Animal Behavior and Soil Nutrient Redistribution in Continuously Stocked Pensacola Bahiagrass Pastures Managed at Different Intensities

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ABSTRACT

Animal excreta return to pastures plays a major role in nutrient cycling. Improvement in excreta distribution may increase nutrient recovery by pasture plants. Pasture management may modify animal behavior and excreta distribution. This study evaluated the effects of management intensity on animal behavior and soil nutrient concentration in continuously stocked 'Pensacola' bahiagrass (*Paspalum notatum* Flügge) pastures. The three management intensities were: Low (40 kg N $ha^{-1}yr^{-1}$ and 1.4 animal units [AU, one AU = 500 kg live weight] ha^{-1} stocking rate [SR]), Moderate (120 kg N ha^{-1} yr^{-1} and 2.8 AU ha^{-1} SR), and High (360 kg N ha^{-1} yr^{-1} and 4.2 AU ha^{-1} SR). Management intensity did not affect animal behavior ($P > 0.05$), but it did affect soil nutrient concentration ($P \leq 0.10$). Surface-soil N, K, and Mg concentrations were greater at the greatest intensity ($P \leq 0.10$), but intensity had no effect deeper in the profile ($P \geq 0.10$). Soil nutrient concentration after 3 yr was generally greatest ($P \leq 0.10$) closer to shade and water and was associated with a greater proportional time spent and return of excreta by cattle. Increasing air temperature and temperature-humidity index increased time spent under shade and affected patterns of excreta return ($P \leq 0.10$). Efforts to increase uniformity of excreta distribution, e.g., movement of portable shade and water troughs, are likely to have greatest impact in warm-climate areas or during warm seasons in temperate zones.

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Abbreviations: AU, animal units; Solrad, average solar radiation; SOM, soil organic matter; SR, stocking rate; THI, temperature-humidity index; WSP, average wind speed.

A small proportion of the nutrients ingested by grazing livestock are retained in animal tissues or exported in animal products; most nutrients are returned to the pasture in excreta (Wilkinson and Lowrey, 1973; Haynes and Williams, 1993). Grazing animals modify soil nutrient distribution in pastures by ingesting nutrients in forages and depositing excreta in different locations across the pasture. Excreta is not uniformly deposited and a higher density of deposition occurs around lounging areas (West et al., 1989; Mathews et al., 1994a; Mathews et al., 1999; White et al., 2001). Nutrients also are excreted in different proportions in dung and urine. Most of the P and Mg, for example, are excreted in the dung, while most of the K is excreted in the urine (Mathews et al., 2004).

Enhancing uniformity of soil nutrient distribution across the pasture is an important goal of grazing management. Expected results include greater nutrient-use efficiency, more economical farming production, and less environmental pollution due to

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lower nutrient loading of ground water. Peterson and Gerrish (1996) suggested that short grazing periods with high stocking rates enhance uniformity of excreta distribution; however, results from warmer climates have not always been consistent with this conclusion (Mathews et al., 1994b; Mathews et al., 1999). Under high temperature conditions, animals stayed in small areas of the pasture and congregated under shade and close to watering points, regardless of stocking rate or grazing method (Mathews et al., 1994b; Mathews et al., 1999; White et al., 2001). Additional research evaluating the linkages among animal behavior, soil nutrient concentration, and pasture management practices is needed to better understand nutrient dynamics in grazed ecosystems (Mathews et al., 1999). Thus, the objective of this study was to evaluate the effects of different intensities of pasture management on animal behavior and soil nutrient distribution across continuously stocked 'Pensacola' bahiagrass (*Paspalum notatum* Flügge) pastures.

MATERIALS AND METHODS

Experimental Site

A grazing experiment was performed at the University of Florida Beef Research Unit, northeast of Gainesville, FL (29°43′ N lat) on Pensacola bahiagrass pastures. Soils were classified as Spodosols and included sandy siliceous, hyperthermic Ultic Alaquods from the Pomona series and sandy siliceous, hyperthermic Aeric Alaquods from the Smyrna series. Soil pH averaged 5.9, and Mehlich-I extractable soil P, K, Ca, and Mg concentrations at the beginning of the experiment were 5, 28, 553, and 98 mg kg^{-1}, respectively.

Treatments and Design

This experiment evaluated the effect of three management intensities of continuously stocked bahiagrass pastures on animal behavior and soil nutrient distribution in different pasture zones. Zones were defined according to their distance from shade and water locations. Treatments were combinations of stocking rate and N fertilization and are defined here as management intensities.

The three management intensities tested were Low (40 kg N ha^{-1} yr^{-1} and 1.4 AU ha^{-1} stocking rate), Moderate (120 kg N ha^{-1} yr^{-1} and 2.8 AU ha^{-1} stocking rate), and High (360 kg N ha^{-1} yr^{-1} and 4.2 AU ha^{-1} stocking rate). Treatments were replicated twice in a randomized complete block design. Defining intensity as a combination of N fertilization and SR levels was done because in most practical production systems these two factors are directly linked, i.e., to achieve greater stocking rate while avoiding overgrazing, greater N fertilization is often needed. These specific management intensity treatments were selected because Low approximates current bahiagrass management practice in Florida cow-calf systems, Moderate represents the upper range of current practice, and High is well above what is currently in use. The choices of N level and SR for High were based on data from Burton et al. (1997) and Twidwell et al. (1998) who found that bahiagrass forage production was approximately three times greater for N rates near the highest compared to the lowest used in the current study, thus keeping forage mass and SR nearly in balance across these treatments. The bahiagrass pastures were continuously stocked from 26 June to 16 Oct. 2001 (112 d), 8 May to 23 Oct. 2002 (168 d), and 12 May to 27 Oct. 2003 (168 d). Dry spring and early summer conditions in 2001 delayed the start of the study.

Two crossbred (Angus × Brahman) yearling heifers with average initial liveweight of 327 kg were assigned to each experimental unit. Pasture area varied according to the treatment and decreased as the management intensity increased. Pasture areas for Low, Moderate, and High were 1.0, 0.5, and 0.33 ha, respectively. Constructed shade (3.1 m × 3.1 m) was provided on each of the experimental units and cattle had free-choice access to water and a salt-based mineral mixture. The water troughs were always located under the constructed shade, and the mineral mix troughs (one per pasture) were moved weekly throughout the pasture. The Low treatment received all N (40 kg N ha^{-1}) in one application at the beginning of each grazing season; the Moderate treatment received three applications of 40 kg N ha^{-1} in the beginning, mid-, and late-grazing season; the High treatment received four applications of 90 kg N ha^{-1} each grazing season. Because drought delayed the start of grazing in 2001 (50 mm rainfall in April and May vs. the 30-yr average of 147 mm), only 270 kg N ha^{-1} was applied that year on the High treatment. Phosphorus (17 kg ha^{-1} yr^{-1}) and K (66 kg ha^{-1} yr^{-1}) were applied to all treatments before N application in 2001 (17 April), and with the initial N application in 2002 (30 April) and 2003 (23 April). There was a second application of the same amount of P (17 kg ha^{-1} yr^{-1}) and K (66 kg ha^{-1} yr^{-1}) for Moderate and High treatments only in 2002 (15 July). This application reflects the P and K recommendations for bahiagrass pastures in Florida that are based on soil nutrient concentrations, as determined by soil test, and the amount of N fertilizer being applied. Micronutrients were applied on 23 Apr. 2003 at a rate of 400 kg ha^{-1} of the following formula: 0.9 g B kg^{-1}, 6.8 g Fe kg^{-1}, 9.1 g Mn kg^{-1}, and 3.6 g Zn kg^{-1}.

Response Variables

Soil Sampling

Soil was sampled in the three zones of each experimental unit immediately before the beginning (spring) and immediately after the end (autumn) of each of the three grazing seasons (2001–2003). Zones were defined based on their distance from shade and water. Zone 1 consisted of a semi-circle with an 8-m radius and included the shade structure and water trough. Zone 2 was the area located between an 8- to 16-m radius away from the water trough, and Zone 3 was the remaining area of the pasture (Fig. 1). In each zone of all pastures, a composite was prepared from 20 samples (2-cm diameter core) for the 0- to 8-cm depth and for the 8- to 23-cm depth, taken along a zigzag line within the zone. Each composite was mixed thoroughly and split, with one sample air dried and analyzed for Mehlich-I P, K, and Mg. The other sample was frozen and following a subsequent 2-M KCl extraction (2:1) was shaken for 1 h, filtered using Whatman Number 5 paper (Whatman, Inc., Piscataway, NJ), stored in plastic vials, and frozen until laboratory analysis for NH_4 and NO_3 using a semi-automated colorimetric analysis (USEPA Method 353.2). A subsample was taken from each frozen soil sample to determine soil moisture. Results were corrected for soil moisture and are expressed as mg kg^{-1} dry soil.

Before the beginning of the first year of the experiment (2001), five transects were established in each experimental unit. Each transect was a line parallel with the sides of the pasture and perpendicular to the ends. The middle transect line bisected the pasture equally, and there were two transects on each side of the middle transect that were equidistant from each other. In Low pastures (100 × 100 m in area), the middle transect was 50 m from either side. Other transects occurred at 12-m increments. Thus, transects were located 26, 38, 50, 62, and 74 m from one edge of the pasture. Moderate pastures were 50 × 100 m in area, and transects were 1, 13, 25, 37, and 49 m from a given side. High treatment pastures were 66.7 × 50 m in area and transects were 9, 21, 33, 45, and 57 m from a side. A given transect was considered to begin (zero m) at the end of the pasture where the shade and water were located, and the water trough was adjacent to the zero point of the middle transect. Sampling points on the transects were located 2, 6, 10, 14, 18, 26, 42, and 74 m from the zero point. The exception was the High treatment pastures where smaller pasture area did not allow for the 74-m sampling point. Close spacing of sampling points near zero was done because that region was nearest shade and water, and soil chemical changes were expected to be greater there than at points farther from shade and water.

At the beginning of the first year and again after the end of the third year of the experiment (2003), three soil cores to a 0- to 15-cm depth were taken near (within 10-cm radius) each sampling point on all transects. The three cores per sampling point were composited into a single sample for analysis. All samples were analyzed for Mehlich I extractable P, K, and Mg.

Animal Behavior

Animal behavior was monitored continuously by observers during 12-h periods (0700–1900 h). Both heifers on each experimental unit were observed. Observers were located outside the pasture to minimize influence on cattle behavior. All treatments in one replicate were observed simultaneously in a given day. The second replicate was observed 1 wk later except for the first observation in 2002 when both replicates were observed during the same day. A total of nine animal behavior evaluations were performed, five in 2002 (21 May; 4 and 11 June; 26 June and 3 July; 12 and 19 August; and 22 and 29 September) and four in 2003 (9 and 16 June; 30 June and 7 July; 15 and 22 August; and 27 September and 4 October). Behavior observations were not made in 2001.

Behavior observations included quantity of time spent grazing and lounging in each zone by each animal, as well as location (zone) and time of every dung and urine event. The three zones were delimited by colored flags in a way that allowed the observers to visually separate activity in each zone without being present in the pasture. Indices of total time spent grazing or lounging, urine distribution and dung distribution were calculated by dividing the percentage of an activity (total time spent per zone, number of dung events, and number of urine events) that occurred in a given zone by the percentage of the pasture area occupied by that zone. Weather data were averaged from 0700 to 1900 h on the evaluation days and included air temperature, relative humidity, solar radiation, and wind speed. These data were obtained from the Alachua automated weather station located 15 km from the research site. Temperature-humidity index was calculated based on Osborne (2003).

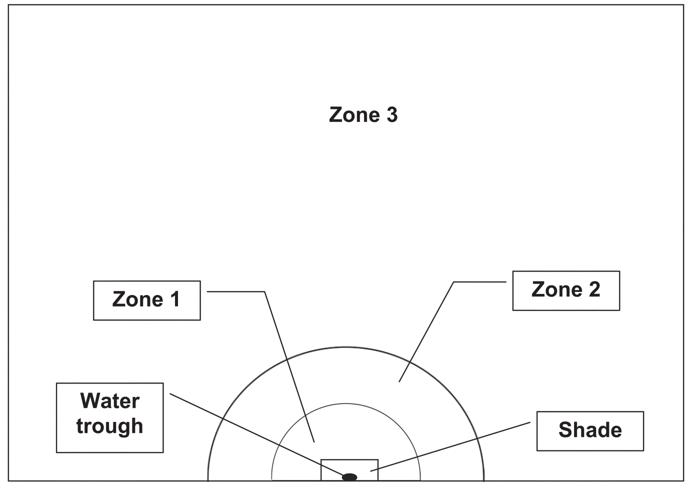

Figure 1. Diagram showing the three pasture zones. Zone 1 is an 8-m radius semi-circle extending out from the watering point and including shade. The shade structure is 3.1 × 3.1 m. Zone 2 is the area between the 8- to 16-m radii from the watering point, and Zone 3 is the remaining area of the pasture. Figure is not drawn to scale.

Statistical Analyses

Animal behavior response variables included grazing time, total time spent in each zone, urine index, dung index, and total time index. These were evaluated using a strip-split plot experiment in a randomized complete block design, and each treatment was replicated twice. Management intensity was considered the main plot, evaluation the sub-plot, and zone the strip-split plot. Zonal soil samples were analyzed using the final soil nutrient concentration (October 2003) as the response variable and the initial concentrations (June 2001) as a covariate. Soil data were analyzed using a strip-split plot with management intensity considered the main plot, zone the subplot, and soil layer the strip-split plot. Statistical analyses of animal behavior and soil nutrient concentration were performed using Proc Mixed from SAS institute (SAS, 1996). Management intensity, zone, evaluation date, and soil layer were considered fixed effects, and replicate was random. The PDIFF test of the LSMEANS procedure was used to compare treatment means. Transect soil sample data were analyzed using semivariogram and block kriging procedures (Trangmar et al., 1985). The transect data analyzed were the change in soil nutrient concentration from just before the beginning to just after the end of the three-year experiment. Multivariate regression was performed to relate time that cattle spent under shade and weather data using Proc Reg from SAS. For animal behavior data, means were declared different when $P \leq 0.05$. Because of the large spatial heterogeneity associated with soil nutrient concentration, soil response means were declared different when $P \leq 0.10$.

RESULTS AND DISCUSSION

Animal Behavior

Management intensity did not affect animal behavior, but behavior did differ in the pasture zones and at different evaluation intervals. Cattle spent more total time and grazing time in Zone 3 followed by Zones 1 and 2 (Tables 1 and 2). Zone 3 represented 96, 92, and 88% of the pasture area for Low, Moderate, and High treatments,

Table 1. Total time cattle spent per zone, total time index, urine distribution index, and dung distribution index on continuously stocked bahiagrass pastures during 2002–2003.

Zone†	Total time per zone (min evaluation^{-1})	Total time index‡	Urine distribution index‡	Dung distribution index‡
1	164 b§	9.8 a	6.3 a	5.7 a
2	53 c	3.9 b	2.1 b	2.8 b
3	476 a	3.5 b	0.8 b	0.8 b
SE	20	1.0	0.8	0.6

†Zone 1 is an 8-m radius semi-circle extending out from the watering point and including shade. Zone 2 is the area between the 8- to 16-m radii from the watering point (no shade), and Zone 3 is the remaining area of the pasture (no shade).

‡Indices were calculated by dividing the percentage of an activity (total time spent per zone or dung and urine events) that occurred in a given zone by the percentage of the pasture area occupied by that particular zone.

§Least squares means within a column followed by the same letter do not differ ($P > 0.05$) by PDIFF.

respectively. In contrast, Zone 1 represented only 1, 2, and 3% of pasture area for Low, Moderate, and High treatments, respectively, but cattle spent approximately 24% of total time in Zone 1 during observation periods (Table 1). The total time index, which is calculated by dividing the percentage of the total time spent in a given zone by the percentage of the pasture area occupied by that zone, was greater in Zone 1 than in the others, showing that proportionally the heifers spent more time close to the water and shade (Table 1). The urine and dung distribution indices show concentration of both urine and dung events in Zone 1, when compared to the other zones (Table 1). Grazing time ranged from 286 min (26 June and 03 July) to 398 min (4 and 11 June) in 2002 and from 250 min (9 and 16 June) to 420 min (27 September and 4 October) in 2003 (Table 2). Canopy and non-canopy factors may explain this variation in grazing time among evaluations. Usually grazing time was least in mid-summer, which was associated with greater air temperature and relative humidity. Greater herbage mass (Stewart et al., 2007) during this time may have contributed to a reduction in grazing time due to greater bite weight.

Table 2. Grazing time in pasture zones on different evaluation dates of continuously stocked bahiagrass pastures during 2002–2003.

Evaluation dates	Zone† 1	Zone† 2	Zone† 3
	min evaluation^{-1}		
21 May 2002	15 a B‡	39 ab B	269 b A
4 and 11 June 2002	6 a B	34 ab B	358 a A
26 June and 3 July 2002	18 a B	31 ab B	237 bc A
12 and 19 Aug. 2002	11 a B	22 b B	256 bc A
22 and 29 Sept. 2002	20 a C	77 a B	207 c A
9 and 16 June 2003	16 a B	19 b B	215 c A
30 June and 7 July 2003	16 a B	34 ab B	276 b A
15 and 22 Aug. 2003	12 a B	36 ab B	271 b A
27 Sept. and 4 Oct. 2003	26 a B	38 ab B	356 a A

†Zone 1 is an 8-m radius semi-circle extending out from the watering point and including shade. Zone 2 is the area between the 8- to 16-m radii from the watering point (no shade), and Zone 3 is the remaining area of the pasture (no shade).

‡Least squares means followed by the same letter, lowercase letter within a column and uppercase letters within a row, do not differ ($P > 0.05$) by PDIFF. SE = 18 min evaluation^{-1}.2

Shade and water troughs were located in Zone 1, and animals congregated there during the warmer periods of the day to minimize heat stress associated with high temperature and humidity. Although animal behavior has not been well documented, several studies across a range of environments and grazing methods have shown that nutrient accumulation is greater near shade and water, with shade having greater effect than water location (Sugimoto et al., 1987; West et al., 1989; Gerrish et al., 1993; Macoon, 1999; Mathews et al., 1999; White et al., 2001).

Environmental conditions influence grazing time and may be the most important non-plant factor affecting grazing behavior (Hancock, 1950). Grazing behavior can have a major impact on nutrient redistribution in pastures (Sollenberger et al., 2002). For example, during summer in Florida, grazing time of lactating Holstein cows decreased linearly with increasing average solar radiation and temperature, together accounting for 83% of the variation in grazing time (Macoon, 1999). These factors also explained 99% of the variation in time spent under shade during the day.

In this study, time spent under shade ranged from 30 to 230 min evaluation^{-1}, and a multivariate regression including weather data explained 50% of the variation in this response [Time under shade (min) = −683 + 0.3 Solrad – 7.7 WSP + 29.4 THI; $R^2 = 0.50$; $P = 0.03$].

Solrad is average solar radiation in W m^{-2}, WSP is average wind speed in km h^{-1}, and THI is Temperature-Humidity Index (°C).

A Pearson correlation analysis indicated that the time spent under shade was positively correlated with air temperature (0.53) and with temperature-humidity index (0.54). Therefore, it is likely that in warmer, more humid environments, or during warmer seasons of the year, greater nutrient accumulation will occur under shade and close to water locations than in cooler, drier environments or seasons (Mathews et al., 1994a; Mathews et al., 1999). Nutrient accumulation near shade was studied for pastures in which Holstein heifers grazed bahiagrass in humid southwestern Japan (Sugimoto et al., 1987). On warm, summer days when temperatures exceeded 27°C, 44 to 53% of urinations and 26 to 29% of defecations occurred in shaded areas. In autumn, when maximum air temperature did not exceed 23.5°C, only 11% of urine and dung deposits occurred in shade areas. This may help explain the apparently greater success achieved in using grazing methods to improve uniformity of nutrient distribution in temperate (Peterson and Gerrish, 1996) than in warm climates (Sugimoto et al., 1987; Mathews et al., 1994a; Mathews et al., 1999). Temperatures (average, minimum, and maximum) and relative humidity for the experimental period in 2002 and 2003 are reported (Fig. 2).

Soil Nutrient Concentration

There was management intensity by soil depth interaction for soil nitrate, ammonium, and total-extractable N concentrations (Table 3). The High treatment had greater soil concentrations of NH_4–N and total-extractable N at the 0- to 8-cm depth when compared to other pastures. This was associated with greater herbage accumulation rate (41 vs. 17 kg ha^{-1} d^{-1}) and crude protein concentration (140 vs. 99 g kg^{-1}) in High than Low management intensity treatments in a companion study (Stewart et al., 2007). In the current experiment, there were no differences among treatments for any soil-N fraction at the 8- to 23-cm depth. Higher inorganic-N concentration as N fertilization increased was expected (Vogel et al., 2002). Franzluebbers and Stuedemann (2003) reported average 5-yr means of 1.6 mg NO_3–N kg^{-1} soil and 10.8 mg NH_4–N kg^{-1} soil from the 0- to 6-cm depth for bermudagrass [*Cynodon dactylon* (L.) Pers.] fertilized with 200 kg N ha^{-1} yr^{-1}. These NO_3–N values are similar to those obtained in the Moderate treatment in this experiment, but the NH_4 values are closer to the results obtained in the High treatment. Soil textural differences may alter the inorganic-N distribution in the soil profile due to the influence of texture on soil chemical and physical properties. Ammonium accumulates more at the soil surface due to its interaction with cation exchange sites on soil organic matter (SOM) complexes and because ammonification reactions from organic matter are concentrated near the soil surface (Franzluebbers and Stuedemann, 2003). A root system density of 1 cm root cm^{-3} of soil or greater absorbs most of the nitrate if soil moisture is available (Tinker and Nye, 2000).

Inorganic N concentrations were similar among zones at the 0- to 8-cm depth, but greater in Zone 2 at the 8- to 23-cm depth (Table 4). The NH_4–N and total extractable N were greater at 0 to 8 cm than at 8 to

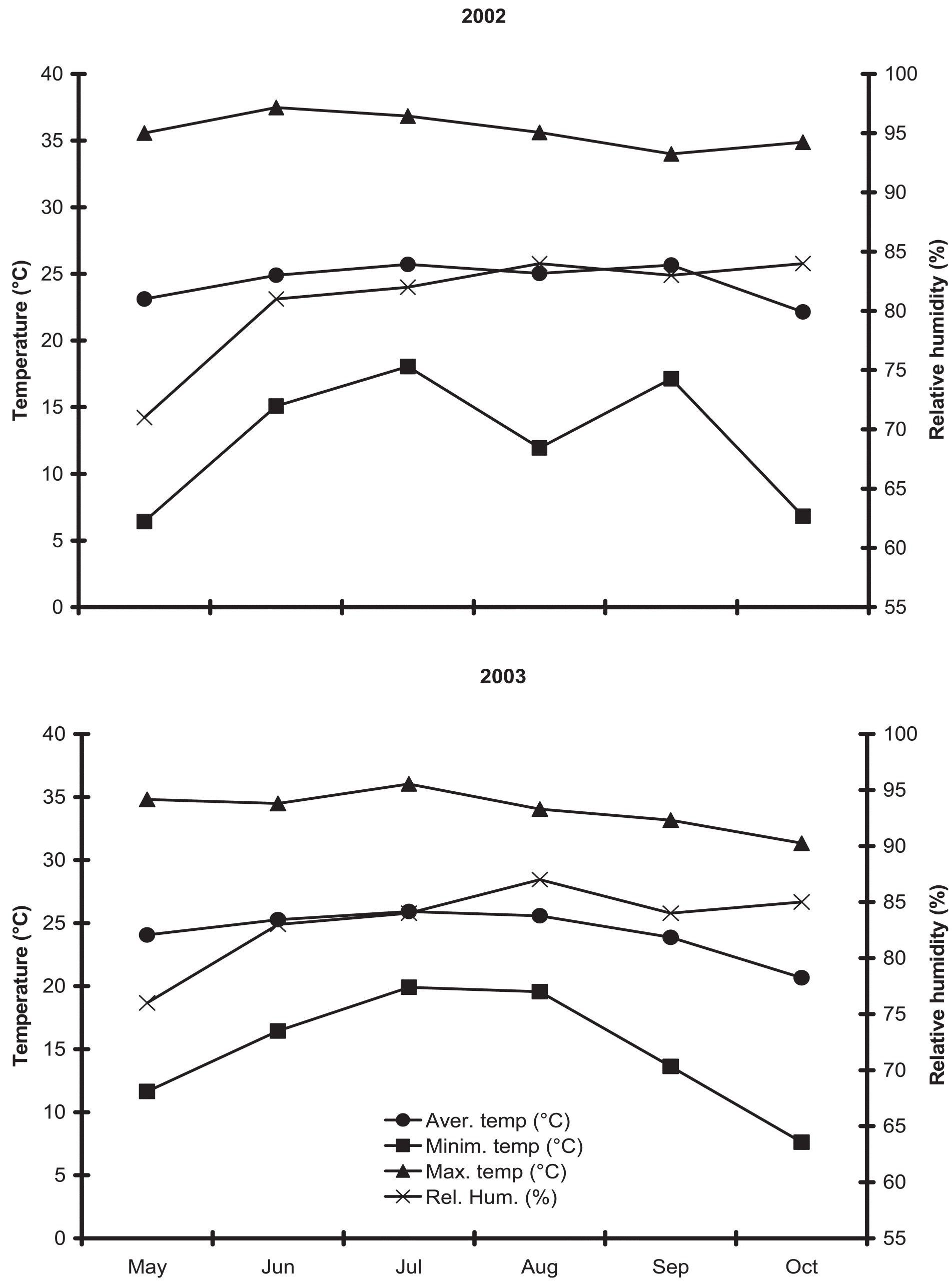

Figure 2. Average, minimum, and maximum temperatures and relative humidity measured at the Alachua Automated Weather Station (15 km from the research site) during the experimental period in 2002 and 2003. Data obtained from the website http://fawn.ifas.ufl.edu/; verified 23 Mar. 2009.

Table 3. Effect of pasture management intensity on soil-N concentration at different soil depths in continuously stocked bahiagrass pastures after 3 yr of grazing. Data are means across three zones and two replicates.

Treatment	Nitrate N			NH_4–N			Total-extractable N		
	0–8 cm	8–23 cm	P[†]	0–8 cm	8–23 cm	P	0–8 cm	8–23 cm	P
	mg kg^{-1} soil								
Low	0.7 a[‡]	3.0 a	0.57	5.5 b	4.1 a	0.17	6.2 b	7.1 a	0.22
Moderate	1.4 a	1.3 a	0.61	4.6 b	3.8 a	0.49	6.0 b	5.1 a	0.26
High	5.3 a	2.1 a	0.04	9.4 a	2.2 a	0.02	14.7 a	4.3 a	< 0.01
SE	2.8	1.7		2.1	2.3		2.3	2.5	

[†]Level of P for comparison of the two soil depths within a nutrient and a management intensity treatment.
[‡]Least squares means within a column followed by the same letter are not different ($P > 0.10$).

Table 4. Effect of pasture zone on soil-N concentration at different soil depths in continuously stocked bahiagrass pastures after 3 yr of grazing. Data are means across three management intensities and two replicates.

Zone†	Nitrate N			NH_4–N			Total-extractable N		
	0–8 cm	8–23 cm	P‡	0–8 cm	8–23 cm	P‡	0–8 cm	8–23 cm	P‡
	mg kg^{-1} soil								
1	3.1 a§	1.1 b	0.13	7.6 a	1.8 b	0.02	10.6 a	2.9 b	0.01
2	1.7 a	4.0 a	0.42	5.1 a	6.7 a	0.60	6.8 a	10.7 a	0.63
3	2.6 a	1.4 b	0.26	6.8 a	1.6 b	0.03	9.3 a	3.0 b	0.01
SE	1.3	1.3		2.3	2.2		2.9	2.9	

†Zone 1 is an 8-m radius semi-circle extending out from the watering point and including shade. Zone 2 is the area between the 8- to 16-m radii from the watering point (no shade), and Zone 3 is the remaining area of the pasture (no shade).

‡Level of *P* for comparison of the two soil depths within a nutrient and a management intensity treatment.

§Least squares means within a column followed by the same letter are not different ($P > 0.10$).

23 cm for Zones 1 and 3, but not for Zone 2 (Table 4). This suggests that either N is moving deeper in the soil profile in Zone 2 or SOM accumulation is occurring to a greater degree in Zone 2 than in other zones. Soil N enrichment in Zones 1 and 2 was expected because these zones were closer to shade and water. Because Zone 1 is where the shade and water are physically located, greater sod disturbance occurred there compared to Zone 2 (visual observation). Thus, it may be that greater bahiagrass ground cover in Zone 2 provided superior conditions for plant growth and SOM accumulation at greater depth.

Soil P concentration was greater for the Moderate treatment at both soil depths (Table 5). Phosphorus fertilization was similar between Moderate and High treatments, so that was not the explanation for higher P levels in the Moderate treatment, although greater P fertilization may have contributed to Moderate being greater than Low. Also, a covariance analysis was performed using initial soil P levels (June 2001) as the covariate. It was not significant; therefore, P levels at the beginning of the experiment were not responsible for the difference observed. Potassium and Mg concentrations in the soil were greater in the High treatment at the 0- to 8-cm depth but did not differ at the 8- to 23-cm depth (Table 5). While most of the K is found in urine, most of the Mg is found in dung (Mathews et al., 2004). Both nutrients were present in greater concentrations in the High treatment, most likely because of greater stocking rate relative to the other management intensities. Nutrients in excreta are relatively highly available and the greater forage utilization that occurred due to greater stocking rate in the High treatment likely increased nutrient return through excreta.

There was an interaction of zone and depth for soil nutrient concentration (Table 6). Phosphorus and K were greater in Zone 1 than in Zone 3 for both depths. Magnesium was greater in Zone 1 than in Zone 3 at the 0- to 8-cm depth, but not different at the 8- to 23-cm depth. Soil nutrient concentration was generally greatest in Zones 1 and 2, showing a clear response in areas near shade and water (Table 6). Dung and urine indices (Table 1) were greater in Zone 1, indicating a higher proportional return of excreta in that area, likely resulting in its higher soil nutrient concentration. The range in concentration of soil nutrients could be even greater in larger pastures because of the smaller relative proportion of shaded area in large pastures. Mathews et al. (1999) reported increasing soil N, P, K, and Mg around cattle lounging areas on kikuyugrass (*Pennisetum clandestinum* Hochst. ex Chiov.) pasture. In the current study, soil P, K, and Mg did not differ between the two soil depths except for Zone 2 Mg (Table 6).

Across the three years of grazing, changes in soil P, K, and Mg concentration were greater in magnitude close to the shade and water locations and near the paddock gate (Fig. 3). Proportionally greater amounts of time spent near shade and water lead to greater excreta deposition indices (Table 1), and this resulted in greater magnitude in soil nutrient concentration changes three years after applying the management intensities. In addition, the presence of animals in neighboring pastures appeared to play a role in determining where cattle spent time and deposited excreta, likely due to social interactions among grazing animals. This is particularly noticeable in the top left portion of the change in soil P figure (Fig. 3). Cattle have a strong herd instinct (Lazo, 1994); as a result, activities such as grazing and camping are usually performed in groups and can accentuate accumulation of soil nutrients.

Table 5. Effect of pasture management intensity on soil P, K, and Mg concentrations at different soil depths in continuously stocked bahiagrass pastures after 3 yr of grazing. Data are means across three zones and two replicates.

Treatment	Phosphorus			Potassium			Magnesium		
	0–8 cm	8–23 cm	P†	0–8 cm	8–23 cm	P	0–8 cm	8–23 cm	P
	mg kg^{-1} soil								
Low	11 b‡	14 b	0.23	63 b	68 a	0.77	149 b	111 a	0.43
Moderate	19 a	21 a	0.53	72 b	75 a	0.84	128 b	110 a	0.72
High	15 b	14 b	0.93	100 a	75 a	0.12	240 a	126 a	0.03
SE	3	3		12	11		36	37	

†Level of *P* for comparison of the two soil depths within a nutrient and a management intensity treatment.

‡Least squares means within a column followed by the same letter are not different ($P > 0.10$).

SUMMARY AND CONCLUSIONS

Management intensity did not affect time spent grazing or in shade, or relative distribution of dung and urine, but it did affect soil nutrient concentration. Nitrogen, K, and Mg concentrations in the soil were greater at the highest management intensity at the shallower soil depth but not deeper in the soil profile. This is an important indication that although soil fertility is increasing in the surface horizon, movement of nutrients to deeper soil horizons may be small when higher management intensity is used on bahiagrass pastures, at least over a three-year period. With the exception of soil P, which increased in Moderate pastures compared to Low, there was virtually no change in soil nutrient concentrations associated with an increase in bahiagrass management intensity from the present industry average (Low) up to the highest level of management currently practiced (Moderate).

Table 6. Effect of pasture zone on soil P, K, and Mg concentration in different soil depths in continuously stocked bahiagrass pastures after 3 yr of grazing. Data are means across three management intensities and two replicates.

Zone†	Phosphorus			Potassium			Magnesium		
	0–8 cm	8–23 cm	*P*‡	0–8 cm	8–23 cm	*P*‡	0–8 cm	8–23 cm	*P*‡
	mg kg^{-1} soil								
1	21 a§	19 a	0.44	103 a	92 a	0.45	198 a	133 a	0.21
2	14 b	17 ab	0.33	80 b	66 b	0.31	197 a	112 a	0.10
3	10 b	13 b	0.17	52 c	59 b	0.59	122 b	102 a	0.66
SE	3	3		9	9		37	37	

†Zone 1 is an 8-m radius semi-circle extending out from the watering point and including shade. Zone 2 is the area between the 8- to 16-m radii from the watering point (no shade), and Zone 3 is the remaining area of the pasture (no shade).

‡Level of *P* for comparison of the two soil depths within a nutrient and a management intensity treatment.

§Least squares means within a column followed by the same letter are not different ($P > 0.10$).

Indices of total time spent by cattle, dung deposition, and urine deposition, as well as measures of soil nutrient concentration were generally greatest in the pasture zones closer to shade and water. Because of the degree to which their location influences animal behavior, frequent rotation of portable shade and water to different pasture areas during the grazing season may improve excreta distribution in continuously stocked swards (Mathews et al., 1994b), reducing the problem of high soil nutrient concentration in localized pasture areas.

Weather variables affected time spent in pasture zones, patterns of excreta return, and, as a result, soil nutrient redistribution. Air temperature and temperature-humidity index were positively correlated with time spent in shade indicating that achieving uniformity in excreta distribution is likely to be more challenging in warm vs. cool climates, and in warm vs. cool seasons in temperate areas. Actions of managers to move portable shade, watering structures, and feeders will be most critical and should be emphasized to the greatest extent in these warm climates or seasons of the year.

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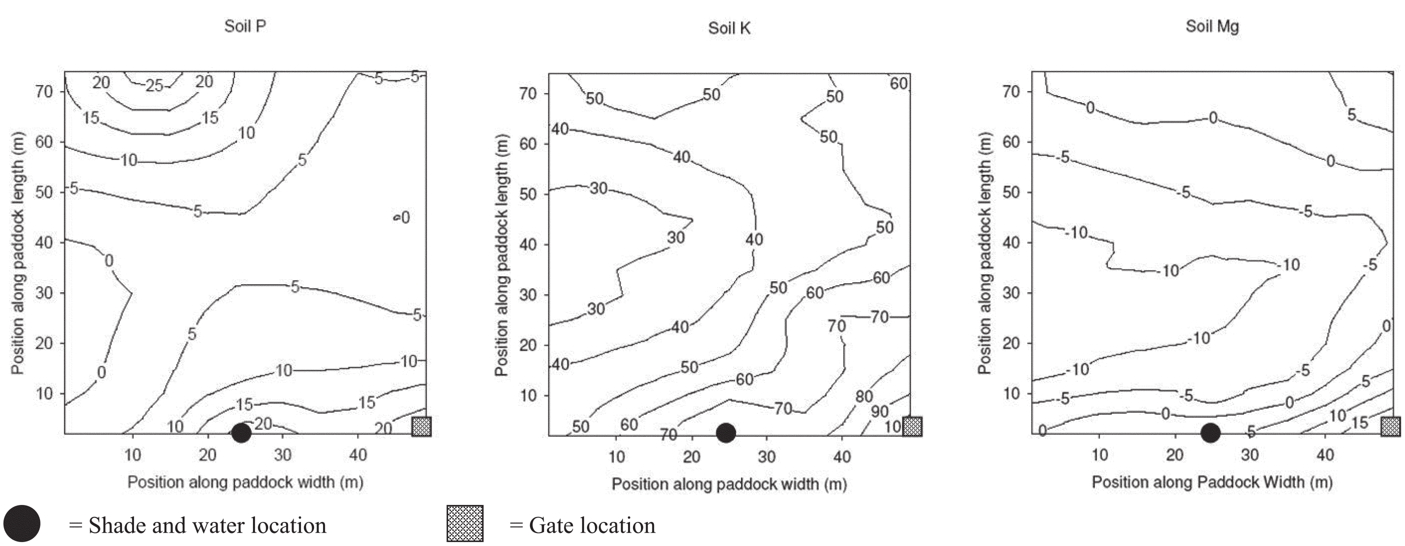

Figure 3. Changes in soil P, K, and Mg concentration (0–15 cm depth) in Pensacola bahiagrass pastures managed at Moderate intensity (120 kg N ha^{-1} yr^{-1} and stocking rate of 2.4 animal units ha^{-1}). Data reflect changes in soil nutrient concentrations that occurred during 3 yr of imposing treatments.

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