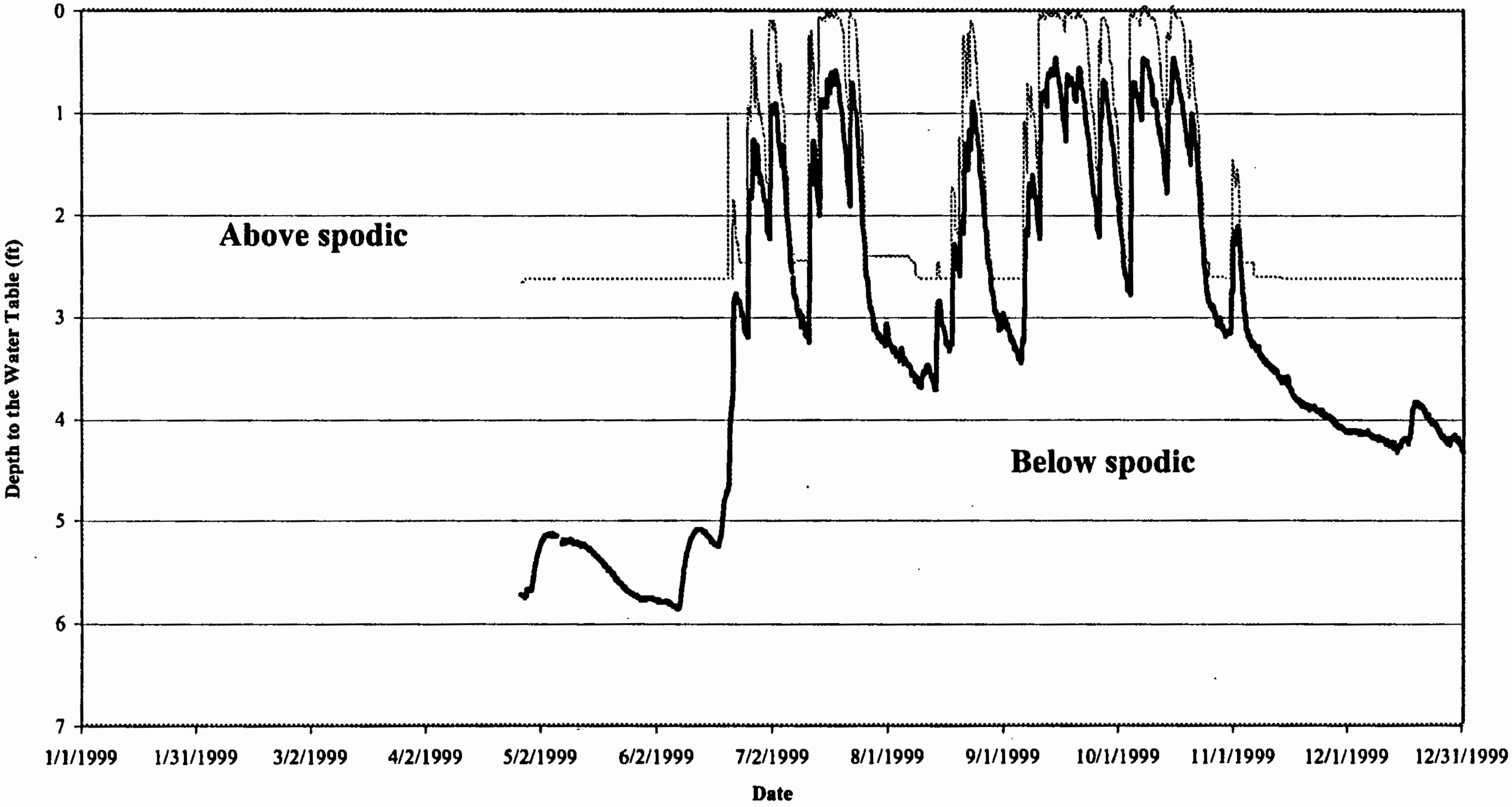

Figure WQFS-1. Watertable above and below the spodic horizon, Williamson ranch, Okeechobee, 1999.

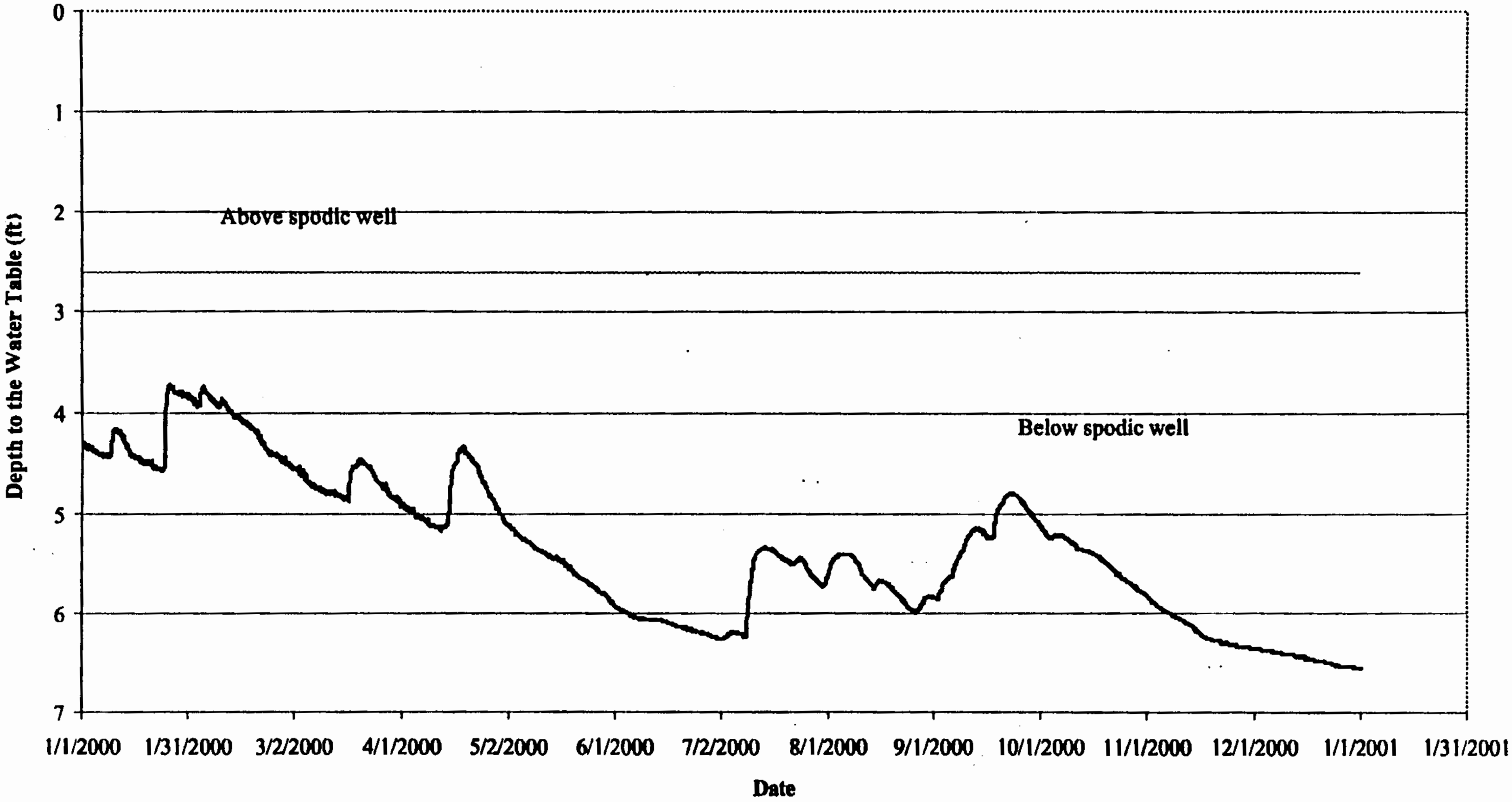

Figure WQFS-2. Watertable above and below the spodic horizon, Williamson ranch, Okeechobee, 2000.

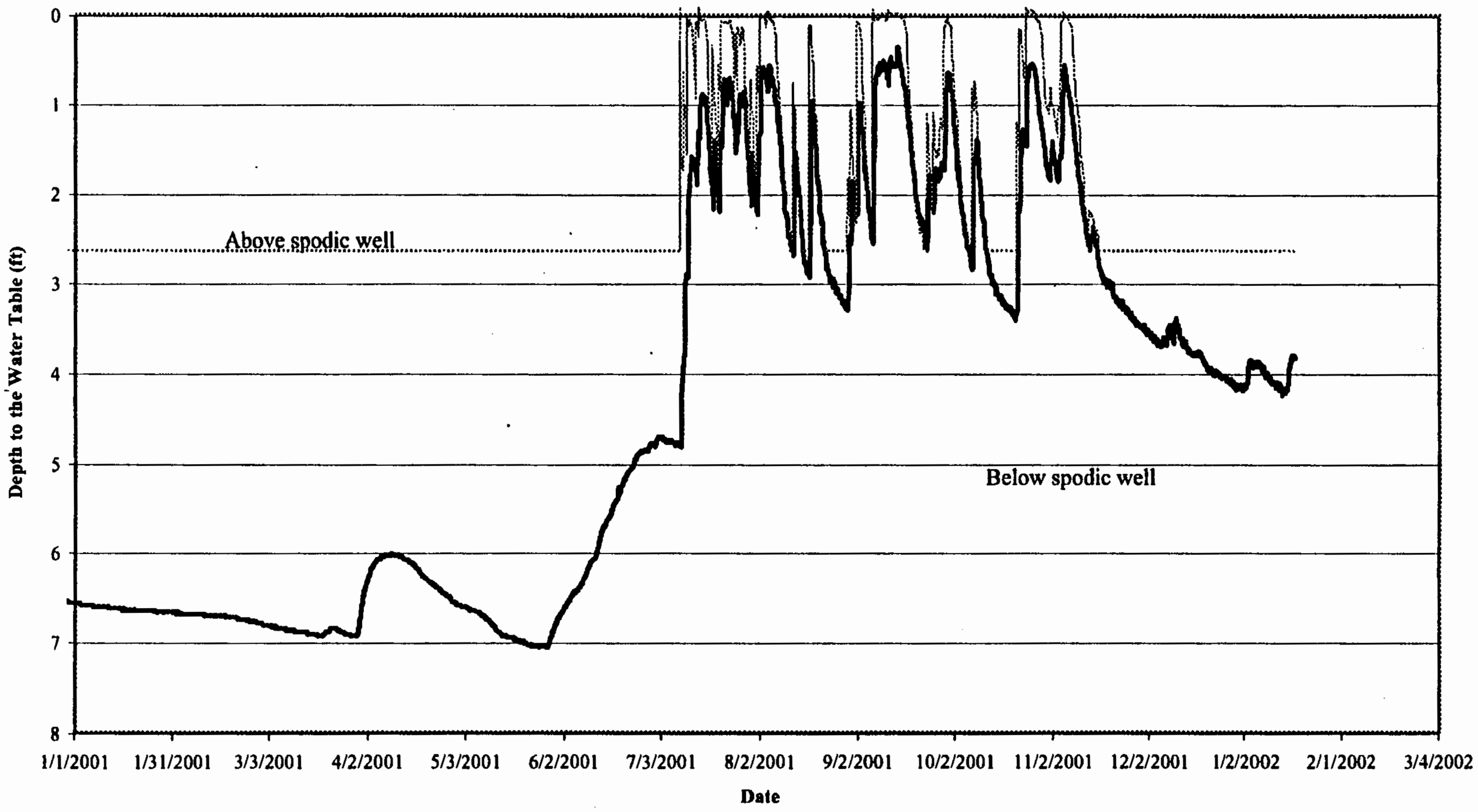

Figure WQFS-3. Watertable above and below the spodic horizon, Williamson ranch, Okeechobee, 2001-2002.

becomes much greater. The equipment blanks show that little or no cross contamination of samples occurred; phosphorus contents were near or below detection levels.

Review of the TP (digested) data indicated that its analyses had problems during some periods, particularly during 2001. The data did not follow the expected trends for the treatments. Fortunately, TP was also analyzed by ICAP (inductively-coupled argon plasma) spectroscopy for many samples, and these data follow the expected trends.

Only the last year (2001) data are presented and used for analyzing the treatment effects because a startup effect of the treatments was observed in the data, i.e. it was clear the treatment effects had not reached equilibrium during the first two years. This decision was further supported by the total lack of runoff during 2000. This startup equilibrium effect was clearly evident in the surface water data where no treatment effects were observed until 2001. The well water samples appeared to come to equilibrium quicker.

Due to cattle traffic in the plots, it was observed that one or two temporary breaches of the plot berms between plots occurred which would have allowed some limited cross flow between the plots. These breaches, however, were repaired as soon as they were found. Though these breaches might have partially mixed the runoffs during one or two storm events, the overall responses to the individual treatments are not likely to be significantly affected over the length of the study and should have little influence on the lack of equilibrium being reached as stated above.

Total P. The water quality data by treatment are presented in Table WQFS-2 in the form of linear regression equations. The ICAP-TP data are used because these TP data were found to be more reliable for calibration hence also for EAAMOD simulation on P levels in water for the study. Table WQFS-2 shows that fertilizer P rates, compared to pH and EC, tended to have the largest coefficient of determination indicating that it is the most important factor associated with P levels in all types of water samples.

EC. Specific conductance results clearly indicate that each of the amendments including P fertilizer increased specific conductance (Table WQFS-2). The treatment response trends were similar for all three sample types (deep and shallow groundwater and runoff). The gypsum amendment had the most dramatic response, due to its very high solubility in water, where higher levels of gypsum significantly increased conductivity levels. Calcium carbonate or Ca lime also had a positive trend to conductivity. Fertilizer P rate appeared to have none to a slight negative trend with EC for the deep well data only, but not significantly. As anticipated, the shallow ground wells had the greatest response and the surface runoff samples the least for conductivity changes .

pH. There appears to be little differences between the treatments for pH (Table WQFS-2). The only response that appeared was a slight negative response (pH dropping with increased application rate) with rates of gypsum. This was for the shallow well samples only, and this was not significant. The pH for the surface runoff appeared to increase with Ca lime application rate, but again this was not significant.

Table WQFS-2. Relationships between pH, EC, or total P (TP) with Ca amendments or fertilizer P rates in surface runoff (Paddlewheels) and water samples above the spodic (Shallow wells) and below the spodic (Deep wells) horizon.

Depth/Treatment	Water variables					
	pH		EC (µmho cm^{-1})		TP (µg L^{-1})	
Paddlewheels	Equation	R^2	Equation	R^2	Equation	R^2
Ca carbonate	Y = 0.039X + 6.420	0.0053	Y = -0.0013X + 61.57	5E-09	Y = -64.75X + 1349.0	0.0189
Gypsum	Y = -0.049X + 6.682	0.0218	Y = 0.9835X + 63.15	0.0072	Y = - 6.86X + 1292.5	0.0002
P rates	Y = -0.0003X + 6.585	0.0001	Y = 0.3102X + 50.17	0.0423	Y = 8.86X + 895.4	0.0485
Shallow wells						
Ca carbonate	Y = -0.050X + 4.953	0.0151	Y = 16.207X + 123.2	0.0966	Y = 282.71X + 5746.8	0.0143
Gypsum	Y = -0.271X + 5.549	0.1554	Y = 77.380X + 140.1	0.1094	Y = 36.73X + 5221.4	0.0002
P rates	Y = -0.006X + 5.029	0.0226	Y = 0.344X + 129.4	0.0072	Y = 8.86X + 895.4	0.0485
Deep wells						
Ca carbonate	Y = -0.047X + 4.487	0.0555	Y = 56.094X + 390.34	0.1614	Y = 182.02X + 908.1	0.0146
Gypsum	Y = 0.186X + 4.505	0.1345	Y = 61.802X + 376.99	0.1135	Y = -268.62X + 1198.2	0.1476
P rates	Y = 0.0004X + 4.431	0.0004	Y = -1.259X + 419.33	0.0086	Y = 28.90X - 40.1	0.2774

EAAMOD Calibration and Verification

The observed problem with the TP data noted earlier has been resolved by primarily using ICAP data for TP calibrations of the model. High TP readings occurred in 1999 for deep well readings. Presumably, these were due to the high P loadings prior to this period. High TP readings occurred in 2001 for shallow well readings. Presumably, these were due to the initial flush of nitrogen in the soil following the very dry year during 2000. Hence, the discussion of TP results are only for the data ICAP-P data. It may be said, however, that TP responses follow the OP results almost exactly and therefore are not repeated here. It should be noted that OP is 80 to 95 % of the TP typically.

The Okeechobee version of the EAAMOD model was used to model the P fertility treatments for the study because this model was specifically adapted for the various land use in the Okeechobee Basin as part of a separate project. The results of this model upgrade for pasture grasses in the Okeechobee basin were presented in the final report to the SFWMD (Final Report: EAAMOD Model Upgrade). The reader is referred to this report for details concerning EAAMOD.

EAAMOD was set up and run for the four fertilizer treatments using the site's weather station data. The first step was to calibrate the hydraulic component of the model. The calibrated soils file (Immokalee.sls) for the Immokalee soil at the site is presented in the completed report (SFWMD). The only other calibration that was needed was to adjust the estimated evapotranspiration data for the site that was generated by the GLEAMS based on latitude and mean max/min temperature data by a factor of 0.7. Figure WQFS-4 shows the exact match of the simulated versus observed water table levels. The model also predicted runoff at all the right times.

The model also accurately modeled the TP concentrations leaving the field as runoff with minor calibration adjustments. Calibration of TP predictions was done by adjusting the initial soil level of P and the partition coefficients in the Immokalee.phs parameter file. Table WQFS-3 provides the predicted versus observed TP concentrations for the four levels of P fertilizer rates during the year 2001. As can be seen the predicted TP concentrations are in good agreement with observed data.

Table WQFS-3. Simulated versus observed TP concentrations for 2001 for P treatments.

P Fertilizer Rate	Simulated TP	Observed TP
kg ha^{-1}	mg L^{-1}	mg L^{-1}
0	0.80	0.83
12.5	0.93	1.07
25.0	1.11	1.14
50.0	1.40	1.31

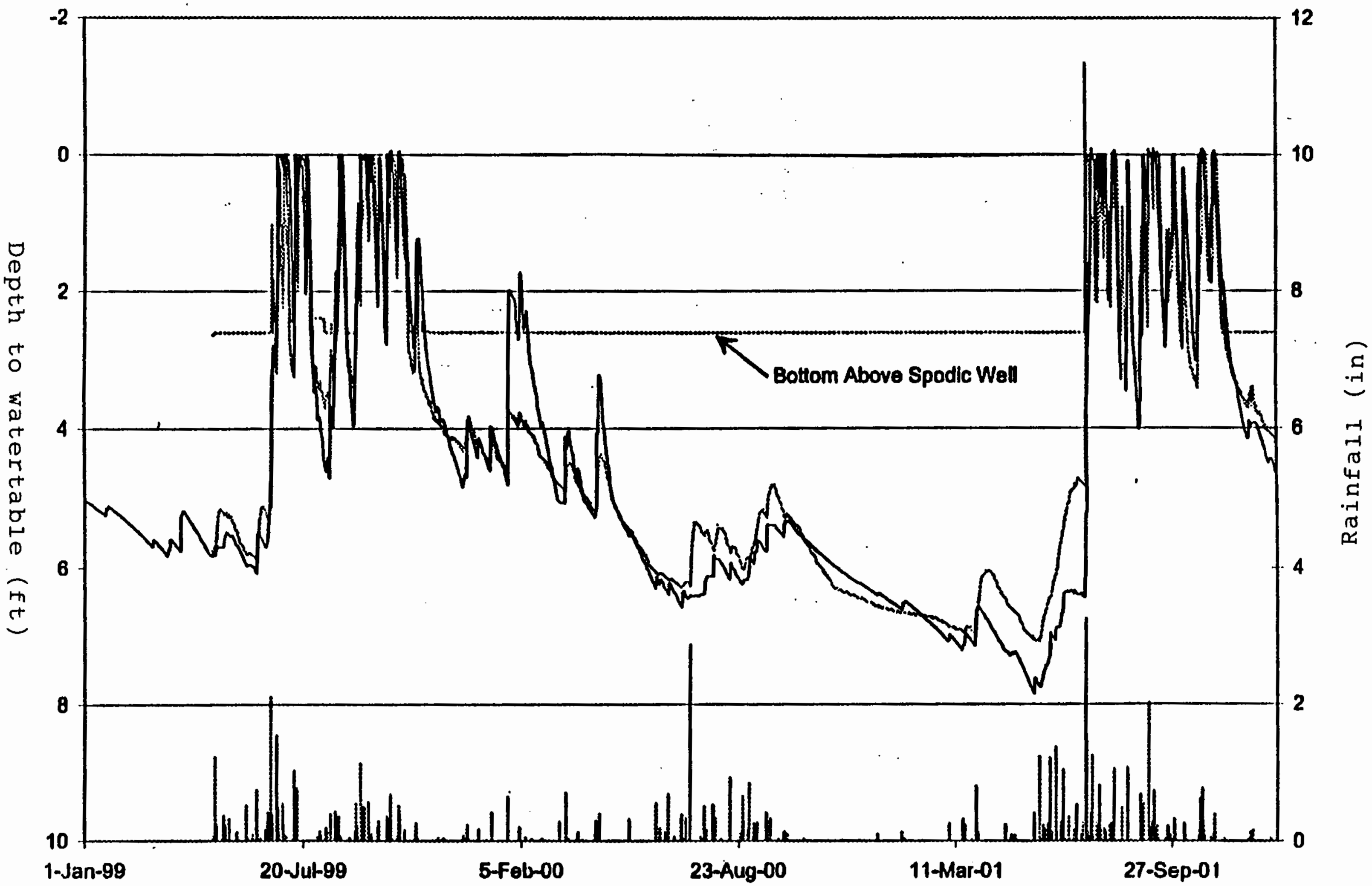

Figure WQFS-4. The EAAMOD simulated versus observed watertable levels above and below the spodic horizon.

Figure WQFS-5 shows the simulated versus observed TP data for zero P fertilizer rate treatment over the entire study period. The predicted TP concentrations are in good agreement with the observed data for zero P rates.

The calcium treatments were simulated by modifying the EAAMod P partitioning coefficients to represent the changes in P partitioning due to changes in pH (Table WQFS-4). The simulated values were highly correlated with the measured values; however, meaningful statistics on predictive abilities of the model due to Ca treatments cannot be made based on this limited data set.

Table WQFS-4. Simulated versus observed TP concentrations for 2001 for Ca treatments.

Ca amendment	P rate	Measured TP	Simulated TP (mg L^{-1})
Mg ha^{-1}	kg ha^{-1}	mg L^{-1}	mg L^{-1}
0	50	1.31	1.40
2	50	1.29	1.27
4	50	1.06	1.16

In order to determine whether the system had reached equilibrium, EAAMod was run for 20 years using 1999 weather data for each year. The treatment of 50 kg/ha P, 0 Mg/ha Ca, and 0 Mg/ha gypsum was used (Figure WQFS-6). The results show that at this P load, the TP outflow concentration will continue to rise for many years. This suggests that the limited number of years used for the treatments were not enough to evaluate their final impacts.

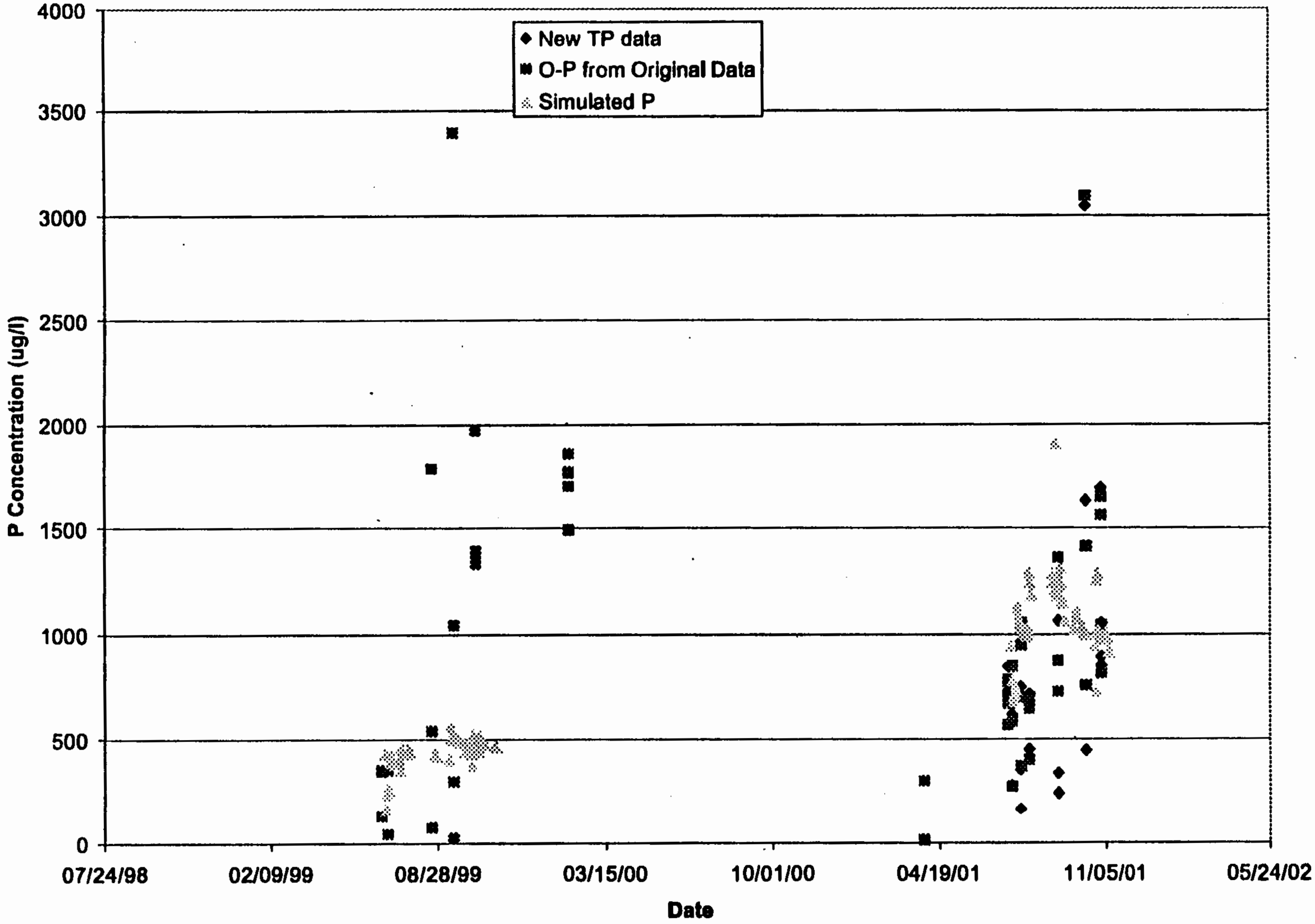

Figure WQFS-5. The EAAMOD simulated total P (TP) versus observed TP and ortho-P (O-P) concentrations.

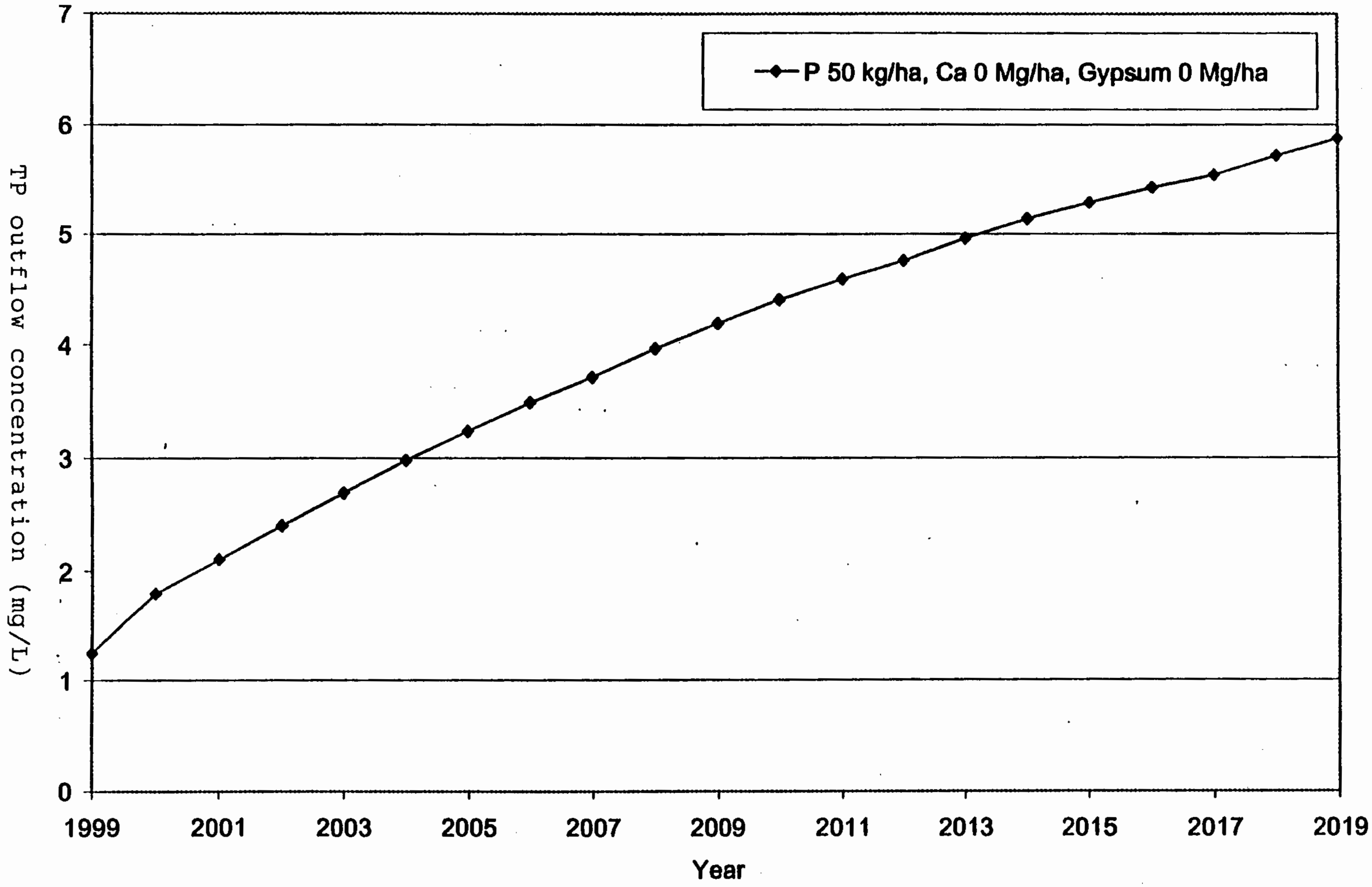

Figure WQFS-6. The EAAMOD simulated total P (TP) outflow concentrations for 20 years using the 1999 weather data each year.

PROJECT SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Greenhouse Studies

Three greenhouse studies were conducted under the project primarily to help explain and/or confirm related field experiment results. Reference to relevant greenhouse observations and/or conclusions may be made in the field study summary.

The basic P retention capacity of the individual horizons of Immokalee fine sand and the influence of Ca amendments were determined in a greenhouse study (GS1). Potted individual soil horizons were used with no stargrass planted. Fertilizer P at 0, 50, and 100 kg P ha^{-1} using triple superphosphate (TSP) and Ca amendments at 0 and 800 kg Ca ha^{-1} were applied to the potted Ap soils. The soils were then leached eight times sequentially, the Ap with deionized water, the E with Ap leachates, and the Bh with E leachates over a 220-day period.

The results showed that the P retention capacity of the horizons with no stargrass planted was in the order of Bh > Ap > E. The E horizon had almost zero P retention capacity as indicated by the leached P:applied P ratios around 1.0. This does not, however, mean that the E soils are devoid of P. Because the E soils are highly permeable, large P losses from lateral flow along this horizon in the field could be expected should drainage ditches cut through it.

The granular lime materials, either calcium carbonate or dolomite, significantly reduced leaching P losses from the Ap horizon. Reduced P concentrations in Ap leachates due to liming could be attributed to slight increases in leachate pH. But with the lime's extremely low solubility, the undissolved lime particles on the surface of the potted Ap soils probably played the major role in reducing P leaching from the Ap horizon by precipitating PO_4 anions unto their surfaces. Calcium carbonate and dolomite were similarly effective in reducing P loss from the Ap horizon. With or without Ca amendments, 94 to 99 % of soil or fertilizer P that leached through the Ap and then through the E horizons was eventually retained in the Bh horizon.

Mined and byproduct gypsum, which are highly soluble, increased Ap leachate P and Ca concentrations and reduced leachate pH. Increase in Ca concentrations and reduction in pH could increase PO_4 mobility with Ca and PO_4 moving together as ion pairs. Substantial reduction in pH could also mobilize the micro elements in soils and make them significant factors in the leaching of P. In addition, SO_4 from gypsum could reduce adsorption of PO_4, keep them in solution, and render them more vulnerable to leaching. Thus, the application of soil amendment that solubilizes into cations and anions in significant amounts could worsen the loss of P through leaching.

Electrical conductivity, Ca, Mg, K, and Al were positively associated with P concentrations in Ap leachates; pH, Ca, Al, and Mn in E leachates; and Mn in Bh leachates. Leachate pH was negatively associated with P concentrations in Ap and E but not in Bh leachates.

The influence of cropping on P retention by the individual horizons of Immokalee fine sand and the capacity of stargrass to utilize fertilizer P were determined in greenhouse study GS2-I. Potted soil horizon samples and commercial pure sand were planted to stargrass and fertilized at 100 kg P ha^{-1} using TSP. Bottom leachates were sampled ten times over a 24-week period.

The results indicated that plant-available soil P in the Ap horizon plus fertilizer P applied at 100 kg P ha^{-1} were far in excess of the ability or capacity of stargrass to utilize them. For ten sampling events, leachate P concentrations ranged from 1.3 to 6.8 for Ap, 0.11 to 0.23 for E, 0.08 to 1.19 for Bh, and 0.0 to 0.17 mg L^{-1} for pure sand. Phosphorus concentrations in E, Bh, and pure sand leachates were not significantly different from one another at each sampling event. The relatively low E and pure sand leachate P concentrations point to the importance of pasture cropping in reducing or preventing fertilizer and/or soil P losses.

Stargrass forage yields in Ap, E, and Bh soils and in pure sand were not different from one another. Despite the different amounts of available P in the various media, such as between Ap and pure sand, P contents in stargrass regrowth forage remained within a narrow range of from 0.27 to 0.29 %. This would mean that unfertilized soils planted to stargrass with regrowth forage P contents within said range do not need any fertilizer P. Any application of P besides being a waste of money would most likely increase P losses through leaching and/or runoff.

The third greenhouse study used potted reconstructed soil profile of Immokalee fine sand also planted to stargrass (GS2-II). Fertilizer P at 0, 25, 50, and 100 kg P ha^{-1} were applied to pots without Ca amendments. Calcium carbonate, dolomite, or mined gypsum, all ground to powder, were applied at 0, 2 and 4 Mg ha^{-1} to pots fertilized at 100 kg P ha^{-1} with no Ca amendment as control.

The results showed that fine-ground Ca amendments failed to reduce P concentrations in soil water of reconstructed soil profile fertilized at 100 kg P ha^{-1} sampled at the bottom of the Ap+E (shallow wells), Ap+E+Bh (deep wells), or Ap+E+Bh+C (bottom leachates) horizon profiles. There were also no meaningful effects of Ca amendments on leachate pH, EC, or Ca concentrations. It is doubtful that these non-effects could be attributed to the influence of stargrass alone because the grinding of the amendments into powder obliterated the important properties that differentiate gypsum from the lime materials, namely, solubility and pH effect. If grinding the lime materials indeed made them ineffective in reducing P losses through leaching, then PO_4 precipitation unto the surfaces of granular lime particles, as hypothesized in GS1, could be the key to the effectiveness of lime in immobilizing P in soils.

Calcium amendments showed no effects on stargrass forage yield relative to the control. Limestone reduced P uptake by stargrass below that of the control indicating less available P to stargrass due, most probably, to some degree of P precipitation. Phosphorus P contents ranged from 0.22 to 0.30. With no differences in yields, this would push P content down to 0.22 as a lower limit at which P fertilization would not result in increased forage yield.

Fertilizer P applied up to 100 kg P ha^{-1} had no effects on P concentrations in deep well (Ap+E+Bh) and bottom leachates (Ap+E+Bh+C). This could only be due to the strong retention capacity of the Bh horizon for P. Although not generally significant, P in shallow wells (Ap+E) tended to increase with increasing rates of fertilizer P. That P concentrations in the control (0 P, no Ca amendment, shallow wells) were not different from the P-fertilized pots strongly indicates that Immokalee fine sand has too much P to more than meet the needs of stargrass for P.

Fertilizer P rates had no effects on forage yield of stargrass. Again, this strongly indicates that Immokalee fine sand has too much P to meet needs for optimum forage yield. But fertilizer P increased forage P contents linearly from 0.20 to 0.30 % as P rates increased from 0 to 50 kg P ha^{-1}. Again, with no increase in forage yield, the lower limit is now 0.20 % P at which P fertilization would be unnecessary as it would not benefit forage yield.

The Ca:P ratios of 3.1:1 for the control and 2.2:1 for the highest fertilizer P rate were well within the desirable Ca:P ratio range of not less than 1:1 to not more than 7:1. These high Ca:P ratios could be due to the leaching of P, but not Ca, out of the root zone upon watering reducing P uptake but keeping soil Ca uptake relatively unaffected.

Agronomic and Water Quality Field Experiments

Fertilizer P as TSP was applied annually at 0, 12.5, 25, and 50 kg P ha^{-1} to stargrass pasture from 1999 to 2001. Calcium carbonate or mined gypsum was applied at 0, 2 and 4 Mg ha^{-1} to plots and fertilized at 50 kg P ha^{-1}. Treatments were replicated four times.

In the field experiment, P fertilizer did not increase forage yields, as the two greenhouse studies did show, nor improve forage quality measures such as crude protein (CP) contents and *in vitro* organic matter digestibility (IVOMD). Forage from plots where no fertilizer P was applied for three crop years did not show any deterioration in forage yield and in quality on the third year. Forage yields were influenced more by crop year, which had distinctly different rainfall levels during the growing season, than by P fertilization.

Phosphorus fertilization increased P contents significantly. The three-year average P contents of regrowth forage ranged from 0.19 to 0.34 % as fertilizer P increased from 0 to 50 kg P ha^{-1} applied annually. With no increase in forage yield, the field results indicate that no P fertilizer is needed for stargrass pastures having regrowth forage P contents of 0.19 % or more. These field results are supported by the data from the two greenhouse studies GS2-I and GS2-II.

Calcium increased only slightly resulting in the deterioration of the Ca:P ratio to levels that could be detrimental to animal growth and development and to feed efficiency. Phosphorus fertilization as low as 12.5 kg ha^{-1} reduced Ca:P ratio close to the acceptable lower limit of 1:1 just after three years of application. The highest rate of 50 kg ha^{-1} reduced Ca:P ratio to less than 1 by the second year of application. At this rate of P fertilization, Ca sources such as calcium carbonate or gypsum at the highest rate of 4 Mg ha^{-1} applied at the beginning of the study failed to increase Ca:P ratio beyond the lower acceptable limit after three years of high P fertilization.

Evaluation of P uptake by stargrass indicated that P fertilization only helped to build up soil P at the rate of at least 0.70 kg P for each kg of fertilizer P applied per ha per year with no agronomic benefits. The accounting of soil and fertilizer P in the three greenhouse studies supports such build up which could only increase the potential loss of soil P through runoff and/or leaching. Phosphorus fractionation of greenhouse (GS1) and field samples indicates that Immokalee fine sand has already high soil P in Ap, E, and Bh horizons even without P fertilization.

Considering the major agronomic findings, it is concluded that stargrass on Immokalee fine sand does not need any P fertilization. Hence, it is recommended that IFAS re-evaluate its recommendation on P fertilization of stargrass and other similar improved pastures species on Immokalee fine sand.

With an Ap soil pH of 4.4, the forage yield data indicate that stargrass in the area may benefit from liming using calcium carbonate which showed some tendencies to increase forage yields. The potential of lime materials to reduce P losses through leaching (GS1) would certainly be an added benefit to their on these soils. The greenhouse studies indicate that granular lime materials would be more effective to retain P in the soil than highly soluble fine-ground ones.

The water quality analysis indicates that the P fertility response for the stargrass is similar to what the previous bahiagrass study showed, that increased P application rates appear to exponentially increase soil-water P levels as fertilizer rates exceed grass uptake rates. Greenhouse study GS1 demonstrated that increased P rates increased P concentrations in the Ap leachates. The runoff TP concentrations also increased with P fertilizer rate, but more linearly. The study also showed that the soil amendment Ca lime only slightly decreased TP concentration in runoff while the gypsum amendment appeared to have slightly increased TP concentrations. These tendencies were noted in greenhouse study GS1 but in more pronounced and significant degrees.

The data also indicate that the field was probably not fully equilibrated to the treatment trials, which means that the treatment effects observed could possibly become even greater over more time. The dry conditions during the first two years of the study increased the equilibration time resulting in only the third year of data being useful for assessing the treatment effects. In spite of the equilibrium issue, the results clearly show that over fertilization will result in higher P losses. Though promising, the long term benefits of the Ca lime amendment are not clear from this study due to the equilibrium effect, and therefore should be further investigated. Gypsum is clearly not a beneficial amendment for reducing P losses from pastureland.

After calibration, the EAAMOD model was able to accurately simulate the P fertilizer treatment effects observed at the site. The simulated and observed values for 2001 were highly correlated for the various phosphorous treatments. Regressing the simulated and observed TP outflow concentrations gave a slope of 1.01 and an R2 of 0.76 indicating a good trend and correlation between simulated and observed values. The model simulated the TP discharge concentration changes as influenced by P fertilizer rates, and therefore should be a useful tool for investigating other potential fertility BMPs on other soils and crops in the area.

The most important conclusion that can be drawn from all the studies is that Immokalee fine has too much plant-available P to require P fertilization of stargrass or, probably, other improved grass species as well. Hence, it is strongly recommended that IFAS reconsiders its P fertilizer recommendations for stargrass and similar improved grass species.

The study also demonstrated pasture cropping as a major method or practice to reduce, if not totally, prevent P losses through leaching and, possibly, also runoff.

In order to minimize soil and/or fertilizer P losses from agricultural lands, the following should be considered: (1) increase the capacity of the Ap horizon to retain P by use of appropriate soil amendments like limestone or dolomite, (2) prevent P-loaded water atop the Bh horizon, that is in the E horizon, from reaching into open ditches that drains into open bodies of waters or lakes, hence, construction of drainage ditches should be discouraged or when necessary must not go deeper than the depth of the Ap horizon, (3) allowing surface water time to leach through the Bh horizon by confining excess water in wetlands, and (4) leaving no significant portion of land left uncovered or unplanted to pasture grasses.

The economic justification of applying lime solely to retain P in the soil profile in Spodosols does not appear to be warranted because, as long as P is not permitted to be lost through runoff and/or lateral flow through the E horizon into drainage ditches, 95 % of Ap soil P and at least 99 % of fertilizer P are eventually screened out from the percolating water or leachates and retained. It is, however, a bonus in a liming program to achieve desired soil pH. To use lime to retain fertilizer P in the Ap horizon in P-deficient soils to keep it readily accessible to plant roots may be worth the investment.

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APPENDICES A: Water Sample Collection Protocol

Water Sample Collection Protocols

A. Surface water from paddlewheel samplers

Equipment needed:

1. Pre-cleaned and acidified sample bottles (see 5 below if not pre-acidified). Approximately 40 bottles should be taken to the field.
2. A two-liter plastic graduated cylinder.
3. Field-filtering apparatus.
4. Two gallons of analyte-free water (de-ionized water), a pressured sprayer is handy.
5. H_2SO_4 acid if pre-acidified sample bottles are not provided. It is anticipated that most bottles will come from the laboratory with the required preservatives already in the bottle. If this is the case, great care should be exercised so the bottles do not tip over and that the lids are secure. If the sample bottle does not contain the acid preservative, then H_2SO_4 will need to be added to samples that will be analyzed for TKN, nitrate + nitrite, ammonia, and total P. Concentrated H_2SO_4 should be added to the samples until the pH of the samples are < 2.0 using a litmus strip. Noting the volume of acid it takes to reach the proper pH will allow future additions of acid to be done using a constant volume.
6. Sample log-sheets.
7. Crescent wrench and 7/16" end wrench for opening sampler if needed.

Sampling Procedure:

1. Upon arrival at site, take one equipment blank sample, i.e. rinse graduated cylinder with analyte-free water then add 125ml of analyte-free water and swirl within the cylinder and collect sample. If field filtering is being done, then place 125 ml of analyte-free water in the field-filtering apparatus and collect sample. A second equipment blank(s) is to be taken at the completion of sampling following a normal rinse procedure for the graduated cylinder and field-filtering apparatus.
2. Open sample chamber on paddlewheel sampler, note any irregularities such as insects, water, or problem with collection pan and tubing.
3. Remove sample container carefully so as not to spill contents (container does not have a tight lid). If sample is present then label sample bottle(s) (see sample coding procedure below) appropriately and collect sample (step 4), otherwise go to step 6.
4. Secure lid of container and shake contents, then pull into the 2-liter graduated cylinder. Record volume on log-sheet and then swirl cylinder before filling one sample bottle (note field duplicates are taken at the same time, see below schedule). If a field-filtered sample is to be collected, then put the appropriate volume of sample from the graduated cylinder into the field-filtering apparatus and collect the filtered sample.
5. If additional water remains in the container, then continue using the graduate cylinder to measure and record the total volume of water collected in the container.
6. Replace the empty container in the sample chamber and then connect the sample tube from the collection tray to the container. Secure the sample chamber lid.
7. Inspect paddlewheel sampler for clogging and be sure the wheel is spinning freely. Make any necessary repairs.
8. Collect a field duplicate sample once every ten samples, e.g. fill a second bottle for samplers 5, 15, 25, and 31 from the 2-liter graduated cylinder (see step 4) if every well has water in it, otherwise, just every tenth sample.
9. Collect an equipment blank sample just after the last field sample is collected using the normal rinse procedure for the graduated cylinder prior to sampling (see step 1).
10. Deliver all samples to the refrigerator located on site as soon as possible.

B. Collection from subsurface ground water (wells)

Equipment needed:

1. Pre-cleaned and acidified sample bottles (see 5 below if not pre-acidified). Approximately 80 bottles should be taken to field.
2. Tubing and well pump.
3. Measuring tape or well sounder for measuring water levels.
4. Four gallons of analyte-free water (de-ionized water).
5. H_2SO_4 acid if pre-acidified sample bottles are not provided. It is anticipated that most bottles will come from the laboratory with the required preservatives already in the bottle. If this is the case, great care should be exercised so the bottles do not tip over and that the lids are secure. If the sample bottle does not contain the acid preservative, then H_2SO_4 will need to be added to samples that will be analyzed for TKN, nitrate + nitrite, ammonia, and total P. Concentrated H_2SO_4 should be added to the samples until the pH of the samples are < 2.0 using a litmus strip. Noting the volume of acid it takes to reach the proper pH will allow future additions of acid to be done using a constant volume.
6. Sample log-sheets.

Sampling Procedure:

1. Upon arrival at site, take one equipment blank sample, i.e. rinse pump and tubing with analyte-free water then pump 125 ml of analyte-free water from a clean bottle to a sample bottle. If field filtering is being done, then place 125 ml of analyte-free water in the field-filtering apparatus and collect sample. A second equipment blank(s) is to be taken at the completion of sampling following a normal rinse procedure for the graduated cylinder and field-filtering apparatus.

2. Note any unusual occurrences at the wells.

   Steps 3 through 7 are for well purging and water level measurements only. Note no samples are collected during this phase.

3. Measure water level in wells (from the same point on the top of the casings every time to the nearest 1/10th foot minimum) using either a measuring tape or well sounder. Record depth to water on log-sheet. Rinse tape or sounder with analyte-free water before and after use.
4. Lower suction tube of peristaltic pump so that the intake is approximately one half inch from the bottom of the well. Pump three well volumes from the well or until dry, which ever is less. Rinse pump and tubing with analyte-free water before and after use. To determine the well volume use the following formula $V=(0.041)(d^2)(h)$, where V is volume in gallons, d is well diameter in inches, and h is water depth in feet.
5. Measure water level and purge all wells prior to sampling.
6. Return to the first well purged to start sample collection. Maximum time between purging and sampling should be six hours.
7. If sufficient sample is available in well, label sample bottle (see label code requirements below) and collect sample by lowering the suction tube of peristaltic pump so that the intake is approximately one inch from the bottom of the well. It is critical that the tubing be rinsed with analyte-free water prior to being lowered into well. Start the pump and let at least 10 ml of sample go to waste prior to filling a temporary sample bottle (aliquot in this bottle is field filtered prior to being put into the labeled bottle) . If sufficient volume is available then additional water should be wasted prior to sampling. See item 5 under equipment above for acidification requirements. Once sufficient sample is drawn, turn off pump and remove tubing.

8. Use field filtering apparatus if filtering is required – filtering is required only if sample is cloudy or muddy. The filtering apparatus and temporary sample bottle must be raised with analyte-free water between uses.
9. Collect a field duplicate sample once every ten samples, e.g. fill a second sample bottle from every tenth well just after the primary sample is collected.
10. Collect an equipment blank sample after every twenty samples. This sample is collected after the normal rinse procedure for the pump and tubing (see step 1).
11. Rinse pump and tubing with analyte-free water before going to the next well and record sample data in log-sheet.
12. Deliver all samples to the refrigerator located on site as soon as possible or delivered directly to the UF laboratory in Ona.

C. Sample Preservation and Holding Times

Parameter	Container*	Preservation	Max Time	Min. Volume (ml)
Ammonia	P,G	Cool, 4°C, H_2SO_4 to pH<2	28 days	30
TKN	P,G	Cool, 4°C, H_2SO_4 to pH<2	28 days	30
Nitrate + Nitrite	P,G	Cool, 4°C, H_2SO_4 to pH<2	28 days	30
Phosphorus, TDP & total	P,G	Cool, 4°C, H_2SO_4 to pH<2	28 days	30
Phosphorous, ortho	P,G	Cool, 4°C, field filtered	48 hrs	30
Solids, total, dissolved, suspended, volatile	P,G	Cool, 4°C,	7 days	100

*P = Polyethylene, G=Glass

Sample preservation will be performed immediately upon collection and samples will be analyzed as soon as possible after collection (and always within the holding times shown).

The amount of H_2SO_4 to be added to preserved samples will be based on experience of laboratory personnel. Verification of correct pH will be done during the first sampling event for each sample source using narrow range pH paper. An aliquot of sample poured into a disposable container, or a dummy sample in a disposable container will be tested for proper pH. The laboratory will supply all acid, containers to store acid, and disposable squeeze droppers to measure and transfer acid. Fresh preservatives will be obtained prior to each sampling event. Acid will be added to samples in small increments until the desired pH is reached. The required volumes of acid will be recorded in the field notebook and used during future sampling events. After the initial visit, only one sample per each parameter will be checked unless an abnormal amount of acid had to be used during the initial testing. The same amount of acid will be added to appropriate equipment blanks as added to the corresponding sample.

All samples will be tightly sealed and placed in the refrigerator or into an ice chest that contains ice and bubble packaging to prevent breakage (if required). Each container will be placed upright, and surrounded with ice. A separate ice chest will be used for each site. The ice chest will periodically be drained of any melted ice, and additional ice will be added if necessary. After sampling is complete, or a separate segment is complete, the ice chest will be sealed with chain of custody tape, and will be shipped or transported by the project team to the lab.

D. Sampling Bottle Labeling

The following codes along with the date should be placed on each sample bottle:

Paddlewheel Sampler Code:

OPS for Okeechobee phosphorus study, P for paddlewheel, 1-32 for plots, date of sampling, repeated plot number for duplicate; E for experimental (Alcordo) runoff samplers.

Groundwater Sample Code:

OPS for Okeechobee phosphorus study, D for deep well, S for shallow well, 1-32 for plots, date of sampling, and repeated plot number for duplicate.

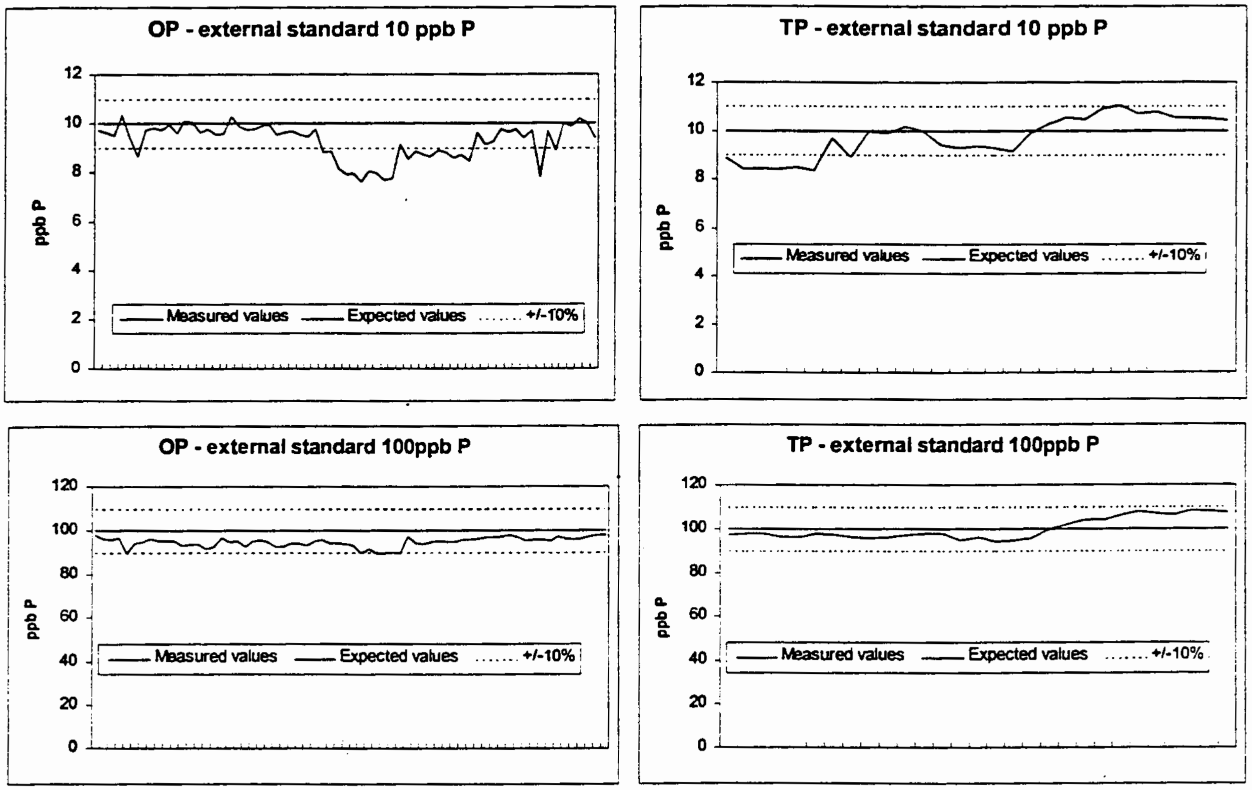
APPENDICES B: Quality Assurance: Chemical Analytical Procedures

QUALITY ASSURANCE: CHEMICAL ANALYTICAL PROCEDURES

Analytical QA/QC. Quality assurance checks were used to ensure analytical data quality for water samples analysis. Since the main objective of the study is P and its forms, special attention was paid to P determination. On the ALPKEM automated analyzer, sample reruns, external standards and spike samples were run every 20 samples. Detection and determination limits of the method were calculated from standard deviation results of a set of blank samples. For detection limit, the standard deviation was multiplied by 3; for determination limit by 10. Values obtained were 2.5 and 8.3 µg P L^{-1} or ppb for orthophosphate and 2.7 and 9.2 ppb for total phosphate.

Figure 1 shows results of measurements of external standards. For both orthophosphate and total P, values obtained from 100 ppb P standard are in the range 10 % of expected value, which means good accuracy. Data obtained from 10 ppb P standard in several cases dropped to about 80 % of expected value. This concentration is already close to the determination limit of 10 ppb P of the method, and achieving 80 % of expected value may be considered quite accurate.

Figure1. Results of external standards for dissolved ortho-P (OP) and total P (TP).



Duplicate measurements were consistent, with relative difference not exceeding 10 % for both OP and TP on most samples with concentrations higher than the determination limits of the methods. Slightly lower precision of the TP determination can be explained by possible additional errors that could have been introduced during digestion of samples and standards. At concentrations lower than determination limit of the method the precision decreased. This is well apparent on the graph for OP. Since the samples for rerun were selected randomly only a few samples with concentrations below the determination limit were measured twice for TP. Absolute differences between duplicate measurements did not exceed 5 ppb P for both P forms.

Effect of matrix composition on P measurement was assessed by measuring spiked samples, i.e. mixtures of a sample and a standard in 2:1 ratio. In most cases, observed concentration was in the range of 90 to 110 % of expected value, with an average 98.1 % for dissolved orthophosphate P and 95.9 % for total dissolved P. This means that the effect of matrix was not important; higher relative differences were recorded only on samples with low concentrations which resulted rather from lower measurement precision in this range as discussed above than from matrix effect.

Methods as QA/QC. A set of water samples from the reconstructed soil profile study were analyzed for P using different methods, namely, inductively coupled plasma (ICP), ion chromatography (IC), and the colorimetric methods for dissolved ortho-P (DOP or simply OP) and total dissolved P (TD-P or simply TP). The comparisons were made using leachates from shallow wells (high P levels), deep wells (medium P levels), and on bottom leachates (low P levels). The results are shown in Table 1.

For shallow well water samples, all four methods were closely correlated and their values, with the exception of ICP-P, were not significantly different. The ICP-P values differed from IC-P, OP, and TP with the probability of 0.05, 0.01, and 0.001, respectively. It was supposed that TP should be the highest and ICP-P should provide values close to it. Values for IC and the Mo-method for OP should correspond to each other since both determine the same P form and, if any other P forms were present, they should be lower than TP. It is surprising that the lowest values were obtained for TP. This can be attributed to increased errors introduced with dilutions needed to get to the desired measurement range and to the digestion of the samples which could lead easily to loss of samples. However, since there was no statistical difference between OP and TP values, this would mean that all or almost all P in the shallow well water samples was present in OP form.

The OP concentrations in water samples from deep wells and in bottom leachates were significantly lower than the TP which implies presence of some other important P forms. Phosphorus concentrations in these samples were low so that the less sensitive methods (ICP and IC) did not provide satisfactory results. This was shown by the poor correlation between ICP-P with OP or with TP. For ion chromatography, the concentrations were below detection limit so that the method yielded zero values.

Thus, it is concluded that the colorimetric method of Murphy and Riley (1962) for OP or TP analysis gave more reliable and accurate results for P determination at lower levels of P in water samples than inductively coupled plasma (ICP) method or ion chromatography (IC). The latter two methods, however, were also found reliable and accurate for water samples with high P concentrations which Table 1 indicates would be about 2.0 ppm P.

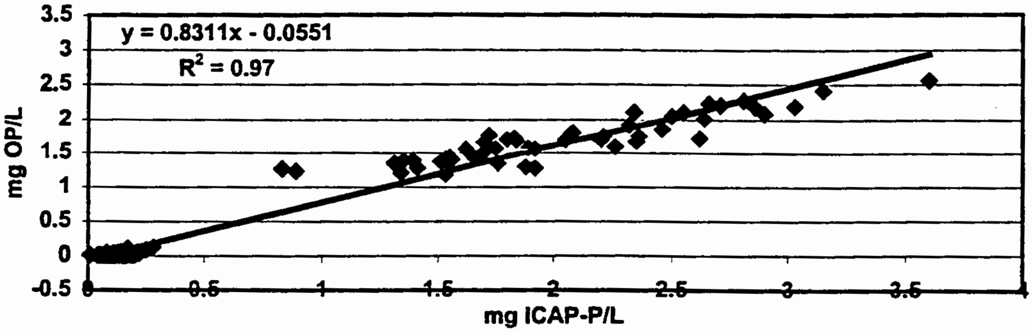
Table 1 Comparison and relationships of results of different methods for P determination: inductively coupled plasma (ICP), ion chromatography (IC), colorimetric method for dissolved orthophosphate P (DOP) and for total dissolved P (TDP); average content and correlation coefficients.

		ICP	IC	DOP	TDP
		Shallow wells leachates			
Average concentration, mg L^{-1}		2.85	2.35	2.25	2.03
Number of samples		37	37	37	37
Correlation coefficient	ICP	1.000			
	IC	0.927	1.000		
	DOP	0.950	0.871	1.000	
	TDP	0.892	0.839	0.947	1.000
		Deep wells leachates			
Average concentration, mg L^{-1}		0.19	0.00	0.040	0.068
Number of samples		45	45	45	45
Correlation coefficient	ICP	1.000			
	IC	-	-		
	DOP	0.487	-	1.000	
	TDP	0.425	-	0.703	1.000
		Bottom leachates			
Average concentration, mg L^{-1}		0.12	0.00	0.006	0.031
Number of samples		52	52	52	52
Correlation coefficient	ICP	1.000			
	IC	-	-		
	DOP	0.133	-	1.000	
	TDP	0.225	-	0.431	1.000

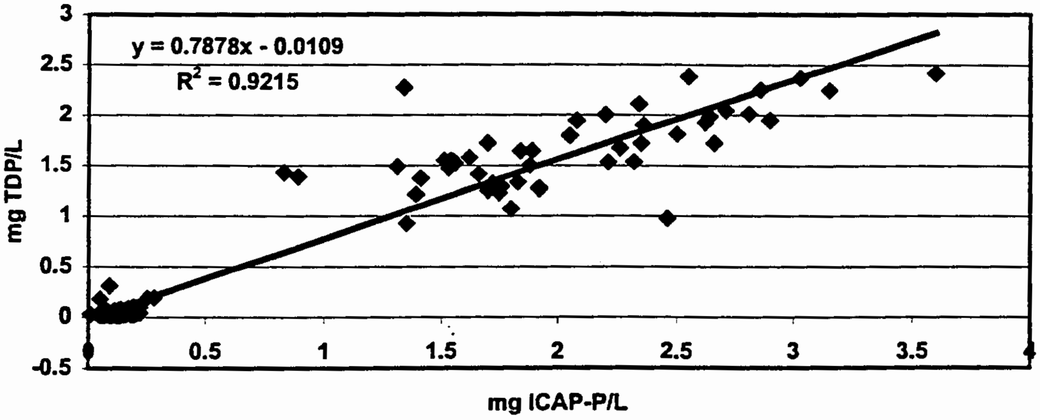
APPENDICES C: Relations Between OP, TP, and ICAP-P

Figure GS2. Relations between analytical forms of P in leachates from reconstructed soil profile of Immokalee fine sand planted to stargrass fertilized at 50 kg P/ha, all Ca amendments and depths.

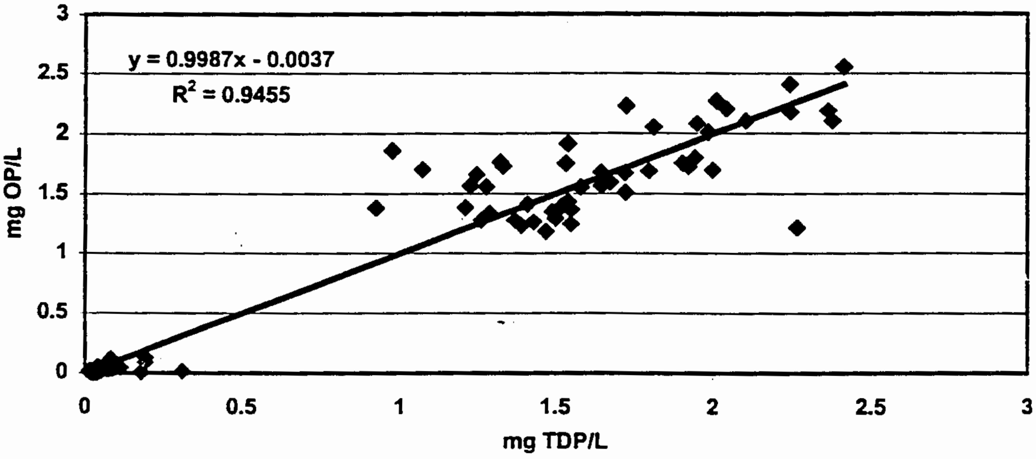
ICAP-P versus Ortho-P (OP)



Total dissolved P (TDP) versus ICAP-P



Ortho-P (OP) versus Total dissolved P (TDP)



APPENDICES D: Quality Assurance Samples: Duplicates

QUALITY ASSURANCE SAMPLES - Duplicates

Sample ID	Date	ph	Electric Conductivity	OP (ppb P)	TP (ppb P)
Paddle Wheel Data					
20	6/21/99	6.8	27	94	81
20P2	6/21/99	6.7	26	23	31
	% Error	-0.01	-0.04	-0.76	-0.62
5	9/15/1999	7.5	211		
5P2	9/15/1999	7.3	215		
	% Error	-0.03	0.02		
10	9/15/1999	7.3	106		
10P2	9/15/1999	7.4	120		
	% Error	0.01	0.13		
15	9/15/1999	7	212		
15P2	9/15/1999	6.9	203		
	% Error	-0.01	-0.04		
25	9/15/1999	7	135		
25P2	9/15/1999	6.6	138		
	% Error	-0.06	0.02		
5	10/12/1999	7.5	106	1800	1627
5P2	10/12/1999	7.6	106	1742	1766
	% Error	0.01	0.00	-0.03	0.08
15	10/12/99			-	-
15P2	10/12/99			-	-
	% Error				
16	10/12/1999	7.5	125	1943	1997
16P2	10/12/1999	7.4	125		
	% Error	-0.01	0.00	-1.00	-1.00
25	10/12/1999	7.1	73	1372	1312
25P2	10/12/1999	7.1	72	1349	1272
	% Error	0.00	-0.01	-0.02	-0.03

Sample ID	Date	ph	Electric Conductivity	OP (ppb P)	TP (ppb P)
Paddle Wheel Data					
5	1/31/2000	-	-	-	-
5D2	1/31/2000	-	-	-	-
	% Error				
15	1/31/2000	-	-	-	-
15D2	1/31/2000	-	-	-	-
	% Error				
****					
25	1/31/00			1767.7	1971.6
25-2	1/31/00			-	-
	% Error				
5P	7/10/01			2204.0	1739.0
5P2	7/10/01				
	% Error			-1.00	-1.00
15P	7/10/01			1566.0	1195.0
15P2	7/10/01				
	% Error			-1.00	-1.00
16P	7/10/01			490.1	381.0
16P2	7/10/01				
	% Error			-1.00	-1.00
25P	7/10/01			778.1	643.3
25P2	7/10/01				
	% Error			-1.00	-1.00
5P	7/27/01			1302.0	
5P2	7/27/01			1369.0	
	% Error			0.05	
15P	7/27/01			795	
15P2	7/27/01			880	
	% Error			0.11	

Sample ID	Date	ph	Electric Conductivity	OP (ppb P)	TP (ppb P)
Paddle Wheel Data					
16P	7/27/01			1585	
16P2	7/27/01				
	% Error			-1.00	
25P	7/27/01			945	
25P2	7/27/01			1054	
	% Error			0.12	
5P	8/6/01			1326	
5P2	8/6/01			1468	
	% Error			0.11	
15P	8/6/01			....	
15P2	8/6/01			....	
	% Error				
16P	8/6/01			1820	
16P2	8/6/01			1896	
	% Error			0.04	
25P	8/6/01			643	
25P2	8/6/01			697	
	% Error			0.08	
14P	9/10/01			3018	
14P2	9/10/01			2211	
	% Error			-0.27	
26P	9/10/01			....	
26P2	9/10/01			2040	
	% Error				
5P	10/12/01			862	
5P2	10/12/01			1098	
	% Error			0.27	
5P	10/31/01			1230	
5P2	10/31/01			1157	
	% Error			-0.06	

Sample ID	Date	ph	Electric Conductivity	OP (ppb P)	TP (ppb P)
Paddle Wheel Data					
15P	10/31/01			1029	
15P2	10/31/01			908	
	% Error			-0.12	
25P	10/31/01			1647	
25P2	10/31/01			1559	
	% Error			-0.05	