Forage Performance in Crop–Livestock Systems Designed to Reduce Water Withdrawals From a Declining Aquifer

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On the Ground

- In the semiarid Texas High Plains, integrating crops with grazing systems could conserve irrigation water and increase perennial grassland.
- We combined irrigated and nonirrigated exotic and native grasses with cotton production.
- We grazed and hayed the grasses, harvested grass seed, and harvested cotton.
- Strategically combining different forages, fertilizer, and water inputs can extend the grazing season, improve the quality of available forage, and provide a buffer against moderate drought.
- Nonirrigated, seeded native grass mixtures can provide valuable grazing and decrease total water use of an integrated crop-livestock system.

Keywords: water conservation, grazing, forage, irrigation, Ogallala Aquifer, crude protein, fiber.

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As water in the Ogallala Aquifer declines and pumping restrictions are enacted, farmers and researchers in the Texas High Plains of the United States seek alternative cropping systems to conserve water.[1,2] Integrating crop and livestock production could address water conservation and other agricultural concerns, including pest control, soil quality deterioration, nutrient concentration, energy efficiency, ecological capital, system resilience, and economic performance.[1,3–6] Additionally, integrated systems that use perennial forages could improve wildlife habitat by revegetating cropland that was previously farmed.[7] Using native plant species can have the added benefit of improving habitat for some wildlife species.[8]

In the Texas High Plains, we previously described and evaluated productivity of two integrated crop–livestock systems based on perennial forages.[9] Both systems reduced irrigation needs below levels typically used for irrigated crops in the region[9] and the perennial forages in these systems improved soil aggregate stability and soil organic C accumulation potential relative to cotton, the dominant regional crop.[10] We previously evaluated animal performance,[9] but because stocker steers (*Bos taurus*) in these systems grazed multiple forages in sequence, the contribution of individual forages to stocker performance could not be determined from animal performance alone. Better understanding of how each component of the systems functioned within the systems could help fine-tune overall performance.

Clipping forage samples from system paddocks and subjecting samples to laboratory analysis to determine nutritive value and quantity is one method of obtaining information on the contribution of individual paddocks in a grazing system. Such information allows grazing managers to match forage to animal needs. This is essential to efficient production for young ruminants with rapid growth rates because of their high requirements for digestible energy and crude protein (CP)[11]. Nutritive value of the individual grasses in our previous experiment[9] has not been previously evaluated in grazing systems subject to the weather extremes of the Texas High Plains. During this experiment, precipitation ranged from the driest year on record (2011; 96 mm precipitation) to a year 44% above mean annual precipitation (2010; 680 mm). Here, we report the nutritive value of the grazed forages in these two integrated crop–livestock systems under these weather extremes, and provide suggestions for optimizing their use in future grazing systems.

Site Description

We conducted research at the Texas Tech Agricultural Field Research Laboratory, 24 km northeast of Lubbock, TX (101°47' W, 33°45' N; 993-m elevation). The predominant soil was Pullman clay loam (fine, mixed, superactive, thermic Torrertic Pauleustolls[12]) on 0% to 1% slopes. Soil properties at 0 cm to 5 cm and 5 cm to 20 cm depths were as follows: bulk density 1.09 g/cm^{3}and 1.43 g/cm^3; pH 7.7 and 7.9; organic matter 2.2% and 1.8%; and total soil nitrogen 0.06% and 0.05%. Long-term mean annual precipitation was 471 mm, with more than 75% falling between April and October.[13]

Description of Agricultural Systems

Beginning in 2002, we established two integrated crop–livestock systems in a randomized block design with three blocks. The focus of this article is from 2009 to 2011, when we determined selected measures of forage nutritive value in the systems. We designed systems to decrease irrigation relative to typical irrigated crops in the region[9]; thus, we did not irrigate to maximize production, but rather to strategically supplement precipitation to produce more consistent growth and to meet needs of forages and grazing stocker steers.

Each block of the low-irrigation system (LOW; 10.1 ha per block) consisted of four paddocks. Three paddocks were nonirrigated: 4.5 ha of a native perennial grass mixture (1.12 kg pure live seed [PLS]/ha blue grama [*Bouteloua gracilis*], 2.24 kg PLS/ha sideoats grama [*Bouteloua curtipendula*], 2.24 kg PLS/ha buffalograss [*Buchloe dactyloides*], and 0.56 kg PLS/ha green sprangletop [*Leptochloa dubia*]), 1.7 ha of foxtail millet (*Setaria italica*), and 1.7 ha of cotton (*Gossypium hirsutum*). Foxtail millet and cotton rotated annually. The fourth paddock was under subsurface drip-irrigation (mean: 215-mm water per year) and consisted of 2.1 ha of "WW-B. Dahl" old world bluestem (*Bothriochloa bladhii*). Old world bluestem was deferred from grazing in late summer to permit a grass seed harvest each autumn. Cotton was not grazed. Mean annual rates of N fertilizer application in kg/ha were: native grass 20; foxtail millet 60; cotton 67; and old world bluestem 67.

The moderate-irrigation system (MOD; 3.8 ha per block) consisted of three subsurface drip-irrigated paddocks: 2.1 ha of old world bluestem (mean: 224-mm water per year), and two, 0.9-ha paddocks of "Tifton 85" bermudagrass (*Cynodon dactylon*; mean: 275 mm water per year). Management of old world bluestem in MOD was similar to LOW. Mean annual rates of N fertilizer application in kg/ha were bermudagrass 178; old world bluestem 67.

Grazing Description

Angus and Angus-cross stocker steers (mean initial body weight 260 ± 24 kg) grazed within each system from May to September or October each year, except in 2011, when no grazing occurred as a result of severe drought. The LOW system was stocked with 8 steers in 2009 and 10 in 2010. The MOD system was stocked with 15 steers per year. Based on grazed area (excluding cotton) for each system, stocking rates were 1.1 and 0.85 ha per steer for LOW in the two respective years and 0.26 ha per steer for MOD in both years. We vaccinated and implanted steers with Revalor G (Merck, Summit, NJ, USA) before grazing and reimplanted and weighed them at 90-day to100-day intervals. Salt and mineral supplements were available ad libitum. In 2009, we provided cottonseed cake (38% CP) supplement when forage CP did not meet requirements for daily gains of at least 0.45 kg.[11]

Our general grazing strategy for both systems was to always provide forage quantity sufficient to meet steers' demands, and for quality to be as high as possible over the course of the grazing season, subject to several limiting criteria. In years and seasons of abundant forage, this required moving cattle from one paddock to the next relatively quickly to maintain introduced forages in a vegetative growth stage. When forage in the MOD system exceeded that required by steers to the degree that grazing could not keep it in a vegetative state, we hayed bermudagrass. Hay cutting had two benefits: first, it gave us a valuable product, and second, it enabled grazing the higher-quality regrowth that followed hay cutting. The first of the limiting criterion was to leave sufficient standing mass so that the perennial grass longevity would not be damaged. The second limiting criterion was that grazing must not interfere with farming operations. For old world bluestem, this meant that paddocks were deferred from grazing in late summer to allow a seed harvest. Actual dates when steers grazed each paddock are shown in Fig. 1. Based on previous research with the experimental forages at this site,[1,9] we set initial stocking rates at the maximum levels we expected to be able to maintain throughout the growing season in most years. Further details on the site, systems, and field layout were reported elsewhere.[9,14]

Sample Collection and Analyses

We collected samples for forage mass and nutritive value at 28-day intervals from each pasture block from May to October from 2009 to 2011. For chemical analysis, we composited 15 to 25 subsamples collected from diagonal transects within each pasture. We collected forage mass samples from the same transects within six quadrats (0.24 m^2 each) in each pasture. Mean coefficients of variation for pasture subsamples were native grass 0.39; old world bluestem 0.50; bermudagrass 0.33; foxtail millet before grazing 0.26; and foxtail millet after grazing 1.3. Clipping height represented heavy grazing pressure. We clipped sod-forming grasses slightly above the mat of stolons, young bunch grasses at 2 cm, and older bunchgrasses at 8 cm for native grasses and 15 cm for old world bluestem, to stay above the dense and decadent crown material. We included live and dead plant material in nutritive value samples, but species that we observed to be consumed very little relative to their abundance were excluded. The most common species excluded were silverleaf nightshade (*Solanum elaeagnifolium*) and ground cherry (*Physalis* spp.). We did not exclude any species from estimates of forage mass. We dried samples at 55°C for 48 hours or longer if required to reach a constant weight and ground in a Wiley mill to pass a 1-mm screen for chemical analysis.

We used conventional laboratory procedures to estimate acid detergent fiber (ADF)[15] and CP for all native grasses and foxtail millet, and for a subset of bermudagrass and old world bluestem. Percentage CP was determined by combustion. For

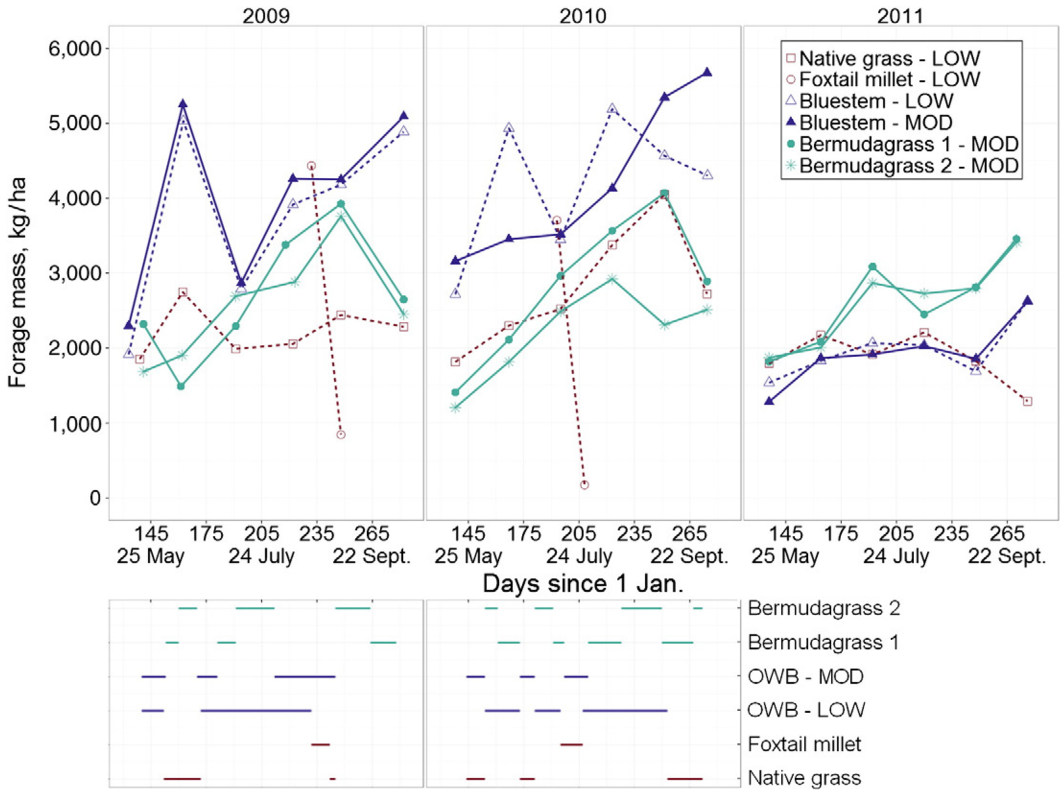

Figure 1. Mass (top figure) of forages in grazed pastures of croplivestock systems with low (LOW) or moderate (MOD) irrigation quantity. Days each forage was grazed are indicated (–) at the figure bottom. Least significant difference for comparing two means within the same month and year is 1085; for 2 months within the same year and field is 876; and for 2 years within the same month and field is 952. Foxtail millet was not statistically analyzed. OWB indicates old world bluestem.

bermudagrass and old world bluestem, we combined results from conventional laboratory procedures with results from other experiments and used them to develop prediction equations with near infrared spectroscopy (NIRS; NIRSystems, Inc., Model #5000, Silver Spring, MD, USA, and NIRSystems' software NIRS 2, Version 3.10). Thus, results reported for bermudagrass and old world bluestem were those predicted by NIRS.

We estimated CP requirement of steers based on the metabolizable protein system.[11] For each steer, we estimated live weight on a given day by fitting a quadratic equation to observed weights. We calculated animal units (AU) as follows[16]:

$$AU = \frac{(steer\ \ live\ \ weight, kg)^{0.75}}{(500\ \ kg)^{0.75}} \tag{1}$$

We calculated animal unit grazing days as:

$$\frac{Animal\ \ unit\ \ grazing\ \ days}{ha} = \frac{AU}{ha} * days \tag{2}$$

where days was the number of days of grazing in a given pasture or system and ha was the size of the pasture or system. This included the cotton area for the LOW system, although cotton was not grazed. Note that AU grazing days is not synonymous with AU days,[16] which is a measure of forage quantity. We analyzed forage mass, CP, and ADF using analysis of variance with the random effect of block, main effect of field, repeated measure of year, and repeated measure of month within year. We did not include foxtail millet in the analysis because it was not sampled on the same schedule as the perennial forages. We included in the models all possible interactions among fixed effects, and when interaction terms were statistically significant, main effect terms included in the interaction were ignored. We conducted mean separation using the ***F***-protected technique and error terms as described by Little and Hills[17] at the highest level interaction with a significance level of $\boldsymbol{P} = 0.05$.

Forage Production

2009 was dry (274 mm precipitation), 2010 was wet (680 mm), and 2011 was the driest (96 mm) since recordkeeping began in 1911. Mean annual irrigation was 219 mm for old world bluestem and 255 mm for bermudagrass from 2009 to 2011.[9] By comparison, regional irrigated cotton and corn for grain used averages of 366 mm and 500 mm of irrigation water, respectively, in producer fields during these 3 years.[2] Forage mass, CP, and ADF were all affected by a field × month × year interaction. Forage mass decreased for all forages in 2011 (Fig. 1) because of the drought and cessation of irrigation for much of the growing season. At the beginning of the 2011 growing season, we watered and fertilized the irrigated paddocks normally; however, as the drought lengthened and

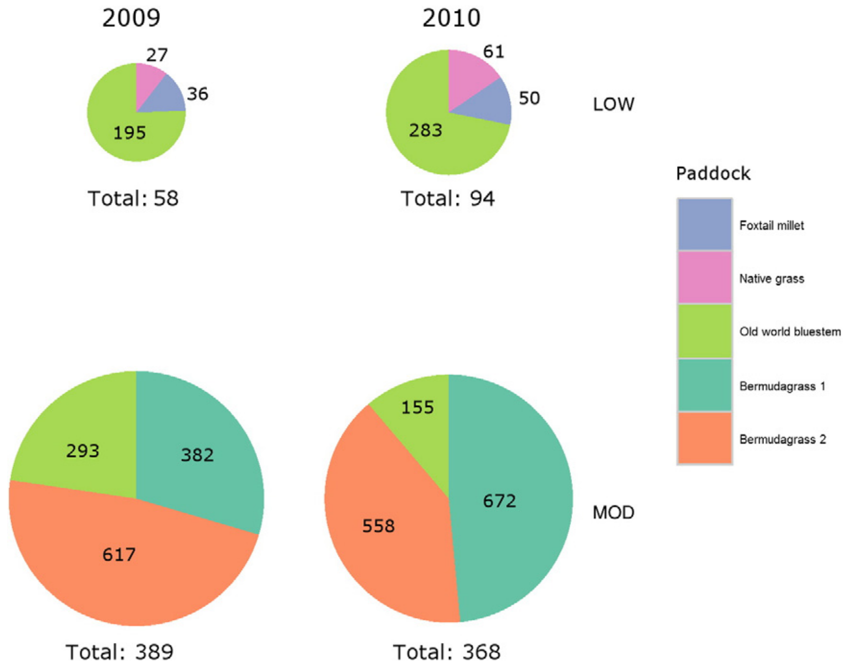

Figure 2. Animal unit grazing days/ha/year for steers grazing in integrated croplivestock systems with low (LOW) or moderate (MOD) irrigation quantity. Values are for whole systems and for individual forages within systems. Old world bluestem was deferred from grazing in late summer to permit a grass seed harvest each autumn. The two bermudagrass pastures produced an annual mean of 1270 kg/ha hay, combined, in addition to being grazed.

we determined that grazing would not occur, we suspended irrigation and fertilization until the end of August. At the end of August, we reinstated irrigation and fertilization with the intention of harvesting bermudagrass hay and old world bluestem seed. The late-season infusion of water was reflected in a small increase in forage mass of these paddocks at the end of the growing season (Fig. 1). In contrast, nonirrigated native grass forage mass decreased throughout 2011 because much of the standing forage was the previous year's growth, gradually decaying. Drought prevented planting of foxtail millet in 2011.

In 2009 and 2010, old world bluestem fields nearly always maintained the greatest forage mass, but the difference was not always statistically significant (Fig. 1). Bermudagrass also yielded large amounts of forage, but it was grazed more heavily than old world bluestem, and did not accumulate as much forage mass. Excess bermudagrass forage was harvested as hay from one pasture each year. Native grasses grew little throughout the dry summer of 2009 despite lower grazing pressure, but mass climbed throughout the wet summer of 2010 before decreasing rapidly from September to October as a result of grazing and plant senescence. Annual heavy grazing in early autumn can be detrimental to long-term persistence of a native grass stand.[18] Nonetheless, even after grazing native grasses late in the 2010 season, 2,700 kg/ha residue remained, well above recommended guidelines for mid-grasses.[18] Foxtail millet forage mass, also produced under dryland conditions, decreased rapidly after grazing commenced. Maximum forage mass of foxtail millet was greater in the dry year (2009) than in the wet year (2010) because grazing was deferred about 1 month in 2009 until nitrate concentrations, which had been in excess of 10,000 ppm, decreased to levels safer for beef cattle; during subsequent grazing, steers did not display symptoms of nitrate toxicity. Although only standing forage was measured, we observed that much foxtail millet was trampled on the ground, indicating low harvest efficiency.

The number of AU grazing days supported by each field was a reflection of the forage mass produced by that field and its role within its system. Bermudagrass had the greatest AU grazing days per ha of any forage in all years (Fig. 2). This occurred even though we fertilized bermudagrass at rates below those typically used in higher rainfall regions and we hayed excess bermudagrass. Alternatively, old world bluestem could have supported more AU grazing days per ha if it had not been deferred for seed production. If old world bluestem was grazed later in the summer, steers would have required an increase in CP supplementation to meet nutritional requirements[11] based on CP concentration of clipped samples. In 2010, the abundance of rainfall and forage growth meant that old world bluestem in the MOD system was not grazed after 29 July because there was sufficient forage in the bermudagrass pastures. This was not the case in the LOW system, and the differences were reflected in a greater number of AU grazing days in the LOW system (Fig. 2) but a lesser quantity of forage mass in late summer (Fig. 1). AU grazing days per ha were similar between native grass and foxtail millet, despite the additional chemical and mechanical inputs required to produce foxtail millet. Additionally, foxtail millet created nitrate toxicity concerns.

Forage Nutritive Value

CP of clipped samples of native grass and old world bluestem remained below the CP requirement for steers

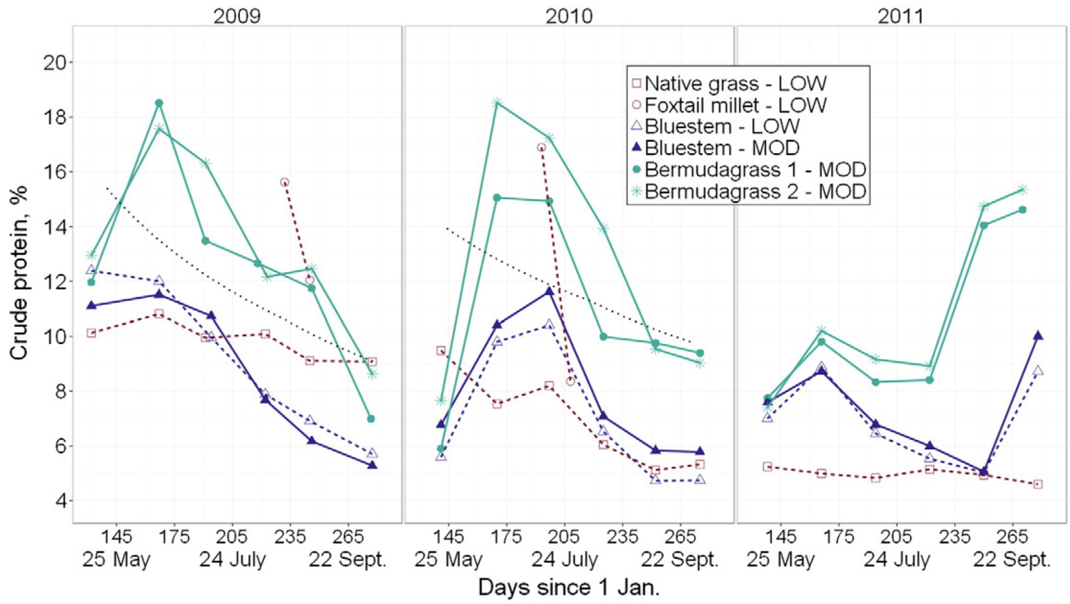

Figure 3. Crude protein (CP) content of forages in croplivestock systems with low (LOW) or moderate (MOD) irrigation quantity. Least significant difference for comparing two means within the same month and year is 1.32; for 2 months within the same year and field is 1.07; and for 2 years within the same month and field is 1.25. Foxtail millet was not statistically analyzed. Dotted lines in 2009 and 2010 represent theoretical levels of dietary CP required to achieve observed steer weight gains.

during the grazing seasons in 2009 and 2010 (Fig. 3); however, forage samples were probably lower in quality than what was actually grazed because grazing cattle are known to select higher-quality diets than the average of what is available.[19,20] Actual diets on native grass and old world bluestem pastures were probably adequate in CP to meet a goal of 0.45 kg actual daily gains until August or September; actual daily gains for the entire grazing period exceeded 1 kg per steer, but some CP supplementation was provided late in the season.[9] In contrast, foxtail millet had more than adequate CP throughout most of the time it was grazed, partly caused by high nitrate concentration. Bermudagrass CP exceeded steers' requirements from June to early September in 2009 and 2010. Percentage of CP decreased from June or July to the end of the grazing season as forages matured and forage mass increased in 2009 and 2010. In the drought year of 2011, however, CP of irrigated forages increased in September and October because of late-season irrigation intended to promote an old world bluestem seed harvest and bermudagrass hay harvest (Fig. 3).

ADF ranged from 30% to 50% of forage dry matter (Fig. 4), varying greatly by species and year. In 2010, fiber content of both systems increased earlier than in 2009 or 2011; this might be explained by more rapid maturity in response to increased water availability.[21] In most months, ADF was least in bermudagrass and greatest in old world bluestem. Foxtail millet was one exception to this rule; during the time that it was available for grazing, foxtail millet ADF was less than or equal to bermudagrass ADF. Native grasses in 2011 were another exception, as they had the highest ADF throughout the year. Native grasses were not irrigated, and the clipped samples in 2011 were composed mostly of the previous year's decadent standing mass.

Interestingly, the year-to-year variation present in native grass and foxtail millet ADF values were absent in old world bluestem and bermudagrass (Fig. 4), perhaps as a result of the irrigation system compensating for decreased precipitation in low rainfall years, thereby creating more uniform soil moisture conditions across years. As the level of the Ogallala Aquifer continues to decline and reduces the availability of irrigation water, this type of variability in quality and yield of forage crops is likely to increase. Nonetheless, old world bluestem and bermudagrass consistently showed a large drop in ADF from May to June, remaining steady thereafter. The early season drop in ADF was probably because old world bluestem and bermudagrass began growth later than native grasses, and May samples of these two forages included a larger proportion of senesced plant material relative to new growth.

Management Implications

Irrigated forages (bermudagrass and old world bluestem) provided the most forage mass, but this was at the expense of using aquifer water at unsustainable rates. Although foxtail millet provided high-quality forage, it raised nitrate toxicity concerns and was ready to graze at a time of year when old world bluestem was growing rapidly; thus, foxtail millet did not fit well in the low irrigation system. Bermudagrass also provided high-quality forage for most of the grazing season, whereas old world bluestem and native grasses were deficient in CP for meeting nutritional needs of the steers for most of the grazing season. Nevertheless, these forages could be grazed early in the spring, when quality was highest, to decrease the need for CP supplementation. Other forages, like bermudagrass, could be hayed or deferred in the spring, and

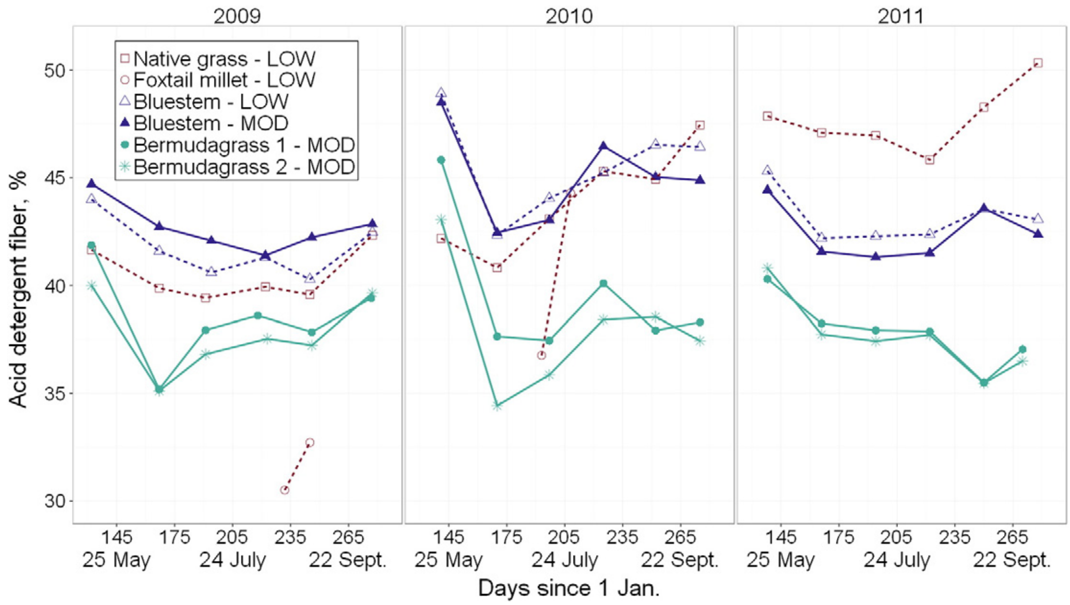

Figure 4. Acid detergent fiber (ADF) content of forages in croplivestock systems with low (LOW) or moderate (MOD) irrigation quantity. Least significant difference for comparing two means within the same month and year is 1.64; for 2 months within the same year and field is 1.43; and for 2 years within the same month and field is 1.44. Foxtail millet was not statistically analyzed.

then grazed more heavily in the fall when quality of old world bluestem and the native grasses declined. Including a native grass mixture as a component of grazing systems, rather than relying on introduced exotic monocultures, has the added benefit of improving habitat for some wildlife species. Additionally, seeded native grasses are less likely than exotics to cause degradation of remaining remnant grassland.

Innovative solutions are necessary to maintain regional agricultural production as the Ogallala Aquifer declines. Such solutions can include integrating different forage species to more uniformly match forage quality and quantity with livestock needs over the grazing season while minimizing the system's overall demand for irrigation water. Strategic use of irrigation and various forage types should continue to be explored to improve soil and water sustainability in the Texas High Plains, while meeting nutritional needs of grazing livestock.

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