Bioenergy for Cattle and Cars: A Switchgrass Production System that Engages Cattle Producers

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ABSTRACT

Switchgrass (Panicum virgatum L.) produced for bioenergy is expected to compete with land resources used for stocker cattle (Bos taurus) grazing in the southern Great Plains. The objective was to determine the effect of stocking rate on animal performance, biomass yield, and quality. Three stocking rates (light [2.5 steers ha⁻¹], moderate [4.9 steers ha⁻¹], and heavy [7.4 steers ha⁻¹]) and an ungrazed control were randomly assigned to twelve 0.81-ha paddocks in 2008, 2009, and 2010. Animal and biomass responses were analyzed using mixed ANOVA models. Average daily gain (P = 0.05) was 0.83, 1.04 and 1.05 kg head⁻¹ for the light, moderate and heavy stocking rates, respectively. Grazing duration was affected (P < 0.001) by stocking rate treatment, realizing 81, 43, and 28 d of grazing, respectively. Steer grazing days were not different (P = 0.22) between stocking rates treatments, producing 81, 86, and 84 d ha⁻¹, respectively. Total gain by treatment were 167, 215, and 199 kg ha⁻¹, respectively, and were different (P = 0.04). The ungrazed control produced more (P < 0.001) harvested biomass at the end of the growing season (15.3 Mg ha⁻¹) compared to the grazed treatments (10.6, 8.1, and 7.8 Mg ha⁻¹, respectively). Forage quality decreased (P < 0.05) throughout the growing season for all treatments. Results indicate switchgrass has the potential to extend the cool-season grazing season in the region while also allowing for the production of an annual supply of bioenergy feedstock for conversion into biofuel.

Under the Energy Independence and Security Act of 2007, United States renewable fuel standards required the production of 60.5 gigaliters of ethanol from cellulosic biomass feedstocks by the year 2022 (BRBD, 2008). Early research sponsored by the United States Department of Energy in the 1990s identified switchgrass (Panicum virgatum L.) as a primary next generation cellulosic feedstock that could help the United States achieve its cellulosic ethanol production goal. Switchgrass was identified as a candidate due to its high biomass potential, perennial life-form, adaptability to marginal soils and soil carbon sequestration potential (Frank et al., 2004; McLaughlin and Kszos, 2005; Vogel and Mitchell, 2008; Vogel, 2004).

Lowland switchgrass ecotypes (e.g., Alamo variety) have been identified as ideal feedstocks for the southern Great Plains due to their adaptability to the region’s growing conditions (Cassida et al., 2005; Fike et al., 2006; Stroup et al., 2003). Currently, switchgrass lacks a marketable bioenergy feedstock value, which prevents widespread adoption by farmers (Epplin, 2009; Epplin and Haque, 2011; Schnepf, 2010; Smith, 2009). In addition, investors are reluctant to invest in large-scale biorefineries in regions that do not have an established feedstock base (Schnepf, 2010; Tacobucci and Schnepf, 2007). This issue raises the question as to whether or not switchgrass can be incorporated into existing production systems common to the region to encourage investment into large-scale biorefineries.

Production of winter pasture and grazing beef stocker cattle on cool-season pastures is one of the primary agricultural production systems in the southern Great Plains (Taylor et al., 2010). The stocker cattle industry is characterized by the development of young, lightweight calves on forage-based diets before placement in feedlots or being returned to the farm and ranch (Schmitz et al., 2003). According to the Economic Research Service (2010), the United States beef cattle industry produces about 40 million feeder cattle annually, of which approximately 14 million have been classified as stockers. Many of these stocker cattle are transported into the southern Great Plains to graze cool-season, annual forages such as cereal rye (Secale cereale L.) and wheat (Triticum aestivum L.) Traditionally, these forages are grazed by stocker cattle from November through April (Hossain et al., 2004; Lang and Broome, 2002), at which time heifers are returned to the farm and steers are transitioned to the finishing stages of production using grain-based diets (Hossain et al., 2004; Schmitz et al., 2003). Recent trends in grain and feeder cattle markets indicate that beef cattle producers face increased pressure to achieve greater livestock gains on forage-based diets before being shipped to feedyards (Peel, 2012). Stocker cattle producers, therefore, are seeking forage systems that allow them to extend their traditional pasture-based grazing seasons (McCullum et al., 1990).

Abbreviations: ADF, acid detergent fiber; ADG, average daily gain; CP, crude protein; DANI, days after grazing initiation; hh, head; IVDM, in vitro dry matter digestibility; LR, likelihood ratio; NDF, neutral detergent fiber.

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To date, most of the bioenergy feedstock research has focused on variety development (Taliavero and Das, 2002; McLaughlin and Kszos, 2005), establishment methods (Panciera and Jung, 1984; Monti et al., 2001), and end-of-growing season harvested biomass yield (Guretzky et al., 2011; Kering et al., 2012; Kiniry et al., 2005; Muir et al., 2001; Thomason et al., 2004). We recognized that as a forage crop, switchgrass has been well characterized for the southern Great Plains. Vogel (2004) reported that high quality switchgrass is typically available in early spring for grazing, complementing the cool-season grasses. In addition, several studies report that switchgrass possesses impressive regrowth potential following grazing (Beaty et al., 1978; Griffin and Jung, 1983; Krueger and Curtis, 1979; Vogel, 2004). Earlier studies examined the grazing potential of different switchgrass varieties, concentrating primarily on: varying in vitro dry matter digestibility (IVDMD) levels (Anderson et al., 1988; Ward et al., 1989); grazing capacity (Burns et al., 2011); comparable grazing potential with other grasses (Burns, 2011, Burns et al., 1984); continuously stocked in a put-and-take system (Burns, 2011; Burns et al., 1984); and flash grazed three to four times per year (Sanderson, 2008). However, we emphasize that the potential of using switchgrass to produce stocker cattle gain and bioenergy feedstock has not previously been evaluated in a formal research study. Moreover, information that reports the grazing potential of switchgrass, under different stocking rates in a continuous grazing system and the production of end-of-growing season harvested biomass, were not found in the literature. Using switchgrass for this dual purpose has the potential to mitigate some of the risks associated with the development of a large-scale bioenergy industry in the region. Therefore, the general objective of this study was to evaluate whether or not switchgrass can be managed for use in a combined beef stocker cattle and bioenergy production system. More specifically, our goal was to evaluate the effect of stocker cattle rate on animal performance (average daily gain [ADG], grazing duration, steer grazing days and total gain), forage nutritive values quality [crude protein [CP], acid detergent fiber [ADF], neutral detergent fiber [NDF], and IVDMD] and end-of-growing season harvested biomass production.

MATERIALS AND METHODS

The study was located in south-central Oklahoma near the community of Burneyville (33°53' N, 97°17' W) on 9.72 ha of mature Alamo switchgrass established in 2007. Monthly average rainfall data for the experimental location is presented in Fig. 1. (Oklahoma Climatological Survey, 2011). The study site historically receives an average of 864 mm rainfall annually. The soil type is characterized as Slaughterville fine sandy loam (coarse-loamy, mixed, superactive, warm udic Haplustolls) with 0 to 1% slope (Soil Survey Staff, NRCS-USDA, 2011). This site was under cereal forage production and grazing for at least 15 yr before establishment of switchgrass. Initial soil samples were collected in 2008 from the 0- to 15-cm layer to determine soil nutrient levels and develop fertilizer recommendations. Soil was tested for: pH at a 1:1 soil water (Lierop, 1990), organic matter by high temperature combustion (Nelson and Sommers, 1982), P by the Mehlich-3 procedure (Fixen and Grove, 1990), K via ammonium acetate extraction (Haby et al., 1990) and nitrate-N concentrations by reduction to NO2 by Cd (Dahnke and Johnson, 1990). Soil tests revealed a pH of 6.5, 8 g kg–1 organic matter, 3.5 mg NO3–N kg–1, 31 mg P kg–1, and 116 mg K kg–1. Before grazing initiation in the spring of each year, switchgrass pastures were fertilized uniformly with 78 kg of N ha–1 which is the recommended rate to produce 15 t ha–1 yield (Parrish et al., 2008). Soil samples collected during the trial and following termination revealed sufficient levels of P and K nutrients for switchgrass production (Caddel et al., 2010).

Animal Selection, Management, and Data Collection

Switchgrass pasture was subdivided into twelve 0.81-ha paddocks. A completely randomized experimental design was used with three replications. Three stocking rate treatments: light (2.5 steers ha–1), moderate (4.9 steers ha–1), and heavy (7.4 steers ha–1) and an ungrazed control (0 steers ha–1) were randomly assigned to paddocks and evaluated over three grazing seasons (2008, 2009, and 2010). Commercial steers were purchased from local sale barns in the fall (September) of each year, back-grounded for 45 d and grazed for at least 100 d between mid-November to early April on a cereal rye/ryegrass (Lolium multiflorum Lam.) pasture that was managed to maximize cattle gains. In April, steers (n = 36; 381±89 kg) were randomly selected, re-implanted with Revalor-G, and randomly assigned to the paddocks representing the three grazing treatments. In previous studies, it was determined that delaying initiation of switchgrass grazing until the plant had reached the late jointing stage negatively impacted average daily gain (Anderson et al., 1988). Grazing was initiated when average switchgrass height across all treatments reached at least 36 cm before jointing (before producing central shoot and stem elongation) which was achieved on or about 15 April of each year. Grazing was terminated when forage height was 7.5 cm or forage quality was deemed, via forage nutritive values, to be too low to support animal growth. Quality of forage is deemed low when CP is low, ADF and NDF (fiber content in forage) is high, or IVDMD (digestibility of forage) is low (Ball et al., 2001). Grazing management activities and corresponding dates are reported in Table 1. All steers were individually weighed on the first and last day of grazing following a 16-h feed and water fast. During the trial, cattle had ad libitum access to water and a salt/mineral mix (A and M Monensin mineral medicated) containing Monensin (1620 g T–1).

Fig. 1. Monthly rainfall (mm) for 2008 to 2010 and 30 yr average at study site.
Anderson et al. (1988) found that initiation of grazing before jointing has resulted in optimal average daily gains. While the utilization of a put-and-take system with switchgrass grazing enables a more precise management of forage allowance (Burns et al., 1984; Krueger and Curtis, 1979), we chose to use a continuously stocked grazing system with varying stocking rates to reflect common stocker cattle management practices for the region. Grazing duration is the number of days that the cattle grazed each pasture (i.e., grazing termination date minus grazing initiation date). Steer grazing days were calculated by multiplying grazing days times stocking rate.

**Forage Data Collection and Quality Analysis**

Forage production for each paddock was measured at the time of grazing initiation and again at the end of the growing season (mid-September) after plants reach physiological maturity (i.e., the point during the production season where the plants reach their maximum height, yield, and set seed [Vogel, 2004]). Ten random samples were collected at ground level in each paddock using a 0.19 m² quadrat. Forage yield reported at grazing initiation is reported as “forage mass” whereas at the end-of-growing season it is reported as “harvested biomass”. Fresh weight for each sample was recorded and subsamples (four to five hand grab samples to form a composite subsample) were weighed, following 72 h in a 60°C forced air oven, to determine moisture concentration. Dry samples were ground with a Wiley mill (Thomas-Wiley Laboratory Mill, Thomas Scientific, Swedesboro, NJ) containing a 1-mm screen. Forage nutritive values were estimated using the Foss 6500 NIRS (near infrared spectroscopy) instrument (Shenk and Westerhaus, 1998; Scientific, Swedesboro, NJ) containing a 1-mm screen. Forage nutritive values (CP, ADF, NDF, and IVDMD) were the primary response variables measured. Random effects mixed ANOVA models were used to estimate the effects of stocking rate on the response variables using the PROC MIXED procedure in SAS (SAS Institute, 2002). Stocking rate treatment was treated as a fixed effect and year was treated as a random effect (Beck et al., 2012; Biermacher et al., 2012; and Islam et al., 2011). Fisher’s protected F tests were used to detect differences between treatments for all response variables. Orthogonal contrasts were used to assess linear and quadratic effects of stocking rate on animal performance measures. The statistical models applied the autoregressive (AR1) spatial power covariance structure to help account for temporal autocorrelation in data collected across grazing periods. Individual paddocks were used as local subjects within all analyses, because these represented the units in the study that received the specific treatments over the course of the study. The null hypothesis of no production year random effects was tested with the likelihood ratio (LR) test and rejected at $P \leq 0.0001$ for all dependent response variables analyzed. The LR($\lambda$) was obtained as a ratio of the maximum likelihood value obtained when the mixed model was analyzed with and without the random constraint associated with the production year. The LR depended on the restricted and unrestricted models and under regularity, the test statistic ($-2\ln\lambda$) followed a chi-squared distribution with degrees of freedom equal to the number of restrictions imposed (Greene, 2005).

**RESULTS AND DISCUSSION**

**Forage Mass and Harvested Biomass Yield**

Forage mass at the time of grazing initiation was not different (1705 kg ha$^{-1}$; $P = 0.24$) between the ungrazed control and the three stocking rate treatments. However, harvested biomass at the end of the growing season at physiological maturity was affected by stocking rate treatment ($P < 0.05$; Table 2). The ungrazed control treatment produced the greatest quantity of harvested biomass at 15.3 Mg ha$^{-1}$ and represents the potential maximum quantity that a producer can expect to grow in this region on an annual basis when it is not grazed. The ungrazed control treatment realized similar quantities of harvested biomass production compared to others that evaluated switchgrass in the southern Great Plains (Guretzky et al., 2011; Kering et al., 2012; Kiniry et al., 2005; Muir et al., 2001; Thomason et al., 2004). The light, moderate, and heavy stocking rate treatments yielded, on average, lesser quantities of harvested biomass (10.6, 8.1, and 7.8 Mg ha$^{-1}$, respectively) than the ungrazed control. In addition, within
the three grazing treatments, the light stocking rate treatment realized a greater quantity of harvested biomass \((P < 0.05)\) compared to the moderate and heavy stocking rate treatments.

Compared to the ungrazed control, early spring grazing resulted in a 31% reduction in harvested biomass with the light stocking rate, 47% loss with moderate stocking rate, and 49% with the heavy stocking rate. A “take-half, leave-half” grazing philosophy is typically recommended on native range grasses to reduce problems associated with overgrazing (Redfearn and Bidwell, 2004) and increases in the infiltration rate of water (Bari et al., 1993). These results indicate that at any stocking rate in this study allowed for forage regrowth equivalent to 50% of the forage produced in the ungrazed control, which would be available for feedstock production at physiological maturity at the end of the season. Thus, indicating dual use of switchgrass was sufficiently robust enough to support both grazing and feedstock production.

### Biomass Quality

Forage nutritive value results for all treatments are presented in Fig. 2. Similar to results reported by Anderson and Matches (1983) and Anderson et al. (1988), forage quality (CP and IVDMD) decreased across all stocking rate treatments as the season progressed. Crude protein decreased from 150 to 52 g kg\(^{-1}\); IVDMD decreased from 750 to 550 g kg\(^{-1}\); ADF increased from 320 to 430 g kg\(^{-1}\); and NDF increased from 590 to 770 g kg\(^{-1}\). These declines in forage quality parameters indicate a decrease in overall forage quality as reported by Ball et al. (2001). Crude protein was greatest (153 g kg\(^{-1}\)) at the onset of grazing and steadily decreased with time as the crop progressed from a vegetative stage in April to the reproductive stage at physiological maturity in September. This CP level is similar to what is typically found in winter cereal grain pastures (Islam et al., 2011) and was greater than or equal to summer pastures that are dominated by bermudagrass (Hill et al., 1993). Crude protein declined by 69% (from 153 to 47 g kg\(^{-1}\)) in the ungrazed paddocks and by 55% (from 153 to 68 g kg\(^{-1}\)) across all grazed paddock between grazing initiation in the spring and physiological maturity in the fall. Our results were similar to Mullahey et al. (1992) where switchgrass CP decreased from 120 to 38 g kg\(^{-1}\).

After grazing initiation, the light, moderate, and heavy stocking rates resulted in greater levels of CP and IVDMD of the switchgrass forage than the control system. These differences likely result from the availability of higher quality leaf material associated with regrowth following grazing. These results are in agreement with those reported by Sanderson (2008) where regrowth of switchgrass was reported to have a greater CP concentration. During the later period of the grazing season, herbage in the light stocking rate paddocks had a shift in the stem/leaf ratio (more stem and less leaf) at a greater rate than the other two stocking rate treatments, resulting in decreased forage nutritive value. This is due to cattle not being able to keep up with the switchgrass growth rate causing the stem to elongate rather than being in a leafy stage. Research has documented leaf fractions of switchgrass and other forage grasses to have higher forage quality than stem fractions (Griffin and Jung, 1983). These results also indicate

![Fig. 2. Average forage nutritive values for (a) crude protein, (b) acid detergent fiber, (c) neutral detergent fiber, and (d) in vitro dry matter digestibility across all stocking rate treatment and forage sampling period. A linear polynomial orthogonal contrast was significant at \(p < 0.05\) for all measured variables. DAGI- Days after grazing initiation.](image-url)
that switchgrass had a greater level of forage quality across all the treatments during the spring and early summer, providing suitable forage to extend the grazing period.

**Animal Performance**

Average daily gain for the light, moderate, and heavy stocking rates were 0.83, 1.04, and 1.05 kg hd⁻¹, respectively, and showed a linear response (P = 0.05; Table 2). With increase in stocking rate ADG increased. Results in this study are contradictory to previous grazing studies with both mixed and tall grass prairies where ADG decreased as stocking rate increased (Bodine et al., 1998; Derner et al., 2008). These results agree with Burns et al. (2011) who reported similar ADG's of 1.11, 1.13, and 1.10 kg hd⁻¹, respectively, when switchgrass was grazed at similar forage availabilities. The monoculture stands of switchgrass evaluated in this study appear to be more tolerant of grazing pressure and capable of supporting a heavier stocking rate without compromising animal performance as compared to pastures of mixed species grasses. Average daily gains in the current study were greater than reported by Anderson et al. (1988) who evaluated grazing effects of upland switchgrass cultivars. The higher gains in our study could be due, in part, to the lower stocking rate compared to other studies (Bodine et al., 1998; Hull et al., 1961, 1965). Furthermore, the lower gains for the lighter stocking rate treatment were most likely due to a decrease in forage quality as the growing season progressed and animals expend more energy selecting the leaf portion of the plant (Anderson et al., 1988; Griffin and Jung, 1983). Average daily gains measured in this study were similar to those typically realized in cereal forage (1.05 kg hd⁻¹) grazing systems, the predominant winter pastures used by stocker cattle across the southern Great Plains (Islam et al., 2011).

The results revealed that grazing duration was affected by stocking rate (P < 0.001; Table 1) and showed a quadratic response. Overall, we found that the light stocking rate resulted in duration of 81 d of grazing, whereas the moderate and heavy stocking rates produced 43 and 28 d of grazing, respectively. We found that increasing stocking rate from moderate to heavy stock resulted in only 15 fewer days of grazing, but decreasing the rate from a moderate to lighter resulted in an additional 38 d of grazing. Burns et al. (1984) and Krueger and Curtis (1979) used a put-and-take system and reported that cattle grazed 33 to 40 d, which was similar to the grazing durations obtained with the moderate stocking rate in this study. Other researchers found similar results regarding grazing duration for a moderate stocking rate when grazing initiation commenced following late jointing, further supporting that switchgrass can tolerate variable grazing initiation time frames (Anderson et al., 1988).

Stocking rate had no linear and quadratic effect (P = 0.22) on the total number of steer grazing days between grazing treatments (Table 2). On average, the light, moderate, and heavy stocking rates produced 81, 86, and 84 steer grazing days ha⁻¹, respectively. Even though cattle grazing the lightly stocked paddocks were able to graze for a greater number of days, the increase in cattle numbers associated with the moderate and heavy stocking rates, realized similar number of total steer grazing days. These results revealed that switchgrass has the potential to produce similar steer grazing days at any stocking rate and thereby providing options to producers to adjust the stocking rate according to their current production practices. On average, total gain for the light, moderate, and heavy stocking rate treatments were 167, 214, and 199 kg ha⁻¹, respectively, and showed a quadratic response (P = 0.04; Table 2). Stocking rate has a quadratic effect on the total gain indicating that production efficiency per unit of land area will decrease if heavy stocking rate is employed compared to moderate stocking rate. Both moderate and heavy stocking rates are significantly greater than the light stocking rate. Utilization of moderate and heavy stocking rates produced an additional total gain of 48 and 32 kg ha⁻¹, respectively. Anderson et al. (1988) reported a greater total gain of 311 kg ha⁻¹ across three varieties of switchgrass. The difference in gains reported by Anderson can partly be attributed to a heavier stocking rate (8.3 steers ha⁻¹) that was used to maximize animal gain rather than providing multiple products from a single system. It is important to note, that Krueger and Curtis (1979) used a put-and-take system to evaluate upland switchgrass cultivars. In their study, total gain was lower (147 kg ha⁻¹) than those achieved with continuous grazing managed to maximize system productivity per hectare.

**CONCLUSIONS**

Stocking rate treatment effected end-of-growing season harvested biomass production with grazing treatments producing 50 to 67% of ungrazed, biomass only treatment. Stocking rate also affected grazing duration and total gain, and ADG but produced similar steer grazing days. From grazing initiation until physiological maturity, forage quality decreased across all treatments. Overall, the results from this study suggest that switchgrass pastures have the potential to extend the grazing season of the conventional winter cereal forage production system in the region and also offers the flexibility to support a varying number of stocker cattle on each hectare. Moreover, our results indicate that substantial forage regrowth (after grazing) can be cut, raked, baled, and marketed to large-scale cellulosic-based biorefineries. However, it is noteworthy to point out that differences in forage nutritive values found between the grazing treatments throughout the growing season might be a concern with certain types of biorefineries that rely on a constant, steady supply of an inflexible, predetermined quality of switchgrass biomass (e.g., enzymatic hydrolysis; Adler et al., 2006). The agronomic and animal performance data from this study indicate that this system will allow producers a means to retain cattle on their farms for a longer period of time, achieve heavier livestock gains and produce biomass for the developing bioenergy industry in the region, all on the same unit of land in each production year. Ultimately, then, the choice of the best stocking rate really depends on economic information, including prices of cattle (purchase and sale prices), the expected price of feedstock and costs associated with harvesting activity.

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