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Effects of stocking rate and crude protein intake during gestation on ground cover, soil-nitrate concentration, and sow and litter performance in an outdoor swine production system[1]

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ABSTRACT: Pregnant gilts (n = 126) were assigned randomly to 12 0.4-ha old world-spar bluestem (*Bothriochloa ischaemum*) pastures in an outdoor swine (*Sus scrofa*) production system to examine effects of stocking rates (17.5 or 35 gilts/ha; 7 or 14 gilts per pasture) and dietary N on percentage of ground cover, soil nitrate (NO_3^-) concentration, and reproductive performance. Treatments were arranged factorially with two stocking rates and two diets equivalent in dietary lysine but different in CP (control = 14.7% CP vs experimental = 12.6% CP) with three pastures per treatment. The experiment was repeated during a second parity with the same animals on the same treatments. Each triangular gestation pasture was subdivided into three regions: 1) near the point or radial center; 2) the middle region that contained a hut and a wallow area; and 3) the outer section where gilts were fed each day. Soil samples (15 cm deep) were taken at the beginning and end of the 306-d study, and soil nitrate-N concentrations were determined. Percentage of ground cover was visually estimated initially and every 30 d thereafter through d 306. Before farrowing, gilts were moved to identical pastures for farrowing and were fed a common 16% CP sorghum (*Sorghum bicolor*)-based lactation diet beginning at the time of movement to the farrowing pasture. Pregnant gilts were weighed at the time of assignment to treatments in the gestation pastures, when they were moved to farrowing pastures, and at weaning. Production data included total number of pigs born per sow, number of pigs born alive or dead, average birth weight, number of pigs weaned, average weaning weight, and mortality. No differences ($P > 0.05$) were observed between treatments in soil NO_3^- concentrations. Percentage of ground cover was decreased ($P < 0.01$) by the higher stocking rate when grazing was initiated in March/April but recovered rapidly after removal of pigs. More ($P < 0.01$) pigs were weaned per sow (8.4 vs 7.1 ± 0.34) from higher gestation-stocking rate groups. Pig mortality in farrowing was greater ($P < 0.05$) for lower gestation-stocking rates (25.7% vs. 18.1 ± 1.9%). A stocking rate of 35 sows/ha might have increased production potential but was associated with a rapid loss of ground cover during spring.

Key Words: Pigs, Stocking Density, Sustainability, Environment

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Introduction

Stringent regulations and guidelines are forcing many producers to seek alternative pork production methods that are perceived to be sustainable, especially in European countries (Edwards, 1995). Sustainable animal production systems need to include nutrient management plans to protect the environment. Outdoor swine production systems have several advantages over conventional indoor confinement units, including low initial investment (Honeyman, 1996; PIC, 1997), less odor (Sutton et al., 1999), better health status as a result of pathogen dilution (Malayer et al., 1987; De Boer and Morrison, 1988; Donham, 1991), and improved animal welfare perceptions (Thornton, 1988). The public is becoming concerned with livestock production systems that do not sustain the environment (Crutzen et al., 1986; Johnson and Johnson, 1995; Pimentel et al., 1997). Safe and effective disposal of waste nutrients in swine production depends on reducing the quantity of nutrients excreted coupled with recycling of excess nutrients in a manner that is not harmful to the environment (Sutton et al., 1999). Baker et al. (1990)

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noted that manure could improve soil fertility and alleviate erosion problems that result from some agricultural practices. Manure not only adds nutrients and organic matter but might also improve soil tilth and increase recycling of nutrients. Overstocking with pigs for long periods on the same area, however, may create environmental problems, most notably NO_3^- leaching (Worthington and Danks, 1992) and P accumulation (Jongbloed, 1998).

Our objectives were 1) to investigate effects of diet and stocking rate on soil NO_3^- accumulation and distribution within the pasture; 2) to monitor effects of stocking rate on percentage of ground cover and botanical composition of the pasture; and 3) to determine effects of stocking rate and diet on performance of pregnant gilts and their offspring.

Materials and Methods

Location and Animals

This study was conducted at the Sustainable Pork Farm at Texas Tech University, Lubbock, TX, from March 1999 to December 1999. The farm was located about 36 km northeast of Lubbock near Idalou, TX (latitude 33° 42′ N; longitude 101° 36′ W; elevation 977.2 m). The site was located on a former Conservation Reserve Program area with old world-spar bluestem (*Bothriochloa ischaemum*) as the dominant (98%) forage species. Forage samples were taken and submitted to Southern Plains Range Research Station in Woodward, OK for identification. No grazing by domestic livestock had occurred during the 10 yr before this experiment. Soils were primarily Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustolls). From early March through early April 1999, 126 pregnant Camborough-22 gilts (PIC-USA, Franklin, KY; BW = 206.7 ± 17.2 kg) were assigned at random to pastures in groups of either 7 or 14 per 0.4 ha for a stocking rate of 17.5 or 35 gilts/ha, respectively. Gilts were assigned to treatments as a group but pastures were filled as groups of gilts were diagnosed pregnant. The first groups of gilts entered treatments on March 2, 1999, and the last batch left pastures on December 3, 1999. All pastures could not be occupied concurrently because breeding schedule was set at 14 gilts per week. This resulted in some pastures being empty at times; however, pastures were balanced to contain similar number of stocking rates and time on pasture. Groups of gilts on a given pasture were fed (approximately 19 kg or 38 kg of pelleted feed depending on their group, for expected intake of about 2.5 to 3 kg/gilt) each morning either a control (14.7% CP) or an experimental diet (12.6% CP with 0.2% added lysine) designed to meet nutritional requirements of gestating gilts (Table 1; NRC, 1998). The four pasture treatments were replicated three times. The same gilts were reassigned to the same pastures during the second parity, as described for Parity 1, from mid-July through late August. The Parity-1 gilts were assigned to treatment when they averaged 46 d into pregnancy and stayed on gestation pastures for an average of 68 d, whereas Parity 2 were assigned when they averaged 41 d into pregnancy and stayed for an average of 73 d (Table 2).

A quonset-style hut with dimensions of 4.27 m long × 3.66 m wide × 2.03 m high (to provide shelter from inclement weather), wallow-pool, and continuous fresh water drip were provided in the middle region of each pasture (Figure 1). Feed was spread on the ground close to the outside fence line of the outer region of each

Table 1. Composition of diets fed to gestating gilts and sows on old world-spar bluestem pastures at stocking rates of either 17.5 or 35/ha[a]

Ingredient	Diet: Control 14.7% CP	Diet: Experimental 12.6% CP
	%, as-fed basis	
Grain sorghum	77.0	80.8
Soybean meal without hulls	13.0	9.0
Vit/TM premix[b]	5.0	5.0
Nutri-binder[c]	5.0	5.0
Lysine	—	0.2

[a]Diets were mixed at the Texas Tech University Feed Center (GS-5 Pellet), Lubbock, TX.
[b]Roche vitamin premix supplied the following per kg of diet: vitamin A, 2,057.8 IU; vitamin D_3, 205.9 IU; vitamin E, 5.9 IU; vitamin B_{12}, 0.01 mg; riboflavin, 1.8 mg; niacin, 8.8 mg; d-pantothenic acid, 7.3 mg; calcium d-pantothenic acid, 7.9 mg; choline, 153.1 mg; choline chloride, 176.4 mg; vitamin K, 1.8 mg; menadione sodium bisulfate compound, 5.3 mg. Trace minerals supplied per kg of diet included 175 mg of Fe as ferrous sulfate; 150 mg of Zn as zinc oxide; 60 mg of Mn as manganous oxide; 17.5 mg of Cu as copper sulfate; 2 mg of I as calcium iodate; and 0.10 mg of Se as sodium selenate.
[c]Industrial Grain Products Division, Lafayette, LA.

Table 2. Composition of diets fed to lactating gilts and sows on old world-spar bluestem pastures at stocking rates of either 17.5 or 35/ha[a]

Ingredient	%, as-fed basis
Grain sorghum	65.5
Soybean meal without hulls	29.0
Vit/TM premix[b]	0.5
Calcium	0.55
Dicalcium	2.7
Potassium chloride	0.05
Sodium chloride	0.45
Pelunite[c]	1.25

[a]The diets were mixed at the Texas Tech University Feed Center (LS-5 Pellet), Lubbock, TX.
[b]Roche vitamin premix supplied the following per kg of diet: vitamin A, 2,057.8 IU; vitamin D_3, 205.9 IU; vitamin E, 5.9 IU; vitamin B_{12}, 0.01 mg; riboflavin, 1.8 mg; niacin, 8.8 mg; d-pantothenic acid, 7.3 mg; calcium d-pantothenic acid, 7.9 mg; choline, 153.1 mg; choline chloride, 176.4 mg; vitamin K, 1.8 mg; menadione sodium bisulfate compound, 5.3 mg. Trace minerals supplied per kg of diet included 175 mg of Fe as ferrous sulfate; 150 mg of Zn as zinc oxide; 60 mg of Mn as manganous oxide; 17.5 mg of Cu as copper sulfate; 2 mg of I as calcium iodate; and 0.10 mg of Se as sodium selenate.
[c]Economy Mills Master Feed, Lubbock, TX.

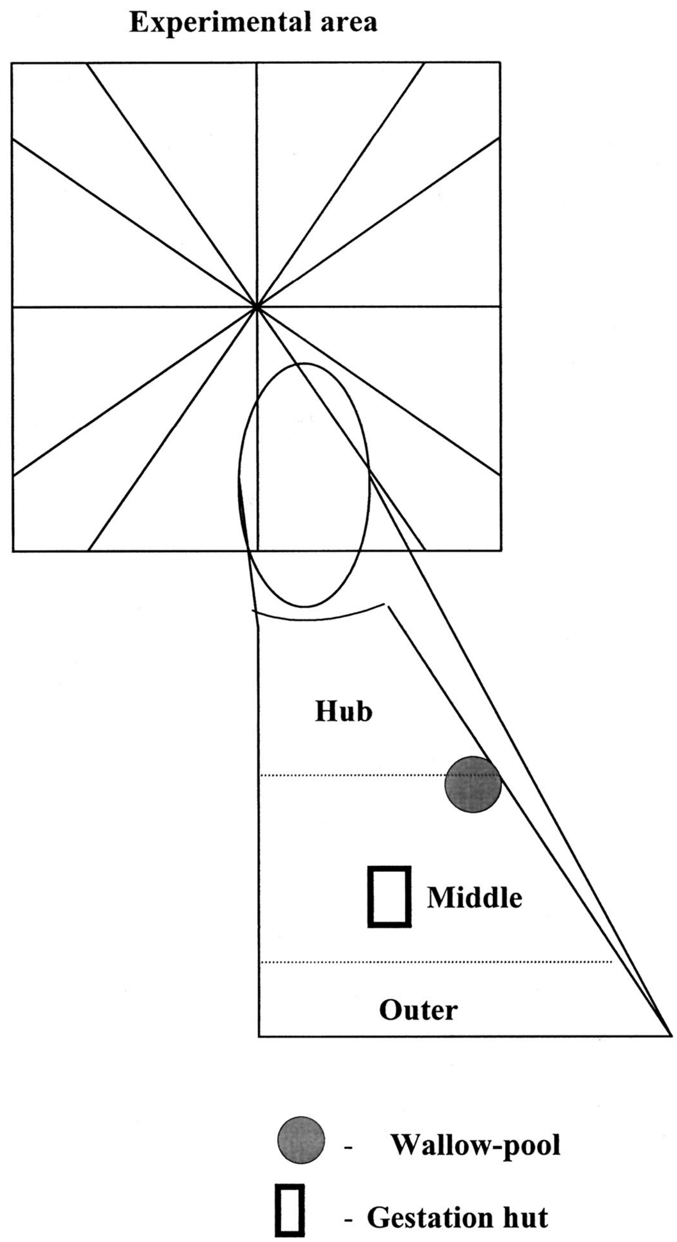

Figure 1. Old world-spar bluestem pastures grazed by pregnant gilts included 12 0.4-ha pastures. For sampling purposes, each pasture was divided into three regions (Hub, Middle, and Outer regions). Gilts had free access across all regions within a pasture.

triangular pasture. For sample collection purposes, each pasture was divided into three regions: 1) the point or inner region of the triangle; 2) the middle region that included a hut and wallow-pool; and 3) the outer region where feeding occurred. Gilts had free access to all these regions, and the three regions contained approximately 0.1, 0.2, and 0.1 ha, respectively. Gilts were gradually moved into a different farrowing pasture, identical in design to gestation pastures, from late April through mid-June, 1999, for Parity-1 gilts and from early September through late November of 1999 for Parity-2 gilts. The study was intended to cover two parities;

Table 3. Analysis of total lysine and CP from old world-spar bluestem forage samples from Parity 1 and 2, and gestation and lactation diets (Parity 1) grazed or fed to sows kept at stocking rates of either 17.5 or 35/ha at the Sustainable Pork Farm near Idalou, TX

Feed source	Total lysine, %[a]	Crude protein, %[a]
Grass sample	0.14	4.57
Control (14.7 CP)	0.56	15.58
Experimental (12.6 CP)	0.50	13.65
Lactation diet	0.88	19.91

[a]Grams per 100 grams sample.

however, because of problems with feed formulation midway during the study, sow performance data from Parity 2 were not as complete as those from Parity 1. Gilts remained on the same treatment from Parity 1 to Parity 2 but they were not necessarily returned to their original pastures. The error in feed formulation involved substitution of the intended vitamin-mineral mix meant for gestating sows with a formulation designed for growing-finishing pigs. The premix substitution error was not discovered until the conclusion of the study. Analyzed samples showed CP concentrations were lower in the 12.6% CP lysine-supplemented than in the 14.7% CP diet as expected (Table 3). Other ingredients of the diet were not affected. Gilts and sows were given ad libitum access to a common sorghum (*Sorghum bicolor*)-based lactation diet (Table 4; NRC, 1998) from the time they were moved to farrowing pastures until weaning. Gilts were transferred into farrowing pastures approximately 5 to 7 d before farrowing. English arc-style farrowing huts (1.12 m high, 2.79 m wide, and 1.65 m long), with metal or wooden fenders attached to the front door keep young pigs from wandering away, were used to house a sow and her litter. Pigs were processed (tail docking, ear notching, castration, and weighing) on d 2 after birth on average. Groups of gilts and sows that farrowed on the same week were weaned together. Pigs were weaned at an average of 23 d.

A weather station (Weather Monitor II, Model 7440, Davis Instruments, Baltimore, MD) was located within the study area. Data collected included hourly temperature, rainfall, humidity, wind speed, and wind direction.

Percentage of ground cover was estimated visually (Abaye et al., 1997) initially before gilts entered pastures and every 30 d thereafter until the end of the study. Briefly, an investigator walked each pasture and visually estimated percentage of open ground vs ground covered by vegetation. Three areas (hub, middle, and outside) were evaluated for each pasture during sample collection. The initial ground cover averaged 94%. Forage mass samples were collected monthly by randomly laying a board of 1.1 m^2 on the ground then clipping all vegetation covered and placing it in paper bags from each of the three areas per pasture. The samples were

Table 4. Duration of stay (d) by gilts and sows on old world-spar bluestem pastures at two stocking rates, two diets, and two parities

Treatment		Avg. no. of days on pasture		
Stocking rate, pigs/ha	Diet CP, %	Parity 1	Parity 2	SEM
17.5[a]	14.7	71	70	4.76
17.5	12.6	62	66	4.76
35[b]	14.7	64	76	4.76
35	12.6	75	81	4.76

[a]Seven pigs/pasture.
[b]Fourteen pigs/pasture.

dried at 50°C in a Grieve Forced-Air Drying Oven (Round Lake, IL) until a constant weight was established. Sample collection was not done during the months of November and December because of limited vegetation height caused by grazing and plant dormancy. Forage samples from each of the three pasture regions were ground and kept in plastic Whirl-Pack bags (Nasco, Fort Atkinson, WI). Forage subsamples taken from each of the three pasture regions for all pastures and gestation and lactation diets were submitted to Experiment Station Chemical Laboratories, Columbia, MO, for total lysine and crude protein analysis. Botanical composition was estimated by the Double DAFOR Scale (Abaye et al., 1997) initially before occupation by pigs and at the end of the study. Because of the dry summer weather, irrigation water was applied continuously at a rate of 0.254 cm daily for 10 d near the end of July through early August with a center pivot system with nozzles suspended approximately 1 m above the ground.

Soil samples (0 to 15 cm) were collected (three from the point, six from the middle, and three from the outside region of each pasture) at the beginning (March) and end (December) of the study. Samples were dried at 50°C overnight in a Grieve Forced-Air Drying Oven (Round Lake, IL) and were stored in plastic bags at room temperature. Samples were ground with a pestle and mortar and then sieved to pass a 2-mm screen. Nitrate-N was determined by A & L Plains Agricultural Labs (Lubbock, TX) using an aluminum-silver sulfate extraction procedure (Gavlak et al., 1994).

Pregnant gilts were individually weighed initially, when they were moved into farrowing units, and at weaning time using a Roose Farm Pride Trailer (Pela, IA) fitted with Weigh-Tronix scale (Model 715, Fairmont, MN). The weighing trailer was calibrated prior to loading gilts in each treatment group onto the trailer. Production data included each gilt's BW, total number of pigs born per gilt, number of pigs born alive, number of pigs found dead (stillborn), individual pig birth weight, number of pigs weaned, individual pig weaning weight, and preweaning pig mortality. Details of sows that were not included in the analysis are shown in Table 5.

Statistical Analyses

Pasture containing 7 or 14 gilts was the experimental unit. The experiment was a completely randomized design, with a 2 × 2 factorial arrangement of treatments (two diets and two stocking rates). Percentage of ground cover data were transformed (square root arcsine) and analyzed as a split-plot treatment arrangement over time (repeated measures). Effects in the model included stocking rate, diet, stocking rate × diet interaction, treatment within pasture (Error a), treatment × time interaction, and residual error (Error b). Forage mass samples and soil NO_3^- concentration were also analyzed as with a split-plot treatment arrangement over time (repeated measures) with subsample effects of pasture region and region by treatment added to the model. The error term for region and treatment interactions within region was the pasture within treatment × region × time effect. Effects of stocking rate and diet on percentage of ground cover, botanical composition, and soil NO_3^- concentration were analyzed at each of the two time periods. Because production data from Parity 2 were not used, production data were analyzed as a simple completely randomized design with a 2 × 2 factorial arrangement of treatments. All data were analyzed using the GLM procedures of SAS (SAS Inst. Inc., Cary, NC), except for sows that were removed from study due to return to estrus, culling, or death, which were analyzed using chi square of Excel (Microsoft, Redmond, WA) software. Dummy (untreated) sows were used to replace removed sows in order to maintain stocking rates. Means were separated by the predicted difference test within GLM when protected by a significant F-value.

Linear regression was used to predict loss of ground cover over time for pastures. The regression equations were calculated within treatments over time using Excel (Microsoft) software.

Results

Environmental Conditions

Monthly mean temperatures were similar to the mean value over the past 52 yr (Figure 2). Precipitation

Table 5. Inventory status during the study of outdoor gestating sows kept on old world-spar bluestem pastures at stocking rates of either 17.5 or 35/ha and fed diets containing 14.7 or 12.6 at the Sustainable Pork Farm of Texas Tech University near Idalou, TX

	Reason for eliminating sows from study, % and stocking rates, sows/ha					
	Recycled[a]		Culled		Died	
Diet	17.5	35	17.5	35	17.5	35
Parity 1						
14.7 CP	0.0	0.8	0.0	0.0	0.0	1.6
12.6 CP	1.6	2.4	0.0	0.0	0.0	0.0
Parity 2						
14.7 CP	4.0	14.3	0.8	0.0	0.8	2.4
12.6 CP	3.2	8.7	0.0	2.4	0.8	1.6

[a]Returned to estrus.

was above average in May but was below average from July to November compared with the long-term mean (Figure 3).

Percentage of Ground Cover and Forage Mass

Diet had no effect on percentage of ground cover but ground cover was lower ($P < 0.01$) on the pastures with higher stocking rate in May and June (Table 6 and Figure 4). No differences between stocking rates were observed during other months. Percentage of ground cover decreased during the spring grazing period at both stocking rates (Figures 4 and 5). Ground cover in pastures with the higher stocking rate decreased at a faster ($P < 0.01$) rate than in pastures with the lower stocking rate during this period. When pigs were removed from pastures by mid-June, recovery of bluestem was rapid, and percentage of ground cover increased for both stocking rates. Irrigation applied in July seemed to aid recovery of all pastures. Little effect of stocking rate was observed on percentage of ground cover when grazing was initiated in July and August. Precipitation, irrigation, and season of use appeared to influence recovery of bluestem stands (Figures 3, 4, and 5). Forage mass was not affected by dietary treatment; however, pastures with higher stocking rate had lower ($P < 0.001$) forage mass (Table 6).

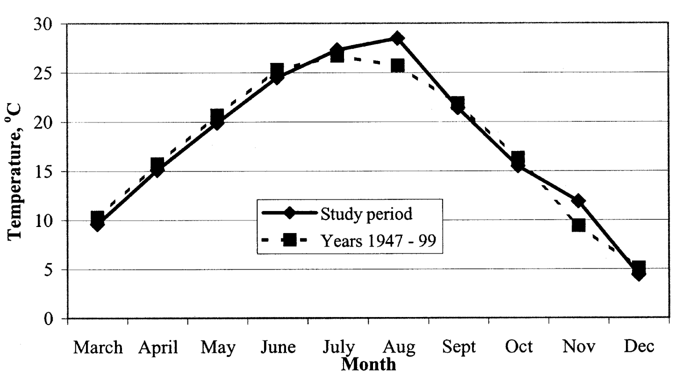

Figure 2. Average monthly temperatures for March through December 1999 (study period) and the 52-yr monthly average from 1947 through 1999 at Idalou, TX. Historical weather data were obtained from the National Climatic Data Center, Climate Service Branch (NCDC, 2001).

Botanical composition of the pastures consisted of approximately 92% bluestem and approximately 8% weeds (mainly clammy ground cherry, *Physalis heterophylla Nees*; silver-leaf night shade, *Solanum elaeagnifolium*; and western ragweed, *Ambrosia psilostachya*) at the beginning of the study. By the end of the study in December, bluestem was dormant and no broadleaf weeds were observed.

Soil Nitrates

Soil NO_3^- concentrations were not affected by stocking rate ($P > 0.93$), diet ($P > 0.97$), or location within pasture and no interactions ($P > 0.26$) were observed (Table 6). However, averaged over stocking rate, diet, and location, soil NO_3^- concentrations tended ($P < 0.11$) to increase by the end of the trial, compared with initial values.

Gilts and Litter Performance

Neither stocking rate nor diet influenced most reproductive performance traits of gilts and sows (Tables 7 through 10). However, for Parity 1, number of pigs weaned per sow was greater ($P < 0.01$) for gilts kept at a higher stocking rate than for gilts kept at the lower stocking rate during gestation (Table 8). This might be attributed, in part, to statistically higher numbers of pigs born per litter from higher stocking rate as well as significantly higher percentage mortality from the lower stocking rate from Parity 1 sows (25.7 vs 18.1). A similar trend for more ($P < 0.01$) pigs born per litter and more ($P < 0.03$) born alive was seen in Parity-2 sows (Table 10). Conception rate was low for Parity 2, with a number of bred sows returning to estrus, especially from among those fed the control diet (Table 5).

Table 6. Effects of stocking rate, diet, and time on soil nitrate levels, percentage ground cover, and forage mass in old world-spar bluestem pastures occupied by pregnant sows

Item	Soil NO_3^-, ppm	Ground cover, %	Forage mass, kg/ha
Diet, % CP			
12.6	6.5[a]	88.0	1.6
14.7	6.4	87.8	1.7
SE[b]	1.19	1.13	0.06
P-value	0.97	0.87	0.53
Stocking rate, sows/ha			
17.5	6.4	92.3	1.8
35	6.5	83.5	1.4
SE[b]	1.19	1.13	0.06
P-value	0.93	0.001	0.001
Location within pasture			
Hub area	6.7	—[c]	1.8
Middle section	5.4	—[c]	1.6
Outer area	7.3	—[c]	1.5
SE[b]	1.44		0.02
P-value	0.58		0.0001
Time			
Initial	5.3	93.8	—
End of study	7.6	92.5	—
SE[b]	0.82	2.67	—
P-value	0.11	0.83	—

[a]n = 6 for each mean, where pasture is the experimental unit.
[b]SE = standard error of the mean.
[c]Data were not collected for regions within pastures.

There were no dietary treatment effects on litter performance (Tables 8 and 10). An examination of the means and standard errors indicated that performance traits for sows were similar at the two stocking rates.

Discussion

Animal management practices can influence N excretion and patterns of N redistribution. These practices include sow behavior in terms of preference for certain locations within the pasture for defecating and resting as well as feeding. Fecal and urinary N excretion depends on total N content of the diet and on the apparent digestibility and retention of that protein, the latter of which is directly related to the raw ingredients used in diet

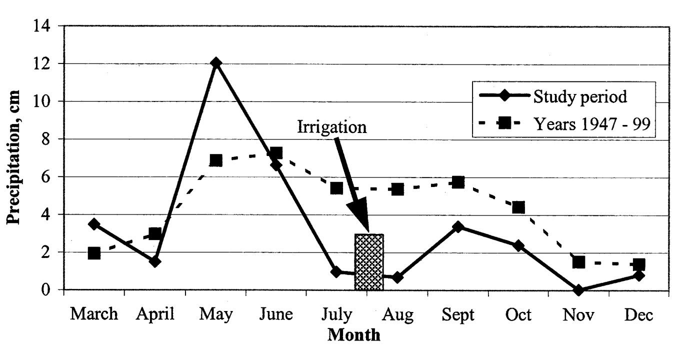

Figure 3. Total monthly rainfall for March through December 1999 (study period) and the 52-yr monthly average from 1947 through 1999 at Idalou, TX. Historical weather data were obtained from the National Climatic Data Center, Climate Service Branch (NCDC, 2001).

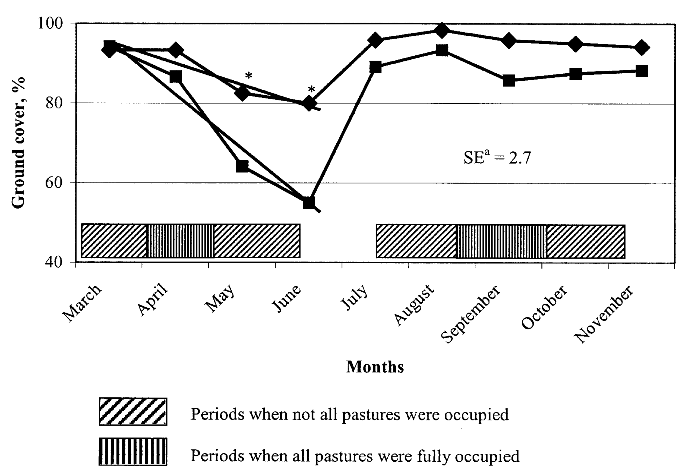

Figure 4. Percentage of ground cover in old world-spar bluestem pastures occupied by gestating sows at stocking rates of either 17.5 (◆) or 35 (■) sows/ha. *Effects of stocking rate ($P < 0.001$). [a]SE = standard error of the mean, n = 6 for each stocking rate. Regression line calculated from March through June. Loss of ground cover during spring grazing (and no growth) of old world-spar blue stem pastures by pregnant gilts with stocking rates of 17.5 (◆, y = –5.082X + 99.995, r^2 = 0.87) or 35 (■, y = –14.001 + 110.01, r^2 = 0.96) sows/ha.

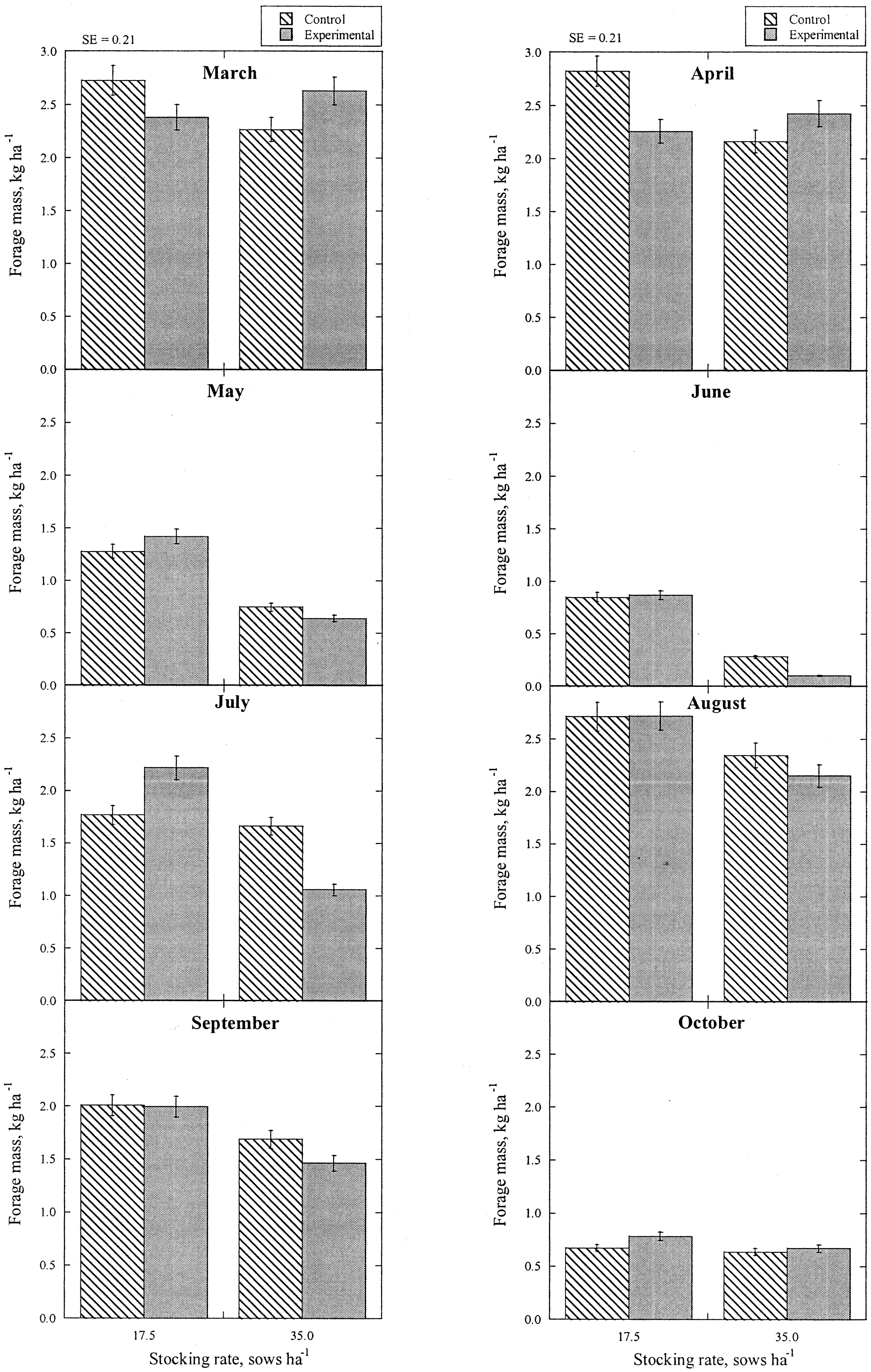

Figure 5. Forage mass (kg/ha) of old world-spar bluestem pastures occupied by sows at two stocking rates (17.5 vs 35/ha) and fed diets containing two CP concentrations (14.7, control vs 12.6%) over a period of 8 mo.

Table 7. Effects of stocking rate and dietary crude protein during gestation on performance of Parity 1 gilts on old world-spar bluestem pastures

Item	Stocking rate, gilts/ha[a]				Diet, % CP[a]			
	17.5	35	SE[b]	*P*-value	14.7	12.6	SE[b]	*P*-value
No. of gilts	41	77	—	—	58	60	—	—
Gilt initial BW, kg	205.1	206.0	17.21	0.98	206.3	206.0	17.21	0.98
Gilt BW at farrowing, kg	236.0	232.4	16.13	0.73	233.6	234.8	16.32	0.91
Gilt BW at weaning, kg	209.7	207.8	10.05	0.78	208.7	208.8	10.17	0.99
Gilt BW change (farrow-wean), kg	–26.49	–24.9	9.42	0.82	–24.9	–26.4	9.53	0.81

[a]n = 6 pastures for each treatment.
[b]SE = standard error of the mean.

formulation (Sauer and Ozimek, 1986). Concentration of dietary protein is of special importance. Risk of pollution related to pig husbandry could be estimated by average quantities of N and mineral excreted per animal and per year for the categories of animals kept under standard conditions (Jongbloed, 1984). However, under field conditions, other factors influence cycling of N and minerals, including temperature, precipitation, soil type and cation exchange capacity, vegetation type, and percentage of ground cover. Under the conditions of the present experiment, the high temperatures, low precipitation, and loss of ground cover would likely lead to increased losses of N by volatilatization. Because evapotranspiration rates greatly exceed precipitation in this region (NCDC, 2001), little leaching of NO_3^- or minerals below the rooting depth of the vegetation was expected to occur.

A number of factors determine the amount of land required for an outdoor pig herd, including soil type, local climate, slope and location of land, and age at weaning (Thornton 1998). Thornton (1998) provided a general recommendation for stocking rate to be about 14 to 19 sows/ha overall, with a 480- to 500-sow breeding herd needing a total of roughly 25 to 35 ha. Approximately 1.2 ha was recommended for a group of 20 to 22 gestating sows. The choice of 17.5 or 35 sows/ha for this study was based on the above recommendations plus the assumption that with supplemental irrigation ground cover on pastures could be maintained throughout the year. The higher stocking rate was expected to have increased amounts of soil-NO_3^- compared with the lower stocking rate due to the fact that more sows were in these pastures.

Results from our study showed that for the two stocking rates and dietary CP concentrations examined, no detectable effects were measured on soil NO_3^- content; however, soil NO_3^- concentration tended ($P < 0.11$) to increase over the course of this experiment in all pastures. Actively growing vegetation might adequately utilize much of the pig-derived NO_3^-, but by the end of this experimental period old world bluestem plants were dormant. Uptake of soil NO_3^- would have declined and eventually ceased as plants became dormant. Although soil NO_3^- concentrations remained relatively low and were less than levels of concern from an environmental perspective (CAST, 2000), the observed increase over the growing season points to the need to further monitor these changes over time, particularly if swine remain on pasture when forage is dormant.

Some of the N from the fecal and urinary excretions might have volatilized during the summer months when

Table 8. Effects of stocking rate and dietary crude protein on performance of litters from Parity 1 gilts reared on old world-spar bluestem pastures

Item	Stocking rate, gilts/ha[a]				Diet, % CP[a]			
	17.5	35	SE[b]	*P*-value[c]	14.7	12.6	SE[b]	*P*-value
No. of litters	41	77	—	—	58	60	—	—
Gestation length	115.2	115.0	0.25	0.63	114.8	115.4	0.25	0.12
Lactation length	23.0	24.1	1.09	0.52	23.3	23.8	1.11	0.72
Pigs born, no./litter	10.3	11.2	0.32	0.10	11.0	10.5	0.32	0.38
Born alive, no./litter	9.7	10.5	0.34	0.12	10.4	9.8	0.34	0.29
Stillborn, no./litter	0.63	0.59	0.09	0.79	0.54	0.69	0.09	0.30
Litter birth wt, kg	20.4	20.6	1.90	0.94	19.2	21.8	1.90	0.39
Pig avg birth wt, kg	2.2	2.1	0.15	0.50	2.1	2.2	0.15	0.84
Litter weaning wt, kg	51.0	56.9	4.10	0.34	54.5	53.4	4.12	0.86
Pig avg weaning wt, kg	11.0	6.9	2.87	0.34	11.0	6.8	2.90	0.34
Pigs weaned, no./litter	7.1	8.4	0.29	0.01	7.8	7.7	0.29	0.78
Pig mortality, %	25.7	18.1	1.85	0.02	23.4	20.4	1.87	0.28

[a]n = 6 pastures for each treatment.
[b]SE = standard error of the mean.
[c]*P*-values for main effects. Interactions were not significant ($P > 0.26$).

Table 9. Effects of stocking rate and dietary crude protein during gestation on performance of Parity 2 sows on old world-spar bluestem pastures

	Stocking rate, sows/ha[a]				Diet, % CP[a]			
Parameters	17.5	35	SE[b]	*P*-value	14.7	12.6	SE[b]	*P*-value
No. of sows	30	47	—	—	35	42	—	—
Gilt initial BW, kg	227.8	238.4	10.68	0.52	231.9	234.3	10.59	0.88
Gilt BW at farrowing, kg	264.5	244.2	7.33	0.08	245.3	263.4	7.25	0.12
Gilt BW at weaning, kg	243.7	241.5	6.46	0.59	240.0	245.2	6.50	0.59
Gilt BW change (farrow-wean), kg	–24.6	–26.7	4.61	0.76	–30.1	–21.3	4.54	0.23

[a]n = 6 pastures for each treatment.
[b]SE = standard error of the mean.

temperatures were high, especially with bare ground where stocking rate was high. Stewart (1970) reported NH_3 losses from urine ranging from 25 to 90% of the added N, whereas Adriano et al. (1974) found that N losses to the air from a mixture of urine and feces approached 50%. However, Eriksen and Kristensen (2001) reported increases in both soil nitrates and phosphorus with increased stocking rates that were closely correlated with distance to pasture feeding sites. They concluded that increased nutrient efficiency in outdoor pig production could be realized through more uniform distribution of nutrients by manipulating sow excretory behavior and adjusting stocking rates to match locally acceptable nutrient needs. It is unlikely that excreted N was moved to lower soil horizons with the observed rainfall and irrigation that was applied. Other nutrients, notably P, were not determined, so we do not know their status. Further studies are needed to examine the status of all nutrients in order to minimize potential negative effects of outdoor swine production on the environment.

In a grazing management system, the number of animals in a given area as well as the duration of grazing influences loss of forage (Popp et al., 1997b). Variations in forage species in terms of persistence and regrowth also play a role in survivability of vegetative cover. As observed in this experiment, with high stocking rates, the rate of vegetation depletion can be accelerated (Popp et al., 1997a). Denudation of vegetation not only results from animal grazing but also from trampling by animals. With high stocking rates, the process of pasture regrowth might be hindered further because of the rooting behavior of sows. Thus, it was not surprising that the high stocking rate from this study resulted in a greater rate and overall depletion of vegetation (Table 6 and Figures 4 and 5). Regression equations (Figure 4) provided estimates of loss of ground cover over time during the initial phase of this experiment.

Typically, grazing land management is aimed at ensuring that solar energy is converted through the process of photosynthesis by plants into a form usable by grazing animals. The grazing animal must efficiently use these plants in such a way that both the individual plants and the desired botanical composition can survive with optimum regrowth rates. However, our objectives were to maintain vegetative cover, not to provide grazable forage, and to ensure that nutrients from swine excreta would be held in soil and plants. The theoretical optimum defoliation point is influenced by such factors as plant species, season of the year, leaf-area index, soil moisture, and temperature, among other factors (Cherney and Al-

Table 10. Effects of stocking rate and dietary crude protein on performance of litters from Parity 2 sows reared old world-spar bluestem pastures

	Stocking rate, sows/ha[a]				Diet, % CP[a]			
Item	17.5	35	SE[b]	*P*-value[c]	14.7	12.6	SE[b]	*P*-value
No. of litters	30	47	—	—	35	42	—	—
Gestation length	114.6	114.5	0.25	0.83	114.7	114.5	0.25	0.55
Lactation length	27.1	26.2	1.03	0.55	27.3	26.0	1.03	0.38
Pigs born, no./litter	10.5	11.7	0.26	0.01	11.4	10.8	0.26	0.14
Born alive, no./litter	9.6	10.8	0.32	0.03	10.4	9.9	0.32	0.30
Stillborn, no./litter	0.9	0.9	0.23	0.93	0.9	0.9	0.23	0.93
Litter birth wt, kg	19.4	19.8	0.50	0.51	20.1	19.1	0.50	0.18
Pig avg birth wt, kg	2.0	2.0	0.27	0.11	2.0	2.0	0.11	0.93
Litter weaning wt, kg	72.4	63.4	6.96	0.39	74.0	61.8	6.99	0.25
Pig avg weaning wt, kg	8.5	7.2	0.46	0.10	7.9	7.9	0.46	0.99
Pigs weaned, no./litter	8.6	8.5	0.62	0.85	9.4	7.7	0.62	0.10
Pig mortality, %	8.6	12.6	5.34	0.61	1.2	19.9	5.37	0.40

[a]n = 6 pastures for each treatment.
[b]SE = standard error of the mean.

len, 1995). Old world-spar bluestem is a warm-season forage and typically breaks dormancy during April. It was during this transition from dormancy to growth that the quantity of ground cover was seriously affected (Figures 4 and 5) by the higher stocking rate; not only were the moisture levels low for forage growth, but gilts also rooted and consumed vegetation before bluestem was actively growing. After October, even though ground cover was still present, forage mass was very minimal, making it practically impossible to collect forage samples (Figure 5). Higher than average rainfall during May might not have compensated completely for this loss of ground cover. When the second group of sows entered pastures beginning mid-July, this warm-season grass was growing vigorously, and the impact of sows on percentage of ground cover was minimal. Finding forages that could maintain ground cover during both the cool and warm seasons without becoming completely denuded remains a challenge in a sustainable outdoor swine production system. Under conditions of late winter dormancy and early spring growth, pastures lost 0.6 to 1.0% ground cover per sow per month (Figure 5). The seasonal effects on percentage of ground cover could reflect a preference by swine for early vegetation growth that might have exacerbated rooting and defoliation. Anderson and Matches (1983) found that caucasian bluestem was more digestible for ruminants during early-season than during late-season growth. Persistence of old world-spar bluestem in the presence of sows during the later-season periods might have reflected both a decrease in palatability as well as an optimum growth period for the warm-season perennial grasses at the time grazing began. When moisture was available and temperatures were warm, ground cover or forage mass did not decrease, even with 35 sows/ha. These data provide a first estimate of short-term forage losses from pastures with pregnant pigs.

Nutrients in a given feed and feeding levels can influence grazing behavior of pregnant gilts. A higher stocking rate could tend to make animals feed more aggressively, especially when they are fed as a group (McGlone, 1986; HagelsØ and Studnitz, 1996). A lower stocking rate would be expected to be associated with less aggressive feeding behavior when the daily dry ration is offered (Popp et al., 1997a). When animals are well-fed, their desire for grazing and rooting should be decreased, unless they have behavioral needs for oral-nasal behavior. All animals in the present study were fed the daily feed allowance and nutrient intake recommended by NRC (1998; Tables 1 and 2). Thus, forage consumption provided energy and other nutrients in excess of requirements for gestation. The lack of destructive effect on ground cover during active plant growth probably reflected both adequate nutrient intake by sows and optimum conditions for growth by old world bluestem. This was further supported by the similar BW of gilt in both dietary groups (Tables 7 and 9).

Little information is available regarding stocking rates of sows in outdoor systems. With swine either kept in individual confinement or group-housing pens, England and Spurr (1969) found no differences in number of live pigs per litter, number of dead pigs, number of mummified fetuses, or their totals. Parry (1986) also found no statistical differences in number of live-born pigs raised in crates or pens, although sows in pens averaged slightly higher number of pigs per litter (10.5 vs 11.3). Weaning weights also did not differ. In our study, similar provision of feed energy for both treatments likely accounted for the comparable gilt BW and changes. Increased weight gain and decreased backfat thickness, as dietary protein increased, have been reported in gestating sows (Kusina et al., 1999). Number of pigs weaned per litter was greater for the higher stocking rate, which might have resulted from the trend for a higher number of pigs born per litter and the lower preweaning mortality rate for that treatment. The physiological basis, if any, for a higher litter size at weaning in gilts at a higher stocking rate is not known. The data do suggest no adverse effect of the higher stocking rate on reproductive performance under the experimental conditions imposed.

High dietary protein (amino acid) concentrations are necessary during both gestation and lactation periods to attain high litter performance (Tokach et al., 1992). All sows in the present experiment received a nutritionally adequate lactation diet (NRC, 1998). Dietary differences within the ranges evaluated did not influence sow performance, which confirms that the diets were nutritionally equivalent.

Dietary protein restriction during pregnancy resulted in low pig birth weights and decreased litter weaning weights (Shields et al., 1985) but has generally not affected litter size. Swick and Benevenga (1977) also noted that restriction of dietary protein intake for pregnant sows had no measurable effect on litter size or birth weight because sows mobilize body reserves to support products of conception. Restriction was, however, found to result in decreased litter growth (Baker et al., 1970) and impaired subsequent reproductive performance (Svajgr et al., 1972). In the present study, supplemental lysine addition to the low-protein gestation diet provided adequate amino acid intake and resulted in normal pig birth weight. Knabe et al. (1996) also reported no effect of lysine supplementation on lactation weight loss or litter size at birth or at 21 d of age. Overall, in our study, decreasing the soybean meal and adding lysine resulted in equal litter productivity between dietary treatments. The added dietary lysine and 25% decrease in soybean meal for pigs fed the low-protein diet during gestation was not sufficient to affect soil NO_3^- concentrations in the outdoor system during the time this trial was conducted. The rate of deposition of pig-derived N seemingly approached that of plant N uptake and other N losses to soil and atmosphere, and little change in soil NO_3^- was observed during the grazing period imposed in this experiment.

Implications

Sustainable animal production systems that protect the environment are a national priority. Outdoor swine production systems show promise as a method for economically producing swine with fewer negative effects on the environment than some conventional confinement systems. Within an outdoor system, higher stocking rates increase the rate of ground cover loss but appear not to be detrimental to the number of pigs weaned per sow. Chances of NO_3^- accumulating in the soil are minimized with maintenance of vegetative cover. Stocking rates of 17.5 or 35 sows/ha for gestating sows and subsequent rotation to farrowing pastures can allow N inputs to be balanced with plant N uptake in outdoor pig production systems.

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