Cattle Grazing Affects Peanut Root Characteristics in a Bahiagrass-Based Crop Rotation System

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ABSTRACT

The critical aspect of production agriculture in the southeastern US with increasing associated costs is to improve economic and agronomic sustainability. A four yr sod-based rotation system consisting of two yr of bahiagrass (*Paspalum notatum* Flueggé) (grazed or non-grazed) followed by a yr of peanut (*Arachis hypogaea* L.) and a yr of cotton (*Gossypium hirsutum* L.), each with winter cover crop (grazed or non-grazed) was established in Marianna, FL. The effect of grazing on root parameters (length, volume, surface area, and diameter) of peanut was observed using a mini-rhizotron. There were differences in several root parameters between grazed and non-grazed plots including: peanut root length (307 mm in grazed vs 167 mm in non-grazed), volume (50 mm^3 in grazed vs. 23 mm^3 in non-grazed), surface area (399 mm^2 in grazed vs. 197 mm^2 in non-grazed), and diameter (2.4 mm in grazed vs. 1.7 mm in non-grazed). Roots at the 45-60 cm and 60-75 cm depths had significantly greater length in the grazed than the non-grazed plots. Likewise, surface area was significantly greater in the grazed plots at the 30-45 cm, 45-60 cm and 60-75 cm depths. Grazed plots at the 40-65 cm depths showed significant increase in root diameter. No significant difference in peanut yield was observed for the grazed or non-grazed treatments. A more developed root system associated with cattle grazing in the sod-based rotation system may enable peanuts to be more resilient in adverse environmental conditions such as drought stress, enhance nutrient cycling without affecting yield, thereby improving long-term sustainability.

Key Words: bahiagrass, cattle, peanut, *Arachis hypogaea* L., grazing, mini-rhizotron, root architecture, water use efficiency

The consolidation of smaller farms into larger farms along with a shift to forestry-based applications and pine production has led to a decline in the number of farms in the southeastern US (Marois *et al.*, 2002). This situation provides an opportunity and necessitates the development of robust cropping systems through environmentally friendly agricultural practices that are profitable and sustainable. These cropping systems must be profitable for small farms by increasing the yields and by maintaining or decreasing production costs. Improved financial benefits from new cropping systems will enable small farms to be competitive (Wright *et al.*, 2007). Integrated crop-livestock production systems provide opportunities for greater diversification and yr round utilization of resources thereby mitigating risk, and providing environmental benefits such as nutrient cycling and energy efficiency impacting overall farm profitability (Clark, 2004; Entz *et al.*, 2005; Hanson and Franzluebbers, 2008; Tanaka *et al.*, 2005). Several studies integrating crop and livestock have indicated an increase in total nitrogen, soil organic C (carbon), soil microbial biomass C, water-soluble aggregate stability, and a decrease in penetration resistance (Acosta-Martinez *et al.*, 2004; Maughan *et al.*, 2009).

Bahiagrass (*Paspalum notatum* Flueggé) has been utilized in reduced tillage systems (sod-based rotations) in the Southeast Coastal Plains (Wright *et al.*, 2005). Deep-rooted bahiagrass leaves soil channels after the decay of bahiagrass roots for the subsequent summer crop to develop roots in these channels (Elkins *et al.*, 1977). Soil quality is also improved by presence of yr-round soil cover, greater water infiltration, reduction in NO_3^- leaching, and soil erosion (Reeves, 1997). Additional benefits of including bahiagrass, a non-host for most of the row crop pests, in the cropping system includes reduction of weeds, nematodes, and diseases and reduced pesticide applications (Katsvairo *et al.*, 2007a; Liebman and Dyck, 1993; Marois, 2003; Sumner, 1982; Tsigbey *et al.*, 2009). Establishment of bahiagrass in the cropping systems has several positive impacts on the soil physical and chemical properties and may often lead to improved crop yields (Brenneman *et al.*, 2003; Katsvairo *et al.*, 2006; Toth, 1998). Also, an increase in earthworm populations (Katsvairo *et al.*, 2007b), organic matter and improved soil structure (Swift and Noordwijk, 2004) has been observed in this system.

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Growers are able to benefit from additional income during the yr bahiagrass is present in the rotation through utilization of livestock to graze these areas. Land associated with crop production is rented at a higher price than pasture land. As 80% of the crop land in the U.S. is rented, adoption of sod-based practices strictly for grazing was hindered. However, a row crop production system including a sod-based rotation with grazing as a component may provide benefits of bahiagrass along with the economic benefits.

The University of Florida, North Florida Research and Education Center (NFREC) has been evaluating benefits of grazing by cattle (*Bos taurus L*) in the sod-based rotations to evaluate the economic sustainability of these systems. Peanut grown in the sod-based rotation system with cattle grazing has shown higher yields with reduced costs (Marois *et al.*, 2002). Grazing in a sod-based rotation system has also shown increased root development (Loison *et al.*, 2012), enhanced microbial and enzyme activity and nutrient recycling (Anguelov *et al.*, 2011; Vendramini *et al.*, 2007; Wright *et al.*, 2010; George *et al.*, 2013).

However, grazing of cattle can adversely impact the soil profile by increasing soil compaction which may negatively impact root development of the subsequent summer crop. Wright *et al.* (2010) observed an increase in soil bulk density of the top 10 to 15 cm soil profile due to grazing in comparison to the non-grazed plots. An increase in the bulk density of top 10 to 15 cm soil profile due to cattle grazing was also reported by Bell *et al.* (2011). However, negative impacts of animal traffic on soil physical characteristics can be mitigated by increase in organic matter content due to perennial grass use and conservation tillage (Franzluebbers and Stuedemann, 2008). Franzluebbers (2007) in his review of the status of integrated crop-livestock systems in the southeastern U.S concluded that there were great opportunities for crop-livestock integration in this region and that research emphasizing the consequences of these systems was limited. Agronomic and economic benefits for the growers can be expected with the adaptation of crop-livestock systems despite the low adoption and management challenges (Franzluebbers and Stuedemann, 2008). We integrated cattle grazing with sod-based rotation systems (2 yr of bahiagrass followed by peanut then cotton) to understand the short- and long-term effects of grazing on soil properties and crop yield.

The objective of this study was to analyze the impact of prior grazing on subsequent peanut root development in a sod-based crop rotation. Peanut crop grown subsequent to bahiagrass may develop a better root system but the negative impacts of soil compaction caused by livestock traffic may counteract some of these benefits. Therefore, it became imperative to quantify the impacts of cattle grazing on the root architecture of peanut.

Materials and Methods

Experimental Site and Crop Rotation. The experiment was located in Marianna (Jackson County), Florida, on the University of Florida-NFREC-Marianna station (N 30°52′25″, W 85°10′56″). The soil was an Ultisol composed of coarse sand and loamy coarse sand on the top 80 cm, coarse sandy loam and sandy clay loam at depths 80 to 110 cm and sandy clay loam at 110 to 200 cm depths (Soil Survey Jackson County FL, 1979). The study consisted of a sod-based rotation system where bahiagrass was established for the first two yr followed by peanut and then cotton. The study was established under a 56 ha center pivot irrigation system divided into 4 equal quadrants. Each quadrant contained one component of the rotation so that all crops of the rotation were present in every yr (Fig. 1). The non-irrigated area (corners) amount to 2.0 ha in each quadrant. Every yr each quadrant changed crop to the following phase based on aforementioned rotation.

Exclusion Cages, Grazing, and Crop Management. In the fall of 2006, large exclusion cages (16 m x 16 m) were fenced off in the rotation scheme where cattle were not allowed to graze, non-grazed (NG) treatment, the bahiagrass and winter cover crops (oats/rye) (Fig.1). Global Positioning System coordinates for the exclusion cages were obtained at first installation so that the fence could be erected at the same location following each crop sequence when cattle are on winter (oats/rye mixture) or summer (bahiagrass) grazing. Fences were taken down to allow timely management of non-grazed areas such as cutting hay, planting of winter grazing and row crops. Outside each exclusion cage, a similar sized plot was established at a distance of 3 m without a fence where cattle grazing was allowed, grazed (G) treatment. The experiment was repeated for three yr with peanut crop grown in a different quadrant each yr as per the aforementioned crop rotation. For more information on experimental design, see George *et al.* (2013).

The rotation system initiated with overseeding of bahiagrass into a grazed oats/rye cover with a grain drill in February and March. In this quadrant, cattle were removed from the field and grazing was discontinued for six weeks around

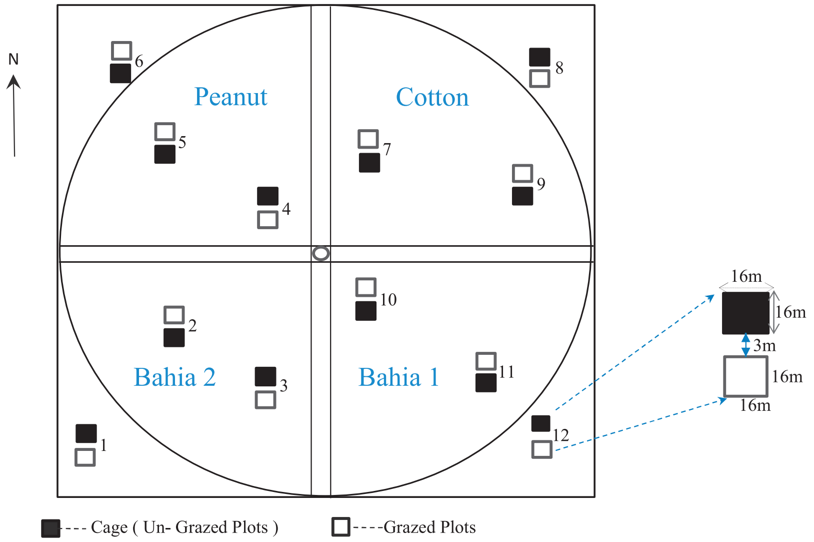

Fig. 1. The sod-based rotation under a center pivot system at the experimental site in Marianna, FL, showing arrangement of exclusion cages and crop in each quadrant.

mid-May to help bahiagrass establishment. Grazing was allowed again on bahiagrass starting early to mid-July and was continued through second yr. Cattle were removed from the field during planting of winter cover crops and were returned for grazing after planting. During first yr fall, annual ryegrass was overseeded with Hay Van no-till drill for winter grazing. During fall of second yr, bahiagrass was killed with glyphosate (Roundup Power Max, Monsanto, St. Louis, MO) followed by planting of oats/rye cover crop mixture for winter grazing from late October till late April to early May when cotton and peanut, respectively, were planted. The bahiagrass was followed by peanut and then cotton in the subsequent first and second summer, respectively. Each fall peanut and cotton were followed by oats/rye winter cover crop mixture, which were grazed. Cattle were managed as a controlled "put and take" grazing system with varying stocking rate. In 2007, there were 1.5 cow/calf pairs per hectare during both winter and summer grazing periods. Cattle were unable to keep up with the aggressive growth of the forage and excess forage was produced in the first yr. In the remaining yr of the study, put and take animals were used to maintain a stocking rate of 2.2 cow/calf pairs per hectare in 2008-2010. Hay was cut from both bahiagrass and winter grazing if excess forage was accumulated each yr.

All crops were planted using conservation tillage methods (strip tillage) unless fields were deemed too rough after winter grazing, thus the field had to be tilled to allow for good soil/seed contact. Information of crop varieties used for this study and planting and harvesting date is given in Table 1. University of Florida Extension recommendations were used for peanut management (Wright *et al.*, 2016). Following harvest peanut residues were disk harrowed twice before being planted to oats/rye. Annual ryegrass was over seeded into first yr bahiagrass for winter grazing using a Hay Van no-till drill. The winter grazing cover crop (oats/rye) was broadcast planted in plots where the preceding crop was cotton, or seeded with a grain drill into plots where peanut or second yr bahiagrass was the preceding crop. Winter cover crop was terminated each yr using glyphosate (depending on amount of residue left after grazing) in early May prior to planting peanut. Peanut yield was measured in both grazed and non-grazed plots.

Peanuts did not receive any fertilization and were managed for any foliar disease. Cotton was fertilized at rate of 26.9 kg/ha N and 44.8 kg/ha P at planting; 89.6 kg/ha N and 156.9 kg/ha K at 30 days after planting (DAP); and 56 kg/ha N at 55 DAP. Bahiagrass was fertilized in May and July at the rates of 44.8 kg/ha N and 84 kg/ha N during first yr and at the rate of 44.8kg/ha and 56 kg/ha N during second yr, respectively. A pre-plant fertilization at the rate of 67.2 kg/ha N, 44.8 kg/ha P, 89.6 kg/ha K and a 67.2kg/ha N at 60 DAP was applied for Anuual ryegrass.

Measurement of Root Growth. Mini-rhizotrons consisting of 1.8 m long with a 5 cm internal diameter transparent tubes (Bartz Technology Corp., Santa Barbara, CA) were installed at a 45° angle with the soil surface. Tubes were installed in each of the grazed and non-grazed areas using a probe and auger assembly mounted on a tractor. The tubes were installed parallel and within a peanut row and the first plant in the row under the tube was approximately 5-10 cm away from the

Table 1. Crop variety, planting dates, harvesting dates, and termination dates during 2007-2010 during sod-based rotation (bahiagrass-bahiagrass-peanut-cotton)

Crop	Variety	Planting date	Harvest or terminating date
First yr bahiagrass	Pensacola	Late February to mid-March	Ryegrass is over seeded for winter grazing
Second yr bahiagrass	Pensacola	Continued from first yr bahiagrass	Late September to early-October
Peanut	Georgiagreen06	Mid-May	Mid-October
Cotton	DP 555 roundup ready	Late-April to early-May	Late-October to early-November
Oats/rye	Horizon oats 201/Abruzzi rye	Late-October	Late-April to early-May
Annual ryegrass	Gulf ryegrass	Late-October	Late-April to early May

point of tube insertion. The tubes were inserted to a depth of 1 m into the soil with approximately 1.4 m of the tube inserted. Images were taken by inserting a camera (BTC 2, Bartz Technology Corp., Santa Barbara, CA) into the tubes. The camera was attached to an indexing handle system that permitted images to be taken repeatedly over time at the same locations. The digital images were saved 1.35 cm along the length of the tube. The field of view for the camera was 1.35 cm vertical x 1.8 cm horizontal. A removable cap was placed and a black color was coated on the protruding end of each tube to prevent light and moisture from entering the tube. In 2007 and 2008, the measurement dates were mid-June, mid-July, mid-August, and mid-September. In 2009, measurements were made only in mid-August and mid-September.

Images were analyzed using WINRHIZO-TRON MF V.2005a software (Regent Instruments Inc., Canada). Root measurements were accomplished by tracing each root in a given image and adjusting diameters accordingly (Patena and Ingram, 2000). Total root length (root length), total root volume (root volume), total root surface area (root surface area), and average root diameter (root diameter) were calculated by the software. The multi framed (MF) version of the software allowed for adjustments based on the new root growth pattern by importing the previous scoring of a tube location. This maintained uniformity and avoided subjective bias in scoring. Root measurements were combined over the following depths: 0-15 cm, 15-30 cm, 30-45 cm, 45-60 cm, and 60-75 cm.

Statistical Analysis. Analysis of variance (ANOVA) was performed using general linear model (GLM) to evaluate the main effects of treatments and their interaction with yr (SAS Institute, 2011). A three yr combined ANOVA in many instances indicated significant yr effects and treatment x yr interactions therefore the data was reanalyzed by yr and summarized for each yr separately. Fisher's protected LSD test with $\alpha = 0.05$ was used for determining statistical differences among treatment means following each ANOVA.

Results and Discussion

Significant differences in root traits from yr to yr were observed but no yr x grazing treatment interaction was observed for root length, root diameter, and root surface area. However, significant yr x grazing treatment interaction was observed for root volume. Significant treatment effects ($P \leq 0.05$) were observed on root length, volume and surface area in 2007 and all root parameters in 2008 ($P \leq 0.001$). However, in 2009, the trends were similar but the differences in root parameters were non-significant.

The mini-rhizotron method allowed *in situ* measurements of these root parameters at several depths over time as compared to other methods which were disruptive, labor intensive, and destructive in nature (Ingram and Leers, 2001). Root length across all the depths and dates was greater in the grazed plots by 71% and 180% in comparison to the non-grazed plots in yr 2007 and 2008, respectively (Table 2). Similarly, root volume increased by 82% and 300%, root surface area increased by 72% and 229%, and root diameter increased by 16% and 78% in the grazed plots in comparison to the non-grazed plots in 2007 and 2008, respectively (Table 2). These root parameters were also numerically higher in the grazed plots in 2009 but the difference with the non-grazed plots were not significant (Table 2). These results confirm that grazing impacted the subsequent peanut crop's root characteristics in the two of three study yr.

Grazing did not impact the root characteristics in the 0-15 cm and 15-30 cm depth (Table 3). However, significant differences in root characteristics were observed in grazed and non-grazed plots at lower depths. Root length and root diameter were significantly higher in the grazed plots when compared to the non-grazed plots at depth of 45-60 cm and 60-75 cm (Table 3). Root length increased

Table 2. Treatment and yr effect on total root length, total root volume, total root surface area, and average root diameter of peanut in grazed (G) and non-grazed (NG) plots.

	Total root length		Total root volume		Total root surface area		Average root diameter	
Yr	G	NG	G	NG	G	NG	G	NG
	mm		mm^3		mm^2		mm	
2007	439 a[a] x[b]	256 b x	62 a x	34 b x	536 a x	311 b x	2.6 a x	2.2 a x
2008	318 a xy	113 b y	56 a xy	14 b y	431 a xy	131 b y	2.6 a x	1.5 b y
2009	198 a y	164 a y	31 a y	28 a xy	245 a y	185 a y	2.0 a x	1.6 a y

[a] Means within a row in a treatment group followed by the same letter are not significantly different according to LSD at α=0.05.

[b] Means within a column followed by the same letter are not significantly different according to LSD at α=0.05.

by 204% and 179% and root diameter increased by 117% and 95% in the grazed plots when compared to the non-grazed plots at depths of 45-60 cm and 60-75 cm, respectively (Table 3). Root volume and root surface area values were higher in the grazed plots as compared to the non-grazed plots at the soil depths of 30-45 cm, 45-60 cm, and 60-75 cm (Table 3). In the grazed plots, root length, root volume, and root surface area were greater at the soil depths of 30-45 cm and 45-60 cm as compared to the shallower depths. However, in the non-grazed plots such differences in the root parameters at different depths were not observed (Table 3). As previously noted in cotton by Loison *et al.* (2012) grazing did not negatively impact root traits in the top soil due to soil compaction. In a related study on peanut in 2009, a slight increase in bulk density was observed at 0-5 cm in the grazed plots as compared to the non-grazed plots. The bulk density was 1.21, 1.44, 1.58 g/cm^3 in non-grazed and 1.26, 1.33, and 1.48 g/cm^3 in grazed plots at 0-5, 15-20, amd 35-40 cm , respectively. Root growth in the grazed treatments may have been encouraged by more efficient nutrient cycling due to cattle grazing. Wright *et al.* (2010) demonstrated a 3 to 5 fold increase in the nitrate content in the top 20 cm of the soil in the grazed plots.

The development of the peanut root system in the grazed and non-grazed plots was evaluated by assessing root characteristics at different sampling dates. Root characteristics averaged over different depths and yr showed significant effects of prior grazing on subsequent peanut crop roots at each sampling date. The root length increased linearly and was significantly different from June to August in grazed plots, and from June to July in non-grazed plots (Table 4). However, significant differences in root length were observed from June to August and June to July in grazed and non-grazed plots, respectively (Table 4). A significant increase in root diameter was observed in the grazed plots from June to July but not later sampling dates. No significant increase in root volume and root surface area in the grazed plots were observed at different sampling dates. A rapid root development in the grazed treatments seems to be responsible for the non-significant increase of the root characteristics over time. Root length and root volume in the grazed treatment were significantly higher than the non-grazed treatment at sampling dates of June, August, and September (Table 4). Root diameter and root surface area were significantly higher in grazed plots in comparison to non-grazed plots from July to September and from June to September, respectively (Table 4).

The average peanut yield over the 3 yr period of this study was 5316 kg/ha and 5592 kg/ha in the grazed and non-grazed treatments, respectively, indicating that grazing does not have an

Table 3. Soil depth effect on total root length, total root volume, total root surface area, and average root diameter of peanut in grazed (G) and non-grazed (NG) plots.

	Total root length		Total root volume		Total root surface area		Average root diameter	
Depth	G	NG	G	NG	G	NG	G	NG
cm	mm		mm		mm^2		mm	
0-15	159 a[a] z[b]	90 a z	27 a yz	28 a x	179 a z	138 a y	2.0 a y	1.5 a xy
15-30	170 a z	173 a xyz	19 a z	20 a x	178 a z	190 a xy	1.7 a y	2.1 a x
30-45	320 a y	254 a x	54 a x	27 b x	421 a y	276 b x	2.4 a y	2.1 a x
45-60	599 a x	197 b xy	108 a w	24 b x	832 a x	233 b xy	3.4 a x	1.6 b xy
60-75	288 a yz	103 b yz	46 a xy	16 b x	387 a y	135 b y	2.5 a y	1.3 a y

[a] Means within a row in a treatment group followed by the same letter are not significantly different according to LSD at α=0.05.

[b] Means within a column followed by the same letter are not significantly different according to LSD at α=0.05.

Table 4. Total root length, total root volume, total root surface area, and average root diameter of peanut at different sampling dates in grazed (G) and non-grazed (NG) plots.

	Total root length		Total root volume		Root surface area		Average root diameter	
Dates	G	NG	G	NG	G	NG	G	NG
	mm		mm^3		mm^2		mm	
June	216 a[a] y[b]	90 b y	40 a x	14 b x	305 a x	119 b y	1.9 a y	1.5 a x
July	324 a xy	214 a x	54 a x	31 a x	427 a x	250 b x	2.7 a x	1.9 b x
August	396 a x	209 b x	65 a x	26 b x	517 a x	252 b x	2.8 a x	1.9 b x
September	292 a xy	143 b x	44 a x	18 b x	358 a x	158 b xy	2.2 a xy	1.5 b x

[a] Means within a row in a treatment group followed by the same letter are not significantly different according to LSD at α=0.05.

[b] Means within a column followed by the same letter are not significantly different according to LSD at α=0.05.

adverse effect on crop yield. Increased root growth may have resulted in increased vegetative growth without influencing harvest index, although this was not investigated. Junjittakarn *et al.* (2014) indicated that root traits are not significantly correlated to harvest index or peanut pod dry weight. Moreover, a water limiting situation would perhaps have increased the significance of enhanced root development on crop yield.

We have also reported the effect of grazing bahiagrass and winter annuals on soil physical and chemical properties such as increased volumetric water content, reduced or comparable bulk density and greater N, P, and K cycling in the top 30 cm depth in the grazed treatments as compared to non-grazed treatments (George *et al.* 2013). Organic matter in grazed treatments was also greater than non-grazed plots (George *et al.*, 2013). Efficient nutrient recycling as well as decomposing soil organic matter may be more readily available as sources of nutrients in a grazed treatment relative to non-grazed treatments, thereby driving greater root growth and development. Watt *et al.* (2005), McNeill *et al.* (1999), Khan *et al.* (2001), and Nuruzzaman *et al.* (2005) have all suggested the theory of root-root interaction where actively growing crop roots gravitate toward dead roots from the previous crop seeking nitrogen and phosphorus. A greater root residue in peanuts from grazed plots will therefore contribute to nutrient availability to subsequent crops, usually cotton, in the cropping systems prevalent in the region.

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