2004

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COMMUNICATIONS IN SOIL SCIENCE AND PLANT ANALYSIS
Vol. 35, Nos. 7 & 8, pp. 975–990, 2004

Levels and Changes of Soil Phosphorus in Subtropical Beef Cattle Pastures

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ABSTRACT

Long-term pasture management is believed to change soil chemical properties, but little is known about whether pasture management, such as fertilizer application, grazing, or haying can initiate such change in sandy and well-drained subtropical beef pastures. The objective of this study was to investigate the long term effect of pasture management (grazing + haying, GZ + HY) on soil phosphorus (P) dynamics (levels and changes) in subtropical beef cattle pastures with bahiagrass (BG, *Paspalum notatum*) and rhizoma peanut (RP, *Arachis glabrata*) with (WP) or without (WNP) P

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DOI: 10.1081/CSS-120030573 0010-3624 (Print); 1532-2416 (Online)

fertilization in Brooksville, FL from 1988 to 2000. Soil P dynamics in Subtropical Agricultural Research Station (STARS) was significantly affected by P fertilization ($p \leq 0.001$) and pasture management ($p \leq 0.0001$). The soil P levels across years from the fertilized fields of $119.0 \pm 4.9\,mg\,kg^{-1}$ was significantly higher than those pasture fields with no P fertilization ($62.8 \pm 7.8\,mg\,kg^{-1}$). However, during the past 12 years, there was no P build up despite of the annual application of P-containing fertilizers in addition to the daily in-field loading of animal waste bi-products like fecals and urine. The average soil test values for P in STARS had declined by about 28.3%. The soil test values of P in BG-GZ was about 23% higher than that of BG-GZ + HY, suggesting that GZ followed by HY could have lowered levels of soil P. Soil testing program in the station should continue to measure the amount of soil P that is proportional to what is available to BG and RP, and also continue looking at alternative soil P tests that are better predictors of the loss and/or build up of total and dissolved P to soil and water systems.

Key Words: Phosphorus; Subtropics; Beef cattle; Pasture management; Phosphorus fertilization; Nutrient balance.

INTRODUCTION

Florida's grazinglands have considerable variability in soils, climate, and growing season, which not only affect the types of forage that can be grown, but also the overall environmental and biodiversity management. The role of how pasture management (stocking rate, grazing system, etc.) and fertilizer application affect nutrient dynamics and water quality in flatwood and ridge soils are issues of increasing importance to environmentalists, ranchers, and public officials in the state. Runoff from flatwood soils with high water tables can cause high losses of P.[1] Reduction of P transport to receiving water bodies has been the primary focus of several studies because P has been found to be the limiting nutrient for eutrophication in many Florida aquatic systems.[2–4]

The ability to determine the effect that differing fertility and grazing systems have on the levels and changes of soil P in subtropical beef cattle pastures will improve our understanding of P dynamics and cycling in soil system. Knowledge of the relationship of grazing intensity and the temporal and spatial accumulation of soil nutrients[5–7] is necessary for developing improved grazing management, which could be both economically and environmentally discreet. Nutrient dynamics in various agro-animal-ecosystems are continually evolving in response to changing management practices. Utilization of pastures through intensive grazing during fall may cause a buildup of mineralized soil nutrients when plant growth and nutrient uptake is slow.[8] Grazing animals affect the movement and utilization of nutrients through the soil and plant system, and thus on the fertility of pasture soils.[9,10] Grazing has been documented to modify both the magnitude and distribution of soil organic carbon, nitrogen, and phosphorus.[11–13] Intensive grazing may decrease the input of organic matter into soils in the immediate vicinity of individual plants and eventually reduce nutrient concentrations beneath plants by limiting availability of photosynthesis and/or merismatic tissues necessary for growth.[14,15]

Long-term pasture management is believed to change soil chemical properties, but little is known about whether pasture management, such as fertilizer application, grazing, or haying can initiate such change in subtropical beef pastures. A quantitative assessment of soil quality attributes may serve as an indicator of a soil's capacity for sustainable production of crops and animals in an economically sound, socially acceptable, and environmentally friendly manner.[16] The objective of this study was to investigate the effects of long term beef cattle (*Bos spp.*) grazing and haying systems along with P fertilization on the levels and changes of soil P in subtropical Florida.

MATERIALS AND METHODS

Study Sites and Description

The Subtropical Agricultural Research Station (STARS) is a cooperative research unit of the USDA-ARS and the University of Florida and is located seven miles north of Brooksville, FL. The station has three major pasture units with combined total area of about 1538 ha with 1295 ha in permanent pastures. Cattle used for nutritional, reproductive, and genetic research on the station include about 500 head of breeding females with a total inventory of about 1000 head of cows, calves, and bulls. Most of the soils at STARS can be described as well-drained, loamy, siliceous hyperthermic family of the Grossarenic Paleudults.[17] Forage production potential of the soils in the station is generally low to medium; the main limitation being droughtiness.

Table 1 shows some of the selected properties of surface (0–25 cm) soils in the pasture units of STARS. The average annual precipitation in the station was about 1262 mm with approximately half of this amount

Table 1. Selected properties of surface soil (0–25 cm) averaged within respective beef pasture field of STARS, Brooksville, FL.

Property	MS[a] (28.60–28.63°N; 82.36–82.38°W)	TY[b] (28.58–28.62°N; 82.26–82.29°W)	Average
Texture ($g\,kg^{-1}$)			
Sand	750	825	787.5
Silt	200	125	162.5
Clay	50	50	50.0
pH in water	6.27	6.38	6.32
Calcium ($mg\,kg^{-1}$)	1145.3	602.9	874.1
Magnesium ($mg\,kg^{-1}$)	97.9	88.8	93.4
Potassium ($mg\,kg^{-1}$)	79.0	48.0	63.4
Soil Organic C ($g\,kg^{-1}$)	3.4	3.5	3.45

[a]Values reported here are averages of the following paddocks (MS5, MS6, MS8, MS25, MS26, and MS27) in the Main Station (MS).
[b]Values reported here are averages of the following paddocks (TY1A, TY10, TY11, TY12, TY33, TY34, TY37, TY38, and TY39) in the Turnley (TY) unit.

occurring during mid-June through mid-September. The lowest average temperature of 14°C occurs during January, but frosts are frequent during the winter months. The highest average temperature occurs during August although highs in the mid-30°C range occur regularly from May through September.

Cattle production at the station is forage based with the tropical grass, BG, the predominant forage species (1295 ha). Most of the BG pastures have been established for over 30 years. The other major forage species (255 ha) is RP, a tropical legume with forage quality similar to alfalfa (*Medicago sativa*). Rhizoma peanut pastures are not pure stands of legume, but are mixtures with BG and bermudagrass (*Cynodon dactylon*). Most of the RP stands were planted between 1980 and 1990.

Pasture Management and Fertilization

Throughout the years, fertility and management practices at the station have been based on University of Florida recommendations as described by Chambliss[18] and Williams and Chambliss.[19] In general, all pastures were grazed during the spring of the year when normal drought conditions limit forage production. After the start of summer rainy season, pastures that were to be hayed were dropped out of the grazing cycle (usually starting in July) and forage growth allowed to accumulate for hay production.

Prior to about 1988, pasture fields with BG were fertilized in the spring with 90 kg N ha^{-1}, and 45 kg K_2O ha^{-1} (Table 2). At the beginning of 1990, all BG pasture fields that were included in the study received a reduced rate of N fertilization (76.5 kg N ha^{-1}). Rhizoma peanuts were fertilized annually with P (38.5 kg P_2O_5 ha^{-1}) and K (67.5 kg K_2O ha^{-1}) since establishment at TY pasture fields in 1988. Pastures in STARS were managed for grazing in the spring until July followed by haying in late summer/early fall of each year.

Soil Sampling and Soil Analyses

Soil analyses were conducted in 1988, 1997, and 2000. Soil samples were collected using a steel bucket type hand auger to a depth of 25 cm. Soil samples were air-dried and passed through a 2-mm mesh sieve prior to chemical extraction of soil P and other soil chemical properties. Soil chemical analyses were conducted at the University of Florida-Institute of Food and Agricultural Sciences Soil Testing Laboratory, Gainesville, FL. Soil P was analyzed following the procedures outlined in Mehlich 1 (0.05 N HCl in 0.025 N H_2SO_4) method.[20] Due to variation in land use as required by research projects and pasture establishment, only selected sets of pastures (grazed + hayed BG and RP) were included in our data analyses. These pastures are listed in Table 2.

Data/Statistical Analysis

The repeated measures of variance procedures (SAS PROC GLM) were used to test the effects of pasture location, pasture management, P fertilization and their interactions on soil P dynamics. The levels and changes of soil P (0–25 cm depth) were analyzed using the PROC GLM split-plot procedures of SAS[21] with pasture location (MS and TY) as the main plot while pasture management and P fertilization as the sub-plots. Where the *F*-test indicated a significant ($p \leq 0.05$) effect, means were separated following the procedures of least significant differences (LSD) and Duncan Multiple Range Test, DMRT.[21]

Table 2. Grazing management and fertilizer application in STARS, Brooksville, FL (1983–2000).

Pasture unit	Year	Sampling site	Forage type	N (kg ha^{-1} yr^{-1})	P_2O_5 (kg ha^{-1} yr^{-1})	K_2O (kg ha^{-1} yr^{-1})	Pasture mgt.
MS	1983–1989	MS25, MS26, MS27	BG	90	0	45	GZ
		MS5, MS6, MS8	RP	—	—	—	GZ + HY
	1990–1997	MS25, MS26, MS27	BG	76.5	0	0	GZ
		MS5, MS6, MS8	RP	0	38.8	67.6	GZ + HY
	1998–2000	MS25, MS26, MS27	BG	90	0	67.6	GZ
		MS5, MS6, MS8	RP	0	38.8	67.6	GZ + HY
TY	1983–1989	TY37, TY38, TY39	BG	90	0	45	GZ
		TY1A, TY10, TY11,TY12	BG	90	22.5	45	GZ + HY
		TY33, TY34	RP	0	38.8	67.6	GZ + HY
	1990–1997	TY37, TY38, TY39	BG	76.5	0	0	GZ
		TY1A, TY10, TY11,TY12	BG	76.5	0	0	GZ + HY
		TY33, TY34	RP	0	38.8	67.6	GZ + HY
	1998–2000	TY37, TY38, TY39	BG	76.5	0	0	GZ
		TY1A, TY10, TY11,TY12	BG	76.5	0	0	GZ + HY
		TY33, TY34	RP	0	38.8	67.6	GZ + HY

BG—Bahiagrass.
RP—Rhizoma Peanuts.
GZ—Grazed Pasture.
HY—Hayed Pasture.

RESULTS

Soil P Levels

The levels of soil P in STARS were significantly affected by the different pasture management combinations ($p \leq 0.0001$) between pasture locations ($p \leq 0.05$) from 1988 to 2000 ($p \leq 0.01$). The average soil P level (across forage type and pasture management) in TY was 89.8 mg kg^{-1} and the soil P level in MS unit was 75.8 mg kg^{-1}. There was a significant decrease ($p \leq 0.05$) in soil P values over time in pasture units that were grazed only, but variable soil P values in pasture units that were grazed in early spring and hayed during the late summer/early fall (Fig. 1). Mean soil P level in 1988 (averaged across pasture locations and year) of 94.1 ± 41.9 mg kg^{-1} was not significantly different from the mean soil P in 1997 (80.8 ± 36.3 mg kg^{-1}), but significantly higher than soil P level in 2000 (69.2 ± 26.6 mg kg^{-1}).

The levels of soil P varied widely and significantly ($p \leq 0.001$) among the different pasture management combinations in MS and TY (Fig. 2). The soil P levels of pastures in MS (averaged across years) with RP that were grazed in spring and hayed (116.2 ± 42.1 mg kg^{-1}) in early fall were higher than those BG pastures (63.3 ± 17.7 mg kg^{-1}) that were grazed all year long. The soil test value of P in BG-GZ was about 23% higher than that of BG-GZ + HY, suggesting that grazing followed by haying of BG could have lowered the level of soil P in TY (Fig. 2). However, the average soil P levels did not vary significantly across location. The average levels of soil P in MS and TY with BG-GZ were 63.3 ± 17.7 mg kg^{-1} and 71.7 ± 14.5 mg kg^{-1}, respectively. The average soil P levels in MS with RP-GZ + HY was 116.2 ± 42.1 mg kg^{-1} compared with soil P levels in TY with RP-GZ + HY of 123.3 ± 26.7 mg kg^{-1}.

The levels of soil P in STARS beef cattle pastures with or without P fertilization from 1988 to 2000 are shown in Table 3. The levels of soil P between the fertilized and the unfertilized pastures were statistically different from each other in 1988 ($p \leq 0.001$), 1997 ($p \leq 0.0001$), and in 2000 ($p \leq 0.007$). The average level of soil P across pasture locations with P fertilization were 140.0 ± 40.9, 121.8 ± 33.9, and 95.2 ± 19.9 mg kg^{-1} compared with soil P levels from pasture fields with no P fertilization of 71.2 ± 15.5, 60.3 ± 11.6, and 56.2 ± 19.1 in 1988, 1997, and 2000, respectively. Levels of soil P in pasture fields with no P fertilization were consistently lower than those of the fertilized fields by about 49.1, 50.5, and 40.9% in 1988, 1997, and 2000, respectively (Table 3). The average of soil P across years from the fertilized fields of

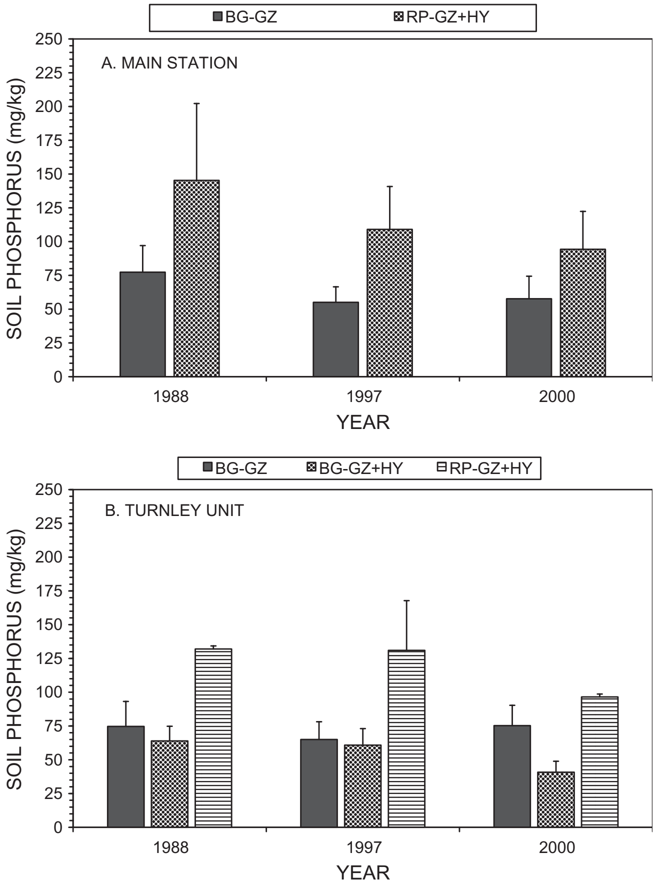

Figure 1. Soil P levels between pasture locations with bahiagrass and rhizoma peanut in STARS, Brooksville, FL from 1988 to 2000.

$119.0 \pm 4.9\,mg\,kg^{-1}$ was significantly higher than those pasture fields with no P fertilization ($62.8 \pm 7.8\,mg\,kg^{-1}$).

Changes in Soil P Levels (1988–2000)

During the last 12 years (1988–2000), soil test values for P in MS and TY have declined by about 17.6 and $10.8\,mg\,kg^{-1}\,yr^{-1}$, respectively (Fig. 3). The regression models that best describe the changes and/or

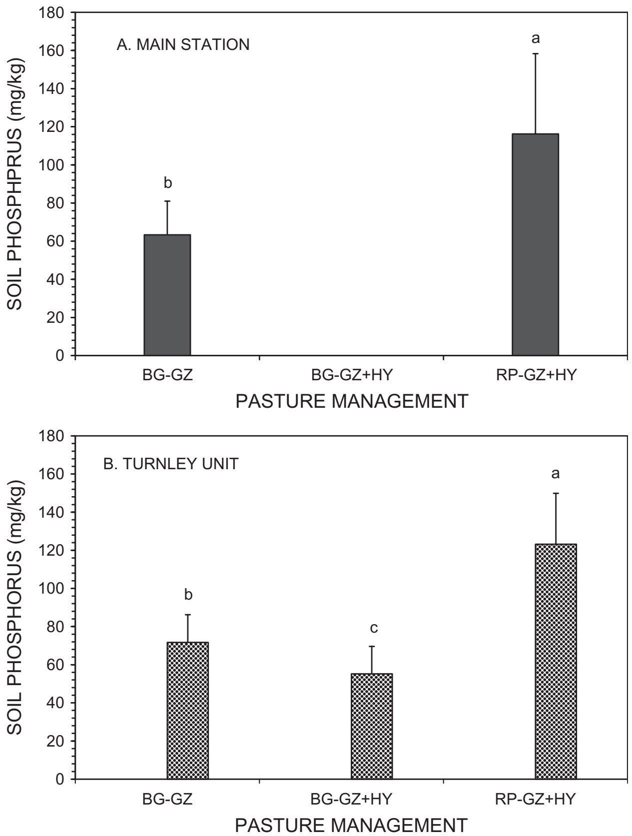

Figure 2. Comparative levels of soil P between pasture locations under different pasture management in STARS, Brooksville, FL.

Table 3. Levels of soil phosphorus in STARS beef cattle pastures with or without P fertilization from 1988 to 2000.

Fertilizer treatment	1988	1997	2000	Mean
With P fertilizer	140.0 ± 40.9a[a]	121.8 ± 33.9 a	95.2 ± 19.9a	119.0
No P fertilizer	71.2 ± 15.5b	60.3 ± 11.6 b	56.2 ± 19.1b	62.6
Mean	105.6	91.1	75.7	

[a]Means on each column followed by common letter are not significantly different from each other at $p \leq 0.05$.

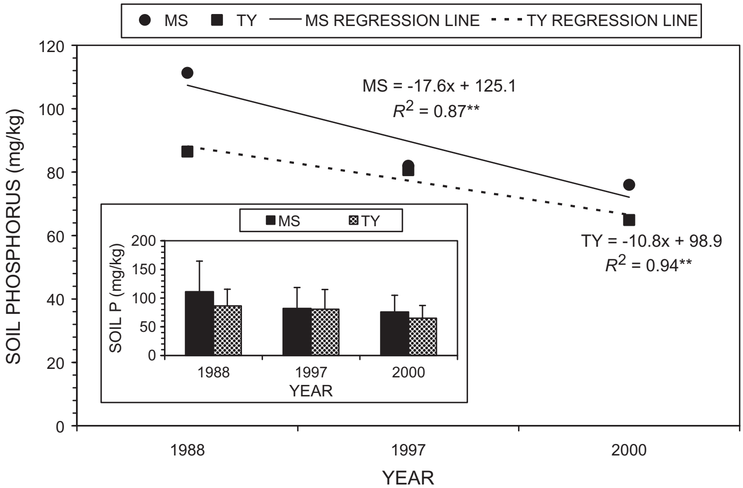

Figure 3. Changes in soil P levels from 1988 to 2000 from two pasture locations under different pasture management in STARS, Brooksville, FL.

depletion rate of soil P in MS and TY are given in Eqs. (1) and (2),

$$\text{Soil P}_{\text{MS}} = -17.6t + 125.1 \quad R^2 = 0.87^{**} \quad p < 0.001 \tag{1}$$

$$\text{Soil P}_{\text{TY}} = -10.8t + 98.9 \quad R^2 = 0.94^{**} \quad p < 0.001 \tag{2}$$

in which Soil P_{MS} and Soil P_{TY} = soil P depletion (mg kg^{-1} $year^{-1}$) in MS and TY and t = time (year). The average level of soil P in MS for 1988 was 111.3 ± 53.3 mg kg^{-1}, 82.0 ± 36.5 mg kg^{-1} in 1997, and 76.0 ± 28.8 mg kg^{-1} for 2000, while average soil P levels in TY for 1988, 1997, and 2000 were 82.7 ± 30.6, 80.0 ± 38.3, and 64.7 ± 25.8 mg kg^{-1}, respectively (Fig. 3).

Using the regression model in Fig. 3, the level of soil P in STARS was declining at the average rate of about 28.4 kg P ha^{-1} yr^{-1}, hence soil P build up is not likely to occur.

DISCUSSION

Results reported in this study can be interpreted in two ways, i.e., from the standpoint of pasture management and from the environmental point of view. Environmentally, soil P levels in STARS are declining. During the past 12 years, there was no P build up despite of the annual P fertilization. The average soil test values for P in MS and TY have declined by about $18\,mg\,kg^{-1}\,yr^{-1}$ and $11\,mg\,kg^{-1}\,yr^{-1}$, respectively.

Differences in soil P values among pastures with P fertilization may still not foreboding environmentally, but are important from a fertility management point of view. The average levels of soil P in 1988 of about $94.1\,mg\,kg^{-1}$ and in 2000 of about $69.2\,mg\,kg^{-1}$ were not high enough to be of environmental concern, so annual additions of P-fertilizer would be still practical to sustain plant and animal productivity in subtropical beef cattle pasture units. Losses of soil P by overland flow are becoming a big concern when the test values for soil P exceeded $330\,kg\,P\,ha^{-1}$ in the upper 20-cm of soil.[22] The risk of P export from land to water increases with increasing soil test P levels. Dissolved P concentrations in leachate have been shown to increase proportionally with soil test P levels.[23,24]

Changes in soil P levels in STARS from 1988 to 2000 were responsive and sensitive to P fertilization. The soil P values from the fertilized pastures with RP at any given year were always higher than the soil P values in the BG pastures with no P fertilization (Table 3). Pasture units with BG were fertilized only with nitrogen (N) containing fertilizers while pasture units with RP have continuously received P fertilizers annually from 1988 to 2000. The higher soil P values in pastures with RP can be attributed to the amount of P-containing fertilizers (e.g., 0-10-20; 20-5-10) applied to sustain its optimum growth and productivity. The average annual P application (1988 to 2000) on pasture fields with RP ranged from 22.5 kg to $38.8\,kg\,P_2O_5\,ha^{-1}\,yr^{-1}$. High levels of available P in soils are required in order to maintain the presence of N_2-fixing bacteria in pasture fields with RP.[10] Conversely, BG pastures in STARS with no P-fertilizer application received $225\,kg\,ha^{-1}$ of NH_4NO_3 or about $79\,kg\,N\,ha^{-1}$ annually. Adjie[25] claimed that N is the most limiting nutrient to warm-season grass production in Florida. Blue[26] reported that oven-dry forage yields of BG were 3 to $4\,Mg\,ha^{-1}$ without applied N and $12\,Mg\,ha^{-1}$ or more for $224\,kg\,N\,ha^{-1}$.

During the past 12 years, soil test values for P (average across locations, pasture management, and fertilizer treatments) have declined by about 28.3%. Rates of soil P depletion can be attributed to the different pasture management being practiced in STARS. The different pasture management practice would include grazing of pasture fields with BG and RP in spring until July followed by haying of pastures in late summer and early fall. It should be noted that P is not effectively removed from the forage system by grazing livestock. Nutrient removal is accomplished only by removing forage as hay crop and transporting the nutrient away from the application site. Grazing, for most part, recycles most the nutrient back into the forage system. Continued use of fertilizer under grazed-only systems will lead to increased nutrient accumulation at that site. Grazed-only system will not effectively remove nutrients from an application site since most of the applied nutrients, especially P and K, are recycled to the land during the grazing process.[27,28] The combined grazing in spring and haying in early fall can be considered a good pasture management in maintaining nutrient balance in the pasture fields, thereby avoiding negative impact to the environment.

Forage production potential of the soils in the research station is generally low to medium; the main limitation being droughtiness as shown by the number of months having higher negative departures from a 50-year rainfall average in STARS especially in 2000. In 2000, negative monthly departures ranging from -20 to -100 mm were observed in the months of Jan.–May, Aug.–Oct. The drought conditions and low levels of soil moisture in STARS may have pronounced effect on the P uptake of RP and BG and on the levels and changes of soil P. Forage crops like RP and BG in STARS with less adequate soil moisture will take up small fraction of added soil P as fertilizer and tend to take up less in succeeding year, and it may be still less in the following years, resulting in soil P build up with time. The ideal ion uptake is a function of available and adequate soil moisture.[29]

Phosphorus is a relatively immobile element in the soil and does not move much with the soil water. Placement and rate of application of P-fertilizer in the soil zone that is moist will enhance plant uptake. Soil P from a P-fertilizer only move very slowly from where the fertilizer has been placed, unless the soil is cultivated or disturbed because of the very low solubility of applied soil P. Because of the inherent low solubility of soil P coupled with very low soil moisture in STARS pasture units, annual build up of residual P or high levels of P in the soil is likely to occur. Large portion of applied P can be "tied up" by soil iron, aluminum, and calcium. The average levels of calcium (mg kg^{-1}) in MS and TY were 1145.3, and 602.9, respectively (Table 1). Phosphorus accumulation may occur when minerals in the soil have the ability to bind or hold them. Sandy or silty soils or soils with near-neutral pH do not bind or hold much phosphorus. The type of soil in the station, which is high in sand or quartz materials, ranging from 750 to 825 g kg^{-1}, has only a limited capacity to convert insoluble forms of P to soluble forms to establish soil's pool of labile phosphate at a definite thermodynamic potential.

SUMMARY AND CONCLUSIONS

The overall results and observations in this study could be briefly summarized as follows:

1. Environmentally, soil P levels in STARS are declining. During the past 12 years, there was no P build up in STARS despite of the annual application of P-containing fertilizers in addition to the daily in-field loading of animal waste bi-products (fecals, urine, etc.). The average soil test values for P in STARS have declined by about 28.3%.
2. Levels and changes in soil P levels in STARS from 1988 to 2000 were responsive and sensitive to P fertilization. Levels of soil P in pasture fields with no P fertilization were consistently lower than those of the fertilized fields by about 49.1, 50.5, and 40.9% in 1988, 1997, and 2000, respectively.
3. Differences among the pasture units for soil P may still not of particular concern environmentally, but are important from a fertility management point of view. The levels of soil P in 1988 of about 94.1 $mg\,kg^{-1}$ and in 2000 of about 69.2 $mg\,kg^{-1}$ were not high enough to be of environmental concern, so annual additions of P-fertilizer would be still practical to sustain plant and animal productivity in subtropical beef cattle pasture units. Losses of soil P by overland flow are becoming a big concern when the test values for soil P exceeded 330 $kg\,P\,ha^{-1}$ in the upper 20-cm of soil.

Results of this study have brought up a renewed focus on substantially improving the fertilizer efficiency in subtropical beef pasture, so that we can maximize benefits from every unit of fertilizer applied to the soil. Soil testing program in the station should continue to measure the amount of soil P that is proportional to what is available to BG and RP, and also continue looking at alternative soil P tests that are better predictors of the loss and/or build up of total and dissolved P to soil and water systems. Maintaining a balance between the amount of nutrients added to the soil as manure and fertilizer and the amount of nutrients removed as forages, hay, or livestock is critical for productive crop growth and water quality protection. If more nutrients are added that can be used for productive forage growth, nutrients will build up in the soil, creating high risk for runoff and water contamination.

ACKNOWLEDGMENTS

The authors wish to express their sincere thanks and appreciation to Dr. Nick Z. Saliendra, Plant Physiologist, USDA-ARS, Forage and Range Research Laboratory, Logan, Utah and to Dr. Hari Pant, Research Associate, Dept. of Soil and Water Sciences, University of Florida, Gainesville, FL for reviewing the manuscript. Special thanks are also extended to Ms. Kirstin D. Foulks (USDA-ARS) for her technical assistance, especially in the compilation of data and to Mr. Lee Adams (USDA-ARS) for his assistance in providing the historical fertilizer information.

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