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Research paper

# Breakeven price of biomass from switchgrass, big bluestem, and Indiangrass in a dual-purpose production system in Tennessee

Christopher N. Boyer [a,*], Andrew P. Griffith [b], David W. McIntosh [c], Gary E. Bates [c], Patrick D. Keyser [d], Burton C. English [e]

[a] Department of Agricultural and Resource Economics at University of Tennessee-Knoxville, 302-I Morgan Hall, Knoxville, TN 37996, USA
[b] Department of Agricultural and Resource Economics, The University of Tennessee-Knoxville, 314B Morgan Hall, Knoxville, TN 37996, USA
[c] Department of Plant Sciences, The University of Tennessee-Knoxville, 2431 Joe Johnson Dr., Knoxville, TN 37996, USA
[d] Department of Forestry, Wildlife, and Fisheries, The University of Tennessee-Knoxville, 274 Eillington Plant Science Bldg., Knoxville, TN 37996, USA
[e] Department of Agricultural and Resource Economics at University of Tennessee-Knoxville, 308-B Morgan Hall, Knoxville, TN 37996, USA

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ABSTRACT

The objective was to determine the breakeven price for switchgrass (SG) (*Panicum virgatum* L.), a mix of big bluestem (*Andropogon gerardii* Vitman) and Indiangrass (BBIG) (*Sorghastrum nutans* L. Nash), and a combination of SG and BBIG (SG/BBIG) produced under three harvest treatments. Two-harvest treatments included a forage harvest at early boot (EB) and at early seedhead (ESH) plus a biomass harvest at fall dormancy (FD). The third harvest treatment was a single biomass harvest at FD. Mixed models were used to determine if there were differences in yield, crude protein, and nutrient removal for each of the native warm-season grass (NWSG) treatments at each harvest. The EB plus FD harvest system would be preferred over the ESH plus FD harvest system for all NWSG treatments. BBIG was the only NWSG treatment with a breakeven price for biomass that decreased with an EB harvest. For all three NWSG treatments, a producer would be better off harvesting once a year for biomass than twice for forage and biomass. The cost of harvesting and replacing the nutrients for the forage harvest was greater than the revenue received from selling the forage.



## 1. Introduction

Concerns about the effect of the corn-based biofuel industry on food prices [1–3] and environmental damages such as water contamination by nutrients and chemicals and soil erosion [4,5] have resulted in a growing interest in using lignocellulosic biomass to produce biofuel. Switchgrass (SG) (*Panicum virgatum* L.), a native warm-season grass (NWSG), has been identified as a potential lignocellulosic biomass crop in the southeastern United States [6–14]. SG can achieve high yields with minimal inputs on marginal land for crop production [11,12]. Nutrients such as nitrogen (N), phosphorus (P), and potassium (K) translocate from the aboveground biomass into the root system following crop senescence, resulting in a reduction of nutrient replacement when harvesting after senescence [13,14]. Moreover, SG has been found to have positive effects on soil quality and stability, provide habitat for wildlife, reduce greenhouse gas emissions, and mitigate water pollution [15]. Similar to SG, big bluestem (BB) (*Andropogon gerardii V.*) and Indiangrass (IG) (*Sorghastrum nutans* L. Nash) are NWSGs that have also been considered as possible lignocellulosic biomass crops [16–20]. Relative to SG, research has mostly found BB and IG to be a more expensive biomass crop alternative than monoculture SG [16–19]; however, Mulkey et al. [20] found a mixture of SG and BB to be the lowest cost source of biomass.

A significant amount of research has been conducted to analyze NWSG [12,19,20] establishment methods [21], production decisions [22–27], harvesting, storage, and transportation methods [11,28,29] to reduce the cost of production for biomass. Despite making significant strides in developing these NWSGs for biomass, a reliable market for biomass has not been established in the southeastern United States, yielding little economic incentive to produce NWSGs for biomass. Even if a market is established, demand for biomass for biofuels could fluctuate with the world energy prices [30]. Analyzing an alternative market for NWSGs to

*Abbreviations:* BBIG, big bluestem and Indiangrass; CP, crude protein; EB, early boot; ESH, early seedhead; FD, fall dormancy; NWSG, native warm-season grass; SG, switchgrass; SG/BBIG, switchgrass/big bluestem and Indiangrass.

* Corresponding author. University of Tennessee, Department of Agricultural and Resource Economics, 302-I Morgan Hall, Knoxville, TN 37996, USA.

*E-mail addresses:* cboyer3@utk.edu (C.N. Boyer), agriff14@utk.edu (A.P. Griffith), dmcintos@utk.edu (D.W. McIntosh), gbates@utk.edu (G.E. Bates), pkeyser@utk.edu (P.D. Keyser), benglish@utk.edu (B.C. English).

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hedge against biomass price risk in a regional bioenergy market would be beneficial to producers. Dicks et al. [31] and English et al. [6] showed that biomass production will primarily compete with cattle producers for pasture and hay land in the southern United States. Thus, the most likely and viable alternative market to hedge against biomass price risk would be the forage market.

Fescue is the primary forage cattle producers rely on in the Southeast, but during the summer NWSGs can be an important supplemental forage for livestock [32]. SG, BB, and IG are common NWSGs produced in the southeastern United States to supplement fescue in the summer [32]. SG also has potential to be a nutritional forage source for beef cattle in the summer months [32]. BB can contain high levels of crude protein (CP) and be highly palatable for cattle [32]. IG is known to be highly adaptable to the eastern United States, with excellent forage value that is highly palatable to cattle [32]. Cattle producers largely value hay based on CP with the value increasing as CP increases. In fact, the United States Department of Agriculture Agricultural Marketing Service (USDA-AMS) classifies grass hay as premium, good, fair, and low based solely on the percentage of CP found in the forage [33]. Grass hay is considered premium if the CP level is over 13%, good if the CP level is between 9 and 13%, fair if the CP is between 5 and 9%, and low if the CP level is below 5% [33]. While several studies have analyzed the economics of multiple harvests of NWSGs for forage or biomass [20,34], little is known about the economics of producing NWSGs as a “dual-purpose” (both forage and biomass) crop.

Guretzky et al. [11] evaluated SG for dual-purpose use at two locations in Oklahoma from 2008 to 2009. The SG forage harvest occurred after boot and the biomass harvest occurred after frost. They found forage quality to be poor when harvested after boot, and suggested that SG would need to be harvested in early summer to have quality attributes that would make it an attractive forage source for livestock producers. Furthermore, Mosali et al. [35] estimated stocking rate, animal performance, biomass yield, and quality for SG in Oklahoma. They found SG could be a viable grass to grow beef cattle through the summer, but that CP levels decrease over the summer grazing season. These studies provide insight into the dual-purpose use of SG; however, neither study analyzes other NWSGs or discuss the economics of the dual-purpose forage and biomass harvest system.

Recently, there has been little economic research focusing on hay production and most of the literature focuses on alfalfa [36–38]. On the other hand, there has been a significant amount of economic research on biomass production. Most of the previous economic research on biomass production has primarily focused on estimating the farm gate breakeven price for biomass [19,27,39]. Under a dual-purpose system, several production decisions could impact the producers' net returns. For example, Guretzky et al. [11] and Mosali et al. [35] showed that CP levels drop as the summer progresses and the plant matures. Higher CP levels in forage will likely translate into a higher price received for the forage. Therefore, the timing of the forage harvest will impact CP levels, which will impact the price of the forage. Additionally, Guretzky et al. [11] found the forage harvest removed more nutrients than the single biomass harvest, but the overall yield was greater for a two-harvest system than the single biomass harvest system. A biomass producer would have to determine if the additional return from the increased yield is greater than the additional costs of replacing more nutrients under the dual-purpose system.

The objective of this study was to determine the breakeven price for SG, a mix of BB and IG (BBIG), and a combination of SG and BBIG (SG/BBIG) grown as a bioenergy crop under three different harvest treatments. Two of the harvest treatments included a forage harvest at early boot (EB) and early seedhead (ESH) plus biomass harvest at fall dormancy (FD), and the third harvest treatment was a single biomass harvest at FD. Mixed models were used to find differences in yield and CP for each NWSG treatment and at each harvest treatment. The results were used to estimate the breakeven price of biomass with and without the forage harvests. This is a unique economic perspective on using an alternative marketing outlet for biomass producers to manage biomass price risk.

## 2. Data

The experiment was conducted from 2010 to 2012 at three locations across Tennessee, each of which represents unique growing conditions found in the mid-South region. Study locations were at the East Tennessee Research and Education Center in Knoxville (35°54′ 2″, −83° 57′ 36″), the Plateau Research and Education Center at Crossville (36° 2′ 38″, −85° 9′ 48″), and the Highland Rim Research and Education Center near Springfield (36° 28′ 22″, 86° 49′ 7″). The soil types were Etowah silt loam (fine-loamy, siliceous, semiactive, thermic Typic Paleudults) at Knoxville, Mountview silt loam (fine-silty, siliceous, semiactive, thermic Oxyaquic Paleudults) in Springfield, and Lily loam (fine-loamy, siliceous, semiactive, mesic Typic Hapludults) at Crossville [40]. Establishment for Knoxville and Crossville were in 2009 and the Springfield location was planted in 2008. An application of 2.24 kg ha$^{-1}$ glyphosate [*N*-(phosphonomethyl) glycine] was applied to the study area to eradicate existing vegetation prior to establishment, and a second application of glyphosate was made two weeks prior to planting. Stands were drilled on tilled and cultipacked soils. Experimental plot size at the Knoxville location was 1.8 × 7.6 m, and the plot size was 1.5 × 7.6 m at Crossville and Springfield.

The experiment was a randomized complete block design with four replications. The three planting treatments of NWSGs selected were SG, BBIG and SG/BBIG. The three harvest treatments included: (1) a forage harvest at EB and a biomass harvest at FD (EB + FD); (2) a forage harvest at ESH and a biomass harvest at FD (ESH + FD); and (3) a single biomass harvest at FD. The EB and ESH harvests were based on plant phenology of the SG treatment in order to time the harvests by different growing season conditions and not on a set date, and final FD harvests were done after the first frost at each location and after the plants reached senescence. The EB harvest was typically taken from the last week in May to the first week of June, and the ESH harvest was typically in the last week of June. The NWSG were harvested at a 15 cm residual height using a flail-type small-plot harvester with a 91 cm swath (Carter Mfg. Co., Inc. Brookston, IN; Swift Machine and Welding Ltd., Swift Current, SK).

The NWSG mixtures used for the experiment consisted of the following: 100% SG; 65% big bluestem 35% Indiangrass blend for the BBIG; and 50% SG, 35% BB, and 15% IG for SG/BBIG. The seeds ratios were mixed based on mass of pure live seed (PLS). Seeding rate for SG was 6.2 kg ha$^{-1}$, BBIG blend was 5.4 kg ha$^{-1}$ of BB and 2.8 kg ha$^{-1}$ IG; and SG/BBIG was 3.1 kg ha$^{-1}$ of SG, 2.7 kg ha$^{-1}$ of BB, and 1.4 kg ha$^{-1}$ IG. During establishment, plots were mowed twice to decrease weed competition. During year two, metsulfuron (14.0 g ha$^{-1}$) [2-[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]-oxomethyl]sulfamoyl]benzoic acid methyl ester] was applied, to any plot that included BB and IG in the mixture, for broadleaf weed control in late April. Weed control was not needed in year three due to stand density of the NWSG. Soil samples were taken to correct for nutrient deficiencies in pH with lime, N, P, and K. N was applied at 101 kg ha$^{-1}$ annually to the FD treatment at green-up in mid-April, and the forage and biomass treatments received half of the N at green-up and half after the forage harvest.

Yield and forage quality data were collected from 2010 to 2012 at all three locations for each of the three NWSG treatments for the three harvest treatments. Plots were harvested at a 15 cm residual height. To determine moisture content and dry matter forage yield, harvested plots were weighed and a subsample was dried at 60 °C in a forced-air oven for 72 h. Total dry matter forage and biomass yield were calculated for all harvest treatments and NWSG treatment. Table 1 shows the average yield in Mg ha$^{-1}$ by year, NWSG, and harvest treatment. Samples were analyzed using a FOSS 6500 near-infrared spectrometer (NIRS) for CP as a percent of dry matter (DM) (Foss NIR System, Inc., Laurel, MD). Equations for the forage nutritive analysis were standardized and checked for accuracy using equations developed by the NIRS Forage and Feed Consortium (NIRSC) (Hillsboro, WI). The grass hay equation supplied by the NIRSC was expanded to include samples from this study. Samples determined by the NIRSC as necessary additions included the NWSG mixtures for all harvest treatments and expansion was performed to include biomass material harvested at full senescence. Wet chemistry was performed on the selected samples and compared to these equations. Software used for NIRS analysis was WINSI II supplied by Infrasoft International LLC (State College, PA). Using the NIRSC equation allowed the samples to be run against the Global $H$ statistical test in the WINSI II program for accuracy [41]. All forage and biomass samples fit the equation with the ($H < 3.0$) and were used to report results.

For hay price, data from the USDA-AMS [33] were used from the Harrisonburg, VA hay auction, which is the closest reported hay market to Tennessee. For the EB harvest, the May price was used for the price of forage since the EB harvest likely happens in May, and for the ESH harvest, the June price was used as the price of forage since the ESH harvest likely happens in June. The average hay price by fair, good, and premium quality was calculated by month using data from 2010 to 2012 (Table 2).

Enterprise budgets for the production of dual-purpose forage and biomass production system do not currently exist thus budgets were developed (Table 3). The producer would establish the NWSG treatment in year zero and have 10 years of production for each NWSG treatment before replanting. The establishment cost is annualized over the 10-year useful life using a risk-adjusted annual discount rate of 5.4%. The discount rate is the producer's opportunity cost of investing in the NWSG pasture, representing the net return a producer would receive from an alternative investment (e.g., Treasury bond). The discount rate is equal to the risk-free discount rate plus the risk premium. It was assumed there was a 10% chance the producer would not be successful in establishing the NWSG in year zero and will retry establishing the stand the following year [42,43]. The establishment costs for biomass production of NWSG were developed using University of Tennessee Crop Budgets [42] and other previous research [27].

The prices for N, P, and K were average prices from 2010 to 2012 for the southeastern United States [44] (Table 3). For the EB + FD and ESH + FD harvests, the annual N–P–K rate was assumed to be 101 kg ha$^{-1}$ of N, 22 kg ha$^{-1}$ of P, and 50 kg ha$^{-1}$ of K, and the annual N–P–K rate for the FD harvest only was 101 kg ha$^{-1}$ of, 11 kg ha$^{-1}$ of P, and 34 kg ha$^{-1}$ of K. The N–P–K rates for the FD harvest only was estimated using the several switchgrass budgets [27,42]; however, the budgets do not exist for the dual-purpose NWSG system; therefore, the recommended P and K rates were approximated from previous nutrient removal studies [11,13,45]. The average price of land was determined using the 2010–2012 pasture cash rent rate for Tennessee [44]. The price of labor, herbicide, and harvesting were estimated using Mooney et al. [27] and University of Tennessee Crop Budgets [42] (Table 3). Table 3 reports all the costs included in the NWSG budgets.

**Table 2**
Grass hay prices ($ Mg$^{-1}$) by month and grade from 2010 to 2012.

| Month | Grade | | |
|---|---|---|---|
| | Fair | Good | Premium |
| May | 73.50 | 110.09 | 98.73 |
| Jun | 58.38 | 89.85 | 115.67 |
| July | 62.62 | 84.45 | 127.58 |
| August | 41.00 | 90.16 | 114.85 |
| Average | 58.87 | 93.64 | 114.21 |

Source USDA-AMS [33].

**Table 3**
Input prices for the NWSG budgets.

| Inputs | Unit | Price |
|---|---|---|
| Annualized establishment for SG | ha | $64.43 |
| Annualized establishment for BBIG | ha | $101.46 |
| Annualized establishment of SG/BBIG | ha | $82.95 |
| Nitrogen | kg | $1.68 |
| Phosphorus | kg | $1.70 |
| Potassium | kg | $1.83 |
| Land | ha | $51.21 |
| Harvest machinery | ha | $373.97 |
| Harvest bailing/staging | Mg | $1.93 |
| Labor | ha | $32.12 |
| Herbicide | ha | $62.15 |

Source: USDA-NASS [43]; Mooney et al. [27]; Griffith et al. [19]; University of Tennessee crop budgets [42].

## 3. Statistical analysis

Mixed models were used to perform an ANOVA on the effects of each harvesting treatment on yield and CP for each NWSG. Random

**Table 1**
Average yield (in Mg ha$^{-1}$) by NWSGs, harvest treatment, and year.

| Treatment | 2010 | | | 2011 | | | 2012 | | |
|---|---|---|---|---|---|---|---|---|---|
| | BBIG | SG | SGBBIG | BBIG | SG | SGBBIG | BBIG | SG | SGBBIG |
| *Forage* | | | | | | | | | |
| EB | 5.37 | 6.95 | 6.10 | 5.94 | 11.82 | 9.26 | 5.67 | 10.08 | 8.93 |
| ESH | 5.04 | 8.53 | 8.69 | 9.12 | 20.27 | 18.82 | 9.18 | 16.02 | 14.90 |
| *Biomass* | | | | | | | | | |
| FD after EB | 5.01 | 7.87 | 5.97 | 10.43 | 19.88 | 13.46 | 14.87 | 13.18 | 11.63 |
| FD after ESH | 2.56 | 6.43 | 5.23 | 6.65 | 11.49 | 13.02 | 10.02 | 12.94 | 13.07 |
| FD | 5.23 | 9.21 | 6.48 | 11.39 | 27.24 | 22.44 | 9.91 | 24.05 | 15.53 |
| *Total* | | | | | | | | | |
| EB + FD | 10.38 | 14.82 | 12.07 | 16.37 | 31.71 | 22.72 | 20.54 | 23.26 | 20.56 |
| ESH + FD | 7.60 | 14.95 | 13.92 | 15.77 | 31.76 | 31.84 | 19.20 | 28.95 | 27.97 |
| FD | 5.23 | 9.21 | 6.48 | 11.39 | 27.24 | 22.44 | 9.91 | 24.05 | 15.53 |

Note: EB is early boot, ESH is early seedhead, and FD is fall dormancy harvest, BBIG is big bluestem and Indiangrass, SG is switchgrass, and SG/BBIG is switchgrass, big bluestem, and Indiangrass. Biomass harvest is the expected yield for the FD harvest only.

effects were included for year and location variability due to stochastic weather events, soil differences, and disease. The following model was estimated for forage and biomass yield

$$y_{tljk} = \gamma_0 + \sum_{j=1}^{J-1} \gamma_j I_j + \sum_{k=1}^{K-1} \delta_k X_k + v_t + u_l + \varepsilon_{tljk}, \quad (1)$$

where $y_{tljk}$ is the yield in Mg ha$^{-1}$ at time $t$ at location $l$ for the $j$th harvesting treatment and for the $k$th NWSG treatment; $\gamma_0$ is the intercept coefficient; $I_j$ is an indicator variable for the $j$th harvest treatment ($j = 1, \ldots, 3$); $\gamma_j$ is the coefficient for harvest treatment $j$; $X_k$ is an indicator variable for NWSG treatment $k$ ($k = 1, \ldots, 3$); $\delta_k$ is the coefficient for NWSG treatment $k$; $v_t \sim N(0, \sigma_v^2)$ is the year random effect; $u_l \sim N(0, \sigma_l^2)$ is the location random effect; and $\varepsilon_{tljk} \sim N(0, \sigma_\varepsilon^2)$ is a random error term. Independence was assumed across the three stochastic components. One of the $j$ treatments and $k$ grasses were dropped to avoid multicollinearity issues, but was captured by the intercept coefficient. The null hypothesis was yield were not different across the three NWSG treatments for each harvesting treatment.

A mixed model with two random effects for year and location variability was estimated for changes in CP for each NWSG and harvest treatment. This equation was specified as

$$CP_{tljk} = \gamma_0 + \sum_{j=1}^{J-1} \gamma_j I_j + \sum_{k=1}^{K-1} \delta_k X_k + v_t + u_l + \varepsilon_{tljk}, \quad (2)$$

where $CP_{tljk}$ is the DM percentage of CP at time $t$ at location $l$ for the $j$th harvesting treatment and for the $k$th NWSG treatment. CP was the measurement used by the USDA-AMS to determine if grass quality hay is low, fair, good, or premium [42]. Prices of hay depend on the quality grade given by the USDA-AMS. CP for each NWSG was estimated at the EB and ESH harvest to price the hay according to the quality. The MIXED procedure in SAS 9.2 was used to estimate the models in Equations 1 through 4, and the PDIFF function of LSMEANS was used to compare means [46]. Significance was determined at $p \leq 0.05$.

## 4. Economic modeling

Enterprise budgets were used to estimate the cost of production for each of the harvesting treatments and for each NWSG treatment. A producer would establish the NWSG treatment in year zero and have 10 years of production for each NWSG treatment before replanting. In the establishment year, the producer prepared the field for planting by correcting deficiencies in the soil, spraying herbicides, and planting the seed. NWSGs normally do not reach full maturity until year two [14]. Therefore, the year one expected yield for each NWSG treatment was the first year in the budget. In years 2 through 10 in the budget, the expected yield for NWSG treatment in years two and three were used. This is the same approach used by Mooney et al. [27] to calculate the breakeven price of biomass from SG. The mixed model results for CP levels were used to determine the price of forage a producer would receive. The annual expected returns for years 1–10 for each NWSG and harvest treatment were calculated. The producers' annual net returns after establishment for each NWSG treatment was expressed as

$$E\left[R_{jk}\right] = E\left[p_{jk}^f y_{jk}^f + p_{jk}^b y_{jk}^b - h^f\left(y_{jk}^f\right) - h^b\left(y_{jk}^b\right) - rN - wP - cK - L - W - H - PC_j\right] \quad (3)$$

where $R_{jk}$ is the expected returns in \$ ha$^{-1}$ for the $j$th harvest and for the $k$th NWSG treatment; $p_{jk}^f$ is the price of forage for the $j$th harvest and for the $k$th NWSG treatment in \$ Mg$^{-1}$; $y_{jk}^f$ is the forage yield in Mg ha$^{-1}$ for the $j$th harvest and for the $k$th NWSG treatment; $p_{jk}^b$ is the biomass price in \$ Mg$^{-1}$ for the $j$th harvest and for the $k$th NWSG treatment; $y_{jk}^b$ is the biomass yield in Mg ha$^{-1}$ for the $j$th harvest and for the $k$th NWSG treatment; $h^f(y_{jk}^f)$ is the harvest costs for the forage harvest in \$ Mg$^{-1}$, which is a function of the yield; $h^b(y_{jk}^b)$ is the biomass harvest costs in \$ Mg$^{-1}$, which is also a function of the yield; $r$ is the price of N in \$ kg$^{-1}$; $N$ is the amount of N applied in kg ha$^{-1}$; $w$ is the price of P in \$ kg$^{-1}$; $P$ is the amount of P applied in kg ha$^{-1}$; $c$ is the price of K in \$ kg$^{-1}$; $K$ is the amount of K applied in kg ha$^{-1}$; $L$ is the rental rate in \$ ha$^{-1}$ for cropland in Tennessee; $W$ is the costs of labor \$ ha$^{-1}$; $H$ is the cost of herbicide \$ ha$^{-1}$; and $PC_j$ is the annualized establishment costs ha$^{-1}$.

The returns are summed over the useful life of the NWSG treatments, and the equation is rearranged to solve for the price of biomass, which is the present-value breakeven price of biomass for the harvest treatment and each of the three NWSG treatments. Since a different expected yield is used in years one compared to years two through ten, this was calculated as

$$E\left[p_{jk}^b\right] = E\sum_{t=0}^{10}\left[\frac{p_{tjk}^f y_{tjk}^f - h^f\left(y_{tjk}^f\right) - h^b\left(y_{tjk}^b\right) - rN - wP - cK - L - W - H - PC_{tj}}{y_{tjk}^b}\right]. \quad (4)$$

## 5. Results

### 5.1. Yield and protein

Expected yield by NWSG and harvest treatment are presented in Table 4. Results are presented for the forage harvests and the FD biomass harvests separately as well as total yield for combined harvest treatments. The expected yield for SG and SG/BBIG at the EB and ESH harvests were statistically ($P \leq 0.05$) greater than the expected yield for BBIG at the EB and ESH harvests. For the biomass harvests, the expected yield for SG was 3.6 Mg ha$^{-1}$ greater than the expected yield for BBIG and 3.3 Mg ha$^{-1}$ greater than SG/BBIG at the FD harvest after the EB harvest. Expected FD yield after the ESH harvest for SG and SG/BBIG were 3.9 and 4.0 Mg ha$^{-1}$ greater than BBIG, respectively. When the NWSG were grown strictly for biomass, the expected biomass yield for SG was 11.3 Mg ha$^{-1}$ greater than BBIG and 5.3 Mg ha$^{-1}$ greater than SG/BBIG. The expected biomass yield for SG/BBIG was 6.0 Mg ha$^{-1}$ larger than the expected yield for BBIG. For all the NWSG treatments, the expected yield was larger for the two-harvest treatments than the single-harvest biomass harvest at FD.

The DM percent of CP is shown in Table 4 by NWSG and harvest treatment. The level of CP was higher for BBIG than SG and SG/BBIG at the EB harvest. Nonetheless, the forage from all three NWSG

**Table 4**
Average Yields (in Mg ha$^{-1}$) and Average Crude Protein (DM %) by NWSGs and Harvest Treatment.

| Treatment | Yield (Mg ha$^{-1}$) | | | Crude protein (DM%) | | |
|---|---|---|---|---|---|---|
| | BBIG | SG | SG/BBIG | BBIG | SG | SG/BBIG |
| *Forage* | | | | | | |
| EB | 5.67$^{a}$ | 9.62$^{b}$ | 8.09$^{b}$ | 11.48$^{b}$ | 10.67$^{a}$ | 10.68$^{a}$ |
| ESH | 7.68$^{a}$ | 14.93$^{b}$ | 14.14$^{b}$ | 9.30$^{a}$ | 8.68$^{a}$ | 8.84$^{a}$ |
| *Biomass* | | | | | | |
| FD after EB | 10.11$^{a}$ | 13.67$^{b}$ | 10.35$^{a}$ | 3.95$^{a}$ | 4.62$^{b}$ | 4.14$^{a}$ |
| FD after ESH | 6.40$^{a}$ | 10.30$^{b}$ | 10.43$^{b}$ | 4.59$^{a}$ | 5.65$^{b}$ | 4.62$^{a}$ |
| FD | 8.85$^{a}$ | 20.16$^{c}$ | 14.82$^{b}$ | 4.28$^{b}$ | 3.48$^{a}$ | 4.01$^{b}$ |
| *Total* | | | | | | |
| EB + FD | 15.77$^{a}$ | 23.29$^{b}$ | 18.44$^{a}$ | – | – | – |
| ESH + FD | 14.08$^{a}$ | 25.22$^{b}$ | 24.57$^{b}$ | – | – | – |
| FD | 8.85$^{a}$ | 20.16$^{c}$ | 14.82$^{b}$ | – | – | – |

Note: EB is early boot, ESH is early seedhead, and FD is fall dormancy harvest, BBIG is big bluestem and Indiangrass, SG is switchgrass, and SG0/BBIG is switchgrass, big bluestem, and Indiangrass. Biomass harvest is the expected yield for the FD harvest only. $^{a,b,c}$ Paired mean tests are performed for each NWSG and for harvest treatment. If the letter is the same across all NWSG within each harvest, the numbers are not statistically different at the 0.05 level.

treatments would be graded as good quality grass forage [33]. For the ESH harvest, there was no statistical difference in CP levels across the NWSG treatments. The CP levels for all the NWSG treatments at the ESH harvest were on the border of the good and fair quality grade for grass forage [33].

### 5.2. Breakeven price

The breakeven prices for biomass at the FD harvest are presented in Table 5 by NWSG and harvest treatment. If BBIG was grown for forage and biomass, a producer would need to receive a price of \$113.64 Mg$^{-1}$ for biomass at FD to breakeven when the forage harvest occurred at EB. Harvesting BBIG forage at ESH instead of EB would result in the breakeven price of biomass at FD increasing by \$18 Mg$^{-1}$. For a single biomass harvest at FD, the breakeven price was \$102.25 Mg$^{-1}$. A producer would be better off producing BBIG for a single biomass harvest than for a forage and biomass harvest. Thus, the cost of the forage harvest was greater than the value forage produced.

For SG, the breakeven price for biomass was \$49.31 Mg$^{-1}$ with the single-harvest at FD. Considering the dual-purpose system, harvesting SG at EB for forage increased the breakeven price for biomass at the FD harvest by approximately \$14 Mg$^{-1}$. Similarly, harvesting SG at ESH resulted in the breakeven price for biomass at FD increasing \$63 Mg$^{-1}$ relative to the single biomass harvest. The breakeven price also increased \$27 Mg$^{-1}$ relative to the EB + FD harvest because the quality of the hay at ESH decreased from good to fair, which reduces the value of the hay.

The breakeven price for biomass from SG/BBIG was \$59.45 Mg$^{-1}$ for the single-harvest at FD. For the EB forage harvest, the breakeven price for biomass at FD harvest increased to \$90.96 Mg$^{-1}$. The breakeven price for biomass at FD with the ESH harvest decreased \$11 Mg$^{-1}$ for SG/BBIG when compared to the single biomass harvest at FD. The reason the breakeven price decreased from the EB + FD to ESH + FD was due to the additional 6.13 Mg ha$^{-1}$ of biomass produced with the ESH + FD harvest verses the EB + FD harvest (Table 5).

**Table 5**
Breakeven price for biomass (in \$ Mg$^{-1}$) by NWSG treatment and harvest treatment.

| Treatment | BBIG | SG | SG/BBIG |
|---|---|---|---|
| EB + FD | \$113.64 | \$62.32 | \$90.96 |
| ESH + FD | \$132.43 | \$76.38 | \$77.23 |
| FD | \$102.25 | \$49.31 | \$59.45 |

Note: EB is early boot, ESH is early seedhead, and FD is fall dormancy harvest, BBIG is big bluestem and Indiangrass, SG is switchgrass, and SG/BBIG is switchgrass, big bluestem, and Indiangrass.

## 6. Discussion

The results for the three NWSGs treatments in monoculture and mixture indicated that SG has a greater economic potential to be a biomass crop in the southeastern United States than BBIG and SG/BBIG in both a biomass only and a dual-purpose system. This is due to a lower breakeven price for biomass for BBIG and SG/BBIG. The breakeven price for biomass from SG was within the range of breakeven prices for biomass found in the literature [19,27,39]. Previous studies demonstrated SG to outperform BB and IG in other regions of the United States [16–19], but this is the first time these NWSGs have been compared for biomass in the southeastern United States. The breakeven price for biomass from SG/BBIG was between the breakeven price for biomass from SG and BBIG. The mixture of SG/BBIG would be preferred over BBIG by producers, but SG would be preferred over the mixture of SG/BBIG and BBIG. Griffith et al. [19] showed similar results with monoculture SG having a lower breakeven price to produce biomass than several mixtures of NWSGs.

As previously discussed, producers considering a dual-purpose production system for NWSGs will be confronted with several complex decisions about how to manage yield, quality, and cost of replacing nutrients while maximizing profits. Multiple harvest production systems would require more annual fertilizer due to more nutrients being removed during harvest [11,13]. Nutrients translocate from the aboveground biomass into the root system following crop senescence, resulting in a reduction of nutrient replacement when harvesting after senescence [13,14].

Additionally, the timing of the forage harvest impacted the breakeven price for biomass for all NWSG treatments. The EB + FD harvest system would be preferred over the ESH + FD harvest system. While forage yield were higher at ESH than EB, the quality of the hay decreased from good to fair, and the cost of replacing nutrients increased. Guretzky et al. [11] suggested that SG would need to be harvested in early summer to have good forage quality attributes for livestock producers, which is the finding in this study. As noted, the EB harvest likely occurs in May and the ESH harvest will likely occur in June. The price difference between June fair quality hay and May good quality hay was \$57 Mg$^{-1}$ on average (see Table 2). By delaying the forage harvest until ESH, rather than at EB, results in a decrease in quality grade from good to fair, which translates into a substantial decrease in the value of the hay.

The motivation for this study was to analyze an alternative market for NWSG being produced for biomass to hedge against biomass price risk for a regional bioenergy industry. Another possible alternative market might be grazing NWSGs in early summer and harvest the biomass at FD. Mosali et al. [35] found SG could be a potential NWSG that could extend the grazing days into the summer and still be harvested for biomass. Mosali et al. [35] found that animal performance and the quality of the SG was comparable to winter wheat grazing in Oklahoma. The economic benefits of grazing instead of mechanically harvesting the NWSG for hay such as reducing the cost of harvesting and nutrient replacement might make a grazing and biomass dual-purpose system more economically feasible. In future research, an economic analysis is needed to calculate the breakeven price to produce biomass under a dual-purpose grazing and biomass production system.

## 7. Conclusions

The level of CP in all three NWSG treatments decreased from good to fair from the EB to ESH harvest. Differences in the forage and biomass yield varied across the NWSGs, but the expected yield for SG was always higher than the expected yield for BBIG for all harvests. The breakeven price of producing biomass with a single-harvest was the lowest for SG, making it a more economically viable bioenergy crop than BBIG and SG/BBIG. Under a dual-purpose production system, the EB plus the FD harvest system would be preferred over the ESH plus the FD harvest system for all NWSGs if the objective is profit maximization. For all three NWSG treatments, a biomass producer would be better off harvesting once a year for biomass than twice for hay and biomass.

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