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Gilbert Sigua, Samuel Coleman, Chad Chase, Albano

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RESEARCH ARTICLE

Absence of negative environmental effects of increased soil P levels in cattle congregation zones

Gilbert C. Sigua · Samuel W. Coleman · Chad C. Chase · Joseph Albano

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Abstract Determining soil nutrient distribution in pasture with beef cattle operation is critical to identifying which area is at risk of nitrogen or phosphorus buildup and loading. Characterizing spatial variability of soil nutrients in relations to landscape location is important for understanding the effects of future land use change on soil nutrients and water pollution. We hypothesized that cattle congregation site may have higher concentrations of phosphorus and nitrogen than in the pasture and grazing site or the adjoining forest site. This study assessed levels of Mehlich-1 extractable P, total inorganic N, and soil P saturation in relation to landscape locations in subtropical beef cattle pasture. Soil samples were collected during the spring and fall of 2005 to 2007 from three 19 adjoining landscape sites that are associated with beef cattle operation. These sites consisted of three locations: congregation, grazing, and forest sites. The levels of extractable P, total inorganic N, and P saturation in soils varied with landscape location. Congregation site had the highest concentration of extractable P of 36.1 mg kg^{-1}, followed by grazing site of 17.7 mg kg^{-1}, and forest site of 8.2 mg kg^{-1}. Spatial distribution of total inorganic nitrogen across the landscape was higher for congregation site (2.3 mg kg^{-1}) than forest site (0.9 mg kg^{-1}) and grazing site (0.7 mg kg^{-1}). The overall spatial distribution of extractable P from congregation site to forest site can be described by $P=-4.2x+45.8$; ($R^2=0.97^{**}$); the best-fit models for total inorganic N was $0.04x^2-0.6x+3.5$; ($R^2=0.89^{**}$) and for soil P saturation was $-3.6x+36.2$; ($R^2=0.92^{**}$). Results show that the levels of extractable P, total inorganic nitrogen, and soil phosphorus saturation were decreasing from the congregation site to forest site. Although our results may have had supported our hypothesis that congregation site typical on Florida ranchers have greater concentrations of extractable P than in grazing site and forest site, the average extractable P at all three landscape locations did not exceed the crop requirement threshold of 36 mg kg^{-1} and the water quality protection threshold of 150 mg kg^{-1}. Our current pasture management including cattle rotation in terms of grazing days and current fertilizer application had thus no negative environmental impact on landscape with cow–calf operation.

Keywords Phosphorus · Total inorganic nitrogen · Phosphorus saturation · Landscape locations

1 Introduction

Understanding how nutrient resources vary across landscapes has become the focal point of much ecological, forest, and agricultural research for decades (Sigua et al. 2011a, b; Sigua and Coleman 2010; Sigua et al. 2009; Canham et al. 2001; Foster et al. 1977; Odum 1969; Watt 1947). Areas in pastures where animals congregate (e.g., mineral feeders, water troughs, and/or shaded/trees) can be important point sources of nutrient pollution and are often perceived to have higher levels of soil nutrients compared with less frequented parts of the landscape (Sigua and Coleman 2010; Sigua et al. 2009; Sigua and Coleman 2007; White et al. 2001).

G. C. Sigua (✉) · S. W. Coleman · C. C. Chase
United States Department of Agriculture-Agricultural Research Service,
Brooksville, FL 34601, USA
e-mail: gilbert.sigua@ars.usda.gov

J. Albano
United States Department of Agriculture-Agricultural Research Service,
Fort Pierce, FL 34945, USA

Livestock concentration areas in pastures can be important point sources of nutrient pollution and are often perceived to have higher amounts of soil phosphorus and nitrogen compared with less disturbed areas of the pasture. The arrangement of food, water, and shelter and their concurrent interactions with topographic and/or landscape features obviously influence the distribution of animals and their simultaneous uses of landscape's resources (Ganskopp 2001). Spatial distribution and movement patterns of cattle are particularly valuable in allocating and assessing impacts of utilization on a given landscape. Movement of free-ranging cattle varies due to spatial arrangement of forage resources (Senft et al. 1985), water (Ganskopp 2001; Holechek 1988), mineral feeders (Martin and Ward 1973), and shade (Sigua et al. 2009).

The rate at which soil phosphorus and nitrogen accumulates in terrestrial beef agroecosystem is uncertain, as are the mechanisms responsible for the current phosphorus and nitrogen sinks and/or sources. Lack of a clear relationship between grazing practices and phosphorus dynamics has been attributed to inherent soil variations, depth of soil sampling, and insufficient evaluation of phosphorus distributions within pasture system (Manley et al. 1995; Schuman et al. 1999). Holloway and Stork (1991) have listed a number of features that should be used in the selection of good ecological indicators that should give an accurate response to some aspect of the functioning of the ecosystem. Broad knowledge of cattle movement in pastures therefore is critical to understanding their impact on agroecosystems. Landscape location in pasture settings with beef cattle operation could be playing a major role as an integrator of several environmental attributes which can influence nutrients dynamics that are related to soil erosion, oxidation, mineralization, leaching, and other related soil processes (Hontoria et al. 1999; Fu et al. 1999; Lepsch et al. 1994). Most measures of changes in soil quality across landscape are comparative and made with references to a baseline level (Saviozzi et al. 2001; Gregorich et al. 1994; Gough and Marrs 1990).

Landscape location and land use may be the dominant factors of soil properties under a hillslope because landscape location influence runoff, drainage, soil temperature, and consequently soil formation. Differences in soil formation along a hillslope may result in differences in soil properties (Wang et al. 2001; Brubaker et al. 1993), which can affect pattern of plant productions, litter productions, and nutrient dynamics. Sigua and Coleman (2010) reported that soils on the north-facing slope contained the greatest amount of soil P (12.4±2.7 mg kg^{-1}) when compared with other slope aspects in pastures with beef cattle operation. The differences may be attributed to topographic aspect-induced microclimatic differences, which are causing differences in the biotic properties of soil. Slope aspect may be acting as an important topographic factor influencing local site microclimate mainly because it determines the amount of solar radiation received.

Studies on landscape attributes, on slope aspect in particular, have produced contrasting results. Foresters have traditionally viewed south aspects as less productive than north aspects, yet there is substantial evidence that the assumption of lower site productivity on south aspects may be incorrect (Coble et al. 2001). Despite substantial measurements using both laboratory and field techniques, little is known about the spatial and temporal variability of phosphorus and nitrogen dynamics across landscape location, especially in agricultural ecosystem with cow–calf operations. There is a continued interest in estimating the grazing-induced changes in soil levels of phosphorus and nitrogen. Further research effort on characterizing spatial variability and distribution of soil nutrients in relation to landscape location is therefore warranted. We hypothesized that cattle congregation site may have higher concentrations of Mehlich-1 extractable phosphorus and total inorganic nitrogen than in the grazing site and forest site. In order to assess our hypothesis, soil samples were collected during the spring and fall of 2005 to 2007 from three adjoining landscape sites with beef cattle operation. These sites consisted of three locations: congregation, grazing, and forest sites. The objective of this study was to assess the level of Mehlich-1 extractable phosphorus (MP), total inorganic nitrogen (TIN), and soil phosphorus saturation (SPS) in relation to landscape location in subtropical beef cattle pasture.

2 Materials and methods

2.1 Study sites and description

The Subtropical Agricultural Research Station (STARS) is a cooperative research unit of the US Department of Agriculture (USDA)—Agricultural Research Service (ARS) and the University of Florida and is located 7 mi north of Brooksville, FL, USA. Cattle production at the site is forage-based with the tropical C_4 grass, bahiagrass (BG, *Paspalum notatum*, Flügge), the predominant forage species, which have been established for over 30 years. This study was conducted at Turnley Research Unit (82.29° W; 28.62° N; 729 ha). Soils (Candler fine sand) at the study site are well-drained hyperthermic uncoated Typic Quartzipsamments. Parent materials consist of marine and/or aeolian sediments (Hyde et al. 1977). Table 1 shows some of the selected properties of surface (0–25 cm) soils in the pasture unit of STARS.

In general, all pastures were grazed during the spring of the year. 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.

Table 1 Selected properties of surface soil (0–20 cm) averaged within respective beef cattle pasture field of STARS, Brooksville, FL, USA

Soil property	Turnley research unit (28.58–28.62° N; 82.26–82.29° W)	Analytical method
Texture, g kg^{-1}		Gee and Bauder (1986)
Sand	825	
Silt	125	
Clay	50	
Bulk density, g cm^{-3}	1.5	Blake and Hartge (1986)
pH in water	6.4	Thomas (1996)
Calcium, mg kg^{-1}	602.9	Sumner and Miller (1996)
Magnesium, mg kg^{-1}	88.8	Sumner and Miller (1996)
Potassium, mg kg^{-1}	48.0	Sumner and Miller (1996)
Phosphorus, mg kg^{-1}	59.8	Kuo (1996)
Total nitrogen, mg kg^{-1}	0.6	Mulvaney (1986)
SOC, g kg^{-1}	3.5	Nelson and Sommers (1996)

The average annual precipitation in the station is about 1,262 mm with approximately half of this amount, occurring during mid-June through mid-September (Fig. 1). 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 to September.

2.2 Pasture management and fertilization

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. 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 forage availability based on plant height and not based on pasture measurement. Starting in 2000, cattle were rotated on a 3-day grazing interval with 24 days of rest between pastures. For this study, the average number of grazing cattle was about 2.91 animal unit (450 kg cow) per hectare and grazing days of about 5.46 on a monthly basis. Prior to about 1988, pasture fields with bahiagrass were fertilized in the spring with 90 kg N ha^{-1} and 45 kg K_2O ha^{-1}. At the beginning of 1990, all bahiagrass pasture fields received a reduced rate of N fertilization (76.5 kg N ha^{-1}).

2.3 Soil sampling, sample preparation, and analyses

Soil samples were collected during the spring and fall of 2005 to 2007 from three landscape sites: congregation (n=255), grazing (n=206), and forest (n=96) sites. The forest site was adjacent to the grazed pasture on the north and not accessible to cattle. Soil samples were collected from two soil depths (0–15 and 15–30 cm) at different locations following a sampling pattern at 0.9, 1.7, 3.3, 6.7, 13.3, 26.7, 53.3, 500, and 3,000 m from the approximate center of the congregation site. This radial sampling scheme was conceived in order to assess the spatial variability of soil nutrients near the center and/or away from the center of the congregation sites that was based on our secondary hypothesis (i.e., higher concentrations of nutrients near center of

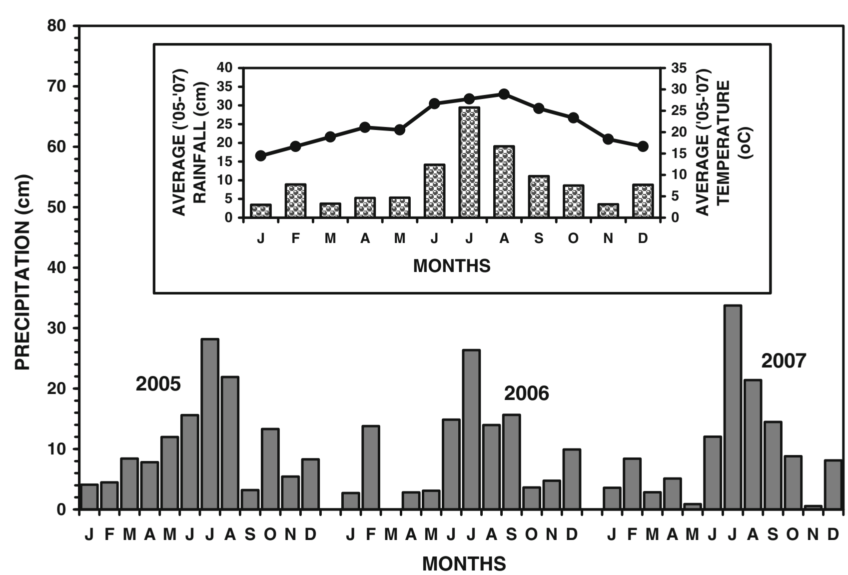

Fig. 1 Monthly average (2005–2007), monthly total rainfall distribution, and monthly average (2005–2007) of temperature in the study area (Brooksville, FL, USA)

congregation structure where animals tend to congregate most of the time). The radial sampling scheme in this study was similar to the sampling scheme employed by Sigua et al. (2011a, b). The congregation sites in this study consisted of water troughs, mineral feeders, and shaded areas. For the purpose of this study, sampling sites between 0.9 and 6.7 m from the center of congregation sites were referred to as the "congregation site," while sites located between 13.3 and 53.3 m from the center of congregation sites were referred to as the "grazing/pastures area." Sites between 500 and 3,000 m away from the center of congregation sites were referred to as the "forest area."

Soil samples were air-dried and passed through a 2-mm mesh sieve prior to chemical extraction of soil total phosphorus and total inorganic nitrogen. Sample extractions were conducted at USDA-ARS Laboratory located in Brooksville, FL, USA. Soil total phosphorus (Mehlich-1 P) was extracted with double acid (0.025 N H_2SO_4+0.05 N HCl) as described by Mehlich (1953) and analyzed using an inductively coupled spectrophotometer at USDA Horticultural Laboratory located in Fort Pierce, FL, USA. Soil total inorganic nitrogen (NO_3–N+NH_4–N) was extracted with 2 N KCl and analyzed with a Nitrogen Autoanalyzer (Mulvaney 1986). Bulk density was also assessed on separate soil cores (Blake and Hartge 1986).

The degree of soil saturation with phosphorus as described in Eq. 1 was computed using the phosphorus, iron, and aluminum contents (milligrams per kilogram) of the soil (Hooda et al. 2000).

$$\mathrm{SPS}\ (\%) = ([\mathrm{P}] \times 100)/[\mathrm{Fe} + \mathrm{Al}]) \quad (1)$$

2.4 Statistical analysis

Data were analyzed with a three-way ANOVA using PROC GLM (Statistical Analysis System 2000). The model included year (Y), landscape location (LL), and soil depth (SD). The pooled data (2005–2007) were tested initially for normality (Statistical Analysis System 2000). For this study, *F* test indicated highly significant ($p \leq 0.0001$) year and landscape location effects, so data for Mehlich-1 extractable phosphorus, total inorganic nitrogen, and soil phosphorus saturation were sorted by year and landscape location using PROC SORT (Statistical Analysis System 2000) followed by mean separation following the procedures of Duncan's multiple range test (Statistical Analysis System 2000). The principle of PROC REG (Statistical Analysis System 2000) was followed to establish the relationship of Mehlich-1 extractable phosphorus, total inorganic nitrogen, and soil phosphorus saturation with landscape location.

3 Results and discussion

3.1 Concentration of total inorganic nitrogen

There was landscape location×year of sampling interaction ($p \leq 0.001$) and landscape location×depth of sampling interaction ($p \leq 0.001$) on the concentration of total inorganic nitrogen (Table 2). Concentration of total inorganic nitrogen also varied significantly among landscape locations ($p \leq 0.001$), time of sampling ($p \leq 0.001$), and depth of sampling ($p \leq 0.001$). Averaged across time and depth of sampling, the greatest concentration of total inorganic nitrogen was from the congregation site (2.3.mg kg^{-1}) followed by forest site (0.9 mg kg^{-1}) and grazing site (0.7 mg kg^{-1}), respectively (Fig. 2).

In our study, average concentrations of total inorganic nitrogen among the different congregation sites, except for the shaded areas were comparable to the concentrations of total inorganic nitrogen for forest site and grazing site. The greatest concentration of total inorganic nitrogen was from the shaded areas (7.8±10.5 mg kg^{-1}) in 2006, while the least amount of total inorganic nitrogen was from the water trough sites (0.5±0.05 mg kg^{-1}) in 2007. The average concentration of total inorganic nitrogen in 2005 was about 0.9±0.1 mg kg^{-1} and 1.9±0.2 mg kg^{-1} in 2006. The average total inorganic nitrogen concentration in 2007 was about 1.4±0.3 mg kg^{-1} (Table 3).

There was a general decline (Fig. 2) in the concentration of total inorganic nitrogen away from the center of the congregation sites to the edge of the pasture/grazing site (500 m). On the average, the level of total inorganic nitrogen showed a decreasing trend from the congregation sites to the forest site (3,000 m). However, the trend from the edge of the grazing site (13.3 m) to the forest site (3,000 m) was not significant because the levels of total inorganic nitrogen were statistically similar between the grazing/pasture area and the forest area (Fig. 2). Of the congregation sites, the

Table 2 Analysis of variance (*F* values) on soil carbon in forage-based cow–calf congregation sites

Sources of variations	Soil total inorganic nitrogen	Soil phosphorus
Among landscape location (LL)	72.83***	100.32***
Among year of sampling (Y)	16.26***	118.99**
Among depth of sampling (SD)	14.35***	0.08 ns
LL×Y	6.31***	2.15*
LL×SD	10.06***	1.18 ns
LL×Y×SD	0.51 ns	0.09 ns

ns not significant

***$p \leq 0.001$; **$p \leq 0.01$; *$p \leq 0.05$

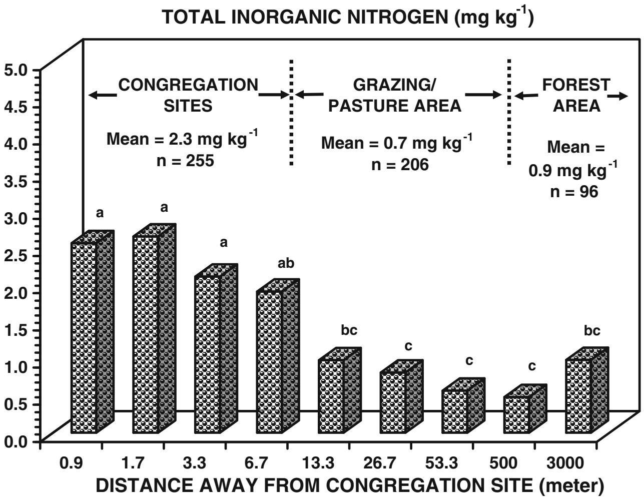

Fig. 2 Concentration of total inorganic nitrogen (TIN) across landscape location and at or away from the center of the congregation site (TIN=$0.04x^2-0.65x+3.5$; $R^2=0.89$**). Means of TIN are significantly different ($p\leq0.05$) when *superscripts located at top bars* are different

average decline in the concentrations of total inorganic nitrogen was about 64%. The average decline in the amount of total inorganic nitrogen within the pasture/grazing zone to the edge of the forest area was about 42%. Approximately 100% increase in the concentration of total inorganic nitrogen was noted from the edge of the pasture site (500 m) to the forest area (Fig. 2). The overall landscape location dynamics of total inorganic nitrogen in our study can be described by Eq. 2 below.

$$\mathrm{TIN} = 0.04(\mathrm{x}^2) - 0.65(\mathrm{x}) + 3.5; \quad R^2 = 0.89 ** \tag{2}$$

Levels of total inorganic nitrogen showed a significant ($p\leq0.05$) downward trend across the landscape locations (congregation site to forest site). The concentrations of total inorganic nitrogen in soils from water troughs (1.07 mg kg^{-1}), forest site (0.98 mg kg^{-1}), mineral feeders (0.93 mg kg^{-1}), and grazing site (0.77 mg kg^{-1}) were similar, but their concentrations were significantly lower than the levels of total inorganic nitrogen in soils from the shaded/tree sites (5.08 mg kg^{-1}). It appeared that sites with trees in the pasture might have had influenced the levels and spatial distribution of total inorganic nitrogen in the landscape. Spatial distribution of total inorganic nitrogen (milligrams per kilogram) across the landscape was in this order: congregation site (2.3)>forest site (0.9)>grazing site (0.7). The trend observed in this study is in agreement with the results reported by Sigua and Coleman (2007). Higher total inorganic nitrogen content at the congregation site may have been more likely due to frequent urination of animals. An accumulation of inorganic nitrogen immediately adjacent to congregation site could lead to a potential point source that would be susceptible to leaching or gaseous losses to the environment (Sigua et al. 2010; Franzluebbers et al. 2000).

On the other hand, the lower concentration of soil total inorganic nitrogen in forest site, probably as a result of low inputs of plant residues (longleaf pines) in this forest, where other sources of total inorganic nitrogen such as under wood and understory are lacking. Unlike in grazing site where vegetation is dense and evenly distributed, the absent or lacking of understory in the forest site may have had affected the cycling of soil nitrogen across the landscape location. Our results were supported by early work of Moar and Wilson (2006). They reported that root length and root production were significantly greater in grassland/pasture than in forest. Similar to other reports (Hodge 2004; Hutchings et al. 2003; Partel and Wilson 2002; Jackson et al. 1989). This difference suggests that the two vegetation types may have the potential to differ in their responses to nutrient cycling and nutrient heterogeneity. Differences in root patches between the grazing site and forest site are probably responsible for the differences in soil total inorganic nitrogen in our study. Trees and grasses may also differ in root production and nutrient turnover.

Differences in the concentration of soil total inorganic nitrogen across the landscape could be explained further by

Table 3 Concentration of total inorganic nitrogen across the different landscape locations (2005–2007) with beef cattle operation. Average total nitrogen across the study sites= 0.61±0.2 mg kg^{-1}

Landscape location	2005		2006		2007	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Congregation area						
Mineral feeders	1.1±0.2	0.9±0.1	1.1±0.2	0.8±0.2	0.6±0.3	0.9±0.1
Shaded areas	3.9±0.6	1.8±0.3	7.8±1.4	4.1±1.2	3.1±0.7	3.5±0.9
Water troughs	0.8±0.2	0.7±0.1	1.3±0.2	1.2±0.2	0.7±0.1	0.5±0.05
Mean	1.9±0.9	1.1±0.2	3.4±0.6	2.1±0.5	1.5±0.4	1.6±0.4
Pasture/grazing area	0.6±0.03	0.4±0.03	1.1±0.09	0.8±0.09	0.9±0.05	0.8±0.7
Forest area	0.4±0.08	0.3±0.02	1.9±0.5	1.2±0.2	1.6±0.04	1.2±0.05
Mean	0.9±0.1		1.9±0.2		1.4±0.3	

the current land use and management of the study sites. The grazing site with bahiagrass was fertilized in the spring with 76 kg Nha^{-1}, while the sources of nitrogen in the congregation site include urine and feces of grazing cattle. The average low soil test value of total inorganic nitrogen across landscape location (congregation site −2.4 mg kg^{-1}, n=255; forest site −0.98 mg kg^{-1}, n=96; grazing site −0.78 mg kg^{-1}, n=206) would indicate that current pasture management including cattle rotation in terms of grazing days and current fertilizer application (inorganic+feces+urine) may not have negative impact on the environment.

3.2 Concentration of Mehlich-1 phosphorus

There was no significant interaction effect of landscape location×year×depth of sampling on the average concentration of Mehlich-1 extractable phosphorus. However, Mehlich-1 extractable phosphorus varied significantly ($p \leq 0.05$) with landscape location and year of sampling (Table 2). Averaged across sampling depths, the greatest concentration of Mehlich-1 extractable phosphorus of 57.9±7.0 mg kg^{-1} was from congregation site in 2005, while the least concentration of Mehlich-1 extractable phosphorus was from forest site (2.8±0.6 mg kg^{-1}) in 2006 (Table 4). The concentration of Mehlich-1 extractable phosphorus when averaged across landscape location and sampling depths had a declining trend from 2005 (42.9±2.5 mg kg^{-1}) to 2007(17.8± 1.4 mg kg^{-1}).

The greatest Mehlich-1 extractable phosphorus concentration of 36.1 mg kg^{-1} was from the congregation site, while the lowest concentration of Mehlich-1 extractable phosphorus was from the forest site (8.2 mg kg^{-1}). The average concentration of Mehlich-1 extractable phosphorus in the grazing site was about 17.7 mg kg^{-1} (Fig. 3). Between the congregation site and forest site, concentration of Mehlich-1 extractable phosphorus declined from 41 to 11 mg kg^{-1} or about 73% reduction (Fig. 3). The average decline of Mehlich-1 extractable phosphorus within the congregation site was about 25% and about 10% within the grazing site. The average decline of about 16% was between the edge of grazing site and the forest site (Fig. 3). The overall decline in Mehlich-1 extractable phosphorus in the landscape (congregation site to forest site) can be described by a linear relationship given in Eq. 3; where x is the distance away from the center of congregation sites:

$$\mathrm{MP} = -4.2(x) + 45.8; \quad R^2 = 0.97** \qquad (3)$$

Spatial trends of Mehlich-1 extractable phosphorus in our study may be a function of feces and urine deposition where animals clustered and phosphorus fertilization. Where animals congregate (congregation site) may tend to develop some hot spots in the landscape. Although our results may have had supported our hypothesis that congregation site typical on Florida ranchers have greater concentrations of Mehlich-1 extractable phosphorus than in grazing site and forest site, the average Mehlich-1 extractable phosphorus at all three landscape locations did not exceed the crop requirement threshold of 50 mg kg^{-1} and the water quality protection threshold of 150 mg kg^{-1}. Averaged across years, congregation site had the highest concentration (milligrams per kilogram) of Mehlich-1 extractable phosphorus (36.1) followed by grazing site (17.7) and forest site (8.2). The concentrations of Mehlich-1 extractable phosphorus decreased linearly with distance away from the center of the congregation site. The overall spatial relationship of Mehlich-1 extractable phosphorus across the landscape in our study could be best described by a linear model: $-4.2(x)+45.8$; R^2=0.97**.

Dense and evenly distributed vegetation in grazing site while the absent or lacking of understory in the forest site may have had affected the spatial distribution of Mehlich-1 extractable phosphorus across the landscape location. Again, differences in root patches between the grazing site and forest site are probably responsible for the differences in

Table 4 Concentration of Mehlich-1 extractable phosphorus across the different landscape locations (2005–2007) with beef cattle operation. Average Mehlich-1 extractable phosphorus across the study sites=59.8± 5.3 mg kg^{-1}

Landscape location	2005		2006		2007	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Congregation area						
Mineral feeders	79.9±7.9	80.7±11.7	17.2±4.5	18.4±4.4	23.2±3.2	34.2±2.9
Shaded areas	59.8±7.6	69.6±10.2	24.3±4.5	25.3±4.8	44.1±2.7	48.7±4.8
Water troughs	30.9±4.3	26.6±3.4	–	–	3.2±0.5	2.6±0.3
Mean	56.9±6.6	58.9±8.4	20.8±4.5	21.9±4.6	23.5±2.1	28.5±2.7
Pasture/grazing area	30.6±9.5	27.1±8.6	18.4±9.8	16.9±9.1	9.4±1.7	8.4±1.9
Forest area	16.8±2.5	20.2±6.7	3.1±0.4	2.6±0.7	3.8±0.6	2.9±0.4
Mean	42.9±2.5		18.6±1.6		17.8±1.4	

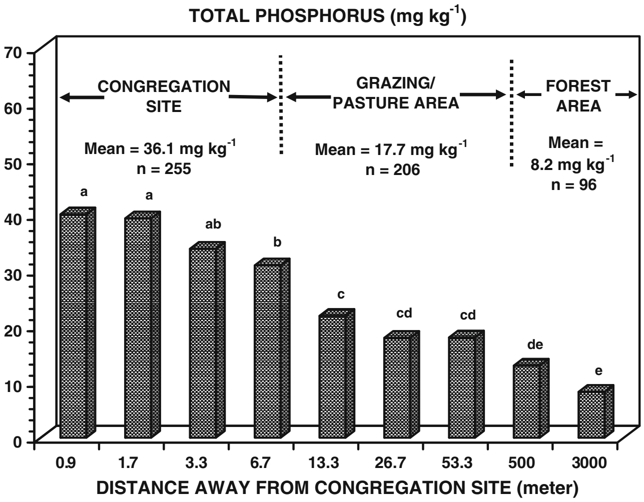

Fig. 3 Concentration of Mehlich-1 extractable phosphorus (MP as total phosphorus) across landscape location and at or away from the center of the congregation site (MP=−4.2x+45.8; R^2=0.97**). Means of MP are significantly different (p≤0.05) when *superscripts located at top bars* are different

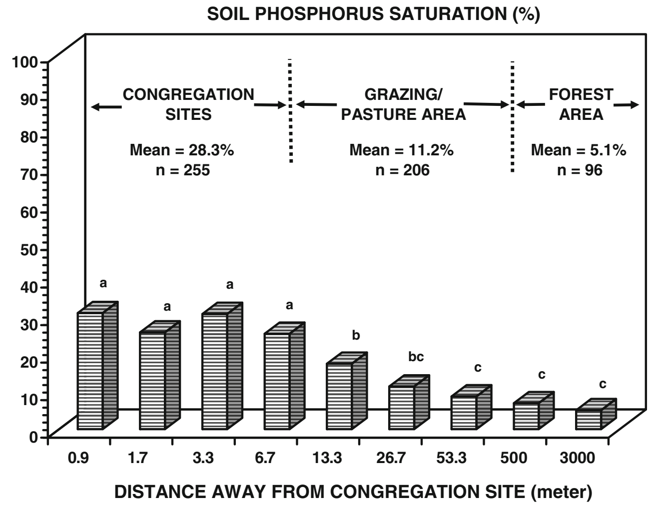

Fig. 4 Degree of soil phosphorus saturation (SPS) across landscape location and at or away from the center of the congregation site (SPS=−3.6x+36.2; R^2=0.92**). Means of SPS are significantly different (p≤0.05) when *superscripts located at top bars* are different

soil Mehlich-1 extractable phosphorus in our study. Differences between growth forms in roots responses have documented in many greenhouse (Hutchings et al. 2003; Hodge 2004), but not in natural vegetation (Smilauerova 2001; Bilbrough and Caldwell 1997; Pregitzer et al. 1993). In the field, contrasting growth forms, such as trees and grasses, differ in their effects on soil resource heterogeneity (Moar and Wilson 2006). Soils dominated by woody plants are characterized by greater spatial heterogeneity than soils supporting grasses (Kleb and Wilson 1997; Schlesinger et al. 1996). Moar and Wilson (2006) reported that root length and root production were about twice as high in grasslands as in forest. Trees and grasses may also differ in root production and phosphorus turnover. Moreover, animal excreta in the congregation site and grazing site can contribute to the higher contents of phosphorus in the pasture soils compared with forest soils.

3.3 Degree of phosphorus saturation

The degree of phosphorus saturation in soils is shown in Fig. 4. The average soil phosphorus saturation in congregation site was about 28.3%, while the average soil phosphorus saturation in grazing site and forest site were 11.2% and 5.1%, respectively. The levels of soil phosphorus saturation within the congregation site did not vary among the distance away from the center of the congregation site, while the levels of soil phosphorus saturation within the grazing site were comparable with the average levels of soil phosphorus saturation within the forest site (Fig. 4). The overall soil phosphorus saturation levels within landscape location in our study had a declining trend and can be described by a linear model given in Eq. 4.

$$\mathrm{SPS} = -3.6(x) + 36.2; \quad R^2 = 0.92** \tag{4}$$

The degree of soil phosphorus saturation varied significantly across the landscape location. The varying amount of aluminum and iron across the landscape location may have had affected the spatial distribution of soil phosphorus saturation (Table 5). The forest site soils had the greatest concentration of aluminum (averaged across years and soil depth) of 190.9±64.0 mg kg^{-1} followed by grazing site soils (115.1±18.4 mg kg^{-1}) and soils from congregation site (112.1±19.6 mg kg^{-1}). On the other hand, soils from the congregation site had the greatest concentration of iron

Table 5 Average concentrations of aluminum and iron across the different landscape locations with beef cattle operation

Landscape location	Structure	Soil depth (cm)	Al (mg kg^{-1})	Fe (mg kg^{-1})
Congregation area	Mineral feeders	0–15	59.9±13.5	7.8±1.9
		15–30	46.1±10.6	6.7±1.7
	Shaded areas	0–15	129.6±29.6	1.5±0.4
		15–30	165.9±36.8	1.7±0.5
	Water troughs	0–15	58.2±13.6	86.9±17.6
		15–30	58.9±13.5	64.3±14.4
Mean			112.1±19.6	28.2±6.1
Grazing area	–	0–15	118.6±18.8	6.9±2.7
		15–30	111.5±17.9	8.7±3.9
Forest area	–	0–15	212.7±73.4	15.9±3.9
		15–30	169.1±54.6	10.6±2.2

(28.2±6.1 mg kg^{-1}) followed by forest site soils (13.2±3.1 mg kg^{-1}), and grazing site soils (7.8±3.3 mg kg^{-1}).

The average soil phosphorus saturation in congregation site was about 28.3%, while the average soil phosphorus saturation in grazing site and forest site were 11.2% and 5.1%, respectively. The high concentrations of aluminum and iron in forest site may explain the lowest soil phosphorus saturation in forest site. Our results showed the variable effects of aluminum and iron on soil phosphorus saturation and our observations are quite similar to the results reported earlier (Penn et al. 2005). The preference of phosphorus for aluminum over iron may have resulted because the soil aluminum may be more saturated than iron or because the soil iron was more saturated in phosphorus than aluminum. The degree of soil phosphorus saturation has been suggested as an indicator for the risk of phosphorus loss from agricultural soils (Hooda et al. 2000; Maguire et al. 2001). Overall, the degree of soil phosphorus saturation from pastures in our study did not exceed the environmental threshold of phosphorus saturation. Early studies conducted by Heckrath et al. (1995) and Hooda et al. (2000) have found that the degree of phosphorus saturation in soils needs to exceed 60% before dissolved reactive phosphorus becomes an environmental problem.

4 Summary and conclusion

Soil nutrient dynamics is an issue of increasing importance to environmentalists, ranchers, and public officials. The rate at which phosphorus and/or nitrogen accumulates and is utilized within the landscape is uncertain. Because of the continued interest in estimating the grazing-induced changes in soil levels of phosphorus and nitrogen, our results may help in understanding the rate at which soil phosphorus and nitrogen accumulates in terrestrial beef agroecosystem, so as the mechanisms responsible for the current phosphorus and nitrogen sinks and/or sources across the different landscape locations. Characterizing spatial variability of soil nutrients in relations to landscape location is important for understanding the effects of future land use change on soil nutrients. Results of this study may have had affected by the nature of energy transformations and biogeochemical cycling across landscape positions. The pasture/grazing area is likely to be associated with an open nutrient cycling while forest area may have a closed nutrient cycling. Higher concentrations of nitrogen and phosphorus in the pasture/grazing area than in the forest area because of longer residence time. Residence time indicates how long on average for nitrogen and/or phosphorus would remain within the system before leaving the system. A closed system like the forest area would tend to have a short residence time where the inputs and outputs are negligible when compared to internal changes.

The degree of soil phosphorus saturation in the three pastures were below the environmental threshold of phosphorus saturation (SPS≥60%), suggesting that phosphorus buildup and/or release is not a predicament anywhere in the landscape, including the congregation and forest sites. These results may have significant implications for the transport of phosphorus and nitrogen to surface waters and our ability to predict and model losses of phosphorus and nitrogen from congregation zone or grazing zone of pastures with cow–calf operations. Additionally, the average low soil test values of nitrogen and phosphorus across landscape location would indicate that current pasture management including cattle rotation in terms of grazing days and current fertilizer application (inorganic+feces+urine) may not have negative environmental impact on forage-based landscape with cow–calf operation.

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