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The value of native, warm-season perennial grasses grown for pasture or biofuel in the southern Great Plains, USA

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Abstract. The Renewable Fuel Standard under the Energy Independence and Security Act of 2007 mandated the production of 60.5 GL (1 GL = 1×10^9 L) of cellulosic biofuel by 2022. Switchgrass (*Panicum virgatum*) has been identified as a primary feedstock because it is a perennial adapted to a wide environmental range and produces high yields. Development of the cellulosic biofuel industry has been slow, one reason being a lack of available feedstock driven by lack of a developed market. Rather than considering it only as a dedicated biofuel feedstock, we examined switchgrass potential for both grazing and biofuel feedstock. In a series of experiments testing dry matter yield, grazing preference and animal bodyweight gain, switchgrass (cv. Alamo) was found to produce greater total yield (17.7 kg ha^{-1}) than 15 other warm-season perennial grasses, was the most preferred by stocker cattle in a grazing preference study, and produced good average daily gains in a grazing study (0.84–1.05 kg $head^{-1}$). These results demonstrate the potential of switchgrass for both grazing and biofuel feedstock. However, the feedstock price would need to increase above US\$83 Mg^{-1} before the economics of dedicated switchgrass feedstock production would surpass that of a combination of switchgrass grazing and feedstock production.

Additional keywords: biofuel feedstock, grazing, switchgrass.

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Introduction

The history of the United States (USA) ethanol industry began in 1978 with passage of the National Energy Act, which established a government subsidy at a rate of 10.6 cents per litre and launched the ethanol fuel industry (Tyner 2008). The subsidy was in the form of a tax credit for refiners that blended ethanol into gasoline. In 2011 the subsidy and a tariff on imported ethanol expired (Loris 2012), but blending ethanol into gasoline is still mandated under the Energy Policy Act of 2007, which was expanded under the Energy Independence and Security Act of 2007 (EISA). The EISA mandates that by 2022, 60.5 gigalitres (GL, 1 GL = 10^9 L) of biofuels be blended into transportation fuel while placing a cap on corn-starch ethanol production at 56 GL per year (Bracmort 2012). Of the 60.5 GL, 60 GL is mandated to be cellulosic biofuels (Bracmort 2012). In 2013, USA production capacity of ethanol was 56 GL derived from 211 plants operating in 29 states (RFA 2013). Consumption of ethanol in 2011 was 49 GL, with >90% of gasoline being blended with ethanol (U.S. Energy Information Administration 2012). In the agricultural marketing year of 2010–2011, 40% of the USA corn crop was used for ethanol production (U.S. Energy Information Administration 2012).

To support the development of the cellulosic biofuel industry, the USA federal government passed the Food, Conservation and Energy Act of 2008 as part of the 2008 farm bill. This act provided >\$1 billion to support and develop the cellulosic industry through research, grants, and guaranteed loans (Bracmort 2012). Estimated production of cellulosic ethanol in 2012 was 1.9 million litres (ML), which is below EISA targets. Cellulosic ethanol production failed to meet EISA targets in 2009, 2010, and 2011 (U.S. Energy Information Administration 2012). Today in the USA, there are nine cellulosic ethanol facilities with a capacity of 10.72 million gallons (US; i.e. 40.58 ML) (USA Energy Information Administration, Biofuels Issues and Trends, October 2012). None of these facilities is using switchgrass as a single-source biofuel feedstock. Seventeen cellulosic ethanol facilities are proposed, and of these, only one will use switchgrass as a major feedstock.

The cellulosic industry is developing in the USA at a slower than anticipated pace. There are several reasons for this: cellulosic biofuels plants cost roughly three times more to construct than corn ethanol plants; investment risk in cellulosic biofuel plant development is considered high; cellulosic conversion technology is untested in large-scale applications; and limited availability of feedstock (Bracmort *et al*. 2011). Because the switchgrass cellulosic industry in the USA is developing at a slower than anticipated pace, the cellulosic feedstock sources that are being used are crop residues, woodchips, municipal solid waste, and other by-products of currently existing industries. Driving the limitations of the production of a dedicated biomass feedstock crop such as switchgrass is farmer willingness to grow biomass feedstock without a market that is fully developed

(Jensen *et al*. 2006). In order for farmers to shift to the production of cellulosic biomass feedstock crops, the opportunity cost of crops that will be displaced by a biomass feedstock crop will need to be covered (James *et al*. 2010).

In the southern Great Plains, lowland switchgrass ecotypes such as the variety Alamo fit well with the regions environmental conditions (Mosali *et al*. 2013). In Oklahoma, a state representative of the southern Great Plains, switchgrass is a component of native rangeland and, along with introduced grass pastureland, covers 18.7 million acres (7.6 Mha) of Oklahoma. This area of pasture and rangeland supports a cow/calf industry that ranks fifth in the nation, with 4.5 million head (USDA-NASS). Many of the calves produced from this industry are spring-born, weaned in the fall (autumn), and are grazed on annual cool-season pasture (primarily wheat) during the autumn and winter as stocker cattle. For the cellulosic ethanol industry to develop in Oklahoma, it will have to compete for land resources and demonstrate a comparative economic advantage over existing beef cow/calf-stocker production systems.

If considered as a forage crop, switchgrass can complement this existing system. Of the introduced pasture species in Oklahoma, bermudagrass (*Cynodon dactylon*) is the most prevalent. Bermudagrass is productive from May to October. Forage availability of annual, cool-season pasture becomes limiting in April and is depleted by May (graze-out). In the current system there is a gap in forage availability from April to June. This forage gap prohibits additional stocker bodyweight gain on forage following depletion of annual, cool-season forage and the availability of bermudagrass. At this point, stocker cattle will be sold, or if additional weight gain is desired they will be fed hay, grain or a combination of both while waiting for bermudagrass pasture to develop. In reaction to high grain prices, developing heavier weight stocker cattle on forage has been favourable in the market (Peel 2012). Switchgrass can produce quality forage before the availability of bermudagrass (Burns *et al*. 1984). Producers can add bodyweight gain to stocker cattle by grazing switchgrass as a 'forage-bridge' between the graze-out of annual, cool-season pasture and the adequate availability of bermudagrass pasture for grazing. This could allow switchgrass to be utilised as a spring forage crop, with the re-growth following grazing deferred to the end of the year and harvested as biofuel feedstock. This system would complement existing forage systems and it would allow producers to become familiar with switchgrass production as the feedstock market develops.

The objectives of this paper are: (*i*) to examine the suitability of native, warm-season grasses for cellulosic feedstock production, (*ii*) investigate biological and economic suitability of a cellulosic feedstock produced for both grazing and biofuel, and (*iii*) use biological study data to simulate the economics of cattle gain/bioenergy feedstock systems.

Methods

Three experiments were conducted to examine the suitability of native warm-season grasses for cellulosic feedstock production and their suitability for feedstock and grazing. In Expt 1, 15 introduced and native warm-season perennial grasses (Table 1) were planted in plots 3.0 m by 6.0 m to evaluate biomass yield, yield distribution, and nutritive value over a 2-year (2004–2005) period. The study site was at the Noble Foundation's Pasture Demonstration Farm near Ardmore, OK, USA (34.2N, 97.2W) on a Wilson silt loam (Fine, smectitic, thermic Oxyaquic Vertic Haplustalfs; Web Soil Survey 2010) soil. The plots were originally established in May 1998 in a randomised complete block design with three replicates. From 1999 to 2003, plots were maintained and harvested once each year at the end of the growing season. In April 2004, plots were soil-tested to 15 cm depth, and based on the soil-test report, 78.0 kg N and 52.0 kg P_2O_5 ha^{-1} was surface-applied. Soil testing was repeated in April 2005, and based on the soil-test report, 78.0 kg N ha^{-1} was applied. Plots were harvested each year by species when each species reached boot stage of reproductive development, using a Hege plot harvester (Wintersteiger Inc., Salt Lake City, UT, USA). A strip 1.52 m by 6.0 m was harvested from the centre of each plot and fresh weights from each plot were recorded. Subsamples were obtained from each plot, dried in a 60°C forced air oven for 3–4 days until a constant weight was obtained, then weighed for dry matter yield calculations. Samples were then ground with a Wiley mill (Thomas-Wiley Laboratory Mill; Thomas Scientific, Swedesboro, NJ, USA) to pass a 1-mm screen and scanned using

Table 1. Warm-season perennial grasses evaluated for yield, yield distribution and, nutritive value near Ardmore, OK, USA

Variety	Common name	Species	Origin	Mature height
Alamo (lowland ecotype)	Switchgrass	*Panicum virgatum*	Native	100–300 cm
Blackwell (upland ecotype)	Switchgrass	*Panicum virgatum*	Native	50–150 cm
Blue	Panic grass	*Panicum antidotale*	Introduced (southern Asia)	50–120 cm
Carostan	Flaccidgrass	*Pennisetum flaccidum*	Introduced (Asia)	50–120 cm
Common	Dallisgrass	*Paspalum dilatatum*	Introduced (South America)	50–120 cm
Ermelo	Weeping lovegrass	*Eragrostis curvula*	Introduced (Africa)	60–150 cm
Common	Johnson grass	*Sorghum halepense*	Introduced (Africa)	100–200 cm
Lometa	Indian grass	*Sorghastrum nutans*	Native	100–200 cm
Midland 99	Bermudagrass	*Cynodon dactylon*	Introduced (Africa)	10–50 cm
Morpa	Weeping lovegrass	*Eragrostis curvula*	Introduced (Africa)	60–150 cm
Pensacola	Bahiagrass	*Paspalum notatum*	Introduced	30–75 cm
Plains	Bluestem	*Bothriochloa ischaemum*	Introduced	30–50 cm
Sand Mountain	Bahiagrass	*Paspalum notatum*	Introduced	30–75 cm
Selection 75	Kleingrass	*Panicum coloratum*	Introduced (Africa)	50–120 cm
WW-B.Dahl	Old world bluestem	*Bothriochloa bladhii*	Introduced	50–120 cm

a Foss 6500 NIRS instrument (FOSS NIR Systems Inc., Laurel, MD, USA). Forage nutritive values were determined for crude protein (CP) and acid detergent fibre (ADF) using equations developed by the NIRS Forage and Feed Testing Consortium in Hillsboro, WI, USA. The CP mean, standard error of validation, and r^2 for the equation used were 17.1%, 0.69%, and 0.98%. The ADF mean, standard error and r^2 for the equation used were 35.1%, 1.3%, and 0.96%. Total digestible nutrient (TDN) values were calculated using the Penn State equation: NEL = 1.044 – (0.0119 × ADF) and TDN = 4.898 + (89.796 × NEL), where NEL is net energy of lactation.

In Expt 2, plots from Expt 1 were used in a grazing preference study for 3 years (2007–2009). Each year, three commercial (*Bos taurus*) stocker steers were grazed on the plot area for 12 days in total each year over two grazing periods (June, July). In May each year, based on soil-test reports (15 cm depth) 78.0 kg N plus 52.0 kg P_2O_5 ha^{-1} was applied to all plots.

Blocks were separated by electric fence. Plots were grazed each year in two cycles of 6 days each. A cycle consisted of each replicate being grazed twice in sequential order: replicate 1, day 1 and day 4; replicate 2, day 2 and day 5; replicate 3, day 3 and day 6. Cycles 1 and 2 occurred on 6–11 June and 16–21 July in 2007, 2–7 June and 14–19 July in 2008, and 1–6 June and 6–11 July in 2009. In all 3 years of the study, three individually identified, randomly selected steers were used. In 2007 and 2008, the average steer weight was 282 kg; in 2009, average steer weight was 232 kg.

Each year, 2–3 days before the start of cycle 1, steers were turned into a 1.10-ha bermudagrass holding area that contained water and minerals. Steers were also released into the holding area at the conclusion of each grazing day and maintained in this area between grazing cycles. During the grazing cycles, calves were turned onto a replicate at each morning at 0630. Each individual steer would be assigned an individual recorder, whose responsibility it was to record the bite counts of that steer by species. After a recorder was assigned to a steer, that recorder would record bite counts of that steer through both grazing cycles. Steers were allowed *ad libitum* access to plots within a replicate and allowed to graze until they stopped grazing. Grazing periods lasted ~3 h each morning, then calves would be returned to the holding area until the start of the next grazing day. Between grazing cycles in 2007, plots were clipped to a uniform height and allowed to re-grow, whereas in 2008 and 2009, plots were not clipped between grazing cycles.

In Expt 3, Alamo switchgrass was established near Burneyville, OK, USA (33.5N, 97.2W) on 9.72 ha of a Slaughterville fine sandy loam (course-loamy, mixed, superactive, thermic Udic Haplustolls) and used in a stocker cattle grazing study to determine the value and utilisation of switchgrass in a dual-purpose animal weight-gain and bioenergy-feedstock system. The study area was soil-tested to a 15 cm depth and results indicated soil pH (6.5), P (31 mg kg^{-1}), and K (116 mg kg^{-1}) were sufficient not to limit switchgrass production. Nitrogen was added in spring before the start of grazing at 78.0 kg ha^{-1}. The study area was subdivided into 12 paddocks, each 0.81 ha, with three stocking density treatments of 0 (control), 2.5 (light), 4.9 (moderate), and 7.4 (heavy) steers ha^{-1}, assigned in a completely randomised design with three replications. Stocker calves (381 ± 89 kg) were randomly assigned to treatments when the average switchgrass height across treatments reached 36 cm and terminated when switchgrass was grazed down to a 19.0 cm height or when forage quality parameters of CP and *in vitro* dry matter digestibility (IVDMD) were low and ADF and neutral detergent fibre (NDF) values were high and no longer supported animal weight gain (Ball *et al*. 2001). During the trial, steers were allowed unlimited access to water and a salt/mineral mix. After grazing, switchgrass was allowed to accumulate until physiological maturity (the point during the production season where the plants have attained their maximum height and yield and have set seed) and then harvested. The effect of stock density on feedstock biomass was compared with the ungrazed control. The biological data collected from this study were then used to simulate the economics of six alternative stocker weight gain–bioenergy feedstock systems.

Table 2. Two-year monthly means for dry matter (DM) yield (Mg ha^{-1}), crude protein (CP, % of DM), total digestible nutrient content (TDN, %), and 2-year mean cumulative total DM yield (Mg ha^{-1}) of 15 warm-season perennial grasses near Ardmore, OK, USA

	May			June			August			September			October			Total
	Yield	CP	TDN	Yield	CP	TDN	Yield	CP	TDN	Yield	CP	TDN	Yield	CP	TDN	
Alamo switchgrass	6.1	10.6	57.8	8.9	11.5	56.3	8.4	5.6	52.9	–	–	–	3.6	8.2	58.1	17.7
Blackwell switchgrass	–	–	–	7.3	10.3	55.7	3.9	7.5	56.9	–	–	–	–	–	–	9.2
Blue panic grass	1.0	17.1	60.2	1.1	19.4	65.0	3.5	7.9	54.0	1.8	16.2	64.6	3.0	5.2	53.6	7.0
Carostan flaccidgrass	4.5	13.7	59.0	5.0	11.6	55.3	6.7	5.5	51.1	1.8	9.6	54.9	2.2	6.5	54.4	13.4
Dallisgrass	–	–	–	4.5	12.5	56.9	3.2	8.0	54.9	–	–	–	5.0	5.6	51.6	8.6
Ermelo weeping lovegrass	3.6	11.1	57.6	5.4	11.3	54.8	5.5	6.7	53.8	2.3	7.0	56.9	3.2	6.3	53.1	12.8
Johnson grass	4.6	10.4	56.9	4.9	10.8	54.9	6.2	5.5	51.9	1.6	10.1	59.0	2.5	6.9	54.9	12.2
Lometa Indian grass	–	–	–	6.2	8.9	55.5	–	–	–	–	–	–	5.7	5.5	52.5	9.0
Midland 99 bermudagrass	3.9	13.3	62.2	6.0	8.6	57.1	5.9	5.8	58.1	1.8	8.8	58.9	3.0	8.1	59.3	13.1
Morpa weeping lovegrass	3.3	11.8	57.8	4.0	10.8	53.8	5.1	6.4	54.6	2.0	7.6	57.8	2.9	6.1	53.0	11.1
Pensacola bahiagrass	3.2	13.3	58.2	2.5	11.9	58.2	4.7	8.0	56.8	2.2	8.6	56.9	2.8	6.5	54.8	11.3
Plains bluestem	–	–	–	2.7	10.2	53.1	–	–	–	–	–	–	2.1	2.4	48.1	3.7
Sand Mountain bahiagrass	–	–	–	2.8	15.3	61.9	2.2	7.8	57.3	2.5	12.1	61.9	2.6	7.4	55.7	5.0
Selection 75 kleingrass	4.4	12.2	59.7	6.0	12.3	58.5	7.0	6.2	55.4	2.0	10.3	63.5	2.8	5.9	56.0	14.6
WW-B.Dahl	–	–	–	4.9	10.3	58.2	–	–	–	–	–	–	7.0	3.4	52.0	8.5
l.s.d. (P = 0.05)	1.1	–	–	2.2	–	–	1.6	–	–	1.1	–	–	1.8	–	–	2.6

Results and discussion

Experiment 1

Alamo switchgrass produced a greater 2-year mean cumulative total dry matter yield than other grasses in the study (Table 2). It also produced greater May yield than the other grasses and was similar to Blackwell switchgrass in June and Selection 75 kleingrass (*Panicum coloratum*) in August (Table 2). Selection 75 kleingrass, Midland 99 bermudagrass, Johnson grass (*Sorghum halepense*), Carostan flaccidgrass (*Pennisetum flaccidum*), and Ermelo weeping lovegrass (*Eragrostis curvula*) were all similar in yield, with most yield produced in May, June and August (Table 2). The strong yield potential of Alamo switchgrass in May, June and July suggest opportunities for its use as a dual-purpose grass. Crude protein and TDN of Alamo switchgrass were similar in May and June (Table 2) and would be sufficient to produce animal weight gain (Lalman 2010). Early-season production of Alamo switchgrass could then be grazed or hayed in May and June, followed by deferment of re-growth for biofuel feedstock. This dual-purpose approach would allow a producer to begin to convert small amounts of existing pasture to switchgrass while giving up little, if any, grazing potential. To have this dual-purpose potential of forage production followed by biofuel feedstock production, a warm-season grass will need to have high cumulative DM yield potential, >8000 kg ha^{-1}, with at least one-third of the yield occurring in spring (May–June) (Rogers *et al*. 2012). This would lower the risk for the producer if the biofuel feedstock market were low, as the feedstock could be marketed through grazing or hay. For producers to accept the potential of Alamo switchgrass as dual-purpose forage, its palatability and acceptance by grazing animals requires study, which was the objective of Expt 2.

Experiment 2

Alamo switchgrass was the most preferred of 15 warm-season perennial grasses by bite count over the 3-year study (Fig. 1). Alamo switchgrass was also the highest yielding grass in the previous study (Table 2). Carostan flaccidgrass and Ermelo weeping lovegrass, both of which produced high early-season and high total cumulative yields in Expt 1, were less preferred, potentially limiting their dual-use potential. Results of Expt 2 indicated that cattle will accept Alamo switchgrass as a palatable

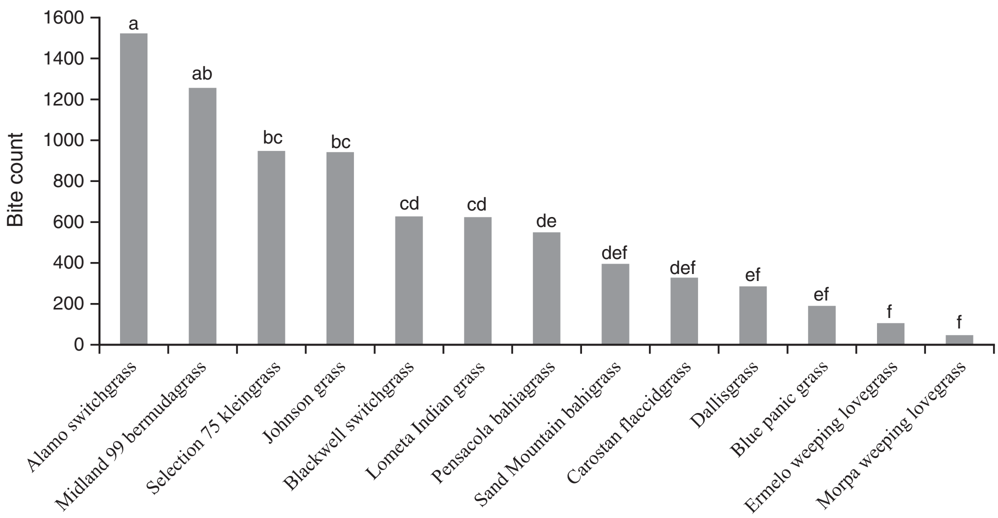

Fig. 1. Mean bite count rankings of warm-season perennial grasses averaged over 3 years of a preference study near Ardmore, OK, USA. Bars with the same letter are not significantly different at $P = 0.05$.

Table 3. Net returns and optimal system by stocking rate, value of gain and feedstock price
Values are US$. After Nichols *et al*. (2012)

		Stock density			$P > F$	System
	Control	Low	Moderate	High		
Value of gain ($ kg^{-1}):	–	1.74	1.54	1.30		
Feedstock price:		*Net returns ($ ha^{-1})*				
$0 Mg^{-1}	–242	7	44	–27	<0.01	Moderate graze
$28 Mg^{-1}	–338	–57	–5	–74	<0.01	Moderate graze
$55 Mg^{-1}	84	232	217	141	<0.01	Light graze + feedstock
$83 Mg^{-1}	509	524	442	353	<0.01	Light graze + feedstock
$110 Mg^{-1}	931	813	667	568	<0.01	Feedstock-only
$165 Mg^{-1}	1776	1393	1112	995	<0.01	Feedstock-only
Breakeven ($ Mg^{-1})	49	33	27	37	–	–

forage, and based on these results, Expt 3 was developed to further test its potential as a dual-purpose forage/biofuel crop.

Experiment 3

Grazing duration of Alamo switchgrass varied ($P < 0.05$) from 80 days for light, to 43 days for moderate, and 28 days for heavy stock-density treatments (Mosali *et al*. 2013). The light stock-density treatment had the lowest animal average daily gain (0.83 kg head^{-1}) compared with moderate (1.04 kg head^{-1}) and heavy (1.05 kg head^{-1}) stock-density treatments (Mosali *et al*. 2013). Total gain for the light stock-density treatment (167 kg head^{-1}) was less than for moderate (214 kg head^{-1}) or heavy (199 kg head^{-1}) stock density treatments (Mosali *et al*. 2013). Reduced animal performance of the light stock-density treatment can be explained by this treatment being understocked, and the grazing animals being unable to keep up with the rapid spring growth of the switchgrass. Although all stock-density treatments experienced a decrease in forage quality as the season progressed, forage quality of the light stock-density treatment due to understocking and rapid switchgrass growth decreased at a greater rate than in the moderate and heavy stock-density treatments, resulting in the lower animal performance of the light stock-density treatment. Feedstock yield with the light stock-density treatment was 10.6 Mg ha^{-1}, which was 31% less ($P < 0.05$) than the control (15.3 Mg ha^{-1}) but greater than the moderate (8.1 Mg ha^{-1}) and heavy (7.8 Mg ha^{-1}) stock-density treatments.

Results from Expt 3 were used to simulate the economics of six alternative (Table 3) cattle bodyweight gain–bioenergy feedstock systems (Nichols *et al*. 2012). Animal bodyweight gain from Expt 3 was combined with Chicago Mercantile Exchange (CME) cattle futures prices to determine the value of bodyweight gain for each stock density treatment (Table 3). The value of animal bodyweight gain varied by stock density treatment due to differences in grazing termination dates, which created varying end market points. The value of animal bodyweight gain for each stock density treatment was determined as US\$1.74, 1.54, and 1.30 kg^{-1} for light, moderate, and heavy stock-density treatments using 2011 CME futures prices (Nichols *et al*. 2012). At a feedstock price of \$55 Mg^{-1}, a combination of light grazing followed by grazing deferment and harvest for feedstock would return the highest net return of the systems (Table 3). Feedstock value would need to reach \$110 Mg^{-1} before the dedicated feedstock production without the addition of grazing would give the highest net return (Table 3).

Conclusions

Alamo switchgrass is a high-yielding, native, warm-season perennial grass with good yield distribution throughout the growing season. Compared with other warm-season perennial grasses, switchgrass has been demonstrated in this study to be a preferred forage and results in good bodyweight gain of stocker cattle during the early season grazing. High early-season forage yield and quality, and high annual total yield, increase the utility of Alamo switchgrass beyond that of a dedicated biofuel feedstock. Profit potential of Alamo switchgrass depends on feedstock and cattle price. As the cellulosic industry continues to develop, easily obtainable byproducts of existing industries such as crop residues, woodchips, and municipal solid waste will form the primary components of feedstock sources, while switchgrass and other grasses grown as dedicated feedstock will be secondary. This is so because, in the USA, the current value of switchgrass feedstock is \$0 Mg^{-1}. By moderately stocking switchgrass early in the growing season and with feedstock prices of \$55–83 Mg^{-1}, a moderate net return per ha is achievable for this dual-production system. Feedstock prices must exceed \$83 Mg^{-1} for switchgrass feedstock to be the most economical without grazing.

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