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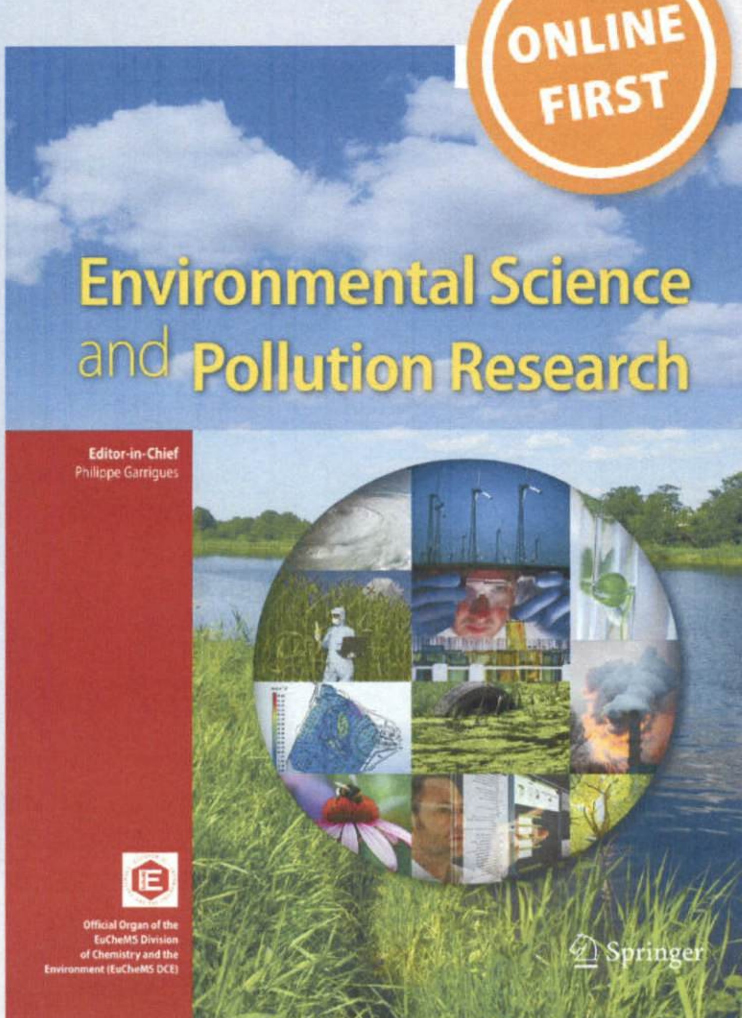

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RESEARCH ARTICLE

Soil-extractable phosphorus and phosphorus saturation threshold in beef cattle pastures as affected by grazing management and forage type

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Abstract Grazing can accelerate and alter the timing of nutrient transfer, and could increase the amount of extractable phosphorus (P) cycle from soils to plants. The effects of grazing management and/or forage type that control P cycling and distribution in pasture's resources have not been sufficiently evaluated. Our ability to estimate the levels and changes of soil-extractable P and other crop nutrients in subtropical beef cattle pastures has the potential to improve our understanding of P dynamics and nutrient cycling at the landscape level. To date, very little attention has been paid to evaluating transfers of extractable P in pasture with varying grazing management and different forage type. Whether or not P losses from grazed pastures are significantly greater than background losses and how these losses are affected by soil, forage management, or stocking density are not well understood. The objective of this study was to evaluate the effect of grazing management (rotational versus "zero" grazing) and forage types (FT; bahiagrass, *Paspalum notatum*, Flugge versus rhizoma peanuts, *Arachis glabrata*, Benth) on the levels of extractable soil P and degree of P saturation in beef cattle pastures. This study (2004–2007) was conducted at the Subtropical Agricultural Research Station, US Department of Agriculture–Agricultural Research Service located 7 miles north of Brooksville, FL. Soil (Candler fine sand) at this location was described as well-drained hyperthermic uncoated Typic Quartzipsamments. A split plot arrangement in a completely randomized block design was used and each treatment was replicated four times. The main plot was represented by grazing management (grazing vs. no grazing) while forage types (bahiagrass vs. perennial peanut) as the sub-plot treatment. Eight steel exclosures (10×10 m) were used in the study. Four exclosures were placed and established in four pastures with bahiagrass and four exclosures were established in four pastures with rhizoma peanuts to represent the "zero" grazing treatment. The levels of soil-extractable P and degree of P saturation (averaged across FT and soil depth) of 22.1 mg kg^{-1} and 11.6 % in pastures with zero grazing were not significantly ($p \leq 0.05$) different from the levels of soil-extractable P and degree of P saturation of 22.8 mg kg^{-1} and 12.9 % in pastures with rotational grazing, respectively. On the effect of FT, levels of soil-extractable P and degree of P saturation were significantly higher in pastures with rhizoma peanuts than in pastures with bahiagrass. There was no net gain of soil-extractable P due to the presence of animals in pastures with rotational grazing. Averaged across years, soil-extractable P in pastures with rotational grazing and with "zero" grazing was less than 150 mg kg^{-1}, the water quality protection. There had been no movement of soil-extractable P into the soil pedon since average degree of P saturation in the upper 15 cm was 14.3 % while the average degree of P saturation in soils at 15–30 cm was about 9.9 %. Overall, average extractable P did not exceed the crop requirement threshold of 50 mg P kg^{-1} and the soil P saturation threshold of 25 %, suggesting that reactive P is not a problem. Our study revealed that rhizoma peanuts and bahiagrass differ both in their capacity to acquire nutrients from the soil and in the amount of nutrients they need per unit growth. Rhizoma peanuts, which are leguminous forage, would require higher amounts of P compared with bahiagrass. The difference in the amount of P

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needed by these forages could have a profound effect on their P uptake that can be translated to the remaining amount of P in the soils. Periodic applications of additional P may be necessary especially for pastures with rhizoma peanuts to sustain their agronomic needs and to potentially offset the export of P due to animal production. Addition of organic amendments could represent an important strategy to protect pasture lands from excessive soil resources exploitation.

Keywords Beef cattle pastures · Degree of soil phosphorus saturation · Forage type · Phosphorus · Rotational grazing · Subtropical · Zero grazing

Introduction

While adequate levels of phosphorus (P) soils are essential to grow crops, P has the potential to induce eutrophication in our water systems. Accumulation of P can result in soils of areas where fertilizers and/or manure applied in excess of the amount required for optimum plant growth. This accumulation increases the potential for loss of P from soil and transport to water and subsequently, the eutrophication of water bodies (Indiati and Sequi 2004). Recent assessments of water quality status have identified eutrophication as one of the major causes of water quality "impairment" not only in the USA, but also around the world (Sigua 2010). Phosphorus is considered to be the limiting nutrient in most freshwater ecosystems (Sundareshwar et al. 2003; Sondregaard and Jeppesen 2007). Controlling P inputs is thus considered the key to reducing eutrophication and managing ecological integrity (Daniel et al. 1998). In most cases, eutrophication has accelerated by increased inputs of P due to intensification of crop and animal production systems since the early 1990s. Cattle manure contains appreciable amounts of nitrogen and P (0.6 and 0.2 %, respectively), and portions of these components can be transported into receiving waters during severe rainstorms (Khaleel et al. 1980). Forage-based animal production systems with grazing have been suggested as one of the major sources of non-point source of P pollution that are contributing to the degradation of water quality in lakes, reservoirs, rivers, and ground water aquifers (Sigua et al. 2006a, b; Edwards et al. 2000; Bogges et al. 1995).

Grazing animals have a dominant effect on the movement and utilization of nutrients through the soil and plant system, and thus on the fertility of pasture soils (Haynes and Williams 1993; Haynes 1981). Grazing can accelerate and alter the timing of nutrient transfers and increase the amount of nutrients cycled from plant to soil (Klemmedson and Tiedemann 1995). The ability to determine the effect that differing fertility and grazing systems have on the levels and changes of soil-extractable P in subtropical beef cattle pastures will improve our understanding of P dynamics and cycling in the soil system. Knowledge of the relationship of grazing intensity and the temporal and spatial accumulation of soil nutrients (Kelly et al. 1996; Franzluebbers et al. 2000; Mapfumo et al. 2000) 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 build-up of mineralized soil nutrients when plant growth and nutrient uptake is slow (Baron et al. 2001). Grazing animals affect on the movement and utilization of nutrients through the soil and plant system, and thus on the fertility of pasture soils (Haynes and Williams 1993). Grazing has been documented to modify both the magnitude and distribution of soil organic carbon, nitrogen, and P (Ruess and McNaughton 1987; Kieft 1994, Kieft et al. 1998). 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 meristematic tissues necessary for growth (Milchunas and Lauenroth 1993; Briske and Richards 1995).

The greatest environmental concern with many grazing areas in Florida is the level of soil-extractable P due to P accumulation in soil, and the subsequent loss of sediment-bound and soluble P in runoff. Available soil-extractable P in various agro-ecosystems is regulated by climate, soil type, vegetation, and management practices. Our ability to estimate the levels and changes of soil-extractable P and other crop nutrients in subtropical beef cattle pastures has the potential to improve our understanding of P dynamics and nutrient cycling at the landscape level. Relatively, little information exists regarding possible magnitudes of P losses from grazed pastures. Whether or not P losses from grazed pastures are significantly greater than background losses and how these losses are affected by soil, forage management, or stocking density are not well understood (Gary et al. 1983; Edwards et al. 2000; Sigua et al. 2004, Sigua et al. 2006a).

Understanding cattle movement in pasture situations is critical to understanding their impact on agro-ecosystems. Movement of free-ranging cattle varies due to spatial arrangement of forage resources within pastures (Senft et al. 1985) and the proximity of water (Holechek 1988, Ganskopp 2001), minerals (Martin and Ward 1973), and shade to grazing sites. A long-term quantitative assessment of soil chemical properties 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 (Lemunyon and Gilbert 1993; Sharpley et al. 1996). Critical to determining environmental balance and accountability is an understanding of P from inorganic fertilizers, P excreted, P removal by plants, and acceptable losses of soil-extractable P within the manure management and crop production systems and export of P off-farm.

One of the first steps in assessing the P level on any farm is to consider total P inputs and outputs. Very little attention to date has been paid to evaluating transfers of P in pasture with varying grazing management and different forage (Sigua et al. 2009). Characterizing how nutrients vary across pastures is important to understanding how soil nutrients' availability is controlling net primary productivity. Therefore, assessing the concentration and saturation of soil-extractable P in relation to animal grazing with different types of forages is critical for predicting rates of ecosystem processes and environmental stability. We hypothesized that the levels of soil-extractable P and degree of soil P saturation are not affected by grazing management. To verify our hypothesis, we examined the comparative concentrations of P and saturation of soil P from inside and outside animal exclosures in pastures located in Brooksville, Florida. The objective of this study was to evaluate the effect of grazing management (zero grazing versus rotational grazing) on the levels of Mehlich-1 extractable soil P and degree of P saturation in beef cattle pastures with bahiagrass and rhizoma peanuts.

Materials and methods

Site description

This study (2004–2007) was conducted at the Turnley Unit (28.62°N; 82.29°W) of the Subtropical Agricultural Research Station, United States Department of Agriculture-Agricultural Research Service located 7 miles north of Brooksville, FL. Soil (Candler fine sand) at this location was described as well-drained hyperthermic uncoated Typic Quartzipsamments (Hyde et al. 1977). Table 1 shows some of the selected properties of surface soils (0–20 cm) at the study sites.

Table 1 Selected properties of surface soil (0–20 cm) averaged within respective beef cattle pasture field with bahiagrass and peanuts in Brooksville, FL

Property	Turnley Research Unit (28.58–28.62°N; 82.26–82.29°W)
Texture, g kg^{-1}	
Sand	825
Silt	125
Clay	50
Bulk Density, g cm^{-3}	1.46
pH in water	6.38
Calcium, mg kg^{-1}	602.9
Magnesium, mg kg^{-1}	88.8
Potassium, mg kg^{-1}	48.0
SOC, g kg^{-1}	3.5

The research station has three major pasture units with a combined total area of about 1,558 with 1,295 ha in permanent pastures. Cattle used for nutritional, reproductive, and genetic research on the station include about 500 heads of breeding females with a total inventory of about 1,000 head of cows, calves, and bulls. Cattle production at the station is forage-based with bahiagrass as the predominant forage species (approx. 1,000 ha). Most of the bahiagrass pastures have been established for over 30 years. The highest average temperature occurs during August although highs in the mid-30 °C range occur regularly from May through September. The lowest average temperature of 14 °C occurs during January, but frosts are frequent during the winter months. The 3-year (2005–2007) monthly average rainfall distribution in the study site is shown in Fig. 1.

Pasture management: fertilization and grazing day intervals

Prior to about 1989, pasture fields with bahiagrass were fertilized in the spring with 90 kg N ha^{-1}, 22.5 P_2O_5 ha^{-1}, and 45 kg K_2O ha^{-1}. All bahiagrass pasture fields that were included in the study received a reduced rate of N fertilization (76.5 kg N ha^{-1}). At the beginning of the 1990s, bahiagrass pastures were fertilized annually in the early spring (March) with 77 kg N, 10 kg P, and 37 kg K ha^{-1} based on the revised fertilizer recommendation suggested by Chambliss (1999). Rhizoma peanuts pastures included in the study were fertilized annually with P (38.5 kg $P_2O_5ha^{-1}$) and K (67.5 kg K_2O ha^{-1}).

Historically, grazing cattle were rotated among pastures to allow rest periods of 2–4 weeks based on herbage mass. The timing of movement for rotationally grazed cattle was determined by the herd manager's perception of herbage mass based on plant height and not based on pasture measurement (Williams and Hammond 1999). Starting in 2000, cattle were rotated twice weekly (3- or 4-days grazing period). We anticipated 24 days of rest between pastures. During this study, the average number of 3.2 cow–calf pair ha^{-1} grazed each pasture for about 10 days each month. Table 2 shows the average number of days grazed for each month (4 years average). This cattle grazing rotation yielded an average annual total manure excretion of about 9,347 kg ha^{-1} or about 17.8 kg ha^{-1} of total P from manure excretions (Sigua et al. 2010).

Pasture exclosures and experimental design

A split plot arrangement in a completely randomized block design was used and each treatment was replicated four times. The main plot was represented by grazing management (grazing vs. no grazing) while forage types (bahiagrass vs. perennial peanut–bahiagrass mixed) as the sub-plot treatment. Eight steel exclosures (10×10 m) were used in the study. Four exclosures were placed and established in four pastures with bahiagrass (T35, T36, T39, and T40) and four exclosures were established

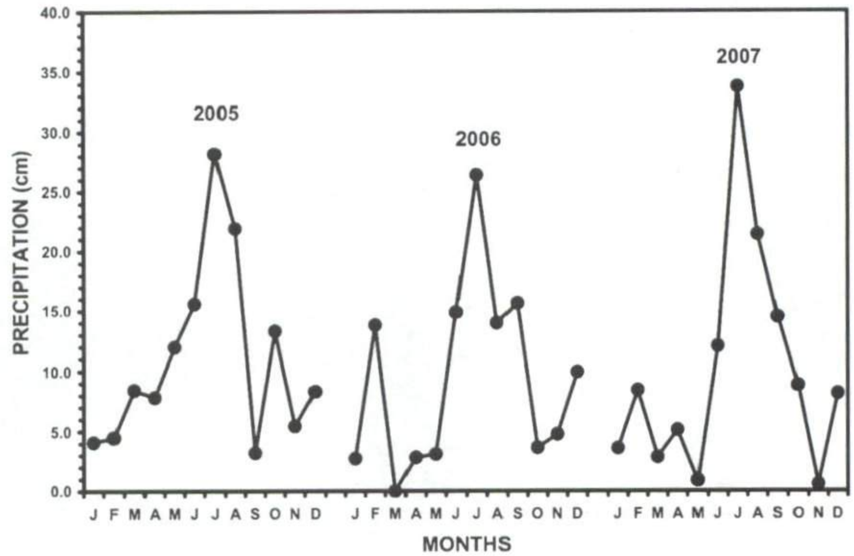

Fig. 1 Monthly rainfall distribution in the study area (2005–2007)

in selected four pastures with rhizoma peanuts (T31C, T32C, T33, and T35) to represent the "zero" grazing treatment. These exclosures were designated as "replications" in the analysis of variance.

Soil sampling, sample preparation and soil analyses

Composite soil samples (eight subsamples) were collected using a steel bucket type auger (6.6-cm diameter) at two soil depths: 0–15 and 15–30 cm from four sampling sites inside and four sampling outside of the exclosures in pastures with bahiagrass and rhizoma peanuts during the summer and fall seasons of 2004 to 2007, respectively. These sites were previously marked using a handheld Garmin GPS and were usually located at/or near the center of the four sides of the exclosures. A total of 256 soils samples were collected and analyzed from 2004 to 2007 (year=4; season=2; grazing management=2; forage type=2; soil depths=2; number of replications=4). Soil samples were air-dried and passed through a 2-mm mesh sieve prior to chemical extraction of soil total P. Soil P was extracted with double acid ($0.025N$ H_2SO_4+$0.05N$ HCl) as described by Mehlich (1953) and analyzed using an inductively coupled spectrophotometer. The degree of soil P saturation as described in Eq. 1 was computed using the P, Fe, and Al contents (mg kg^{-1}) of the soil (Hooda et al. 2000).

$$DPS(\%) = ([P] \times 100)/[Fe + Al] \quad (1)$$

Table 2 Monthly summary grazing activity at the study site

Months	Average days grazed per pasture	Average number of animals per ha	Animal Unit per month[1]
January	13.8	2.6	1.0
February	9.4	2.5	0.8
March	13.5	2.1	0.9
April	12.0	2.0	0.7
May	12.7	2.1	0.7
June	12.0	2.4	0.9
July	6.9	3.3	0.7
August	9.1	3.6	0.8
September	8.2	4.8	1.1
October	6.7	5.3	1.1
November	6.6	3.6	0.8
December	9.4	3.7	1.2
Average	10.0	3.2	
Totals	–	–	10.8

[1] Animal units per month (450 kg cow/calf unit)

Statistical analysis

Data were analyzed with a four-way ANOVA using PROC GLM (SAS Institute 2000). The model included year (Y), grazing management (GM), forage type (FT), and soil depth (D) effects. The pooled data (2004–2007) were tested initially for normality (SAS Institute, 2000). Where the F-test indicated a significant ($p \leq 0.05$) effect means were separated by calculation of least significant differences (LSD) using appropriate error mean squares.

Results and discussion

Soil-extractable P

There was a GM × FT interaction ($p \leq 0.001$) effect on the concentration of soil-extractable P (Table 3). The greatest concentration of soil-extractable P (26.14 mg kg^{-1}) was observed

Table 3 Analysis of variance (F values) on soil phosphorus, degree of P saturation, and plant phosphorus in forage-based pasture with cow–calf operation

Sources of variation	Soil phosphorus	Degree of phosphorus saturation
Among grazing management (GM)	0.44 NS	4.9 NS
Among forage types (FT)	93.6***	19.7***
Among soil depth (D)	46.3***	1.6 NS
Among years (Y)	7.56***	2.25*
GM × FT	7.72**	5.4*
GM × D	0.1 NS	0.4 NS
FT × D	0.2 NS	1.3 NS
GM × FT × D	1.1 NS	0.3 NS
GM × Y	0.59 NS	1.82 NS
FT × Y	14.51***	2.15*
D × Y	0.13 NS	0.32 NS
FT × D × Y	1.03 NS	0.27 NS
GM × FT × D × Y	0.62 NS	0.18 NS

NS not significant

***$p \leq 0.0001$ **$p \leq 0.001$ *$p \leq 0.01$

from rhizoma peanut pasture with rotational grazing while the lowest concentration of soil-extractable P (19.65 mg kg^{-1}) was from bahiagrass pasture with zero grazing (Fig. 2). Levels of extractable soil P was also significantly affected by FT × Y interaction (see Table 3). From 2004 to 2007, the yearly average levels of extractable soil P (averaged across GM, FT, and D) in pastures with rhizoma peanuts were showing a net decreasing trend while concentrations of soil-extractable P in pasture with bahiagrass were showing a net increasing trend (Fig. 3).

As stated above, the temporal trends (averaged across GM and D) of soil-extractable P concentrations varied significantly with forage type. The concentration of soil-extractable P decreased linearly with time (2004 –2007) in pastures with rhizoma peanuts while a slight linear increase in soil-extractable P in pastures with bahiagrass with time (see Fig. 3). These results could be well explained by the nutritional P needs for optimum growth of rhizoma peanuts and bahiagrass. These plants differ both in their capacity to acquire nutrients from the soil and in the amount of nutrients they need per unit growth. Rhizoma peanuts, which are leguminous forage, would require higher amounts of P compared with bahiagrass. The difference in the amount of P needed by these forages could have a profound effect on their P uptake that can be translated to the remaining amount of P in the soils. The regression models that described the relationships of soil-extractable P with time for pastures with rhizoma peanuts and bahiagrass are as follows: rhizoma peanut$=-2.21x+31.11$, $R^2=0.51^{**}$, n=32; Bahiagrass$=0.69x+17.69$ $R^2=0.36^{**}$, $n=32$.

Concentration of soil-extractable P was not affected by GM, but varied significantly among FT ($p \leq 0.0001$), D

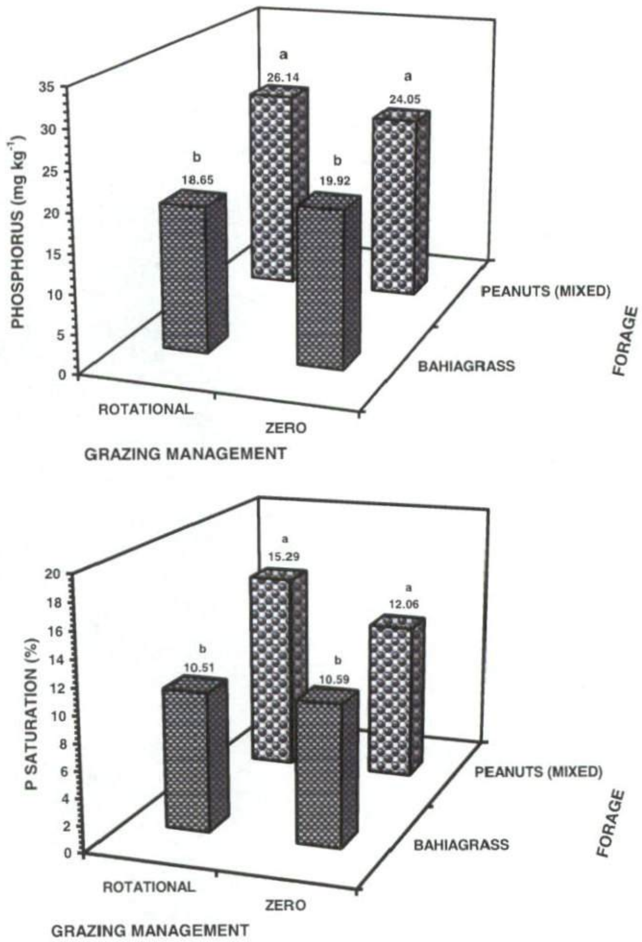

Fig. 2 Interaction effect of grazing management and forage types on soil P and degree of soil P saturation. Means of phosphorus and phosphorus saturation are significantly different ($p \leq 0.05$) when *superscripts* located at *top bars* are different

($p \leq 0.0001$), and Y ($p \leq 0.0001$). The levels of soil-extractable P (averaged across Y, FT, and D) of 22.1 mg kg^{-1} in pastures with zero grazing were not significantly ($p \leq 0.05$) different from the levels of soil-extractable P (22.8 mg kg^{-1}) in pastures with rotational grazing (Table 3). On the effect of FT, levels of extractable soil P were significantly higher in pastures with rhizoma peanuts (25.1 mg kg^{-1}) than in pastures with bahiagrass (19.3 mg kg^{-1}). The concentrations of extractable soil P at a soil depth of 0–15 cm (24.2 mg kg^{-1}) were significantly higher than the concentrations of extractable soil P (20.2 mg kg^{-1}) at a lower soil depth of 15–30 cm (Table 4). Average extractable P did not exceed the crop requirement threshold of 50 mg P kg^{-1} and the water quality protection threshold of 150 mg P kg^{-1}, suggesting that reactive P is not a problem. Concerns for losses of soil P by overland flow was noted when soil exceeded 150 mg kg^{-1} in the upper 20 cm of soil (Johnson and Eckert, 1995; Sharpley et al. 1996).

Soil-extractable P in our study was not affected by feces and urine deposition outside the exclosure or at the grazed

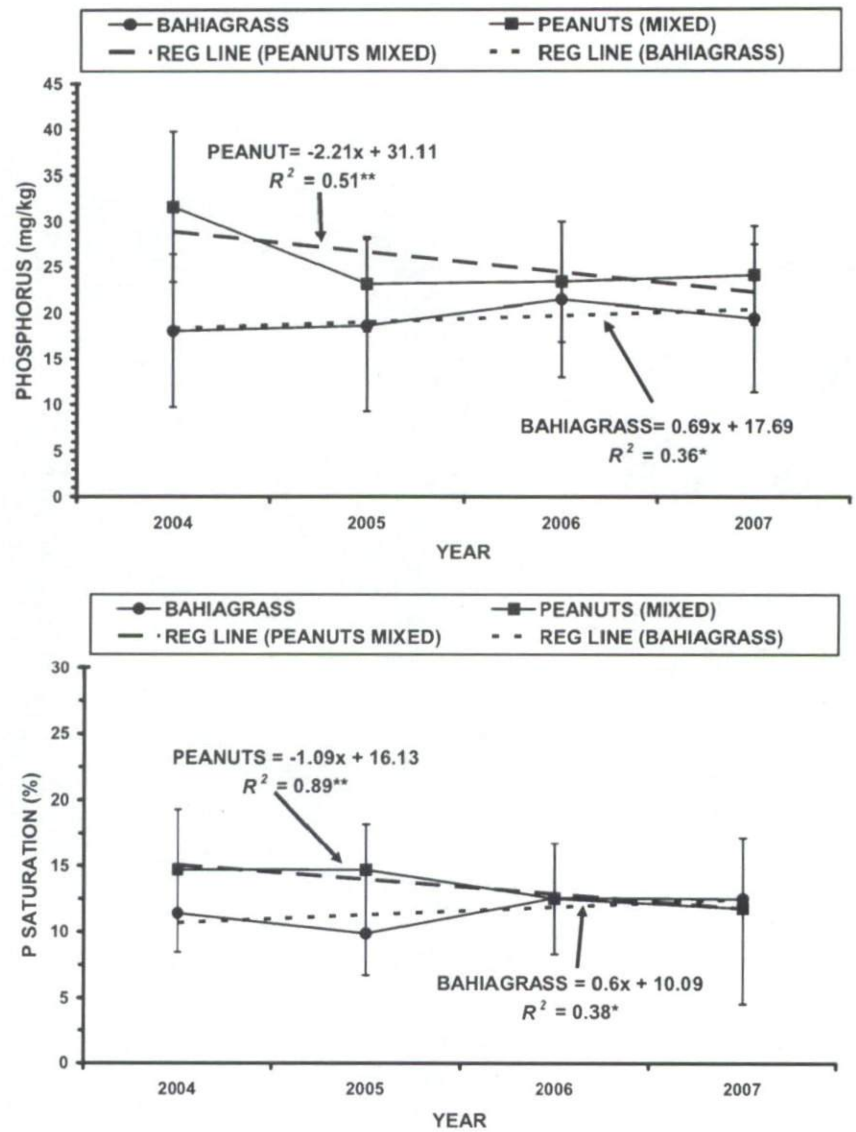

Fig. 3 Yearly average concentration of soil P and degree of soil P saturation in pastures with rhizoma peanuts and bahiagrass (2004–2007)

area. The area outside the exclosure is where animals tend to develop some hot spots in the pasture. Our results did not support the idea that grazed area was likely had the highest concentration of soil-extractable P. Soil-extractable P concentrations inside the exclosure or the "zero grazing treatment" were comparable ($p \leq 0.05$) with the concentrations of soil-extractable P in areas outside the exclosure or the "grazed areas" (see Table 4). Results from our study did not support our hypothesis that grazed areas may have greater amount of soil-extractable P because of urine and feces deposition than in areas with "zero" grazing. Early results of a study suggest that cattle congregation sites (e.g., water troughs, mineral feeders, and shaded areas) and/or grazed areas may not be as P-rich as previously thought and therefore may not contribute more P to surface and ground water (Sigua and Coleman 2007).

Grazing animals in our rotational grazing have a major role in the cycling of soil-extractable and are responsible for increasing or decreasing the rate at which soil-extractable P are cycled. By ingesting herbage, grazing animals encourage pasture plants to grow and therefore take up more nutrients from the soil (Floate 1970). Grazed areas may have intensive trampling that can substantially damage the main components of pasture and/or grassland systems (plants, soil structure, and soil biology). The effects of trampling on plant productivity, root growth, and physical soil properties have been studied (Cluzeau et al. 1992). Trampling during animal grazing may also lead to the destruction of soil aggregates, which could have some significant effects on the dynamics of soil-extractable P within the grazing area. Total destruction of soil aggregates within the grazed areas may result to mixing and spreading of P as a result of the separations among the different aggregate size that makes soil-extractable P more susceptible to surface runoff during rainfall events.

Our study revealed that rhizoma peanuts and bahiagrass differ both in their capacity to acquire nutrients from the soil

Table 4 Levels of soil P and degree of P saturation in pastures as affected by grazing management and forage types

Parameters	Number	Soil P (mg kg^{-1})	Degree of P saturation (%)
Year effect			
2004	128	24.8±11.5a[a]	13.1±5.7a
2005	252	20.9±7.9b	12.3±3.2ab
2006	128	22.5±7.6b	12.6±5.3a
2007	128	21.8±7.2b	10.4±5.7b
$LSD_{(0.05)}$		1.7	2.1
Grazing management			
Zero grazing	316	22.1±8.6a	11.6±5.6a
Rotational grazing	320	22.4±8.7a	12.9±4.1a
$LSD_{(0.05)}$		1.2	1.4
Forage type			
Bahiagrass	316	19.3±6.3b	10.6±3.9b
Peanut (mixed)	320	25.1±8.7a	13.7±4.5a
$LSD_{(0.05)}$		1.18	1.38
Soil depth			
0–15 cm	318	24.2±8.1a	14.3±7.8a
15–30 cm	318	20.2±8.8b	9.9±7.3b
$LSD_{(0.05)}$		1.17	1.28

[a] Means in columns within each subheading followed by common letter(s) are not significantly different from each other at $p \leq 0.05$

and in the amount of nutrients they need per unit growth (Table 5). Rhizoma peanuts, which are leguminous forage, would require higher amounts of P compared with bahiagrass. Phosphorus uptake varied significantly with FT ($p \leq 0.001$), but was not affected neither by GM and the interaction of FT and GM. The average P uptake of rhizoma peanuts at "zero grazing" and rotational grazing were 23.75±2.16 kg P ha^{-1} and 19.05±5.01 kg P ha^{-1}, respectively, compared with bahiagrass uptake of 6.78±2.34 kg P ha^{-1} and 6.99±3.01 kg P ha^{-1} for zero grazing and rotational grazing, respectively (Table 5). The difference in the amount of P needed by these forages could have a profound effect on their P uptake that can be translated to the remaining amount of extractable P in the soils.

Table 5 Dry matter yield and phosphorus uptake of bahiagrass and rhizoma peanuts under different grazing management

Grazing management	Forage type	Dry matter yield (kg ha^{-1})	Phosphorus uptake (kg ha^{-1})
Zero	Bahiagrass	3,068.12±1,256.62	6.78±2.34b[a]
	Peanuts	8,759.33±1,569.03	23.75±2.16a
Rotational	Bahiagrass	2,728.60±1,168.16	6.99±3.0b1
	Peanuts	6,507.32±1,858.63	19.05±5.01a
Sources of variations		*F* value	*F* value
Forage type (FT)		10.61**	13.82**
Grazing management (GM)		NS	NS
FT × GM		NS	NS

NS not significant

[a] Means within column followed by same letter are not significantly different at $p \leq 0.05$

**$p \leq 0.001$

Degree of P saturation in soils

The degree of P saturation was significantly affected by GM × FT interaction ($p \leq 0.01$) and FT × Y interaction ($p \leq 0.01$). Degree of P saturation in soils also varied significantly with FT ($p \leq 0.0001$) and Y ($p \leq 0.01$), but was not affected by GM and D (see Table 3). Soils from pasture with rhizoma peanut under rotational grazing had the greatest degree of P saturation (15.3 %) followed by soils in pasture with rhizoma peanut under zero grazing (12.1 %), soils from zero-grazed pasture with bahiagrass (10.6 %) and soils form pasture with bahiagrass under rotational grazing with an overall mean of 10.5 % (see Fig. 2). From 2004 to 2007, the yearly average degree of soil P saturation (averaged across GM, FT, and D) in pastures with rhizoma peanuts were showing a net decreasing trend while concentrations of soil-extractable P in pasture with bahiagrass were showing a net increasing trend (see Fig. 3). The net decreasing trend of soil P saturation in pasture with rhizoma peanut can be described by a linear equation: $16.1-1.1(x)$, R^2=0.89**, n=32 while the increasing trend of soil P saturation in pasture with bahiagrass was described by this equation: $10.1+0.6(x)$, R^2=0.38*, n=32. The difference in the degree of P saturation was affected by profound differences in the amount P uptake between bahiagrass and rhizoma peanuts. Again, study revealed that rhizoma peanuts and bahiagrass differ both in their capacity to acquire nutrients from the soil and in the amount of nutrients they need per unit growth. The average P uptake of rhizoma peanut and bahiagrass across grazing management were 21.4±3.5 and 6.9±2.7 kg ha^{-1}, respectively (Table 5).

The average degree of soil P saturation of 22.1 mg kg^{-1} in pasture with zero grazing was statistically comparable to the average degree of soil P saturation (22.4 mg kg^{-1}) in pasture with rotational grazing (see Table 4). Pasture with rhizoma peanut had higher degree of soil P saturation (13.7 %) than that of pasture with bahiagrass with average degree of soil P saturation of 10.6 % (see Table 4). The degree soil P saturation (averaged across GM, FT, and Y) at soil depth of 0–15 cm was about 14.3 % compared with 9.9 % degree of soil P saturation at lower soil depth (15–30 cm). The varying amount of Al and Fe among the different pastures with grazing treatment and different forage types may have had affected the spatial and temporal distribution of soil P saturation in our pastures.

Table 6 Comparative concentrations of Al and Fe among different pastures with different forage types as affected by grazing management

Year	Grazing management	Forage type	N	Aluminum (mg kg^{-1})	Iron (mg kg^{-1})
2004	Zero	Bahiagrass	32	165.16±40.34	1.63±0.62
		Peanuts	32	209.74±67.78	2.71±1.11
	Rotational	Bahiagrass	32	154.50±31.92	1.61±0.37
		Peanuts	32	248.91±60.70	2.73±0.94
2005	Zero	Bahiagrass	60	198.31±29.80	2.49±0.55
		Peanuts	64	218.11±43.82	2.34±0.76
	Rotational	Bahiagrass	64	186.62±31.52	2.32±0.47
		Peanuts	64	189.91±60.85	2.14±0.74
2006	Zero	Bahiagrass	32	176.43±22.68	2.29±0.61
		Peanuts	32	196.24±34.22	2.04±0.55
	Rotational	Bahiagrass	32	165.46±19.66	2.19±0.33
		Peanuts	32	195.13±29.47	2.12±0.54
2007	Zero	Bahiagrass	32	217.71±38.50	3.31±0.62
		Peanuts	32	243.12±72.43	2.85±0.85
	Rotational	Bahiagrass	32	220.82±35.69	3.16±0.43
		Peanuts	32	225.72±65.61	2.63±0.76
Source of variations				*F* values	*F* values
Year (Y)				25.53***	23.68***
Grazing management (GM)				5.18*	4.45*
Forage (FT)				59.69***	37.20***
Y × GM				4.52**	2.87*
Y × FT				13.79***	10.15***
GM × FT				0.04 NS	0.46 NS
Y × GM × FT				5.02**	5.38**

NS not significant

***$p \leq 0.0001$; **$p \leq 0.001$; *$p \leq 0.01$

Concentrations of Al and Fe in our study were affected significantly by year ($p \leq 0.0001$), grazing ($p \leq 0.05$), forage type ($p \leq 0.0001$) and the interactions of year *x* grazing *x* forage type (Table 6). Averaged across years, the concentrations of Al of 198.4 mg kg^{-1} in pastures with rotational grazing were comparable with the concentration of Al in pastures with zero grazing (203.10 mg kg^{-1}). Because of comparable concentrations of Al between the grazed pastures and "zero" grazed pastures, the degree of soil P saturations for these pastures was not significantly ($p \leq 0.05$) different from each other (see Table 4). Our results showed the effects of Al and Fe on soil P saturation and our observations are quite similar to the results reported earlier (Penn et al. 2005). The preference of P for Al over Fe may have resulted because the soil Al may be more saturated than Fe or because the soil Fe was more saturated in P than Al. Quantity–intensity relationships such as these have been used to identify change points in several studies (Sigua et al. 2011, Nair et al. 2004, Indiati and Sequi 2004, Maguire and Sims 2002, McDowell and Sharpley 2001).

The degree of soil P saturation has been suggested as an indicator for the risk of P loss from agricultural soils (Hooda et al. 2000; Maguire et al. 2001). Given the average degree of soil P saturation in pastures with zero grazing of 11.6 and 12.9 % for pastures with rotational grazing in our study, the degree of soil P saturation did not exceed the environmental threshold of P saturation. The degree of soil P saturation needs to exceed 60 % before any dissolved reactive P becomes an environmental problem (Hooda et al. 2000). Soil P saturation values from 25 to 40 % are generally associated with greater risk of P losses in leaching or overland flow (Paulter and Sims 2000). A degree of soil P saturation of 25 % or more has been established as a critical value, above which the potential for P losses through runoff and leaching become unacceptable (Breeuwsma et al. 1995). Our results do not even approach this level of soil P saturation, suggesting that P build-up and release is not a predicament in pastures with rotational grazing. Again, our results did not support the hypothesis that grazed areas may have greater soil P saturation compared with pastures with "zero" grazing.

Conclusions

Grazing and movement patterns of cattle are particularly valuable in allocating and assessing impacts of utilization on given pastures. Effective use and cycling of P is critical for pasture productivity and environmental stability. Overall, there was no net gain of soil-extractable P due to the presence of animals in pastures with rotational grazing. Averaged across years, soil-extractable P in pastures with rotational grazing and with "zero" grazing was less than 150 mg kg^{-1}, the threshold above which a crop production and environmental caution. There had been no movement of soil-extractable P into the soil pedon since average degree of P saturation in the upper 15 cm was 14.3 % while the average degree of P saturation in soils at 15–30 cm was about 9.9 %. Several studies have found that soil P saturation needs to exceed 45 to 60 % before reactive P becomes a problem. Our results do not even approach this level of soil P saturation, suggesting that P build-up is not a problem in grazed pasture or in pasture with zero grazing.

Our study further revealed that rhizoma peanuts and bahiagrass differ both in their capacity to acquire nutrients from the soil and in the amount of nutrients they need per unit growth. Rhizoma peanuts, which are leguminous forage, would require higher amounts of P compared with bahiagrass. The difference in the amount of P needed by these forages could have a profound effect on their P uptake that can be translated to the remaining amount of P in the soils. The use of the Mehlich-1 extraction for routine agronomic soil test would simplify the measurement of soil P saturation, and provide a more accessible analytical tool for P management. Periodic applications of additional P may be necessary especially for pastures with rhizoma peanuts to sustain their agronomic needs and to potentially offset the export of P due to animal production. Addition of organic amendments could represent an important strategy to protect pasture lands from excessive soil resources exploitation.

References

Baron VS, Dick AC, Mapfumo E, Malhi SS, Naeth MA, Chanasyk DS (2001) Grazing impacts on soil nitrogen and phosphorus under Parkland pastures. J Range Manage 54:704–710

Bogges CF, Flaig EG, Fluck RC (1995) Phosphorus budget basin relationships for Lake Okeechobee tributary basins. Ecol Eng 5:143–162

Breeuwsma A, Reijerink JGA, Schoumans OF (1995) Impact of manure on accumulation and leaching of phosphate in areas of intensive livestock farming. In: Steele L (ed) Animal waste and the land-water interface, 9th edn. Lewis Publ, Boca Raton, FL, pp 239–249

Briske DD, Richards JH (1995) Plant responses to defoliation: a morphological, physiological, and demographic evaluation. In: Bedunah DJ, Sonebee RE (eds) Wildland plants: physiological ecology and developmental morphology. Society for Range Management, Denver, pp 635–710

Chambliss CG (1999) Florida forage handbook. Univ. Florida Coop. Ext. Serv. SP253

Cluzeau D, Binet F, Vertes F, Simon JC, Riviere JM, Trehen P (1992) Effects of intensive cattle trampling on soil-plant-earthworms system in two grassland types. Soil Biol. Biochem 24(12):1661–1992

Daniel TC, Sharpley AN, Lemunyon JL (1998) Agricultural phosphorus and eutrophication: a symposium overview. J Environ Qual 27:251—257

Edwards DR, Hutchens TK, Rhodes RW, Larson BT, Dunn L (2000) Quality of runoff from plots with simulated grazing. J Am Water Resour Assoc 36:1063–1073

Floate MJS (1970) Decomposition of organic materials from hill soils and pastures. II. Comparative studies on the mineralization of carbon, nitrogen, and phosphorus from plant materials and sheep feces. Soil Biol Biochem 2:173–185

Franzluebbers AF, Stuedemann JA, Schomberg HH (2000) Spatial distribution of soil carbon and nitrogen pools under grazed tall fescue. Soil Sci Soc Am J 64:635–639

Ganskopp D (2001) Manipulating cattle distribution with salt and water in large arid-land pastures: a GPS/GIS assessment. Appl Anim Behav Sci 73:251–262

Gary HL, Johnson SR, Ponce SL (1983) Cattle grazing impact on surface water quality in a Colorado front range stream. J Soil Water Conserv 38(2):124–128

Haynes RJ (1981) Competitive aspects of the grass-legume association. Adv Agron 33:227–261

Haynes RJ, Williams PH (1993) Nutrient cycling and soil fertility in grazed pasture ecosystem. Adv Agron 49:119–199

Holechek JL (1988) An approach for setting stocking rate. Rangeland 10:10–14

Hooda PS, Rendell AR, Edwards AC, Withers PJ, Aitken MN, Truesdale VW (2000) Relating soil phosphorus indices to potential releases to water. J Environ Qual 29:1166–1171

Hyde AG, Law L Jr, Weatherspoon RL, Cheney MD, Eckenrode JJ (1977) Soil survey of Hernando County. Washington, DC and University of Florida, Gainesville, FL, p 152, FL. USDA-NRCS

Indiati R, Sequi P (2004) Phosphorus intensity-quantity relationships in soils highly contrasting in phosphorus adsorption properties. Commun Soil Sci Plant Anal 35:131–143

Institute SAS (2000) SAS/STAT user's guide. Release 6.03. SAS Institute, Cary, North Carolina, p 494

Johnson J, Eckert D (1995) Best management practices:cbrs Land application of animal manure. Agronomy facts AGF-208-95. The Ohio State Univ, Ext. Columbus, OH

Kelly RH, Burke IC, Lauenroth WK (1996) Soil organic matter and nutrient availability responses to reduced plant inputs in shortgrass steppe. Ecology 77:2516–2527

Khaleel R, Reddy KR, Overcash MR (1980) Transport of potential pollutants in runoff water from land areas receiving animal wastes: a review. Water Res 14:421–426

Kieft TL (1994) Grazing and plant-canopy effects on semiarid soil microbial biomass and respiration. Biol Fert Soils 18:155–162

Kieft TL, White CS, Loftin SR, Aguilar R, Craig JA, Skaar DA (1998) Temporal dynamics in soil carbon and nitrogen resources at a grassland-shurbland ecotone. Ecology 79:671–683

Klemmedson JO, Tiedemann AR (1995) Effects of nutrient stress. In: Bedunah DJ, Sosebee R (eds.) Wildland plants: physiological ecology and developmental morphology. Society of Range Management, Denver, pp 414–439

Lemunyon JL, Gilbert RG (1993) The concept and need for a phosphorus tool. J Prod Agric 6:483–486

Maguire RO, Sims JT (2002) Soil testing to predict phosphorus leaching. J Environ Qual 31:1601–1609

Maguire RO, Sims JT, Foy RH (2001) Long term kinetics for phosphorus sorption-desorption by high phosphorus soils from Ireland and the Delmarva Peninsula, USA. Soil Sci 166:557–565

Mapfumo E, Chansynk DS, Naeth MA, Baron VS (2000) Grazing impacts on selected soil parameters under short term forage sequences. J Range Manage 53:466–470

Martin SC, Ward DE (1973) Salt and meal-salt help distribute cattle use on semi-desert range. J Range Manage 26:94–97

McDowell RW, Sharpley AN (2001) Approximating phosphorus release from soils to surface runoff and subsurface drainage. J Environ Qual 30:508–520

Mehlich A (1953) Determination of P, Ca, Mg, K, Na, and NH_4. North Carolina soil test division. Mimeo, Raleigh, NC

Milchunas DG, Lauenroth WK (1993) Quantitative effects of grazing on vegetation and soils over a global range of environments. Ecol Monogr 63:327–366

Nair VD, Portier KM, Graetz DA, Walker ML (2004) An environmental threshold for degree of phosphorus saturation in sandy soils. J Environ Qual 33:107–113

Paulter MC, Sims JT (2000) Relationships between soil test phosphorus, soluble phosphorus, and phosphorus saturation in Deleware soils. Soil Sci Soc Am J 64:765–773

Penn CJ, Mullins GL, Zelazny LW (2005) Mineralogy in relation to phosphorus sorption and dissolved phosphorus losses in runoff. Soil Sci. Soc. Am J 69:1532–1540

Ruess RW, McNaughton SJ (1987) Grazing and the dynamics of nutrient and energy regulated microbial processes in the Serengeti grasslands. Oikos 49:101–110

Senft RL, Rittenhouse LR, Woodmansee RG (1985) Factors influencing selection of resting sites by cattle on shortgrass steppe. J Range Manage 38:295–299

Sharpley AN, Daniel TC, Sims JT, Pote DH (1996) Determining environmentally sound soil phosphorus levels. J Soil Water Conserv 51:160–166

Sigua GC (2010) Sustainable cow-calf operations and water quality: a review. Agron Sustain Dev J 30(3):631–648

Sigua GC, Coleman SW (2007) Sustainable management of nutrients in forage-based pasture soils: effect of animal congregation sites. J Soils Sediments 6(4):249–253

Sigua GC, Hubbard RK, Coleman SW (2009) Quantifying phosphorus levels in soils, plants, surface water, and shallow groundwater associated with bahiagrass-based pastures. Environ Sci Pollut Res 17:210–219

Sigua GC, Williams MJ, Coleman SW (2004) Levels and changes of soil phosphorus in the subtropical beef cattle pastures. Commun Soil Sci Plant Anal 35(7&8):975–990

Sigua GC, Williams MJ, Coleman SW (2006a) Long-term effects of grazing and haying on soil nutrient dynamics in forage-based beef cattle operations. J Sustain Agric 29(3):115–134

Sigua GC, Williams MJ, Coleman SW, Starks R (2006b) Nitrogen and phosphorus status of soils and trophic state of lakes associated with forage-based beef cattle operations in Florida. J Environ Qual 35:240–252

Sigua GC, Hubbard RK, Coleman SW (2010) Quantifying phosphorus levels in soils, plants, surface water, and shallow groundwater associated with bahiagrass-based pastures. Environ Sci Pollut Res 17:210–219

Sigua GC, Myer RO, Coleman SW, Mackowiak C, Adjei M, Chase CC, Albano JP (2011) Regional distribution of soil phosphorus across congregation-grazing zones of forage-based pastures with cow-calf operation in Florida. J Environ Protection 2:408–417

Sondregaard M, Jeppesen E (2007) Anthropogenic impacts on lake and stream ecosystems, and approaches to restoration. J Appl Ecol 44:1089–1094

Sundareshwar PV, Morris JT, Koepfler EK, Fornwalt B (2003) Phosphorus limitation of coastal ecosystem processes. Science 299:563

Williams MJ, Hammond AC (1999) Rotational vs. continuous intensive stocking management of bahiagrass pastures for cows and calves. Agron J 91:11–16