SWITCHGRASS AS A DEDICATED ENERGY CROP: FERTILIZER REQUIREMENTS, LAND USE, YIELD VARIABILITY, AND COSTS

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Abstract: The U.S Energy Independence and Security Act of 2007 (EISA) mandates that 36 billion gallon of renewable fuels be marketed annually (if produced) by 2022 including 16 billion gallons of cellulosic biofuels. Switchgrass (*Panicum virgatum* L.) has been identified as a model native U.S. species to produce biomass that could be used as biorefinery feedstock. The U.S. Department of Energy's 2011 Billion-Ton Update reported that 16 to 24 million hectares of U.S. cropland and pasture could be converted to produce dedicated energy crops such as switchgrass. One advantage of switchgrass is that it can grow in a variety of environmental conditions including on low quality land and under relatively dry conditions. The present study explores different aspects of feedstock production from switchgrass. The first paper investigates the consequences of an extended switchgrass harvest window on production cost. The second paper estimates the value of seed from a genetically improved switchgrass variety. Papers 3 and 4 explore the expected consequences of restricting switchgrass production to less productive land on feedstock production costs as well as on biorefinery profitability for a case study region of 30 Oklahoma counties.

Delaying harvest beyond December resulted in an average 5.4% decline in harvested biomass per month. Delaying harvest beyond November did not result in a significant change in the N concentration in the harvested biomass. Delaying harvest did result in a significant decrease in both P and K content in the harvested biomass. Biomass production cost was similar across the five months considered. In paper 2, assuming a year for establishment, nine postestablishment production years, a farm-gate biomass price of \$50 Mg^{-1}, a discount rate of 6.5%, and environmental conditions similar to those that prevailed during the field experiment, the net present value of seeding a field in the region to Cimarron rather than Alamo would be \$501 ha^{-1}. Paper 3 and 4 found that restricting land use to les reproductive class IV land increases land requirement by 54% and feedstock cost by 29% compared to when land use is unrestricted. Restricting land use decreases the biorefinery expected annual net turns by 11 to 50%.

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PREFACE

The U.S. Energy Independence and Security Act of 2007 (EISA) mandates that 36 billion gallons of renewable fuels, including 16 billion gallons of cellulosic biofuels, be marketed annually by 2022 if produced. Switchgrass (*Panicum virgatum* L.) has been identified as a model native U.S. species that could be grown to produce biomass for use as biorefinery feedstock. The U.S. Department of Energy’s 2011 Billion-Ton Update reported that 16 to 24 million hectares of U.S. cropland and pasture could be converted to produce dedicated energy crops such as switchgrass. One advantage of switchgrass is that it can grow in a variety of environmental conditions including on low quality land and under relatively dry conditions. The optimal size and structure of future biorefineries are unknown. Research is ongoing to determine the most efficient feedstock production system as well as the optimal procurement strategies that future biorefineries could implement to insure a steady flow of biomass feedstock over time. The present study explores different aspects of feedstock production from switchgrass and is composed of four chapters.

In chapter I, I investigate the consequences of an extended switchgrass harvest window on feedstock production cost when nutrient translocation and remobilization is considered. The results show that delaying switchgrass harvest into the winter results in a significant decrease in biomass yield due primarily to plant lodging. Delaying harvest beyond senescence also allows for nutrients to translocate and hence reduces the maintenance fertilization requirement for subsequent years. As a consequence, the study found that, in the region of the study, delaying switchgrass harvest into the winter would not increase the production cost per Mg of feedstock. The findings suggest that it is expected to be economically optimal in the Southern Plains to harvest switchgrass over an extended window. Throughout most of the year, feedstock may be delivered to the processing plant just-in-time without increasing feedstock cost.

In Chapter II, I estimate the value of seed from a genetically improved switchgrass variety. Several switchgrass breeding programs have been established in the U.S. in anticipation of a need for switchgrass biomass to fulfill the provisions of the U.S. Energy Independence and Security Act of 2007. Plant breeding resources are scarce, and cultivar development programs are expensive. Researchers at publicly funded institutions are often requested to document the potential economic benefits of their programs. In the absence of a market for switchgrass biomass, it is difficult to determine the potential benefits from switchgrass breeding programs. However, it is possible to determine differences in expected yields between established and recently developed switchgrass cultivars. This would enable researchers to estimate the difference in seed value between an established and a potential cultivar and hence an estimate of the potential value of the breeding program. The study uses enterprise budgeting combined with stochastic efficiency methods to evaluate yield risk associated with nine switchgrass cultivars. The newly released cultivar, Cimarron was compared to Alamo the best commercially available cultivar in the region. Assuming a year for establishment, nine post-establishment production years, a farm-gate biomass price of \$50 Mg^{-1}, a discount rate of 6.5%, and environmental conditions similar to those that prevailed during the field experiment, the net present value of seeding a field in the region to Cimarron rather than Alamo would be \$501 ha^{-1}.

Chapters III and IV explore the expected consequences of land use policy and switchgrass yield variability on feedstock production and procurement costs as well as biorefinery profitability. Previous studies have suggested that the use of marginal and/or less productive land for the production of bioenergy crops could mitigate the competition with food and fiber crops on better quality land. The proposition has followed from the view that when land that is marginal, and not currently used to produce food and other crops, is converted to switchgrass, indirect land use changes would be negligible. However, prior to completely dismissing the indirect land use issue of dedicated energy crops, several questions remain to be resolved because there is not a standard definition of marginal lands and the practicality of the use of these lands is an issue. Using a clear definition of marginal lands based primarily on land production capacity, papers III and IV show that restricting energy crop production to marginal lands would increase the land requirement to produce sufficient quantity of biomass to meet an assumed biorefinery capacity, by more than 50%. Also restricting second-generation energy crop production to marginal lands would increase feedstock production cost by more than 30% compared to when land use is unrestricted. Specifically, chapter IV shows that because of the increased feedstock production cost, the biorefinery profitability decreases for a given level of biofuel price if land use is restricted to capability Class IV alone. Restricting second-generation energy crop production to marginal land can also increase the travel distance necessary to transport the feedstock from the field to the processing plant and thus reduce the potential net environmental benefits associated with the production of energy crops on marginal lands.

CHAPTER I

YIELD AND NUTRIENT CONCENTRATION RESPONSE TO SWITCHGRASS BIOMASS HARVEST DATE

Abstract

Timing of biomass removal from stands of switchgrass (*Panicum virgatum* L.) impacts the nutrient content of harvested material and fertilizer requirements for subsequent growing seasons. This study was conducted to determine the change in N, P, and K content of harvested switchgrass biomass as a function of the harvest date and to determine the economic consequences of an extended harvest window. Data were produced in a randomized complete block study conducted at the Oklahoma Agricultural Experiment Station, Stillwater, with six replications over three harvest seasons from November of 2007 to March of 2010. Treatments on the established stand of cultivar Kanlow consisted of five harvest dates separated by about 30 d beginning in late November. Regression equations were used to fit yield and N, P, and K concentration response to the harvest date. Delaying harvest beyond December resulted in an average 5.4% decline in harvested biomass per month. Delaying harvest beyond November did not result in a significant change in the N concentration in the harvested biomass. However, delaying harvest did result in a significant decrease in both P and K content in the harvested biomass. Point estimates from the response functions were used to estimate

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production cost for each of five harvest dates beginning with 30 November and ending with 30 March. However, delaying harvest did result in a significant decrease in both P and K content in the harvested biomass. Point estimates from the response functions were used to estimate production cost for each of five harvest dates beginning with 30 November and ending with 30 March. The quantities of P_2O_5 and K_2O fertilizer that would be required to replace the P and K removed with the biomass were used in the budgets. Biomass production cost was similar across harvest dates.

Introduction

Switchgrass has been described as a model native U.S. species to produce biomass that could be used as biorefinery feedstock (Sanderson et al., 2006; McLaughlin et al., 2002). The U.S. Department of Energy's (2011) Billion-Ton Update reported that 16 to 24 million ha of U.S. cropland and pasture could be converted to produce dedicated energy crops such as switchgrass. One advantage of switchgrass is that it can grow in a variety of environmental conditions including on low quality land and under relatively dry conditions (Lewandowski et al., 2003). Prior studies have reported yield decreases associated with delaying switchgrass biomass harvest into the winter (Parrish et al., 1997; Casler and Boe, 2003; Sanderson et al., 2006).

Most studies budgeted switchgrass production costs as if it were a traditional crop (Epplin, 1996; Brown et al., 2000; Perrin et al., 2008; Mooney et al., 2009). Switchgrass is assumed to be harvested during a narrow time frame after maturity when maximum dry matter yield can be achieved (Vogel et al., 2002). This system would result in maximum harvested yield per hectare but would not necessarily be the most economically efficient system to deliver a flow of biomass to a biorefinery. In the southern plains of the United

States, the switchgrass harvest window could extend over many months. An extended harvest season would require fewer harvest machines per biorefinery thereby reducing overall harvest machinery fixed costs (Epplin and Haque, 2011; Haque and Epplin, 2012). An extended harvest window would enable a just-in-time delivery system during harvest months and reduce overall storage cost (Cundiff and Marsh, 1996; Larson et al., 2010; Grisso et al., 2013). However, with an extended harvest window, the expected harvestable yield and the expected fertilization requirement for the succeeding year might differ depending on the harvest date. If harvest is delayed until after the first frost and the initiation of senescence, biomass yield will be maximized and nutrients will have translocated, which may reduce the quantity of fertilizer needed for biomass production in subsequent years (Chapin, 1980; McLaughlin and Kszos, 2005). However, if harvest is delayed, plants may lodge, and delaying harvest until late winter may result in lower harvestable biomass yields. Previous studies have hypothesized that the machinery cost savings and savings from reduction in storage costs from an extended harvest may be sufficient to offset the expected yield losses (Haque and Epplin, 2012).

Nutrient removal by the plant is expected to differ with time of harvest (Fixen, 2007). Information on the economic consequence of the tradeoff between harvestable yield, nutrient removal, storage cost, and harvest machinery investment is sparse (Grisso et al., 2013). Knowledge of the tradeoffs between nutrients removed and biomass yield as switchgrass harvest is delayed is essential to determine the most economically efficient production system. The purpose of the present study is to estimate switchgrass biomass N, P, and K content as well as biomass yield as functions of harvest date and to determine the cost per unit of biomass also as a function of the harvest date.

Data were produced in a field experiment over three production seasons from 2007 to 2010. The aim of the experiment was to determine biomass nutrient (N, P, K) concentration and biomass yield by harvest date. Statistical methods were used to determine the biomass nutrient content and the dry biomass yield as a function of harvest date. Point estimates from these response functions were used to prepare enterprise budgets for each of five harvest dates to determine the economic consequences of an extended harvest season on feedstock production cost.

Materials and Methods

Agronomic

The field experiment was conducted at the Oklahoma Agricultural Experiment Station in Stillwater (36°7.98′ N, 97°6.26′ W). The randomized complete block experiment with five treatments and six replicates was conducted over 3 yr from 2007 to 2010. The Kanlow switchgrass stands were established in 1998. Before beginning the experiment no fertilization or other chemical treatments had been applied on the switchgrass stands for 3 yr to ensure no effects of previous fertilization on yield. Also during the experiment no fertilization occurred. The only treatment on the established switchgrass stand were the harvest dates (24-29 November; 21 or 22 December; 20-29 January; 23-27 February; and 26 March-3 April) with one harvest per year per plot. Post seed set dormancy is a gradual process and for the region of the study begins in November. December and later harvest dates are post-senescence. Monthly precipitation levels for the site and the years of the study are reported in Table I-1. Monthly average daily temperatures are reported in Table I-2.

For each treatment biomass yield was recorded with the moisture content at harvest after swathing and baling using a swather (John Deere MoCo-Model 630, 22 John Deere Co., Moline, IL) and a baler (John Deere–Model 568, John Deere Co., Moline, IL). On each harvest date additional random and hand grabbed samples of nearly 500 g were collected. The sample biomass was dried at 55°C in a forced air oven for 3 to 7 d. After drying, the dry matter was measured. Dry biomass was ground and passed through a 1 mm sieve and analyzed for the biochemical content of N, P, and K (Makaju et al., 2013).

For regression models, a continuous time variable was constructed for the harvest date with 1 July set equal to one and 30 June set equal to 365. A visual inspection of scatter plots of both yield and nutrient content was conducted to formulate hypotheses on functional forms and expected parameter signs in the regression equations. A scatter plot of the observed yields against the harvest dates indicated no perceptible difference between November and December yields. However, yields declined from December to the last harvest dates in early April. Because the observation of the scatter plot of yield revealed that yield decline began after the December harvest, the November harvest biomass yield data were dropped. Two functional forms (linear and inverse transformation) were estimated using the yield data from December to April. The equations were estimated using SAS PROC MIXED (SAS Institute, 2008) with year and replication modeled as random effects. Since the two models have the same number of parameters, the likelihood ratio test proposed by Pollak and Wales (1991) was used to compare the two non-nested functional forms. Misspecification tests for non-normality and heteroskedasticity were conducted to detect the presence of any departure from normality or heteroskedasticity. The D'Agostino (D'Agostino et al., 1990) K2 test for normality based on skewness and kurtosis was used to test non-normality and the RESET test for heteroskedasticity was conducted to test the null hypothesis of homoskedastic residuals.

Scatter plots of the P and the K biomass elemental concentration against the harvest dates indicate decreasing percentages for the two elements as the harvest date is delayed. However, scatter plots of N concentration in the harvested biomass did not reveal a perceptible change across harvest months. Two functional forms (linear and the inverse transformation) were also specified to estimate N, P, and K content as a percentage of dry matter for the five harvest treatment dates using the continuous time variable. The encompassing non-nested hypothesis test (Greene, 2012) was used to select the model that best fits the data. Misspecification tests were conducted to test normality of residuals and heteroskedasticity. Normality was tested using the K2 test. The RESET test was used to test heteroskedasticity.

Because the plots in the experiment were not fertilized and had not been fertilized for 3 yr before the initiation of the experiment, biomass yield from the harvest date plots was expected to be substantially lower than yield from plots that are fertilized and grown for commercial purposes. Fertilized plots of Kanlow switchgrass grown elsewhere at the experiment station during the same years were harvested to produce a yield estimate more reflective of fields commercially managed to produce biomass. The fertilized plots were established in June 2006 with four replications. Soil P and K levels in the fertilized plots had been brought up to sufficient levels before planting. Recommended N rates for switchgrass differ due to regional differences in the length of the growing season, precipitation, and expected yield (Thomason et al., 2004; Fike et al., 2006; Schmer et al., 2008; Haque et al., 2009; Boyer et al., 2012). Haque et al. (2009) estimated an optimal level of 65 kg N ha^{-1} yr^{-1}. Schmer et al. (2008) reported a mean application rate of 74 kg N ha^{-1} yr^{-1} in their study of switchgrass production in the western U.S. Great Plains. Fike et al. (2006) used 100 kg N ha^{-1}

yr^{-1}. Boyer et al. (2012) found that the optimal N rate ranged from 63 to 200 kg ha^{-1} yr^{-1} depending on soil type, N price, and biomass price. Based on the findings of prior studies, the plots were fertilized with 90 kg N ha^{-1} each April and were harvested once per year after frost in November. The harvest and measurement methods were the same as those used on the unfertilized experimental plots.

Yield estimates for economic analysis were synthesized by using the yields obtained from the fertilized plots as harvested in November after frost as the base November–December yield. For yield estimates for subsequent harvest dates, the base yields were adjusted by the percentage changes in harvested biomass as estimated with the yield response to the harvest date function. Estimates of nutrient content from the response functions for specific dates were multiplied by the synthesized biomass yields to obtain an estimate of nutrient removal for plants assumed to be fertilized and managed to produce commercial biomass. The validity of these estimates depends on the assumption that the percentage change in yield response to the harvest date, and the percentage change in nutrient content by the harvest date, is the same for fields that would be fertilized as it was for the unfertilized plots used to estimate yield and nutrient response to harvest date.

Economics

The decision maker's objective is assumed to be to select the harvest date that maximizes the returns to the resources used for switchgrass production. An objective function may be specified as follows:

$$\begin{aligned}\max_{HD} E(\pi) = \max[(p - HCB)Y(HD_t, N, P, K) - EST - HC - r_N N(HD_{t-1}) - r_P P(HD_{t-1}) \\ - r_K K(HD_{t-1}) - r_I I] - FC\end{aligned} \quad (1)$$

where $E(\pi)$ is the expected annual profit (\$ ha^{-1} yr^{-1}), p is the price of biomass feedstock in \$ Mg^{-1}, HCB is the cost of operations that depend on quantity of biomass harvested (baling, wrapping, and transportation [\$ Mg^{-1}]), Y is the dry biomass yield ($\mathrm{Mg\ ha}^{-1}$) that depends on the harvest date HD_t for the current year, HD_{t-1} is the harvest date for the previous year, OC is the cost of other inputs that do not vary across harvest date (establishment, reseeding, land lease, mowing, raking, other inputs, and the associated interest on operating capital [\$ $\mathrm{ha}^{-1}\ \mathrm{yr}^{-1}$]), r_N, r_P, and r_K represent the prices of N, P, and K, respectively (\$ kg^{-1}); N, P, and K are the quantities ($\mathrm{kg\ ha}^{-1}$) of N, P, and K, respectively. Since the price of biomass is unknown, for a given level of fertilizer prices, other costs, and a selected harvest date, the expected profit may be set equal to zero and the equation may be used to determine the breakeven price (\$ Mg^{-1}) which is equivalent to the cost of producing a megagram of biomass feedstock.

Since the fertilized plots received an annual application of 90 kg N $\mathrm{ha}^{-1}\mathrm{yr}^{-1}$ and since this level of N fertilization is within the range reported in prior studies, N fertilizer was budgeted at a rate of 90 kg ha^{-1} of N across all harvest dates. The level of P applied as P_2O_5 and K applied as K_2O can be determined by multiplying the nutrient concentration for the date as predicted by the regression equations, by the yield for the harvest date as simulated using the fertilized experiment yield. For the purposes of budgeting, by this measure, it is assumed that the level of P and K removed in the biomass would be replaced by fertilizer.

Estimates of yields and fertilizer requirements were obtained for each of five harvest dates (30 November, 30 December, 30 January, 28 February, and 30 March). A standard enterprise budget was prepared for each of these five harvest dates. Budgeted field operations are based on the assumptions of Turhollow and Epplin (2012). Based on switchgrass yield and estimated biomass nutrient content, the cost to produce and deliver switchgrass feedstock to a biorefinery was calculated depending on harvest date. The cost scenarios assume an amortized establishment cost of \$41.70 ha^{-1} for a 10-yr amortization period. The land lease cost was estimated at \$111.15 ha^{-1}. The baseline fertilizer prices were budgeted at \$1.23 per kg of N, \$2.70 per kg of P and \$1.37 per kg of K. Sensitivity analysis was conducted by reducing and increasing the fertilizer prices by 50% to reflect the consequences of alternative fertilizer prices.

The fertilizer application cost was estimated at \$5.97 ha^{-1} assuming that the three fertilizers would be applied in blended granular form in one application. The transportation operations were assumed for a 1-h trucking distance that is equivalent to a cost of \$3.75 Mg^{-1}. Some cost elements such as the establishment, reseeding, maintenance, land lease, mowing, and raking and the associated interest on operating capital, are evaluated on a per hectare basis. Other cost elements such as baling, wrapping, and transportation costs are proportional to harvested biomass quantity.

Since predicted values from regression equations were used to estimate feedstock production costs they would be heretoskedastic. Thus, a standard *F* test would not be appropriate to test for differences in cost across harvest dates. Therefore, to test for differences across the mean estimates of costs for the five budgeted harvest dates, the White (White, 1980) heteroskedasticity consistent covariance matrix option in SAS PROC REG was used (SAS Institute, 2008).

Results

Agronomic

Two functional forms (linear and inverse transformation) with the continuous time variable were used to estimate biomass yield response to harvest date. Data from December to April were used to conduct the estimation. The likelihood ratio test indicated that the inverse transformation functional form provides a better fit for the yield data obtained from harvests ranging from 21 December to 3 April (Table I-3). The normality K2 test did not detect the presence of non-normality with the inverse transformation model (K2 = 1.59 and ProbK2 = 0.44). The RESET test for heteroskedasticity also found that the null hypothesis of homoskedasticity could not be rejected at the 5% significance level (*P* value = 0.42).

Based on the inverse transformation model the predicted yield declined by 6.7% from 30 December to 30 January; by 5.1% from 30 January to 28 February; and by 4.3% from 28 February to 30 March. By this measure, from 30 December to 30 March, the average decline in harvested dry matter was 5.4% per month. The results are consistent with previous work on the impact of delaying harvest over the winter period (Thomason et al., 2004). However, most previous work has reported a continuously declining tendency in harvestable yield from the switchgrass maturity in late October to the late winter period (Fike et al., 2006; Guretzky et al., 2010). In the present study, the decline in harvestable yield started after December.

The percentages of N, P, and K in the harvested biomass response to harvest date were also estimated using a linear and an inverse transformation functional form. Results are reported in Table I-4. The slope coefficients for both functional forms for the percentage of N response to harvest date are not significantly different from zero. This finding indicates that the percentage of N in the harvested biomass did not change as harvest was delayed from November to March. This finding is consistent with that reported by Guretzky et al. (2010) who also hypothesized that N translocation from the aboveground biomass to the root system would occur between the early reproductive stage and the seed set.

For P and K contents the inverse transformation of the harvest date was the only variable that was statistically significant in the non-nested encompassing model (*P* = 0.04 and 0.0003 for the P and K biomass content estimation, respectively). Therefore, for the economic analysis the inverse transformation functional forms were used to estimate P and K concentrations in the biomass as functions of the harvest date. The normality test for the biomass P content estimation indicates that the null hypothesis of normality of the residuals is rejected at the 5% significance level (K2 = 21.113 and PK2 = 0.00002). The empirical option of the SAS MIXED (SAS Institute, 2008) procedure was used to adjust for non-normality of the residuals. The heteroskedasticity test indicates that the null hypothesis of homoskedasticity cannot be rejected at 5% significance level for both the P and K content estimation.

Table I-4 summarizes the results for P and K concentration response to the harvest date. The inverse transformation of the harvest date was highly significant in both equations suggesting declining nutrient content as harvest is delayed. Predicted values for the biomass P and K content are plotted in Figure I-1, which illustrates the decline in nutrient concentration corresponding to delayed harvest. The results support the hypothesis that biomass nutrient content would decline when harvest is delayed into late winter. The results are consistent with studies by Guretzky et al. (2010) and Kering et al. (2013), which suggest decreasing nutrient content when harvest is delayed. The predicted K content of switchgrass biomass harvested in late November is 259% greater than the K content of switchgrass harvested in late March. The predicted P content of switchgrass biomass harvested in late November is 84% greater than the P content of switchgrass harvested in late March. Whereas the predicted biomass yield of switchgrass harvested in late December is only 18% greater than the predicted biomass yield of switchgrass harvested in late March. For the economic analysis, the assumption is made that the P and K that is removed will be replaced with fertilizer.

Economic

The average yield of the November harvested fertilized plots was 14.40 Mg ha^{-1}. This quantity is assumed to be the base yield for economic analysis. Since the statistical analysis did not show a significant yield difference between November and December harvested plots, the base yield of 14.40 Mg ha^{-1} is also assumed for December harvests. Yield declines as estimated by the regression model of 6.7, 5.1, and 4.3% were applied to the base yield to obtain biomass expected yield estimates of 13.43 Mg ha^{-1} for a 30 January harvest; 12.76 Mg ha^{-1} for a 28 February harvest; and 12.21 Mg ha^{-1} for a 30 March harvest (Table I-5).

The predicted values for P and K concentration by harvest date from the regression equations were used to determine the quantity of P_2O_5 and K_2O fertilizers that would be required to replace the P and K removed with the biomass. The estimated P_2O_5 and K_2O quantities that would be required to replace the P and K removed with harvested biomass are plotted in Figure I-2. The budgeted quantities of P_2O_5 and K_2O per hectare, for each of the five budgeted harvest dates, are presented in Table I-5.

The cost to deliver one Mg of switchgrass is estimated for each of five harvest dates. The results are summarized in Table I-6. For the baseline fertilizer prices of \$1.23 kg^{-1}, \$2.70 kg^{-1}, and 1.37 kg^{-1} for N, P, and K, respectively, the mean production cost is estimated at \$59 Mg^{-1} for the biomass harvested in November (Table I-6). For biomass harvested in December the production cost is estimated at \$58 Mg^{-1}, which is the lowest production cost (Table I-6). When harvest is delayed until the late winter months, the production cost increases from \$59 Mg^{-1} in January to \$60 Mg^{-1} for February and March harvest (Table I-6).

When the baseline prices of fertilizers are reduced by 50%, the production cost is estimated to be \$52 and \$54 Mg^{-1} for the 30 November and the 30 March harvest dates, respectively (Table I-6). With the low fertilizer price scenario, the production cost is estimated at \$53 Mg^{-1} for the 30 January harvest and at \$54 Mg^{-1} for switchgrass harvested on 28 February and 30 March. Reducing the fertilizer cost by 50% reduced the production cost by 10 to 12%.

In a second sensitivity analysis scenario the fertilizer base prices are increased by 50% to reflect the impact of a fertilizer price increase on the production cost. With the higher prices, the production cost is estimated to be between \$64 and \$66 Mg^{-1}. The 50% increase in prices resulted in an increase in the production cost between 8 and 12% (Table I-6). Table I-6 also includes the fertilization cost percentage of the total production cost. For the baseline fertilizer prices, fertilizer costs decline from 23 to 19% of the total production cost as harvest is delayed from November to March.

Estimated production costs are very similar across harvest dates ranging from 30 November to 30 March (Table I-6). Based on the White (1980) test the difference in production cost across the 5 mo and the six replications was not statistically significant ($P \geq 0.50$). The findings are that even though there were significant declines in harvestable yield across harvest months there was not a significant increase in production cost because less P and K was removed from plots on which the harvest was delayed.

Discussion

Economically competitive biorefineries could be expected to operate continuously throughout the year and require a steady flow of feedstock. A perennial grass such as switchgrass has as a potential advantage in that in some climate regions, the harvest window may extend over many months. Switchgrass feedstock production with an extended harvest window and a one cut system has been examined by several studies. However, these prior studies did not have field estimates of the yield and fertilization consequences of an extended harvest window (Tembo et al., 2003; Mapemba et al., 2007; Hwang et al., 2009). Lengthening the harvest window has the potential to reduce the number of harvest machines required to support a biorefinery thereby reducing harvest costs (Epplin and Haque, 2011; Haque and Epplin, 2012). An extended harvest window would also reduce biomass storage cost (Cundiff and Marsh, 1996; Sanderson et al., 1997; Larson et al., 2010; Grisso et al., 2013).

The present study considered switchgrass biomass feedstock production with a 5 mo harvest window from November to March. The objective was to investigate the combined economic consequences of changes in harvestable yield and in nutrient removal, as harvest is delayed. Results suggest that as harvest is delayed into the winter months in the region of the study, biomass harvestable yield decreases. However, delaying harvest resulted in reduced P and K fertilizer requirements in subsequent years. In general, the reduction in fertilizer cost largely offsets the value of the reduced yield such that the cost to deliver a megagram of biomass is not statistically significantly different across harvest months. By this measure, harvesting switchgrass biomass over an extended window could be expected to be an economically viable business strategy.

A business strategy to extend the harvest season into March would result in a lower average harvestable yield per hectare. Hence, more hectares would be required to support a biorefinery with fixed feedstock requirements. Some of these additional hectares could be expected to be located at greater distances from the biorefinery. Average transportation distances and transportation cost would be greater. However, field storage losses of harvested biomass would be expected to be lower relative to a narrow harvest window (Sanderson et al., 1997). A more comprehensive modeling approach would be required to fully assess the economic consequences of the changes in yield, fertilizer requirements, storage requirements, and transportation costs as an extended harvest window is considered. Additional research would be necessary to evaluate the tradeoffs that affect biorefinery production cost.

As discussed, the percentage changes in yield and nutrient content were estimated from plots that were not fertilized during the study and had not been fertilized for 3 yr before the study. This was done to ensure no effect of previous fertilization on yield. A limitation of the economic analysis component of the study is that the percentage change in yield and the percentage change in nutrient concentration in response to the harvest date were assumed to be the same on a fertilized plot as on the unfertilized plots. Additional research would be required to confirm this hypothesis.

References for Chapter I

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Table I-1. Monthly Precipitation at Stillwater, OK Compared to a 10-Year Average (cm)

Month	2007	2008	2009	2001-2010 10-year Average
January	3.40	1.42	0.43	3.40
February	1.07	6.55	5.28	3.81
March	13.87	10.54	9.22	7.02
April	10.54	14.58	12.88	8.16
May	26.49	16.18	8.28	12.68
June	42.52	12.50	4.39	15.51
July	17.81	12.70	12.60	9.76
August	3.33	3.35	19.05	8.82
September	11.68	4.19	7.80	7.05
October	8.38	5.26	18.39	7.54
November	2.21	6.73	3.94	3.50
December	2.67	1.98	1.40	3.08

Source: http://www.mesonet.org/index.php/weather/monthly_rainfall_table/stil

Table I-2. Monthly Average of Daily Temperatures at Stillwater, OK Compared to a 10-Year Average (ºC) †

Month	2007	2008	2009	2001-2010 10- Year Average
January	1.2	3.1	1.6	2.8
February	4.1	3.7	8.3	4.5
March	14.6	10.2	11.6	10.6
April	13.3	14.3	15.2	16.1
May	20.7	20.6	19.2	20.5
June	23.6	25.5	27.2	25.2
July	26.1	28.0	27.2	27.7
August	28.3	26.4	25.4	27.2
September	23.0	21.1	20.7	22.0
October	17.3	15.2	12.4	15.5
November	10.1	9.2	11.5	10.2
December	2.5	3.1	0.9	3.8

Source: http://cig.mesonet.org/~gmcmanus/monthly_meso/meso_month.cgi? beginmonth=01 &beginyear=1994 &endmonth=07&endyear=2013&stid=STIL&parms=9AVG& SUBMIT= Submit

† The temperature data were converted from degree Fahrenheit to degree Celsius by the authors.

Table I-3. Switchgrass Yield Response to Harvest Date Estimated with a Linear and Inverse Transformation Functional Forms with Data from Plots Harvested From December 21 to April 3

Variable	Linear Model†	Inverse Transformation
Intercept	8.6281* (1.80)‡	3.4637 (1.78)
Date§	-0.01190* (0.0050)	
Invdate¶		544.42* (0.0257)
-2 loglikelihood	298.3	277.1

** Statistically significant at the 0.05 probability level.

† The dependent variable is the dry biomass yield (Mg ha^{-1}).

‡ Numbers in parentheses are standard errors.

§ Date is the number of days from July first to the date of harvest (e.g. 1 July = 1; 1 January = 185). Based on the data used to fit the function the relevant range is from 21 December (Day 174) to 3 April (Day 277).

¶ Invdate is the inverse transformation of the harvest date. For example, the value for a harvest date of 24 November is 185^{-1}, which is equal to 0.005405.

Table I-4. Nitrogen, Phosphorus and Potassium in Harvested Biomass (%) Response to Harvest Date

Variable	Biomass Nitrogen Content†		Biomass Phosphorus Content†		Biomass Potassium Content†	
	Linear model	Inverse transformation	Linear model	Inverse transformation	Linear model	Inverse transformation
Intercept	0.4453 (0.1855)‡	0.3837 (0.1792)	0.1305** (0.0074)	-0.0034 (0.0089)	0.4524** (-0.023)	-0.1529** (0.02)
Date§,	-0.00027 (0.000839)		-0.00032*** (0.00003)		-0.00146*** (-0.0001)	
Invdate¶		0.9890 (33.4118)		13.16*** (1.98)		59.83*** (3.92)
Encompassing test P_value			0.83	0.04	0.22	0.0003

* Statistically significant at the 0.05 probability level.

*** Statistically significant at the 0.001 probability level.

† The biomass N, P, and K content are elemental N, P, and K content measured as percent of dry biomass.

‡ Numbers in parentheses are standard errors.

§ Date is the number of days from 1 July to the date of harvest (e.g. 1 July = 1; 1 January = 185). Based on the data used to fit the function the relevant range is from 24 November (Day 147) to 3 April (Day 277).

¶ Invdate is the inverse transformation of the harvest date. For example, the value for a harvest date of 24 November is 185^{--1}

Table I-5. Biomass Removed and Budgeted Quantities of P_2O_5 and K_2O Estimated to be Required to Replace Nutrients Removed in Harvested Biomass by Harvest Date

Harvest Date	Biomass Removed (Mg ha^{-1})†	P_2O_5 (kg ha^{-1}) ‡	K_2O (kg ha^{-1}) ‡
November 30th	14.40	27	41
December 30th	14.40	23	30
January 30th	13.44	18	21
February 28th	12.76	15	14
March 30th	12.21	13	10

† The removed biomass quantities are calculated by adjusting the observed biomass yield from the fertilized plots with the yield decline rate observed in the unfertilized plots.

‡ P_2O_5 and K_2O equivalent were calculated using the predicted values from regression of P and K biomass concentration response to harvest date from Table I-4.

Table I-6. Cost to Deliver one Mg of Switchgrass by Harvest Date and Percentage of Fertilizer Cost in the Total Cost

Harvest Date	50% Decrease in Baseline Fertilizers Prices†		Baseline Fertilizers Prices‡		50% Increase in Baseline Fertilizers Prices	
	Production Cost ($ Mg^{-1})	Percentage of Fertilizer Cost in the Production Cost (%)	Production Cost ($ Mg^{-1})	Percentage of Fertilizer Cost in the Production Cost (%)	Production Cost ($ Mg^{-1})	Percentage of Fertilizer Cost in the Production Cost (%)
November 30th	52	13	59	23	66	31
December 30th	52	12	58	21	64	29
January 30th	53	12	59	20	65	27
February 28th	54	11	60	20	65	27
March 30th	54	11	60	19	66	26

† The estimated cost is calculated by considering nutrient removed in the switchgrass biomass. When evaluated for all the replications and compared across months the production costs were not statistically different at 5% significance level.

‡ The baseline fertilizer prices are \$1.23 kg^{-1}, \$2.70 kg^{-1} and 1.37 kg^{-1} for N, P, and K, respectively.

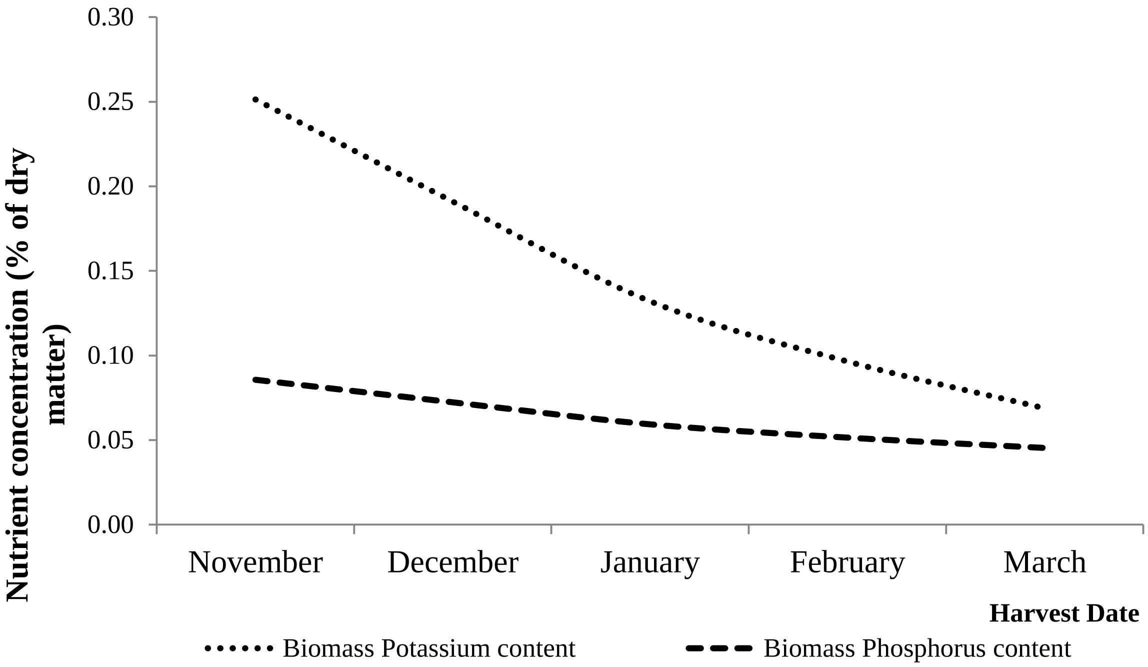

Figure I-1. Predicted switchgrass elemental Phosphorus and Potassium concentration in harvested biomass by harvest date

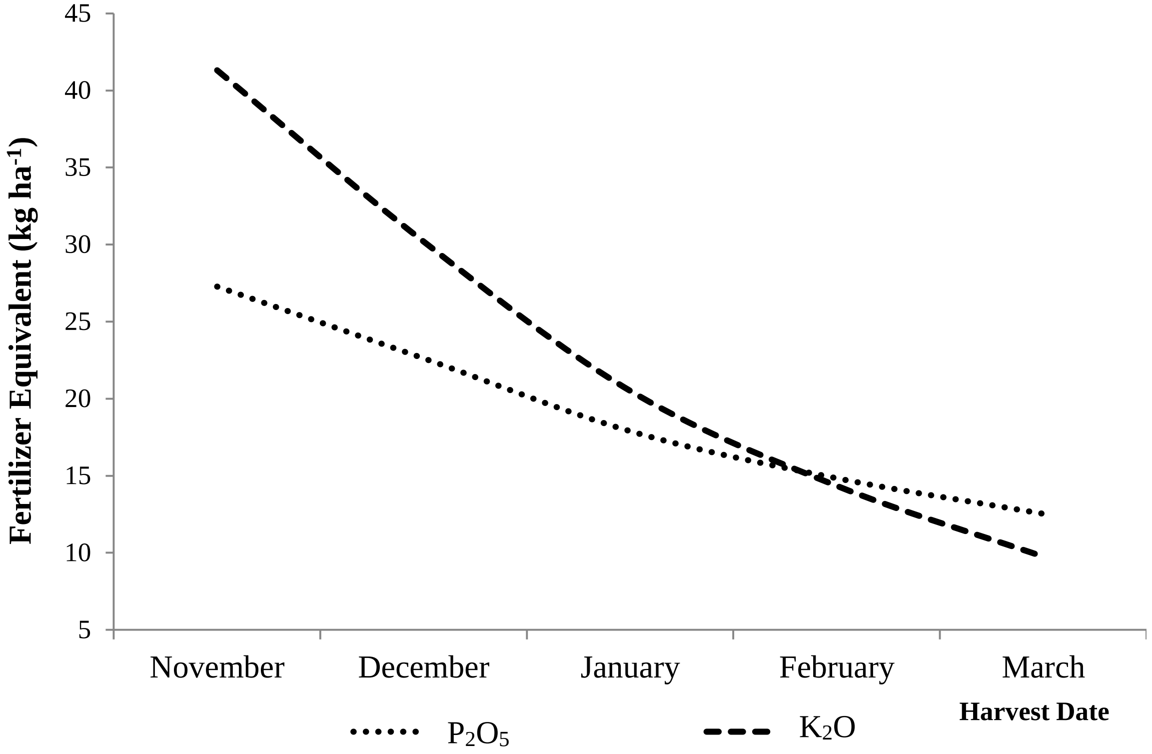

Figure I-2. Switchgrass fertilizer quantity equivalent in the biomass removed by harvest date

CHAPTER II

VALUING THE SEED OF AN IMPROVED SWITCHGRASS CULTIVAR

Abstract

Switchgrass (*Panicum virgatum* L.) has been identified as a model perennial grass species to compete with alternative sources for providing biomass to fulfill cellulosic biofuels provisions of the US Energy Independence and Security Act of 2007. The objective of this study is to determine the value of a more productive switchgrass variety relative to that of the best available alternative. Biomass data were produced in an experiment with four commercial switchgrass cultivars (Alamo, Blackwell, Kanlow, and Cave-in-Rock) and five experimental lines over 4 yr at Stillwater, OK. One of the experimental lines, Cimarron, was released as a cultivar in 2008 during the experiment. The remaining four experimental lines were NL93-2, NSL 2001-1, NL 94-2001-1, and NSU 95-2001. An ANOVA model is used to test for differences in switchgrass yield. Enterprise budgets are used to calculate net returns and stochastic efficiency analysis is used to investigate yield risk. For a farm-gate biomass price of \$50 Mg^{-1}, expected net returns were estimated to be \$80 ha^{-1} yr^{-1} greater in postestablishment years for Cimarron than for Alamo. Assuming a year for establishment, nine postestablishment production years, a farm-gate biomass price of \$50 Mg^{-1}, a discount rate of 6.5%, and environmental conditions similar to those that prevailed during the field experiment, the net present

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value of seeding a field in the region to Cimarron rather than Alamo would be \$501 ha^{-1}.

Introduction

Several switchgrass breeding programs have been established in the United States in anticipation of a need for switchgrass biomass to fulfill provisions of the US Energy Independence and Security Act of 2007. The legislation mandates that 60 billion liters of cellulosic biofuels, if produced, must be marketed annually in the United States by 2022. The US Department of Energy’s (2011) billion-ton update estimates that for a price of \$55 to \$66 Mg^{-1}, 5 to 13 million ha could be bid from current use and converted to production of perennial grasses for biomass feedstock. Switchgrass has been identified as a model perennial grass species for bioenergy feedstock production.

Plant breeding resources are scarce, and cultivar development programs are expensive. Breeding programs at privately funded companies are driven by the profit motive. Private companies must be profitable to be sustainable. Cultivar development programs at government-funded institutions are accountable to the public at large. Researchers are often requested to document the potential economic benefits of their programs. Switchgrass biomass markets do not currently exist. Land devoted to commercial production of switchgrass is limited, and future requirements for switchgrass seed are unknown, making it difficult to forecast economic benefits from a switchgrass breeding program. However, it is possible to determine differences in expected yields between established and recently developed cultivars. This would enable an estimate of the difference in seed value between an established and potential cultivar and hence an estimate of the potential value of the breeding program.

Switchgrass cultivars are classified into two genetically distinct geographic groups based on habitat and the plant morphology: upland and lowland cultivars. In general, the upland cultivars are of northern origin, more cold tolerant, shorter, and lower yielding (Frank et al., 2004). The lowland cultivars produce greater yield than upland ecotypes in the southern plains (Sladden et al., 1991; Casler et al., 2004; Sripathi et al., 2013). Moreover, lowland cultivars are associated with relatively stable yield across different environmental conditions in the southern latitudes (Fuentes and Taliaferro, 2002).

Several switchgrass cultivars based primarily on selections isolated from stands of native prairies have been released and are commercially available, and additional cultivars are expected to be released (Kaiser and Bruckerhoff, 2009; McLaughlin and Adams, 2005). The value of the biomass will be derived from the value of its components, which will depend on the specific use of the feedstock (McKendry, 2002). With no information regarding the value of various components of feedstock, switchgrass breeders could be expected to concentrate their effort on biomass production improvement. Potential growers could be expected to be willing to pay more for seed of a new cultivar if it has a greater expected yield than existing cultivars.

Switchgrass production costs per ton decrease as yield per hectare increases (Thorsell et al., 2004; Griffith et al., 2010; Haque and Epplin, 2012; Turhollow and Epplin, 2012). However, little information is available on cultivar-specific production cost even though yield varies with cultivars. Because field cost of producing feedstock would be a major component of the cost to produce cellulosic biofuel, evaluating feedstock production cost by cultivar could provide useful information for producers facing a cultivar selection decision.

In addition to differences in production cost, switchgrass producers and potential processors could be expected to be concerned about yield variability that would influence both grower-expected returns and processor feedstock availability. Differences in expected yield and returns across switchgrass cultivars have not been addressed by previous studies. Risk-neutral producers would adopt a new switchgrass cultivar only if the cultivar would maximize their expected profit, while risk-averse producers would choose the cultivar that maximizes their expected utility by considering both expected profit and variability thereof (Hiebert, 1974).

In the southern plains of the United States, lowland cultivars have been found to produce greater yields than upland cultivars. For example, Fuentes and Taliaferro (2002) conducted field experiments in Oklahoma and found that lowland cultivars Kanlow and Alamo produced average yields of 15.4 and 14.9 Mg ha^{-1} with standard deviations of 5.21 and 4.86 Mg ha^{-1}, respectively. In the same experiment, the upland cultivars Blackwell and Cave-in-Rock produced average yields of 11.6 and 9.9 Mg ha^{-1} with standard deviations of 3.71 and 4.45 Mg ha^{-1}, respectively. Wilson (2011) reported average yield for Kanlow of 19.8 Mg ha^{-1} with a standard deviation of 5.02 Mg ha^{-1}, also in Oklahoma. The upland cultivars Blackwell and Cave-in-Rock yielded 11.69 and 10.48 Mg ha^{-1} with standard deviations of 3.00 and 2.87 Mg ha^{-1}, respectively. The Hartley test (Hartley, 1950) did not detect significant differences in variance across the cultivars in these experiments.

Depending on a producer’s risk-aversion level, cultivars with greatest yield potential may not be the best alternative choice because of differences in yield variability. Therefore, evaluation of cultivars on the basis of mean yield or mean returns may not provide an adequate decision making tool. The mean net returns and the associated variability may be analyzed simultaneously with a method such as stochastic efficiency analysis (Hadar and Russell, 1969). Stochastic efficiency analysis may be used to determine the relative values of alternative cultivars by considering both mean yield and variability.

The purpose of the present research is to determine the value of a more productive switchgrass cultivar relative to that of the best-available alternative. An ANOVA model is used to estimate switchgrass biomass production depending on cultivars. The yield estimates are used to calculate the farm-gate production cost for each of the cultivars using standard budgeting methods. Net returns are calculated using observed yield data and an assumed feedstock price since there is currently no market for switchgrass biomass. The empirical distributions of net returns are then used to determine the certainty equivalent for each of nine switchgrass cultivars using stochastic efficiency analysis. The additional monetary value produced by the new cultivar is presented in terms of the potential seed price premium that could be paid for the new cultivar relative to the previously best commercially available cultivar. Sensitivity analysis is conducted to simulate the effect of alternative biomass prices on the seed price premium.

Materials and Methods

Agronomic

Dry matter yield data were produced in a randomized complete block design from switchgrass stands established in June of 2006. The experiment was conducted at the Oklahoma State University agronomy experiment station in Stillwater, OK (36°7.98’ N, 97°6.26’ W). The soil type is a Kirkland silt loam (fine, mixed, superactive, thermic Udertic Paleustolls). Four commercial cultivars and five experimental lines (Table II-1)—three upland and six lowland-were included. Four of the cultivars (Alamo, Blackwell, Kanlow, and Cave-in-Rock) were commercially available at the initiation of the experiment. One lowland cultivar, Cimarron, was released in 2008 during the experiment (Wu and Taliaferro, 2012). The remaining four (NL93-2, NSL 2001-1, NL 94-2001-1, and NSU 95-2001) are experimental lines. The design included four replications for each cultivar. Conventional tillage was used to prepare the seedbed. Five rows spaced at 0.3 m were planted in each 1.5 by 6.1 m plot. Yield estimates were based on harvest of the full 6.1-m length of the three middle rows.

Nitrogen fertilizer was applied in April of each postestablishment year at the beginning of the growing season at a rate of 90 kg ha^{-1}. The stands were harvested once per year, after frost in November, over 4 yr from 2007 to 2010. The plots were harvested on the same date for a given year. Biomass dry matter was recorded after swathing and baling using a John Deere swather (Model 630, John Deere Co.) and John Deere baler (Model 568, John Deere Co.). The total monthly and 30-yr average rainfall on the experiment site is reported in Table II-2.

An ANOVA model is specified using the MIXED procedure in SAS (SAS Institute, 2008). The switchgrass cultivars were treated as a fixed effect and following the propositions by previous studies (Biermacher et al., 2006); a random term was included for the year effect. The complete data generating process for yield estimation from the experiment is as follows:

$$\mathrm{y}_{it} = \alpha_0 + \sum_{i=1}^{8} \beta_i V_{it} + \theta_t + \varepsilon_{it} \tag{1}$$

where y_{it} is the yield of variety i in year t, V_i is variety i, α_0 and β_i are parameters to be estimated, θ_t is the year random effect, ε_{it} and θ_t are independently distributed with means zero and variances σ_ε^2 and σ_θ^2 respectively.

The D'Agostino (D'Agostino et al., 1990) K2 test for normality based on skewness and kurtosis was conducted to examine departure from normality. Additional tests were conducted for heteroskedasticity. The individual and the joint tests proposed by McGuirk et al. (1993) were conducted for constant variance in equation (1) using the estimated residuals.

Economics

A discrete-choice expected-utility-maximization model is presented to conceptualize the decision faced by potential switchgrass producers. The decision maker's objective is to select the cultivar that maximizes his or her expected utility. The expected utility depends on the expected yields, expected yield variability, and the decision maker's tolerance for income variability, which is a proxy for risk preference. The objective function is specified as follows:

$$\max_{V_i} EU(\pi|V_i) = \max\{EU[PY(V_i)] - C_i - FC; i = 1,2,...9\} \tag{2}$$

where $EU(\pi)$ is the expected utility of profit (π); P is the feedstock price (\$ Mg^{-1}); V_i is for variety i where set i includes Alamo, Blackwell, Cave-In-Rock, Cimarron, Kanlow, NL 93-2, NL 94-2001-1, NSL 2001-1, NSU 95-2001-1; $Y(V_i)$ is the expected yield for the variety V_i (Mg ha^{-1}); C_i is the variable cost of producing variety V_i (\$ ha^{-1}); FC is the fixed cost (\$); $U(\pi)$ is a constant absolute risk aversion (CARA) utility function.

Standard enterprise budgets were prepared to produce an estimate of the cost to produce switchgrass biomass at a commercial scale. A budget for the no-till establishment system as described by Griffith et al. (2010) is included in Table II-3. The budget is designed to estimate the cost of establishing switchgrass on either cropland harvested in the fall or on pastureland. A fall application of glyphosate followed by an April application of glyphosate is budgeted to be followed by no-till planting of 5.6 kg ha^{-1} of pure live seed in April. A postemergence herbicide is budgeted for application in the May through June period to target broadleaf weeds. A mowing operation with a rotary mower is budgeted for the June through July period. This mowing activity is intended to clip weeds that extend over the top of the switchgrass before the weeds start to canopy the switchgrass. Clipping the weeds at the top of the switchgrass is designed to ensure that sunlight can reach the young switchgrass plants. The establishment budget also includes the cost of reseeding 25% of the land area. For commercial switchgrass production, it is assumed that successful establishment using a no-till system would require that 25% of the area be seeded twice (Turhollow and Epplin, 2012).

An annual maintenance budget is included in Table II-4. It includes the cost for land rental, fertilizer, fertilizer application, and harvest. The budget is based on the assumption that commercial fields would be harvested once per year. Costs were estimated for mowing, raking, baling, field collection, and stacking. Cost sensitivity with respect to N uptake by each cultivar and experimental line was conducted by budgeting N proportionally to the biomass production. By this measure, it is assumed that a switchgrass cultivar with high yield potential would require more N fertilization than one with lower yield potential.

Data from an historical switchgrass biomass market and historical farm-gate prices for biomass are not available. Literature on switchgrass production economics has reported switchgrass farm-gate production cost that ranges from \$25 to \$97 Mg^{-1} (Epplin, 1996; Hallam et al., 2001; Duffy and Nanhou, 2002; Epplin et al., 2007; Khanna et al., 2008; Mooney et al., 2008; Perrin et al., 2008; Haque et al., 2009; USEPA, 2009a,b; Griffith et al., 2010). These studies present a wide range of farm-gate production cost estimates (Table II-5). Differences in production cost estimates are observed because they have not been adjusted for price inflation; yield assumptions differ across regions; and assumptions regarding field operations required to establish, maintain, and harvest also differ across studies. Based on these cost estimates, three expected farm-gate prices of \$50, \$60, and \$75 Mg^{-1} are used to calculate expected net returns.

Empirical distributions of net returns are used to analyze and compare the risk associated with yield variability for the nine switchgrass cultivars. Net returns are compared using stochastic dominance criteria (Hadar and Russell, 1969) that enables pairwise comparisons of all cultivars. The analysis considers that each observation in the data set is equally likely and that the empirical distribution represents the entire distribution of the outcomes when 90 kg N ha^{-1} are budgeted for each cultivar.

Following Raskin and Cochran (1986), the net returns are analyzed on a per hectare basis. Stochastic dominance analysis was conducted using SIMETAR (Richardson and Feldman, 2005). First degree stochastic dominance (FDD) applies to decision makers with positive marginal utility $(U'(\pi) > 0)$ whose Arrow-Pratt absolute risk aversion parameter, *r*, defined as $r\ (\pi) = -U''(\pi)/U'(\pi)$, ranges from negative infinity to positive infinity $(-\infty < r(\pi) < +\infty)$ (Pratt, 1964; Arrow, 1971; King and Robison, 1984). A risky alternative, $f(\pi)$, with cumulative distribution function $F(\pi)$ is preferred to another risky alternative, $g(\pi)$, with cumulative distribution function $G(\pi)$ by FDD, if and only if $F(\pi) \le G(\pi) \forall \pi$ (Hadar and Russell, 1969). In other words, switchgrass varieties that are included in the FDD set would be preferred to varieties not included in the FDD set by producers who have positive marginal utility and whose absolute risk aversion coefficient ranges from negative infinity to positive infinity.

For second degree stochastic dominance (SDD), a strategy $f(\pi)$ is preferred to another alternative strategy $g(\pi)$ if the area under the CDF curve of $g(\pi)$ is greater than the area under the CDF curve of $f(\pi)$ at all level of π. This means that the two distributions can cross each other (Chavas, 2004, p. 57) and we have:

$$\int_{-\infty}^{\pi} F(\pi)d\pi \le \int_{-\infty}^{\pi} G(\pi)d\pi \qquad (3)$$

for all π (King and Robison, 1984; Chavas, 2004, p. 57). Additionally SDD assumes that the decision maker is risk averse with positive and decreasing marginal utility $(U''(\pi) < 0)$ and with a positive absolute risk aversion coefficient $0 < r(\pi) < +\infty$ (Brown, 1987; Hardaker et al., 2004).

Stochastic efficiency with respect to a function, assumes that the upper and lower bounds of the risk aversion parameter are known:

$$r_L(\pi) \le -U''(\pi)/U'(\pi) \le r_U(\pi) \qquad (4)$$

and that the decision maker's utility function is invertible over the range of the absolute or relative risk aversion coefficient (Hardaker et al., 2004). In the present study, stochastic efficiency with respect to a function analysis is conducted assuming a negative exponential utility function that exhibits constant absolute risk aversion. The utility function may be specified as:

$$U(\pi) = 1 - e^{-r\pi} \qquad (5)$$

where $U(\pi)$ is the utility of profit, π, and r is the Arrow-Pratt absolute risk aversion parameter (Pratt, 1964; Arrow, 1971).

Specific values of risk-aversion parameters for switchgrass production are not documented. Because switchgrass is a perennial and is expected to be produced on marginal cropland or pastureland (Haque and Epplin, 2012), risk-aversion parameter intervals commonly applied to monocultures are used (Epplin et al., 1993). The lower and upper limits of the absolute risk-aversion coefficient are calculated using an average whole-farm net worth as an approximation of producer's wealth. The risk-aversion coefficient range was determined following Hardaker et al. (2004) and Anderson and Dillon (1992) by dividing 0.5 and 4 by the average farm net worth per ha. The numbers 0.5 and 4 are the lower and the upper bounds of the risk-aversion coefficient suggested by Anderson and Dillon (1992) for a slightly risk-averse and a strongly risk-averse producer, respectively.

Whole-farm net worth data are not available for Oklahoma but are available for a sample of farms in the adjacent state of Kansas. The Kansas Farm Management Association reported an average net worth of $1,697,363 in December 2013, with an average crop area of 613.9 ha from their sample of 1194 farms (Kansas Farm Management Association, 2014). By this measure, the average net worth is $2,765 ha^{-1}. Dividing 0.5 and 4 by the average farm net worth per ha, as recommended by Hardaker et al. (2004) and Anderson and Dillon (1992), lower and upper limits for the risk-aversion coefficient would be approximately equivalent to $r(\pi) = 0.0002$ and $r(\pi) = 0.001$. The certainty equivalent that represents the amount of money a risk-averse producer is willing to be paid to be indifferent between a cultivar with a lower expected income and one with a greater expected income is calculated for slightly [$r(\pi) = 0.0002$], moderately [$r(\pi) = 0.0005$],and strongly ($r(\pi) = 0.001$) risk averse producers with SIMETAR (Richardson and Feldman, 2005).

To determine the value of a new or experimental cultivar relative to the best-established cultivar, the difference in value of certainty equivalents between the two can be determined and discounted over the life span of the switchgrass stand. The discounted annual difference in certainty equivalent between the two cultivars can be used to determine the seed premium measured, for example, in dollars per kilogram, at which a potential grower would be indifferent between planting the new cultivar and the next best commercially available alternative.

Results

Agronomic

The ANOVA model in Eq. [1] was used to estimate expected yield for each of the nine switchgrass cultivars. The normality test in Eq. [1] indicated that the null hypothesis of normality cannot be rejected at the 5% significance level. However, the test for heteroskedasticity found that the null hypothesis of homoskedastic residuals was rejected at the 5% significance level. The SAS PROC MIXED repeated option was used to correct for the unequal variance of residuals. Yield estimation results found that the six lowland cultivars produced, on average, a significantly greater yield ($P < 0.0001$) than Cave-in-Rock, which produced the lowest yield amongst the nine cultivars. On average, the yield of Cimarron (2008 release) was 9.3 Mg ha^{-1} greater than the yield of Cave-in-Rock (Table II-6). Alamo and Kanlow yielded 6.1 and 5.6 Mg ha^{-1} of feedstock more than Cave-in-Rock, respectively (Table II-6).

Least squares mean estimates from the model show that among the lowland cultivars, Cimarron produced the greatest yield at 19.8 Mg ha^{-1} ($P < 0.001$). Cimarron is followed by NSL 2001-1 with an average yield of 18.7 Mg ha^{-1} (Table II-6). In general, the higher yields of the lowland cultivars were associated with higher variance. The three upland cultivars, Cave-in-Rock, NSU 95-2001-1, and Blackwell, produced mean yields of 10.5, 11.2, and 11.7 Mg ha^{-1}, respectively (Table II-6). There was not a significant difference between the means of the three upland cultivars (Table II-6).

Observed yields were significantly different between Cimarron and Kanlow and Alamo (Table II-6). The differences in yield between Cimarron and NSL 2001-1 and NL 94-2001-1 were not statistically significant at 5% (Table II-6). There were also no significant yield differences between NSL-2001, NL 94-2001-1, NL 93-2, Alamo, and Kanlow (Table II-6). The overall *F*-test indicated that the yield variation explained by the cultivars is statistically significant at the 1% level. Table II-6 presents also the annual average yield for each cultivar over the 4 yr of the experiment. In all years, Cimarron produced greater yield than all the commercially available cultivars. For Cimarron, the annual average yield ranged from 14.25 Mg ha^{-1} in 2008 to 26.25 Mg ha^{-1} in 2007. The annual average yield of Alamo ranged from 11.50 Mg ha^{-1} in 2008 to 23.25 Mg ha^{-1} in 2007. For all cultivars, the yield was greater in 2007 and lower in 2008. The results corroborate that upland cultivars do not produce as much biomass as lowland cultivars in the southern plains (Table II-6). The results are also consistent with those of Alexopoulou et al. (2008) who found that lowland cultivars produced more biomass than upland cultivars in the Mediterranean region.

Economics

Farm-gate production costs were calculated for each of the nine cultivars using budgeting methods. Cimarron produced the greatest yield and lowest production cost per metric ton. The production cost was estimated at $42.30 Mg^{-1} for Cimarron (Table II-7). The greatest production cost was obtained with Cave-in-Rock at $59.21 Mg^{-1} (Table II-7). The difference in production cost was statistically significant between Cimarron and the three other commercially available upland cultivars. The production cost was estimated at $55.16 Mg^{-1} for Blackwell and $55.73 Mg^{-1} for NSU 95-2001-1 (Table II-7). Adjusting N fertilization rates reduces the production cost for the low-yielding cultivars. For example, the feedstock production cost of Cave-in-Rock decreases from $59.21 Mg^{-1}, when the same N rate (90 kg N ha^{-1}) is budgeted for all the cultivars, to $53.70 Mg^{-1} when N cost is proportional to the biomass production (Table II-7). For Blackwell, the production cost decreases by 7% from \$55 Mg^{-1} (with a constant N rate) to \$51 Mg^{-1} (when variable N rates are assumed) (Table II-7).

Estimated production costs were 9, 10 and 40% lower for Cimarron than for Alamo, Kanlow and Cave-in-Rock, respectively (Table II-7). When variable N rates are assumed, depending on the quantity of biomass produced, the difference in production cost across cultivars is reduced. The production cost for Cimarron is 6 and 22% lower than for Kanlow and Cave-in-Rock, respectively, when N cost is adjusted (Table II-7).

The difference in production cost follows from the assumption that several cost components, such as baling costs, are incurred on a per-ton basis. Hence, any differences in harvestable yield will result in differences in total cost (Griffith et al., 2010; Turhollow and Epplin, 2012). These production cost estimates are consistent with previous studies. Griffith et al. (2010) reported farm-gate production cost and breakeven price between \$47 and \$88 Mg^{-1}. Haque et al. (2009) found production cost that ranges from \$39 to \$52 Mg^{-1} with one postsenescence harvest.

For the purpose of economic analysis, three farm-gate feedstock price scenarios of \$50, \$60 and \$75 Mg^{-1} are considered. These prices are based on the range of expected production costs reported in literature and on the expectation that the farm-gate price of switchgrass would have to be sufficient to at least cover production costs to entice production. For equivalent seed price and establishment costs, estimated net returns range from \$373 ha^{-1} for Cimarron to \$36 ha^{-1} for Cave-in-Rock when a feedstock price of \$60 Mg^{-1} is assumed (Table II-7). With a price of \$50 Mg^{-1}, the net returns were estimated at \$175 ha^{-1} for Cimarron and -\$69 ha^{-1} for Cave-in-Rock. With the \$50 Mg^{-1} price scenario, all the upland cultivars would result in negative expected net returns. If the feedstock price is \$75 Mg^{-1}, the average net returns range from \$668 ha^{-1} for Cimarron to \$193 for Cave-in-Rock (Table II-7).

Alamo and Kanlow provided net returns of \$262 and \$240 ha^{-1}, respectively, when the feedstock price is \$60 Mg^{-1} (Table II-7). With a feedstock price of \$50 Mg^{-1}, the two cultivars' respective net returns are \$96 and \$79 ha^{-1}. At the higher price of \$75 Mg^{-1}, Alamo and Kanlow generated expected net returns of \$512 and \$481 ha^{-1}, respectively. The net returns with Alamo are 23 to 46% lower than the net returns with Cimarron across the three feedstock price scenarios. When the price of switchgrass feedstock is assumed to be \$60 Mg^{-1}, the net-return difference between Cimarron and Alamo is \$110 ha^{-1}. For a feedstock price of \$50 Mg^{-1}, the net return difference between the two cultivars is \$80 ha^{-1}. At the higher price of \$75 Mg^{-1} the net return difference between Alamo and Cimarron is estimated at \$155 ha^{-1}.

Risk Analysis

The CDF of net returns are evaluated for the three feedstock price scenarios using stochastic efficiency criteria to assess the yield risk implication with respect to producer's risk aversion. Stochastic dominance pairwise comparisons show that Cimarron dominated all commercially available cultivars by the FDD (Table II-8). By this measure, producers would prefer Cimarron to any of the commercially available cultivars (Alamo, Blackwell, Cave-in-Rock, and Kanlow) regardless of their tolerance for risk. Figures II-1 through II-3 show the CDFs for Alamo, Cave-in-Rock, and Cimarron with three feedstock price scenarios.

Cimarron is the unique cultivar in the SDD efficient set. Cimarron was the least risky alternative when compared to the other cultivars. The SDD analysis established a complete ranking of the nine cultivars (Table II-8). The upland cultivars are not members of the SDD efficient set. Since Cimarron dominates all other cultivars by either FDD or SDD, it is not necessary to use stochastic efficiency with respect to a function (SERF) to discriminate among cultivars. However, SERF criteria were used to determine the certainty equivalent for each of the nine cultivars for the three feedstock prices at different risk-aversion levels. Table II-9 summarizes certainty equivalent values for each of the nine switchgrass cultivars with different feedstock prices. The certainty equivalent is higher for Cimarron, and the second-best commercially available cultivar after Cimarron is Alamo at all feedstock prices and at all risk-aversion preferences. The three upland cultivars have the lowest certainty equivalent values among the nine cultivars.

For a feedstock price of \$50 Mg^{-1}, the certainly equivalent of a slightly risk-averse producer is \$174 ha^{-1} for Cimarron and \$94 ha^{-1} for Alamo. If the farm-gate biomass price is \$60 Mg^{-1}, the certainty equivalent is \$369 ha^{-1} for Cimarron and \$259 ha^{-1} for Alamo for a slightly risk-averse producer (Table II-9). For a higher feedstock price of \$75 Mg^{-1}, the certainty equivalent of a slightly risk-averse producer is \$661 ha^{-1} for Cimarron and \$505 ha^{-1} for Alamo. The difference in certainty equivalent between Cimarron and Alamo is larger at lower feedstock prices. For the \$50 Mg^{-1} feedstock price, the certainty equivalent with Cimarron (\$174 Mg^{-1}) is 85% greater than that for Alamo (\$94 Mg^{-1}).

For strongly risk-averse producers, as expected, the certainty equivalent is lower compared to the certainty equivalent of a slightly risk-averse producer (Table II-9). This fall in certainty equivalent is more noticeable at higher feedstock prices. For a feedstock price of \$50 Mg^{-1}, the decrease in certainty equivalent of a strongly risk-averse producer is between 3 and 9% for all nine cultivars. With a price of \$60 Mg^{-1}, the average fall in certainty equivalent is between 3 and 11% compared with the slightly risk-averse producers' certainty equivalent (Table II-9). The highest drop in certainty equivalent between the strongly risk-averse and the moderately risk-averse producers is observed for Cave-in-Rock for the feedstock price of \$60 Mg^{-1}.

The difference in certainty equivalent between Cimarron and Alamo is constant across risk-aversion levels for a given feedstock price. For a slightly risk-averse producer the expected difference in certainty equivalent between Cimarron and Alamo is \$80, \$110, and \$156 ha^{-1} for expected feedstock prices of \$50, \$60, and \$75 Mg^{-1}, respectively. With the assumption that the same cultivars would maintain their yield performance over the life of the switchgrass stands, the difference in certainty equivalent between Cimarron and Alamo, the second-best commercially available cultivar, is discounted over 10 yr (assuming zero production in the establishment year) for a seeding rate of 5.6 kg seed ha^{-1} and a reseeding rate of 1.4 kg seed ha^{-1}.

Assuming a year for establishment, nine postestablishment production years, a farm-gate biomass price of \$50 Mg^{-1}, and a discount rate of 6.5%, the net present value of seeding a field to Cimarron rather than Alamo would be \$501 ha^{-1} for a slightly risk-averse producer. This value is equivalent to \$72 kg^{-1} of pure live seed when the net present value is discounted over the expected 10 yr life span of the switchgrass stand.

This value is the seed price premium per kg of seed at which the grower with the specific level of risk aversion $r(\pi) = 0.0002$, would be indifferent between seeding Cimarron and seeding Alamo. Of course, not all of these gains would flow to the producers. If the cultivar is protected and patented, some may be captured by the seed developer (Vitale et al., 2010). Some would be required to compensate seed producers, distributors, and merchandizers (Akino and Hayami, 1975; Shiferaw et al., 2008). The price at each level in the seed development, production, and marketing chain would be subject to bargaining. In the absence of a market for biomass, it is difficult to forecast the proportion of benefits that would flow to each sector. The estimated value is sensitive to the farm-gate biomass price. An increase in the biomass price from \$50 to \$75 Mg^{-1}, increases the added value of the improved seed by 94% from \$72 to \$139 kg^{-1}. However, this value is only forthcoming if a market for lignocellulosic biomass develops and then only if switchgrass is an economically competitive feedstock. The value of cultivar development programs depends critically on the value of the products produced by the species and on the yield gain and other benefits attributable to the new cultivar.

Conclusions

The objective of the present study was to determine the value of a more productive switchgrass cultivar relative to that of the best-available alternative cultivar for planting in the US southern plains. When averaged over the 4 yr of the study, Cimarron (which was released in 2008, during the experiment) produced 19% more biomass than Alamo, which is the best commercially available cultivar in the region. The average yield was 19.7 Mg ha^{-1} for Cimarron over the 4-yr period. The ANOVA model confirmed a significant difference in mean yield between the upland and the lowland cultivars. For the region of the study, Cimarron produced more biomass and dominated all the commercially available cultivars by FDD. This means that if the seed price is the same for all cultivars, producers could be expected to plant Cimarron regardless of their tolerance for risk. The value of planting Cimarron rather than Alamo is estimated at \$75 kg^{-1} of seed for a slightly risk-averse producer with a feedstock price of \$50 Mg^{-1}. The present study included data from one location. Extending the study with data from additional locations would be required to confirm the findings. The present study assumes also that the observed 4-yr average yield would be maintained over the life of the switchgrass stands.

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Table II-1. Ecotype and Origin for Nine Switchgrass Commercial and Experimental Cultivars

Cultivar	Origin	Ecotype	Source of Release
Alamo	Frio River (south-central Texas)	Lowland	USDA–NRCS–PMC, Knox City, TX
Blackwell	Blackwell (north-central Oklahoma)	Upland	USDA–NRCS–PMC, Manhattan, KS
Kanlow	Wetumka (east-central Oklahoma)	Lowland	USDA–NRCS–PMC, Manhattan, KS
Cave-in-Rock	Cave-in-Rock (southern Illinois)	Upland	USDA–NRCS–PMC, Elsberry, MO
Cimarron	Oklahoma	Lowland	Oklahoma State University
NL94 2001-1	Oklahoma	Lowland	Not released
NSL 2001-1	Oklahoma	Lowland	Not released
NL 93-2	Oklahoma	Lowland	Not released
NSU95 2001-1	Oklahoma	Upland	Not released

Source: Kaiser and Bruckerhoff, 2009; Wilson, 2011; and Sripathi et al. 2013.

Table II-2. Monthly Precipitation at Stillwater, OK, from 2006 to 2010 and 30-Yr Average (1971–2000)

Month	2006	2007	2008	2009	2010	30-Yr Average
	cm					
January	1.8	3.4	1.4	0.4	2.6	3.3
February	0.2	1.1	6.6	5.3	6.8	4.1
March	4.7	13.9	10.5	9.2	4.2	8.2
April	13.1	10.5	14.6	12.9	9.2	8.8
May	8.5	26.5	16.2	8.3	18.1	13.7
June	6.1	42.5	12.5	4.4	13.9	11.0
July	8.0	17.8	12.7	12.6	11.2	6.8
August	6.1	3.3	3.4	19.1	6.4	7.7
September	3.4	11.7	4.2	7.8	7.1	10.5
October	4.0	8.4	5.3	18.4	4.4	8.2
November	3.1	2.2	6.5	3.9	4.9	6.5
December	7.1	2.7	2.3	1.4	1.3	4.4

Source: http://www.mesonet.org/index.php/weather/monthly_rainfall_table/stil and http://ggweather.com/normals/OK71.htm (accessed 7 Feb. 2015)

Table II-3. Switchgrass Establishment Budget Using No-Till Practice for Oklahoma Conditions[†]

Item	Unit	Price per Unit	Quantity	Value
Land rental	ha	111.15	1	111.15
Switchgrass seed	kg	33.07	5.6	185.19
Planting	ha	33.10	1	33.10
Reseeding (seed)[‡]	kg	33.07	1.4	46.30
Replanting	ha	33.10	0.25	8.28
DAP (18-46-0)[§]	kg	0.74	48.2	35.86
Fertilizer application	ha	5.97	1	5.97
Herbicide (glyphosate)	kg	8.11	1.26	10.22
Herbicide (broadleaf, post emergence)	ha	11.12	1	11.12
Herbicide application	ha	12.20	2	24.40
Rotary mower	ha	8.65	1	8.65
Annual operating capital	$	5%	480.4	24.01
Total cash costs	ha			504.25
Establishment amortized over 10 yr	$	0.065		70.14

[†] Adopted from Turhollow and Epplin (2012) for no-till establishment.

[‡] For commercial switchgrass production, it is assumed that successful establishment using a no-till system would require that 25% of the area be seeded twice (Turhollow and Epplin, 2012).

[§] Depending on soil test result, the application of DAP (diammonium phosphate) may or may not be recommended. The budgeted DAP application includes 8.7 kg of N ha^{-1} and 22.2 kg ha^{-1} of P_2O_5. The budget is based on the assumption that soil pH is within an appropriate range to support switchgrass production and that K levels in the soil would be sufficient, as is the case across most of Oklahoma.

Table II-4. Established Switchgrass Stand Maintenance and Harvest Budget for Oklahoma Conditions (ha)

Item	Unit	Price per Unit	Quantity	Value
Land rental	ha	197.6	1	111.15
Urea (46-0-0)[†]	kg	0.57	variable[‡]	variable
Fertilizer application	ha	5.97	1	5.97
Mowing[§]	ha	30.97	1	30.97
Raking	ha	18.89	1	18.89
Baling (round bales, 624 kg)	Mg	22.29	variable	variable
Twine or wrapping	Mg	3.31	variable	variable
Field collection and staking	Mg	5.54	variable	variable
Annual operating capital	$	5%	variable	variable
Total cash cost	ha			variable

[†] The price of urea is assumed to be \$0.57 kg^{-1}. This price is equivalent to \$1.23 kg^{-1} of actual N.

[‡] Variable indicates that the quantity depends on the yield. For the purpose of computing estimates of production costs over time, the base rate of 90 kg ha^{-1} y^{-1} of actual N as applied during the experiment was adjusted based on relative yield potential.

[§] Harvest operations are scheduled to occur after a frost event in October or November.

Table II-5. Switchgrass Farm-Gate Production Cost Estimates

Study	Yield Range[†]	State or Region	Estimated Cost
	Mg ha^{-1}		\$ Mg^{-1}
Epplin (1996)	7–11	Oklahoma	25.28–32.17
Hallam et al. (2001)	11.13–11.60	Iowa	38.90–47.65
Duffy and Nanhou (2002)	3.71–14.83	Southern Iowa	59.42–66.15
Epplin et al. (2007)	8.4–14.6	Oklahoma	41–58
Khanna et al. (2008)	6.4	Illinois	90
Mooney et al. (2008)	6.84–23.47	Western Tennessee	42.22–80.14
Perrin et al. (2008)	5.0	North Dakota, Nebraska, South Dakota	60
Haque et al. (2009)	8.3–13.8	Oklahoma	39–51
USEPA (2009a,b)	13.8	Tennessee	49
Griffith et al. (2010)	2.2–6.60	Oklahoma	81–97

[†] Yield and field operation assumptions differed across studies. Cost estimates have not been adjusted for inflation.

Table II-6. Least Squares Mean Estimates and Observed Annual Average Yield for Nine Switchgrass Cultivars Grown at Stillwater, OK (Mg ha^{-1})

Cultivar	Estimate[†]	Year Average			
		2007	2008	2009	2010
Cimarron	19.83^{a‡}	26.25	14.25	16.50	22.00
NSL 2001-1	18.71^{ab}	24.25	13.50	17.75	19.50
NL 94-2001-1	18.08^{ab}	22.75	13.25	16.50	20.00
NL 93-2	17.66^{ab}	24.25	11.25	16.25	19.25
Alamo	16.64^{b}	23.25	11.50	13.25	18.00
Kanlow	16.11^{b}	21.25	10.75	14.50	17.75
Blackwell	11.68^{c}	11.25	8.50	11.25	15.50
NSU 95-2001-1	11.17^{c}	12.00	9.25	10.00	13.25
Cave-in-Rock	10.53^{c}	11.75	8.00	8.50	13.75

[†] The dependent variable is yield (Mg ha^{-1}).

[‡] Means with the same letter are not significantly different at 5% level of probability

Table II-7. Production Cost and Net Returns for Nine Switchgrass Cultivars Grown at Stillwater, OK, with three Feedstock Prices Scenarios

Cultivar	Production Cost when N Cost is Based on 90 kg N ha^{-1}[†]	Production Cost when N Cost is Assumed to Differ with Yield[‡]	Net Returns[§] Feedstock Price Scenario		
			\$50 Mg^{-1}	\$60 Mg^{-1}	\$75 Mg^{-1}
	——\$ Mg^{-1}——		——\$ ha^{-1}——		
Cimarron	42	42	176	373	668
NSL 2001-1	43	43	150	337	618
NL 94-2001-1	44	43	132	313	584
NL 93-2	45	44	122	298	563
Alamo	46	45	96	262	512
Kanlow	47	45	79	240	481
Blackwell	55	51	−38	79	254
NSU 95-2001-1	56	51	−51	61	228
Cave-in-Rock	59	54	−69	36	193

[†] The budgeted cost includes establishment, land lease, maintenance, harvest costs, and the associated interest on operating capital.

[‡] It is assumed that Cimarron, which has the highest expected yield, receives 90 kg N ha^{-1}. For the other cultivars, N cost was adjusted proportionally to their expected yield difference compared to Cimarron. By this measure, N cost for Cave-in-Rock is based on a rate of 48 kg N ha^{-1}.

[§] These net returns are based on the assumption that a rate of 90 kg N ha^{-1} is applied across all cultivars.

Table II-8. Stochastic Dominance Findings for Nine Switchgrass Cultivars Grown at Stillwater, OK, with a Farm-Gate Biomass Price of \$50 Mg^{-1}

Cultivar	Alamo	Blackwell	Cave-in-Rock	Cimarron	Kanlow	NL 93-2	NL 94-2001-1	NSL 2001-1	NSU 95-2001-1
First-degree stochastic dominance (FDD)									
Alamo		FDD[†]	FDD						FDD
Blackwell									
Cimarron[‡]	FDD	FDD	FDD		FDD				FDD
Kanlow		FDD	FDD						FDD
NL 93-2		FDD	FDD		FDD				FDD
NL 94-2001-1		FDD	FDD		FDD				FDD
NSL 2001-1	FDD	FDD	FDD		FDD	FDD			FDD
NSU 95-2001									
Second-degree stochastic dominance (SDD)									
Alamo		SDD	SDD		SDD[§]				SDD
Blackwell			SDD						SDD
Cave-in-Rock									
Cimarron[‡]	SDD	SDD	SDD		SDD	SDD	SDD	SDD	SDD
Kanlow		SDD	SDD						SDD
NL 93-2	SDD	SDD	SDD		SDD				SDD
NL 94-2001-1	SDD	SDD	SDD		SDD	SDD			SDD
NSL 2001-1	SDD	SDD	SDD		SDD	SDD	SDD		SDD
NSU 95-2001			SDD						

[†] Alamo dominates Blackwell by FDD. Alamo would be preferred to Blackwell by decision makers who have positive marginal utility of income.

[‡] Cimarron dominates NL 93-2, NL 94-2001-1, and NSL 2001-1 by SDD and all other cultivars by FDD.

[§] Alamo dominates Kanlow by SDD but not by FDD. Alamo would be preferred to Kanlow by decision makers who have positive marginal utility of income and who are risk averse.

Table II-9. Certainty Equivalents for Nine Switchgrass Cultivars Grown at Stillwater, OK

Cultivar	Feedstock Price Scenario								
	$\$50\ \mathrm{Mg}^{-1}$			$\$60\ \mathrm{Mg}^{-1}$			$\$75\ \mathrm{Mg}^{-1}$		
	Risk Aversion[†]			Risk Aversion			Risk Aversion		
	Low	Moderate	Strong	Low	Moderate	Strong	Low	Moderate	Strong
	$\$\mathrm{ha}^{-1}$								
Cimarron	174[‡]	171	167	369	364	356	661	652	635
NL 94-2001-1	131	129	126	311	307	302	579	572	561
NL 93-2	120	118	113	295	290	283	557	547	532
Alamo	94	91	86	259	253	245	505	495	478
Kanlow	78	76	73	238	234	228	476	469	457
Blackwell	-38	-39	-41	78	76	73	251	248	242
NSU 95-2001-1	-51	-52	-53	60	59	58	227	225	222
Cave-in-Rock	-70	-71	-72	35	33	31	191	188	183

[†] The risk-aversion parameter $r(\pi)$ is equal to 0.0002, 0.0005, and 0.001 for the low, the moderate, and the strong risk aversion, respectively.

[‡] Certainty equivalents are calculated assuming constant absolute risk aversion.

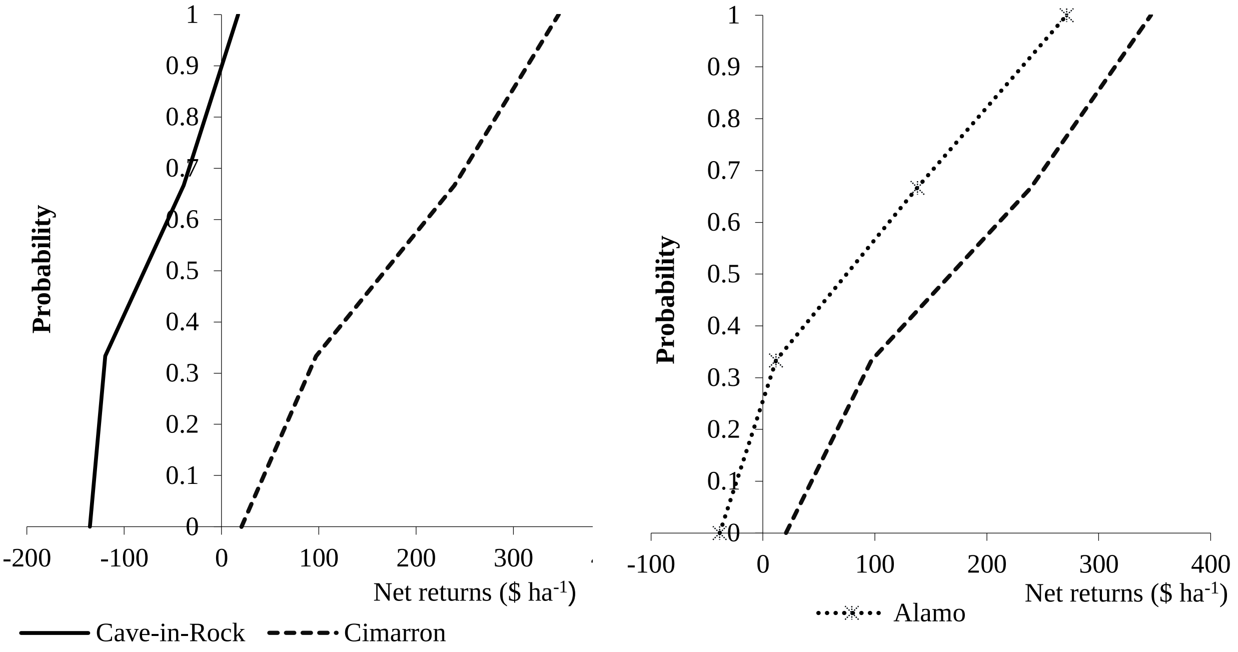

Figure II-1. Cumulative distribution functions of net returns for Cimarron, Alamo, and Cave-In-Rock for a feedstock price of $50 Mg^{-1}

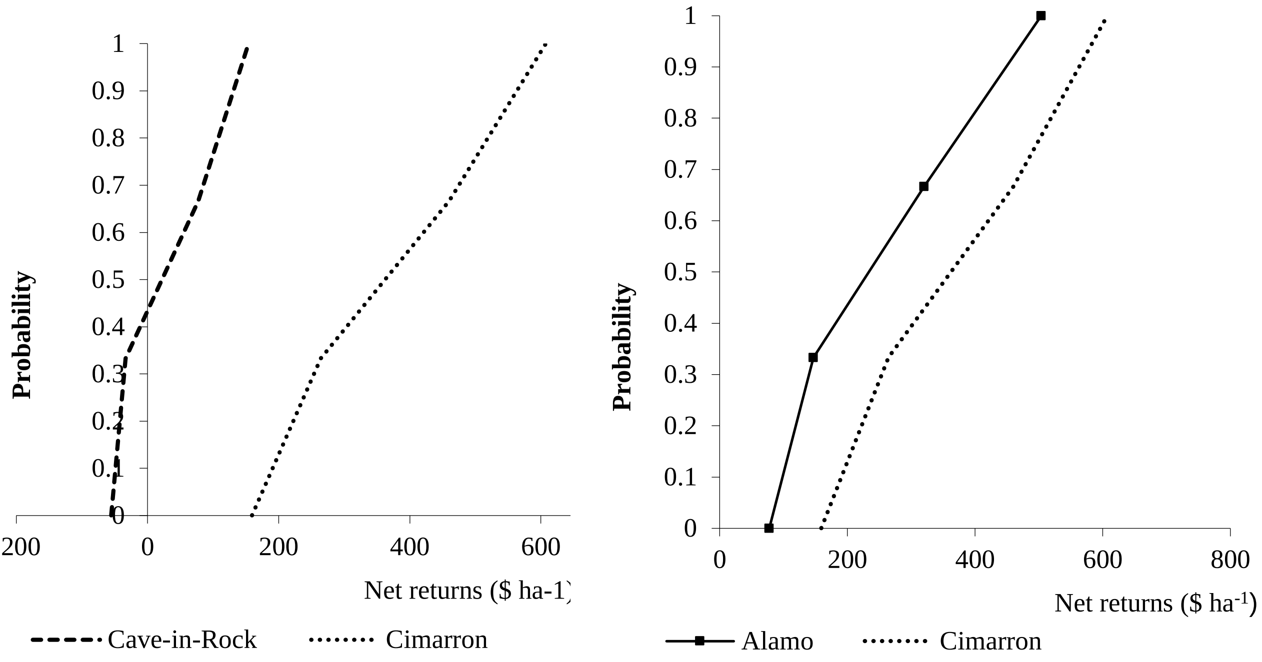

Figure II-2. Cumulative distribution functions of net returns for Cimarron, Alamo, and Cave-In-Rock for a feedstock price of \$60 Mg^{-1}

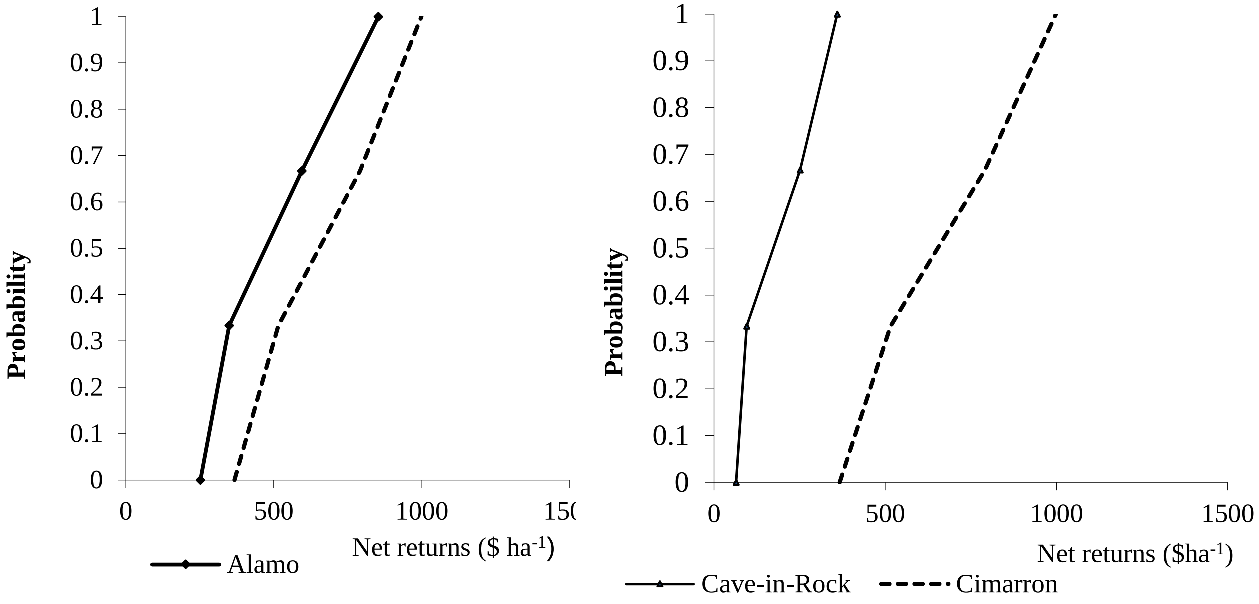

Figure II-3. Cumulative distribution functions of net returns for Cimarron, Alamo, and Cave-In-Rock for a feedstock price of \$75 Mg^{-1}

CHAPTER III

RESTRICTING SECOND-GENERATION ENERGY CROP PRODUCTION TO MARGINAL LAND

Abstract

Production of switchgrass as a dedicated energy crop in the U.S. was proposed as a way to produce valuable products on millions of hectares that had been bid from traditional crop production by a variety of federal programs. The objective of the present study is to determine the expected economic consequences in terms of cost to deliver biomass feedstock, from restricting switchgrass production to marginal land for a case study region, when (a) land use is restricted to class IV; (b) land use is restricted to classes III and IV; and (c) use of land capability classes I, II, III, and IV is permitted. A hypothetical biorefinery with a processing capacity of 2,000 Mg/day is assumed with switchgrass as the single biomass source. Soils and weather data were used in combination with crop management data to simulate switchgrass yields for each land capability class, for 50 years, for each of 30 Oklahoma counties. Land opportunity cost required to bid land from current use for each land capability class and each county were simulated based on the 2013 revealed county average CRP rental rates adjusted across capability class by relative productivity. A mathematical programming model was

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constructed and solved to determine the optimal quantity, location, and quality of the land leased. For the case study region restricting land use to only capability class IV increases the land requirement by 54% and increases the cost to deliver feedstock by 29% compared to when switchgrass production is permitted on land classes I-IV.

Key words: marginal land; EPIC; land capability class; switchgrass; biorefinery

Introduction

In 1978 more than 25 million acres of U.S. cropland were classified as idle as a result of various federal programs including the feed grain, wheat, and cotton commodity programs (Lubowski et al., 2006). In 1985 Hanson (p. 74) noted "…Recognition of the increasing prospect of current excess capacity in U.S. agriculture provides an additional reason for agricultural economists to reconsider the potential of ethanol production as a strategy to improve farm incomes and lower agricultural surpluses…" Idling of "excess" cropland by federal policy was continued in the 1985 legislation that established the Conservation Reserve Program (CRP). By September of 2006, the U.S. government was leasing 36 million acres of cropland from landowners for an annual payment of $1.76 billion (USDA FSA, 2007).

Early proponents of developing dedicated energy crops such as switchgrass, envisioned the production of these crops on "excess" and idle land. Rather than transferring billions of dollars from taxpayers to landowners for land idling programs, it was hypothesized that the land could be put to productive use by growing dedicated energy crops to produce feedstocks that could be substituted for hydrocarbon alternatives (McLaughlin et al., 1999). Development of dedicated energy crops such as switchgrass was envisioned as a way to mitigate the "excess capacity" problem. "…The rationale for developing lignocellulosic crops for energy is that …poorer quality land can be used for these crops, thereby avoiding competition with food production on better quality land…" (McLaughlin et al., 1999). In a highly aggregated study, Perlack et al. (2005) concluded that more than 50 million U.S. acres of low quality land could be converted for biomass production with minimal effects on food, feed, and fiber production (Perlack et al., 2005). They did not address the logistical issues associated with bidding the land from existing use, or the issues related to harvesting and transporting a flow of biomass throughout the year from the land to biorefineries.

In May of 2006, Michael Pacheco, Director, U.S. Department of Energy, National Bioenergy Center, National Renewable Energy Laboratory, testified before a U.S. Senate committee that "…Our goal is to reduce the cost of producing cellulosic ethanol from $2.25 a gallon in 2005, to $1.07 in 2012..." (Pacheco, 2006). In light of the testimony and in anticipation of an economically viable feedstock production and conversion system, the U.S. Energy Independence and Security Act (EISA) of 2007 was passed by Congress and signed by President Bush. It included a provision to mandate that by 2022, if produced, 16 billion gallons of cellulosic biofuels, primarily cellulosic ethanol, be used (U.S. Congress, 2007). The EISA also includes propositions to enable the development of cellulosic biofuels from biomass produced by native prairie grasses including switchgrass.

A year after the 2007 EISA legislation was signed, Fargione et al. (2008) concluded that "…biofuels made …from biomass grown on degraded and abandoned agricultural lands planted with perennials incur little or no carbon debt and can offer immediate and sustained greenhouse gas advantages…" However, Searchinger et al. (2008) reported that using land to produce a dedicated energy crop would result in land use changes with negative environmental consequences. They wrote that "…Biofuels from switchgrass, if grown on U.S. corn lands, increase (greenhouse gas) emissions by 50%..." (Searchinger et al., 2008). Estimates of the global environmental consequences of producing a dedicated energy crop, especially when evaluating indirect land use, vary considerably depending on the models and assumptions used to produce the estimates (Broch et al., 2013). The environmental consequences of establishing monoculture switchgrass on policy-idled CRP lands would be substantially less than those from bidding millions of U.S. acres from a corn-soybean rotation. The former is not likely to induce land use changes elsewhere on the planet. The expected net environmental consequences of substituting biofuels for hydrocarbons when the biofuels are produced from biomass grown on previously policy-idled lands would be positive. However, if land previously used to produce crops is converted to the production of switchgrass, land use changes may be induced such that the aggregate environmental impacts are ambiguous.

Perhaps in recognition of the original intent of developing dedicated energy crops, researchers have attempted to evaluate the production of switchgrass on marginal lands similar to those enrolled in the CRP (Mapemba et al., 2007; Gopalakrishnan, Negri and Snyder, 2011; Kang et al., 2013; Lewis and Kelly, 2014). However, in most studies, what constitutes marginal lands is not clearly defined (Richards et al., 2014).

The concept of marginality relative to land appeared in the economic literature as early as 1817 by Ricardo (1817) who used the concept to describe land rent theory. After Ricardo, the concept of marginal land was used by economists to develop marginal productivity theory (Grieve, 2012). Peterson and Galbraith (1932), for example, reported the major variables that can be associated with marginal land. They described marginal land as land that possesses undesirable characteristics such as irregularity of parcel shape and size or inaccessibility.

In the 1960s, the definition of marginal land took a geospatial characteristic with the use of spatial data to map land capability classes (Bibby and Mackney, 1969). By the 1980s, researchers started to physically map soils with production restrictions for the purpose of removing risky and unproductive land from agricultural production (Larson, Roloff and Larson, 1988).

Even though the term “marginal land” is frequently used in discussions of dedicated energy crop production, no consistent working definition has been established (Lewis and Kelly, 2014). Richards et al. (2014) identified 51 studies published between 2008 and 2012 that included the term “marginal land(s)” and/or “marginal soil(s)”. Only half provided a clear definition of “marginal”. They found that in most of the papers the term “marginal” was subjectively defined. In the extreme case, the word “marginal” appeared only in the paper’s title. Clearly, ambiguity arises over the classification of marginal lands.

A more consistent definition of marginal land would enable enhanced communication especially for comparison across studies. The USDA’s Soil Conservation Service developed a land capability classification system that they introduced in 1939 (Norton, 1939). Soils are categorized into eight soil capability classes. Class I soils have slight limitations, and class II soils have moderate limitations for crop production. Class III soils have severe limitations that reduce the choice of plants and/or require special conservation practices. Class IV soils have very severe limitations that restrict the choice of plants and/or require very careful management (USDA Soil Conservation Service, 1961). Economically viable production of a dedicated energy crop such as switchgrass would be difficult on most soils in classes V-VIII.

Thus, for purposes of second-generation energy crop production, either class IV or classes III and IV could be defined as marginal relative to classes I and II.

The objective of the present study is to determine the expected economic consequences in terms of cost to deliver a flow of biomass feedstock from restricting switchgrass production to marginal land for a case study region of 30 Oklahoma counties, when (a) land use is restricted to class IV; (b) land use is restricted to classes III and IV; and (c) use of land capability classes I, II, III, and IV is permitted. Specifically, the study seeks to determine the cost to produce, harvest and deliver a flow of feedstock to a bioerefinery within the study region in each scenario. A mathematical programming model is constructed and solved to determine the optimal quantity, location, and capability class of land to convert to switchgrass production. The breakeven biofuel price is determined for assumed levels of required investment capital and the operating cost for the biorefinery. Model sensitivity analysis is conducted with respect to the total land available for bidding from current use for conversion to switchgrass production in each county.

Theoretical Framework

For the purposes of modeling, a biorefinery with a predetermined location, that requires switchgrass biomass as unique feedstock, is considered. A model is developed that, for a specific biorefinery location, enables the determination of the optimal location, quantity, and quality of land to be bid from current use and repurposed for the production of switchgrass biomass. The model is solved under three scenarios: (a) land use restricted to class IV; (b) land use restricted to classes III and IV; and (c) unrestricted land use (classes I, II, III, and IV). The land selection decision is assumed to be made in year zero simultaneously with biorefinery construction. The decision is based on the expected switchgrass biomass yield from each land capability class in each county as represented by the mean of 50 yields simulated from 50 years of historical weather. The decision maker's objective function is:

$$\max_{XL} NPV = \sum_{t=1}^{T} \left\{ \begin{Bmatrix} \theta\rho \left(\sum_{c=1}^{C}\sum_{l=1}^{L} AT_{tcl} \right) - \sum_{c=1}^{C}\sum_{l=1}^{L} \lambda_{cl}\, XL_{cl} \\ - \sum_{c=1}^{C}\sum_{l=1}^{L} \tau_{cl}\ AT_{cl} - \ OPC \end{Bmatrix} / \ (1+r)^{t} \right\} - \sum_{c=1}^{C}\sum_{l=1}^{L} EST_{cl}\, XL_{cl} - AFC. \tag{1}$$

where $\theta\rho\sum_{c=1}^{C}\sum_{l=1}^{L} AT_{cl}$ is the annual return from biofuel, XL_{cl} is the quantity of land class l leased in county c, $\sum_{c=1}^{C}\sum_{l=1}^{L}\lambda_{cl}\, XL_{cl}$ is the annual feedstock production cost including land rental cost, maintenance fertilizer, and mowing and raking costs, $\sum_{c=1}^{C}\sum_{l=1}^{L}\tau_{cl}\, AT_{cl}$ is the annual biomass baling and transportation cost, $\frac{1}{(1+r)^{t}}$ is the discount factor, and $\sum_{c=1}^{C}\sum_{l=1}^{L} EST_{cl}\, XL_{cl}$ is the switchgrass establishment cost. Tables III-1 and III-2 include the descriptions of the sets, the parameters, and the variables used in the model as well as the parameter values and the data sources.

Equation (1) is maximized subject to the following set of constraints:

$$XL_{CL} \leq \bar{X}_{CL} \quad \forall\, c, l \tag{2}$$

Equation (2) restricts the quantity of land of class *l* for switchgrass production in county *c* to not exceed the total land of class *l* in the county made available for conversion to switchgrass.

$$\sum_{c=1}^{C}\sum_{l=1}^{L} AT_{cl} \geq \ \Psi \tag{3}$$

Equation (3) requires that the total biomass transported to the biorefinery be sufficient to fulfill the annual biomass feedstock requirement, Ψ, in every year.

$$AT_{cl} \leq \eta_{cl} X_{cl} \quad \forall \ c, l \tag{4}$$

In equation (4) the quantity of biomass baled and transported to the biorefinery from each county c on land class *l* cannot exceed the quantity produced in the county on the given land class. η_{cl} is the mean of the 50 years of simulated switchgrass biomass yield on land class *l* in county c.

$$AT_{cl}, \ XL_{cl} \ \geq 0 \quad \forall \ c, l \tag{5}$$

Equation (5) is a non-negativity constraint. In the scenario with land capability class IV alone, the set of land classes, l, collapses to one element.

Data and Assumptions

Case Study Region

The U.S. Environmental Protection Agency (U.S.EPA) (2010) conducted a regulatory impact analysis to assess the expected consequences of the EISA legislation. The assessment required that the EPA determine which feedstocks would most likely be used to fulfill the cellulosic ethanol production requirements and where the biorefineries would most likely be located. They projected that 56% of the requirement would be fulfilled by crop residues; 25% by forest residues; 13% by urban waste; and 6% by switchgrass. By this measure, 94% of the 16 billion gallons EISA advanced biofuel requirement could be met with crop and forest residues and waste products, for which indirect land use issues would be minimal. They also projected that 85% of the switchgrass would be produced and processed in Oklahoma. Thus, for this case study, a biorefinery location of Okemah, Oklahoma is selected. It is near the geographical center of three switchgrass biomass biorefinery locations (Lincoln, Hughes, and

Muskogee Counties) proposed in the U.S. EPA (2010) study. A 90 mile radius around Okemah is used as the potential feedstock supply shed of the biorefinery. The process results in a case study region and potential feedstock supply shed of 30 Oklahoma counties (Figure III-1).

Land Rental Cost

Land rental cost in each county for each land capability class, is based on the 2013 revealed CRP rental rates as reported by the USDA, FSA (USDA FSA, 2014). The county average CRP rental rate and total CRP land area in the county are reported. The CRP rental rate and the CRP land area are not differentiated by land class. However, previous studies have found that landowners have been more willing to enroll poorer quality land in the CRP program (Isik and Yang, 2003; Hellerstein and Malcolm, 2011). Consequently, it is assumed that 50% of the CRP acres are from land capability class III, and 50% are from land capability class IV. Wheat is the predominate crop in the region. Thus, the revealed CRP rates are adjusted using the expected wheat yield on each land capability class, as reported in the USDA NRCS Soil Survey Geographic (SSURGO) database (USDA NRCS, 2014). SSURGO wheat yields are used as a proxy for land productivity for each land capability class. The average SSURGO wheat yield across the 30 counties in the case study region is 37, 34, 26, and 21 bushels per acre for class I, II, III, and IV, respectively (Table III-3). Based on the USDA wheat production cost estimates (USDA ERS, 2014) for 2012 and 2013, a yield of 34 bushels per acre would have been required to cover production costs for wheat produced in the Prairie Gateway. Given the expected wheat yields as reported in the USDA SSURGO data base, the expected return from growing wheat on class III and IV lands in the region is negative. The negative expected returns from crop production are consistent with the vast majority of class III and IV lands in the region being used for pasture.

The revealed CRP rental rates are adjusted using a two-step procedure. First, for each county an adjustment coefficient is calculated using the assumed proportions of land of capability classes III and IV enrolled in the CRP program in the county. The following equation is used:

$$ADJ_c = \frac{R_c}{\sum_{j=1}^{2} \mu_{cl} P_{cl}} \tag{6}$$

where ADJ_c is the adjustment coefficient (\$/Mg) for the land rental rate in county c, R_c is the revealed CRP rental rate (\$/ha) reported for county c, μ_{cl} is the county level expected wheat yield (Mg/ha) reported in the USDA NRCS SSURGO database on land capability class III (l =1) and land capability class IV (l = 2), P_{cl} is the proportion of land capability classes III (l =1) and IV (l = 2) enrolled in the CRP program in county c. P_{cl} is assumed to be 0.5 for both land capability classes III and IV.

In a second step, the land rental rates are calculated for each land capability class in each county using:

$$\omega_{cl} = ADJ_c \, \mu_{cl} \tag{7}$$

where ω_{cl} is the land rental cost (\$/ha) of land capability class l (1, …, 4) in county c (1, …, 30), ADJ_c and μ_{cl} are as defined above.

The average estimated rental costs, based on the revealed CRP rates and equation (6) for capability classes II, III and IV are 89, 67 and 55% respectively of those of land capability class I (Table III-3). Table III-3 shows a large difference in the expected wheat yield, switchgrass yield, and the land rental rate between land of capability class II and land of capability class III. The result confirms the assertion that land of capability classes III and IV can be defined as marginally productive relative to land of capability classes I and II.

Land Area and Transportation Distances

The quantity of land in each county is determined for land capability classes I–IV from the USDA SSURGO soil database. For each land capability class in each county, the soil with the most hectares within a county is considered to represent the specific land class. In the base scenario, it is assumed that no more than 20% of the total acres of each land capability class can be bid from current use for switchgrass production at the estimated rental rates. Several factors that can limit the land availability for future biorefineries including physical land properties and landowners' willingness to contract with the biorefinery and to convert their land from current uses to switchgrass production (Jensen et al., 2007; Bergtold, Fewell and Williams, 2014).

To produce an estimate of transportation distances, a centroid was determined for each of the four land classes for each county. For example, the SSURGO spatial soil database was used to identify all parcels of class I soil in a county. Then ARCGIS^{TM} was used to determine the centroid of the class I soils in that county. This method was used to identify a centroid for each of the four land classes for each of the 30 counties. After the centroids were identified, the distance between the centroid of each land capability class for each county and the potential biorefinery location near Okemah, Oklahoma, is determined using the geographical coordinates (latitude and longitude) of the two points.

Transportation Cost

Transportation costs are estimated following Wang (2009). The transportation cost is a linear function of the distance between the feedstock production site and the biorefinery location. The following equation was used:

(8) $$\tau_{cl} = \alpha + \beta \, distance_{cl}$$

where τ_{cl} is the transportation cost from the centroid of land class l in county c to the biorefinery location ($ per ton), α is the fixed cost of transporting one ton of feedstock, β is the variable cost of transporting one ton of switchgrass, and $distance_{cl}$ is the one way road distance between the centroid of land l in county c and the potential biorefinery location (miles). Using data from Wang (2009), and the 5-year average diesel price of $3.71 per gallon (EIA, 2015), the estimates for α and β are 0.798 and 0.334 respectively.

Switchgrass Biomass Yield Distribution

Soil data were obtained from the USDA SSURGO soil datamart (USDA NRCS, 2014). Weather data, including daily solar radiation, maximum temperature, minimum temperature, relative humidity, wind velocity, and daily precipitation were obtained from the Oklahoma Mesonet (Oklahoma Climatological Survey, 2014) and National Oceanic and Atmospheric Administration (NOAA, 2014) weather data series. Soils and historical weather data were used in combination with crop management data to simulate historical switchgrass yield data using the Environmental Policy Integrated Climate (EPIC) model.

EPIC is a biophysical comprehensive terrestrial ecosystem model that can be used to simulate crop yield. EPIC was calibrated using the methods described by previous studies for biofuel crops (Mondzozo et al., 2011; Debnath, Epplin and Stoecker, 2014). After calibration, it is used to simulate yields for each of the four land capability classes, for each of 50 years of weather data (1962-2011), for each of the 30 Oklahoma counties in the case study region. For the simulation process, the soil classification with the most acres within each land capability class in each county is used to represent the whole land capability class. Consequently, all the soils within the same land capability class in a county are assumed to produce the same biomass yield.

The simulated yields are compared with observed yields for each of the three experimental sites. The regression of the observed yield on the simulated yield produced an R^2 of 0.79 (Figure III-2). This implies that 79% of the variability in the observed yield is explained by the simulated yield. Table III-4 presents the correlations and the covariances of the simulated yields across counties. Significant correlations were found for yield on land capability classes I and II; II and III; II and IV and III and IV (Table III-4). Table III-4 also indicates that the yield covariances are positive across land capability classes.

Biorefinery Parameter Values for the Case Study

The capital investment requirement for the biorefinery is adopted from EPA (2010) and Wright et al. (2010). A biorefinery with a processing capacity of 770,000 tons per year (Ψ in equation (3)) is considered. The biorefinery is assumed to use a biochemical conversion system using enzymatic hydrolysis. The projected initial investment cost (AFC in equation (1)) is estimated at $220 million for a project life of 20 years. The biomass to biofuel conversion rate (ρ in equation (1)) is assumed to be 90 gallons per ton (EPA, 2010). The annual operation and maintenance cost (OPC in equation (1)) was estimated at $57 million by the EPA (2010). The operation and maintenance cost includes the cost of items such as enzyme cost, enzyme nutrients cost, other raw material cost, waste disposal cost, and taxes. Since the feedstock production and transportation costs are variables to be estimated in the present study, the biomass procurement cost as estimated by the EPA (2010) is not included in the operation and maintenance budget.

The breakeven biofuel price is determined using a grid search approach by iteratively changing the biofuel price, θ in equation (1), to find the price at which the net present value of the investment is zero. The breakeven price is determined for each of the land availability scenarios. A discount rate (r in equation (1)) of 6.5%, is assumed for both the switchgrass establishment and the biorefinery investment costs.

Results

Restricting Land to Capability Class IV

When land use is restricted to no more than 20% per county of land capability class IV, 176,784 acres are optimally selected to fulfill the biorefinery feedstock requirement of 770,000 dry tons per year (Table III-5). Land is leased in 12 counties within the potential biorefinery supply shed (Figure III-3). If 176,784 acres of land of capability class IV are leased, it costs $62.33 to produce and deliver one ton of feedstock to the biorefinery (Table III-5). The production cost includes $46.40 per ton for field operations costs (land, establishment, maintenance, and harvesting) and $15.92 per ton for transportation (Table III-6). The transportation cost is within the range of the costs reported in the literature. Turhollow and Epplin (2012) for example, report switchgrass transportation costs that vary from $3.40 to $7.27 per ton. Brechbill, Tyner and Ileleji (2011) report a cost of $11.09 per ton. Other studies have reported transportation costs that range from $2.99 to $24.04 per ton (Zhang et al., 2013). These cost estimates depend highly on the assumptions of different studies and differ with assumptions regarding transportation distances and the tons per load (Zhang et al., 2013). If available land for leasing is restricted to no more than 20% of class

IV, the average transportation distance is 45.19 miles. With the 20% land availability assumptions, the annual cost of feedstock is $45.30 million. For an investment capital cost of $220 million, a price of biofuel of $2.39 per gallon is necessary for the biorefinery to breakeven (Table III-6).

Restricting Land to Capability Classes III and IV

When it is assumed that up to 20% of land capability classes III and IV in each county can be bid from current use and converted to switchgrass production, 130,749 acres would be leased to produce enough feedstock to meet the biorefinery requirement (Table III-5). The land requirement in this scenario is 35% lower compared to the first scenario when land lease was restricted to land capability class IV. The 130,748 acres are identified in five counties (Figure III-4) and land of capability class IV is only leased in Okfuskee County where the biorefenery is assumed to be located.

If land of capability classes III and IV could be leased, a delivered ton of feedstock would cost $51.14 which is 22% lower than the feedstock cost when only land of capability class IV is available. The average feedstock transportation distance is 27.08 miles for a cost of $9.86 per ton, and the field production cost is $41.28 per ton which includes $2.79 per ton (7%) for land cost (Table III-6). The annual feedstock cost is $38.31 million (Table III-6). For the assumed level of investment and operating costs, the biofuel breakeven price for the biorefinery is $2.12 per gallon. The breakeven price is 13% lower compared to the breakeven price in the scenario with only land class IV (Table III-6). This price is comparable to the breakeven price of $2.12 per gallon reported by Haque and Epplin (2012) for a comparable investment cost and conversion rate.

Unrestricted Land Use (classes I, II, III and IV)

In the third scenario, we assume that up to 20% of the land of each of the four capability classes I, II, III and IV in each county is available for conversion to switchgrass biomass production. At the estimated rental rates, 122,643 (Table III-5) acres would optimally be leased across seven counties (Figure III-5) to meet the biorefinery feedstock requirement. The land requirement is 31% lower compared to the first scenario when only land of capability class IV could be leased and 6.2% lower compared to the land requirement when land of capability classes III and IV is available. Land from capability class III represents 39% of the land leased.

When 122,643 acres of land are identified and leased, one ton of feedstock delivered to the processing plant would cost $47.20 (Table III-6). The average field operation cost for feedstock production is $41.05. Estimated transportation cost is $6.15 per ton (for an average distance of 17.49 miles), which is less than half of the transportation cost when only land of capability class IV is available and 33% lower than the transportation cost in the scenario with land capability classes III and IV. The delivered feedstock cost is 24% lower than the $62.33 per ton when only land class IV is assumed to be available for lease.

The breakeven biofuel price in the third scenario is $2.07 per gallon, and the average annual feedstock cost is $35.21 million. The breakeven price is lower than the breakeven price in the first scenario, which reflects the lower cost of delivered feedstock. At $47.20 per ton, the feedstock production cost is considerably lower than the cost of $54.43 to $60.78 per ton reported by previous studies (Epplin, 1996; Duffy, 2007; Epplin et al., 2007; Khanna, Dhungana and Brown, 2008; Mapemba et al., 2008, Wright et al., 2010; Kazi et al., 2010; Brechbill, Tyner and Ileleji, 2011; Haque and Epplin, 2012). If land availability is not constrained for feedstock production, the land portfolio selection would result in the least feedstock production cost system. The portfolio selection process would consider the tradeoffs between land lease cost, biomass yield, transportation distances, and the total land available for lease. Overall, our results suggest that if the land to produce switchgrass biomass for second generation biofuels is to be determined by profit-seeking entrepreneurs, in the absence of policy restrictions, land selected will not necessarily be "marginal".

Model Sensitivity Analysis: Increasing Land Availability to 25%

In the base analysis, land use is restricted to be no more than 20% of total land within each land class in each county of the study region. When the 20% restriction is relaxed to 25% of the total land in each land capability class in each county, and if only land of capability class IV can be leased (assuming a perfectly elastic supply curve over the relevant range at the estimated rental rates), the land requirement would increase from 176,784 acres to 177,670 acres (Table III-6). With increased acres, the land rental cost increases from $3.61 to $3.84 per ton. However, the feedstock production cost decreases from $62.33 to $60.89 per ton (Table III-6). The most noticeable change in the feedstock production cost components is the reduction in the transportation cost from $15.92 to $14.14 per ton and the transportation distance from 45.19 to 39.88 km The results suggest that if the land constraint is less stringent, the distance over which feedstock is transported (rather than biomass yield or the land rental cost) would be a key factor in determining the optimal land portfolio.

If land lease is restricted to land of capability classes III and IV and if up to 25% of the total land in both classes and in each county is available for leasing, the land necessary to meet the biorefinery requirement is 131,870 acres (Table III-6). The biofuel breakeven price of the system is $2.11 per gallon. Cost to deliver feedstock production cost declines from

$51.14 (when 20% of the total land is assumed to be available) to $49.97 per ton. Biomass transportation cost decreases from $9.86 to $8.25 (16%) per ton.

If 25% of land of capability classes I-IV in each county is available for leasing, the feedstock production cost decreases from $47.20 to $46.63 per ton. When land with greater estimated yield is made available, the quantity of land required to meet the biorefinery biomass requirement decreases from 122,643 to 114,630 acres.

Model Sensitivity Analysis: Decreasing Land Availability to 15%

When only 15% of the total land of capability class IV in each county is made available for leasing, again assuming a perfectly elastic supply curve over the relevant range at the estimated rental rates, the land requirement to meet the biorefinery capacity is 177,120 acres. The land requirement increases compared to the base scenario when no more than 20% of class IV land is assumed to be available for switchgrass biomass production. Estimated cost to deliver feedstock increases from $62.31 per ton in the base scenario to $64.01 per ton when only 15% of class IV land is available (Table III-6). Biomass transportation cost increases from $15.92 per ton to $17.74 per ton.

When l the 15% restriction is imposed on the land classes III and IV scenario, 136,420 acres are optimally leased (Table III-6). Cost to deliver feedstock increases from $51.14 per ton (when 20% of the total land is assumed to be available) to $52.65 per ton (3% greater). The land cost increases from $2.79 per ton (when 20% of the total land is assumed to be leased) to $2.84 per ton, and the biofuel breakeven price increases from $2.12 to $2.14 per gallon. The transportation cost increases by 10% from $9.86 to $10.80 per ton. Restricting land availability increases transportation distance and transportation cost.

When land from classes I-IV is made available, limiting the total land availability does not have a major effect on the quantity of land optimally leased, the feedstock procurement cost, or the land lease cost per ton of biomass. However, the transportation cost increases by 21% when no more than 15% of the land could be leased compared to when up to 20% of the land is available. The results of the sensitivity analyses confirm that land availability and feedstock transportation distances are critical components for biorefineries designed to use switchgrass as an exclusive feedstock.

Discussion

Production of switchgrass as a dedicated energy crop was proposed as a way to produce biomass for bioenergy from millions of hectares that have historically been bid from traditional crop production by a variety of federal programs. Since the policy-idled land was not used to produce crops, using it to grow switchgrass was envisioned as a way to put the land to productive use and to not compete with food and fiber production (McLaughlin et al., 1999; U.S. Department of Energy, 2011). Biorefinery management could be expected to contract for production from, or engage in long term leases from, the most economical portfolio of land. Some of the land selected for conversion to the production of switchgrass may not be of marginal quality. The objective of the present study was to determine the expected economic consequences of land use restrictions on switchgrass biomass production for a case study region. Situations modeled include: (a) land use restricted to land capability class IV; (b) land use restricted to land capability classes III and IV; and (c) switchgrass establishment permitted on land capability classes I, II, III, and IV.

A case study region identified by the U.S.EPA (2010) as a promising U.S. location for a switchgrass biomass biorefinery is defined. For the case study region, restricting switchgrass production to less productive land would substantially increase the land requirement and the cost to deliver a flow of feedstock. When land use is restricted to land capability class IV, the land requirement increases by 31% and the cost to deliver feedstock increases by 24% compared to when switchgrass production is permitted on land classes I-IV. Sensitivity analysis with respect to the total land available for conversion to switchgrass finds that expected differences in switchgrass yield across land class and field to biorefinery biomass transportation cost are important drivers of the relative economics. In the absence of policy restrictions, for the case study region, a profit-maximizing business would be more likely to pay more per hectare to lease more productive land close to the biorefinery than to lease less productive land at a greater distance from the biorefinery as illustrated by the average transportation distances and the average yield on the land selected in each land use scenario (Table III- 6). Policies that impose land use restrictions would increase the cost to produce biofuel.

Similar to Bryngelsson and Lindgren (2013), the present study finds that if the land to produce switchgrass is to be determined by profit-seeking businesses, in the absence of policy restrictions, some of the land on which feedstock is optimally produced, because of transportation cost and yield differences, may be the relatively productive class I. The availability of lower cost marginal land as that identified by Perlack et al. (2005) and others (Gelfand et al., 2013; Liu et al., 2011) as well suited for biomass production would not preclude the bidding of high quality land from food and fiber production. Ultimately, the specific land converted from existing use to the production of switchgrass biomass, or any other dedicated energy crop, will be determined by land owners and biomass businesses. For the case study region, the biofuel production system would be substantially less economical if land use were restricted to less productive class IV land.

Historically, by public policy, the U.S. has compensated land owners to remove land from crop production. Specific information about the land capability classification of policy-idled land is not available. However, it is a reasonable assumption that most of the policy-idled land in a specific county has been relatively less productive than the average acre in the county. Switchgrass will grow and produce biomass on marginal land. Biomass produced by switchgrass on policy-idled marginal land is not likely to cause indirect land use. However, if biorefineries are built by profit seeking businesses they can be expected to seek out the most economical field to fuel system. In the absence of government fiat, for the case study region, businesses would not limit land use to marginal, class IV land. If class I land is bid from crop production, then it could be argued that production of switchgrass may have consequences relative to land use elsewhere on the planet.

As noted by Broch et al. (2013) substantial disagreement exists regarding measurement of indirect land use and the environmental consequences thereof. As long as a lack of consensus regarding the measurement of and accounting for the indirect land use consequences of dedicated energy crops is present, and if these crops bid land from food and fiber production, it will be difficult to argue that the biobased products produced from the biomass are unambiguously good for the environment. This ambiguity complicates policy options.

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Table III-1. Model Sets, Variables, and Parameters

Sets, Variables, and Parameters	Description
Sets	
T	Years: t = {Year1, Year2, …, Year20}
C	Biomass production counties: c = {30 Oklahoma counties}
L	Land capability classes: l = {class I, class II, class III, class IV}
Variables	
NPV	Net present value of the system ($)
AT_{cl}	Quantity of biomass transported to the biorefinery from land class l in county c (ton)
XL_{cl}	Land leased from land class l, in county c for the life span of the project (acre)
Parameters	
θ	Biofuel price ($ per gallon)
ρ	Bioconversion rate (gallons per ton)
λ_{cl}	Feedstock production cost including land rental cost, maintenance fertilizer, and mowing and raking costs in county c for land class l ($ per acre
τ_{cl}	Biomass baling and transportation cost from the centroid of land class l in county c to the biorefinery ($ per ton)
OPC	Annual plant variable operating cost ($)
r	Annual discount rate (%)
EST_{cl}	Switchgrass establishment cost in year zero, in county c on land class l ($ per acre)
AFC	Biorefinery investment cost made once in year zero ($)
$\overline{X}_{cl}$	Total land available for lease from land class l in the county c
ψ	Annual biorefinery processing capacity
η_{cl}	50-year average simulated switchgrass biomass yield on land class l in county c

Table III-2. Parameters Values Used in the Model

Parameters	Values	Units	Source
Biofuel price	Variable	$ per gal	USDA national weekly ethanol summary
Bioconversion rate	90	gal per ton	EPA (2010)
Production cost including land rental	-	$ per acre	
Nitrogen	42.73	$ per acre	Turhollow and Epplin (2012)
Mowing	12.53	$ per acre	
Raking	7.64	$ per acre	
Baling cost	28.21	$ per ton	
Land rental	Variable per county and land class	$ per acre	Estimated by authors using the CRP rental rates
Transportation cost	Variable per county and land class	$ per mile	Estimated by authors
Annual plant variable operating cost	57,000,000	$	EPA (2010)
Biorefinery investment cost	220,000,000	$	EPA (2010)
Annual discount rate	6.5	%	Turhollow and Epplin (2012)
Switchgrass establishment cost	Variable per county and land class	$ per acre	Turhollow and Epplin (2012)
Total land available in each county	Variable per county and land class	acre	Estimated by authors
Annual biorefinery processing capacity	771,000	ton	EPA (2010)
Switchgrass biomass yield	Variable per county and land class	ton per acre	1962-2011 average simulated from EPIC

Notes: In equation (1) the feedstock production cost components are separated into three components: λ_{cl} *is* the sum of land rental and the maintenance, mowing and raking costs, τ_{cl} is the sum of the baling and the transportation costs, and EST_{cl} is the amortized establishment cost.

Table III- 3. SSURGO Expected Wheat Yield, Average EPIC Simulated Switchgrass Yield and Average Rental Rate of four Land Capability Classes in 30 Oklahoma Counties

Item	Class I	Class II	Class III	Class IV
Average SSURGO wheat yield (bu per acre)[a]	37	34	26	21
% of class I wheat yield	100	90	69	57
Average switchgrass yield (tons per acre)[b]	6.74	6.26	5.19	3.96
% of class I switchgrass yield	100	93	77	59
Average rental rate ($ per acre)[c]	52	46	35	28
% of class I rental rate	100	89	67	55

Notes: [a] Source USDA NRCS SSURGO soil data base. The wheat yields are those that can be expected under a high level of management.

[b] Switchgrass EPIC calibrated 50-year (1962- 2011) average yield.

[c] Average rental rates are estimated using the 2013 revealed CRP rental rates for 30 Oklahoma counties.

Table III- 4. Switchgrass Yield Correlation and Covariance Matrices Across four Land Capability Classes

	Class I	Class II	Class III	Class IV
		Correlation Matrix		
Class I	1			
Class II	0.43796 (0.0223)	1		
Class III	0.26688 (0.1784)	0.56026 (0.0024)	1	
Class IV	0.05238 (0.7953)	0.40472 (0.0363)	0.79501 (<.0001)	1
		Covariance Matrix		
Class I	0.78809			
Class II	0.4442	1.30529		
Class III	0.36785	0.99381	2.41059	
Class IV	0.06715	0.66774	1.78252	2.08542

Notes: The number in parenthesis indicates the P-value for the null hypothesis: $\rho = 0$.

Table III-5. Land Leased from four Land Capability Classes in Each of 30 Oklahoma Counties Under three Land Availability Scenarios (acres)

County	Scenario						
	Land Lease Unrestricted				Land Lease Restricted to Land Classes III and IV		Land Lease Restricted to Land Class IV
	Land Class I	Land Class II	Land Class III	Land Class IV	Land Class III	Land Class IV	
Atoka	-	-	-	-	-	-	21,324
Canadian	-	-	-	-	-	-	-
Cleveland	-	-	-	-	-	-	-
Coal	-	4,930	-	-	-	-	7,820
Creek	6,585	-	-	-	19,777	-	18,389
Garvin	-	-	-	-	-	-	-
Grady	-	-	-	-	-	-	-
Haskell	-	-	-	-	-	-	-
Hughes	1,625	12,876	30,011	-	29,924	-	7,020
Johnston	-	-	-	-	-	-	-
Latimer	-	-	-	-	-	-	-
Logan	-	-	-	-	-	-	-
Lincoln	-	-	-	-	-	-	-
McClain	-	-	-	-	-	-	-
McIntosh	67	-	-	-	28,415	-	12,854
Murray	-	-	-	-	-	-	-
Muskogee	-	-	-	-	-	-	-
Noble	-	-	-	-	-	-	-
Okfuskee	3,814	5,688	18,266	10,001	18,266	10,001	10,001
Oklahoma	-	-	-	-	-	-	-
Okmulgee	-	-	-	-	24,278	-	2,097
Osage	-	-	-	21,378	-	-	57,551
Pawnee	-	-	-	-	-	-	-
Payne	-	-	-	-	-	-	5,390
Pittsburg	-	-	-	-	-	-	-
Pontotoc	-	-	-	-	-	-	11,439
Pottawatomie	-	-	-	-	-	-	-
Seminole	593	6,810	-	-	-	-	8,902
Tulsa	-	-	-	-	-	-	13,997
Wagoner	-	-	-	-	-	-	
Sub-total	12,683	30,304	48,276	31,379	120748	10,001	
Total	122,643				130,749		176,784

Notes: The results are from the base scenario in which it is assumed that up to 20% of the total land available in each relevant land class in each county could be bid from current uses for switchgrass production.

Table III-6. Land Leased, Production Cost and Cost Components Under three Land Availability Scenarios

Item	Scenario								
	Land Use Unrestricted			Land Use Restricted to Land Classes III and IV			Land Use Restricted to Land Class IV		
	% of Total Land Available for Lease			% of Total Land Available for Lease			% of Total Land Available for Lease		
	15	20	25	15	20	25	15	20	25
Land leased (1000 acres)	122.36	122.64	114.63	136.42	130.75	131.87	177.12	176.78	177.67
Land cost ($/ton)	5.76	5.20	5.95	5.14	5.07	5.59	6.30	6.54	6.97
Amortized establishment cost $/ton)	2.82	2.78	2.69	3.03	2.91	2.98	3.90	3.92	3.97
Other field production cost ($/ton)	32.39	32.65	31.75	33.67	33.30	33.15	36.06	35.93	35.80
Transportation cost ($/ton)	8.07	6.65	6.15	10.80	9.86	8.25	17.74	15.92	14.14
Feedstock cost ($/ton)[b]	49.04	47.27	46.55	52.65	51.15	49.97	64.01	62.31	60.88
Annual Feedstock cost (million $)	37.84	36.48	35.92	40.63	39.47	38.56	49.39	48.08	46.98
Breakeven price of biofuel ($/gal)	2.12	2.08	2.08	2.16	2.12	2.12	2.42	2.38	2.38
Average transportation distance (miles)	21.75	17.49	16.01	29.91	27.08	22.26	50.64	45.19	39.88
Average yield (ton/acre)	6.30	6.29	6.73	5.65	5.90	5.86	4.35	4.36	4.34

Notes: The study region includes 30 Oklahoma counties considered as the potential supply shed for the biorefinery.

The delivered feedstock cost per ton is the sum of land rental, the amortized establishment cost, the maintenance, mowing and raking costs, the baling cost, and the transportation cost. In equation (1), λ_{cl} is the sum of land rental and the maintenance, mowing, and raking costs; τ_{cl} is the sum of the baling and the transportation costs; and EST_{cl} is the amortized establishment cost.

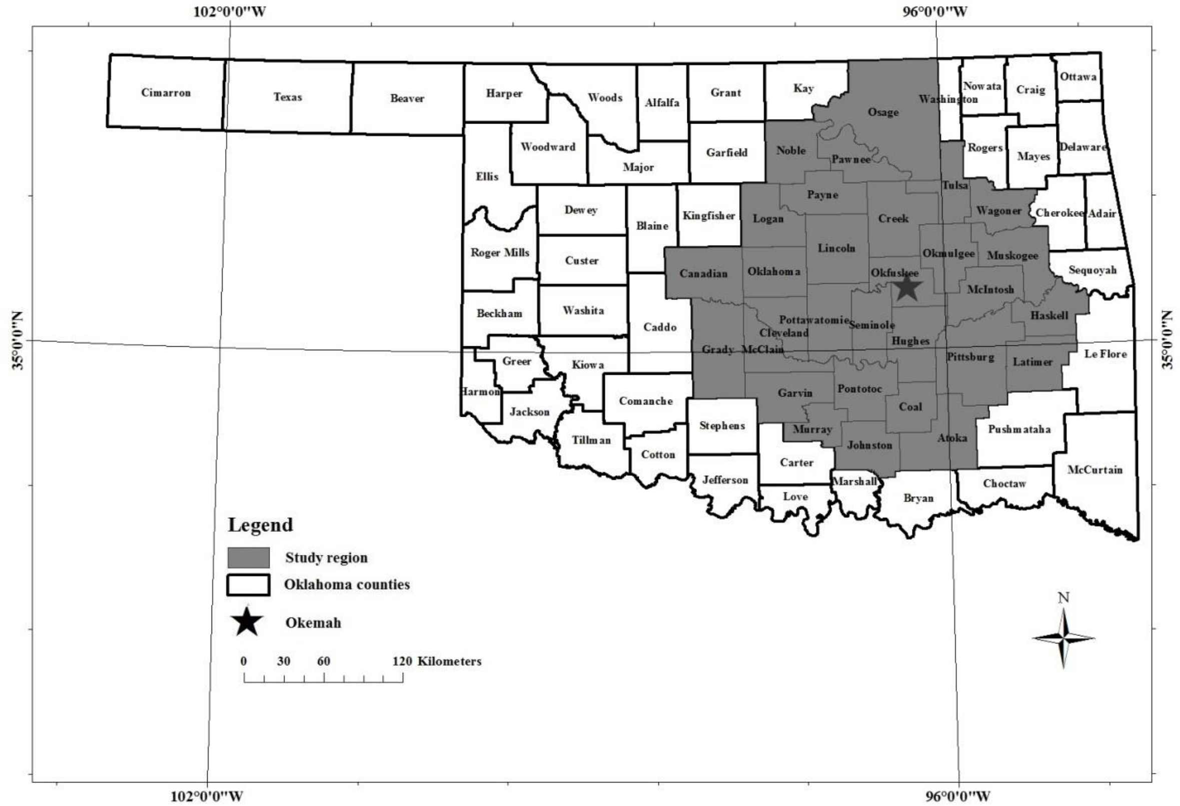

Figure III-1. Delimited study region of 30 counties in Central Oklahoma

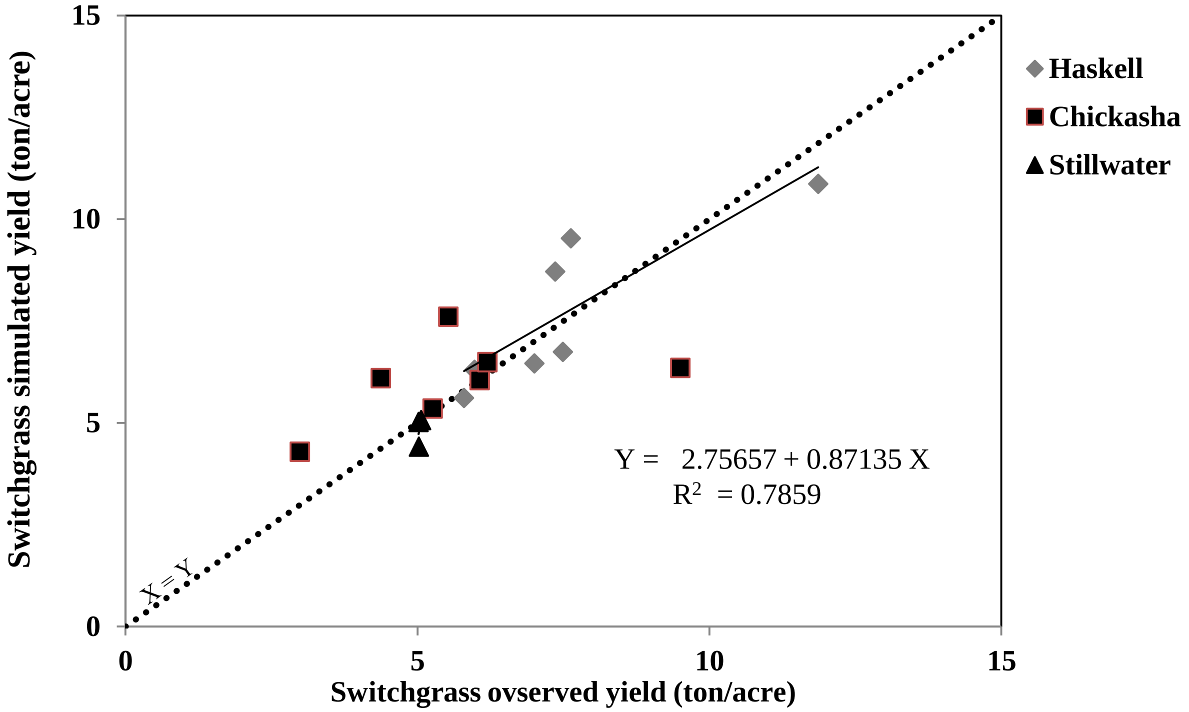

Figure III-2. Epic simulated and observed yields for lowland switchgrass cultivar Alamo at three experimental sites in Oklahoma.

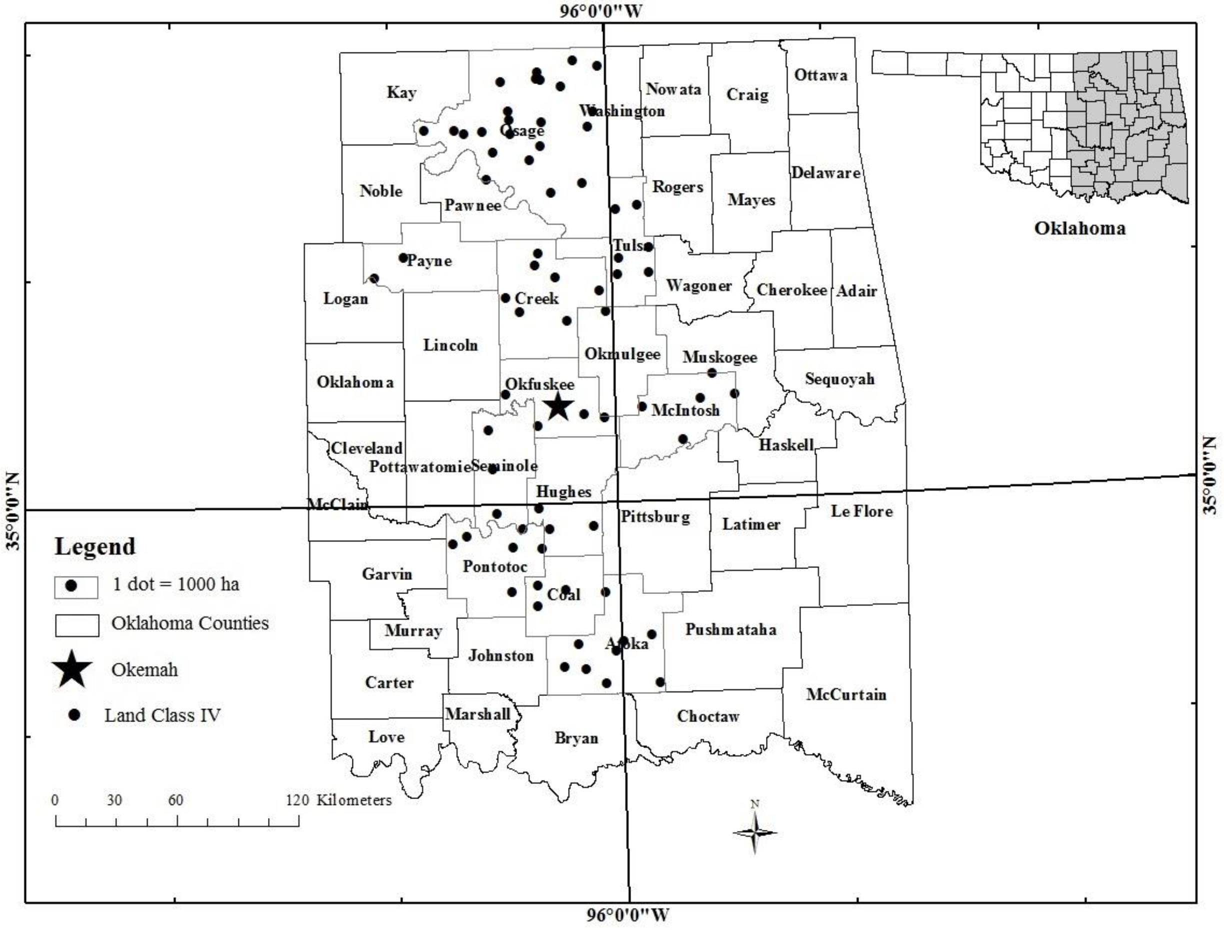

Figure III-3. Land optimally selected in 12 Oklahoma counties when lease is restricted to land of Capability Class IV

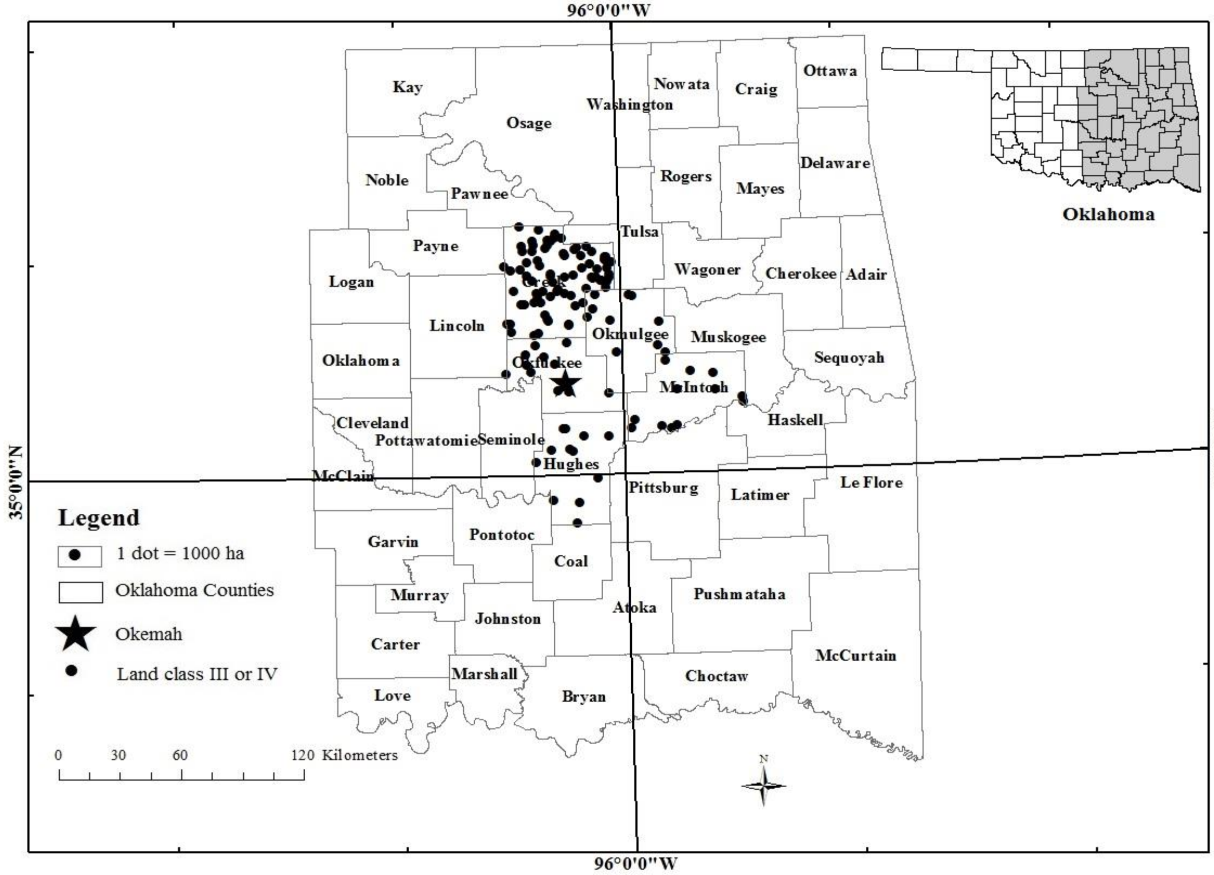

Figure III-4. Land optimally selected in five Oklahoma counties when lease is restricted to land of Capability Classes III and IV

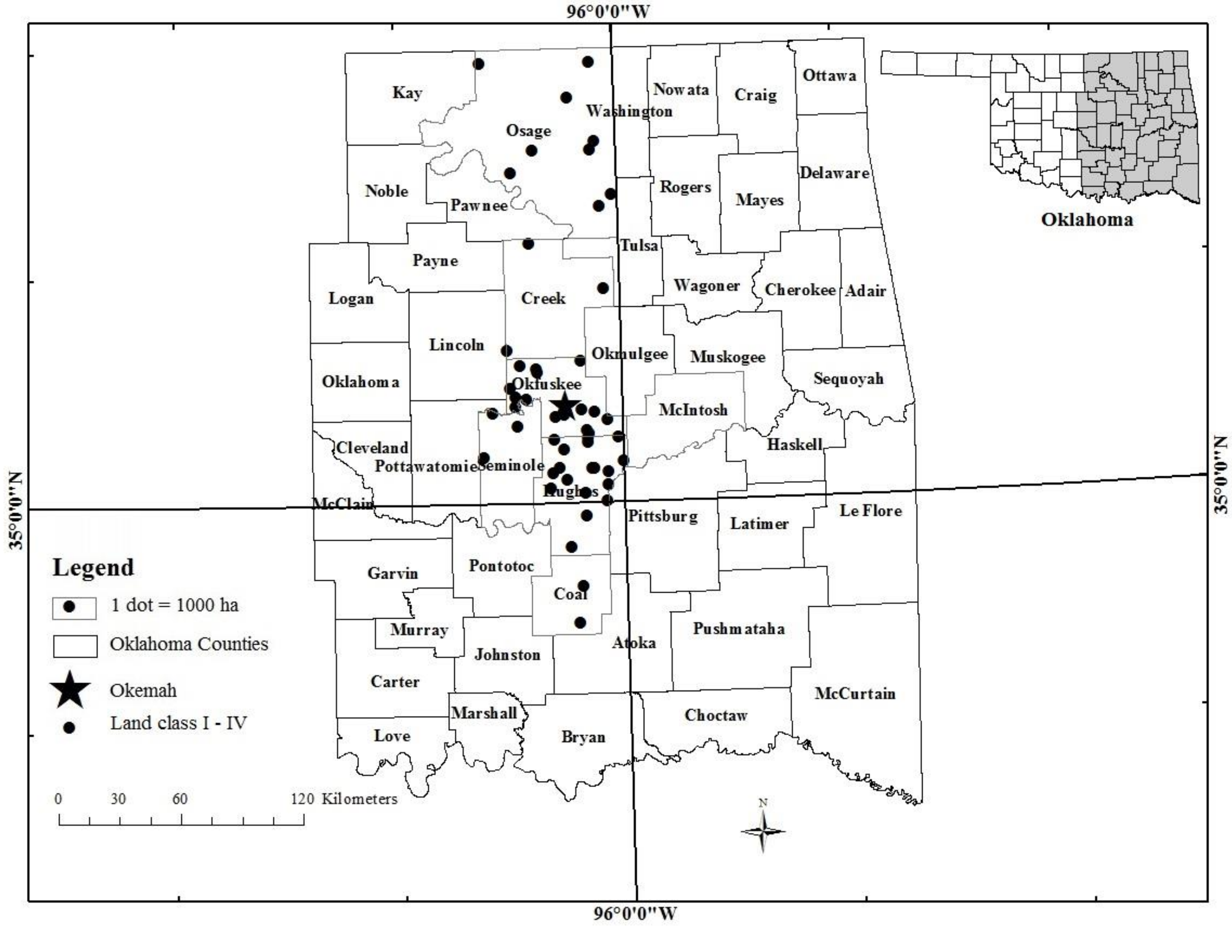

Figure III-5. Land optimally selected in seven Oklahoma counties when lease is unrestricted

CHAPTER IV

LAND REQUIREMENTS, FEEDSTOCK HAUL DISTANCE, AND EXPECTED PROFIT RESPONSE TO LAND USE RESTRICTIONS FOR SWITCHGRASS PRODUCTION

Abstract

Energy crop production has been proposed for land of poor quality to avoid competition with food production and negative indirect land use consequences. The objective of this study was to determine the land area requirements, biomass transportation distance, and expected profit consequences of restricting switchgrass biomass production, for use as biofuel feedstock, to marginal land relative to unrestricted land use. The USA soils capability classification system was used to differentiate between high quality land and land of marginal quality. Fifty years of historical weather data were used in combination with a biophysical simulation model to estimate switchgrass biomass yield distributions for land of different quality for counties in the case study region. A mathematical programming model was designed and solved to determine the economic consequences. For the levels of biofuel price considered ($0.50, $0.75 and $1.00/L), and a 262.5 M L/year biorefinery modeled, restricting land use to marginally productive capability Class IV soils, increases the quantity of land optimally leased by 42 to 52%; increases biomass trucking total transportation distance by 115 to 140%; and reduces the expected net returns by $7 to $16 M/year compared to when land use is unrestricted. In the absence of government restrictions, for-profit companies are not likely to limit energy crop production to land of marginal quality.

Keywords: biorefinery; EPIC; land capability class; marginal land; switchgrass

Introduction

The production of energy crops such as switchgrass (*Panicum virgatum* L.) in the USA was envisioned as a way to reduce the cost of government funded set aside and land retirement programs that had been implemented to reduce what had been described as an excess capacity problem. It was assumed that most of the land in these programs was of lower quality and that it could be put to productive use growing biomass crops that could then be converted to valuable products. For example, McLaughlin et al. wrote "…the rationale for developing lignocellulosic crops for energy is that …poorer quality land can be used for these crops, thereby avoiding competition with food production on better quality land." (McLaughlin et al., 1999, p. 293). In which case, the indirect land use issue confronted when highly productive land is used to produce grain for conversion to ethanol resulting in land elsewhere on the globe converted from grassland to grain production, as described by Searchinger et al. (2008) and others (Leal et al., 2013; Djomo et al., 2015), would not be an issue.

Searchinger et al. (2008) reported that "…biofuels from switchgrass, if grown on USA corn lands, increase (greenhouse gas) emissions by 50%...". Leal et al. (2013) found that bioenergy crop production can result in significant greenhouse gas emissions. Wise et al. (2014) also concluded that dedicated energy crop production would result in land use changes with increased greenhouse gas emissions. Winchester et al. (2015) reported that meeting USA Federal Aviation Administration targets for renewable jet fuel would also result in increased greenhouse gas emissions. However, Bhardwaj et al. (2011) and Dauber et al. (2012) reported that bioenergy crops could provide environmental benefits if grown on less productive land. Dodder et al. (2015) reported that a hypothetical energy portfolio that includes cellulosic biofuels would result in less greenhouse gas emissions and lower food prices. Djomo et al. (2015) studied 40 potential bioenergy production systems and found that the technologies have the potential to reduce greenhouse gas emissions by 8 to 114% relative to fossil fuels even with the inclusion of the direct and indirect land use changes.

A number of other studies have concluded, or assumed, that since millions of ha of marginal land exist, much of it could be converted relatively easily from current use to the production of switchgrass (Perlack et al., 2005; Liu et al., 2011; Gelfand et al., 2013). For example, in a highly aggregated study, Perlack et al. (2005) estimated that more than 20 million USA ha of low quality land could be converted to biomass production with minimal effects on food, feed, and fiber production. If the land is marginal and not currently used intensively to produce food, feed, and fiber crops, it follows that conversion to switchgrass would not impact land use elsewhere and hence negate concern regarding the environmental consequences of indirect land use. However, prior to completely dismissing the indirect land use issue for dedicated energy crops such as switchgrass grown on marginal land, several issues remain to be resolved.

First, there is no universally accepted definition of marginal land (Richards et al., 2014). Second, in the USA and many other countries, most land suitable for switchgrass production is privately owned. Private owners would have to be incentivized to enable establishment of switchgrass on their land. Third, while government incentives may be in place and used, in the USA, the construction of a switchgrass biomass to biofuel biorefinery requires an investor, or group of investors, to provide the capital necessary to build a plant. Prudent investors would require a business plan for providing a daily flow of biomass throughout the year for the expected life of the biorefinery. Fourth, switchgrass yields are variable. A planted land area may produce more biomass than can be processed in some years and insufficient biomass in others. Given the expected yield variability across years, determining the optimal quantity of land to bid from current use and convert to switchgrass is not a trivial matter. Fifth, restricting switchgrass production to marginal land will have economic consequences. Land use restrictions may reduce the profit potential and inhibit investment in cellulosic biorefineries.

The objective of this study is to determine the land area requirements, biomass transportation distance, and expected profit consequences of restricting switchgrass biomass production, for use as biofuel feedstock, to marginal land relative to unrestricted land use. To achieve the objective, a working definition of marginal land is presented. Fifty years of historical weather data are used in combination with a biophysical simulation model to estimate switchgrass biomass yield distributions for land of different quality for counties in a case study region. A mathematical programming model is designed and solved to determine the economic consequences.

In the USA, soils are classified into eight soil capability classes (Norton, 1939). This classification system may be used to provide a definition of marginal land. Classes V-VIII have limitations impractical to remedy that restrict their use to range, forestland, wildlife, and/or aesthetic purposes. Class I soils have slight, and Class II soils have moderate limitations for crop production. Thus, Class I and II soils could be used to produce switchgrass but they are clearly not marginal. Class III soils have severe limitations that reduce the choice of plants and/or require special conservation practices. Class III soils could be considered as marginal. Class IV soils have very severe limitations that restrict the choice of plants and/or require very careful management. Class IV soils are clearly marginal relative to Classes I and II. Thus, for purposes of determining the consequences of restricting crop production for biorefinery feedstock to marginal USA land, either Class IV, or both Classes III and IV, could be defined as marginal.

Conceptual Framework

The modeling effort is based on the assumption that an investor or group of investors would develop a business plan and secure the financing to construct a biorefinery designed to use switchgrass biomass exclusively. For a given biorefinery technology, differences in cost to produce biofuel across locations could largely be attributed to differences in cost of providing a flow of feedstock throughout the year. Given the cost to transport biomass, investors could be expected to select a region for biorefinery location based on expectations regarding the cost to provide a continuous flow of the required quantity of feedstock.

The case study region was identified based on regulatory impact analysis conducted by the USA Environmental Protection Agency (2010). The EPA (2010) estimated potential feedstocks and biorefinery locations for fulfilling the 2022 cellulosic ethanol production mandates included in the USA Energy Independence and Security Act (EISA). In the assessment projections, 56% of the cellulosic ethanol requirements would be met by crop residues, 25% by forest residues, 13% by urban waste, and 6% by switchgrass. The EPA analysis based on expected cost to deliver feedstock, projected that 85% of the switchgrass could be produced and processed in the state of Oklahoma.

Seven of the nine USA switchgrass biorefinery locations identified by EPA (2010) were in Oklahoma. The opportunity cost of land per expected unit of yield is relatively low in the region. In addition, the regional climate would enable an extended nine-month harvest window, from July through March of the following year (Haque and Epplin, 2012). The extended harvest window could facilitate achieving cost economies for harvest machines and a just-in-time field to biorefinery delivery system throughout much of the year, reducing intrayear harvested biomass storage and handling costs. For the present case study, a biorefinery siting was chosen near Okemah, in Okfuskee County, the geographical center of three of the seven Oklahoma locations (Lincoln, Hughes, and Muskogee Counties) identified by EPA (EPA, 2010; Debnath et al. 2014; 2015). A 150 km radius around the biorefinery location is used as the potential feedstock supply shed of the biorefinery encompassing 30 Oklahoma counties (Figure 1).

An economically efficient switchgrass biomass to biofuel production system would require coordination of feedstock production and transportation with processing. The biorefinery could engage in production contracts with farmers (Epplin et al., 2007). Alternatively, the biorefinery could vertically integrate by acquiring control of a sufficient quantity of land with long-term leases such that the expected annual yield on the leased area would be sufficient to fulfil expected annual biorefinery feedstock requirements. Other options such as a closed-membership producer cooperative could be implemented (Katz and Boland, 2002; Jensen et al., 2011). In either case, prior to investing, prudent investors could be expected to require that use rights would be secured to a sufficient land area. Further, the expected annual biomass yield on the secured land would be available for delivery to fulfil expected annual biorefinery feedstock requirements at or below the expected cost estimate described in the business plan.

Based on experience with the USA Conservation Reserve Program (CRP), Oklahoma land owners are willing to engage in long term contracts that provide an annual lease payment (Osborn et al., 2009). This history suggests that at some annual rental rate, land could be bid from existing use. A company could enter into long-term leases with landowners and establish stands of switchgrass. Long-term land leases would facilitate coordination of switchgrass biomass production, the nine-month harvest window, and transportation logistics required to provide an efficient flow of feedstock throughout the year. If the annual feedstock requirements of the biorefinery and annual switchgrass yield were known with certainty, it would be straightforward to determine the quantity of land to lease. However, switchgrass biomass yields vary from year-to-year. In years with unfavorable switchgrass production weather, yields in the feedstock supply shed of the biorefinery may be low, and if too few hectares are leased, production from the leased land may be insufficient to meet the needs of the biorefinery. In other years, more biomass may be produced on the leased land than can be processed. However, in every year, payments must be made for all land leased.

Conceptually, the expected objective of the investors would be to maximize expected net returns or to maximize the return on their investment. Based on this conceptual framework, the land area selected, leased, and seeded to switchgrass, would be determined and fixed in year zero, simultaneously with construction of the biorefinery. In year one and subsequent years, biomass production on the fixed land area would vary depending on environmental conditions. Thus, a nested objective would be to determine the location, quality, and quantity of land to lease.

Two mathematical programming models that integrate both spatial (among counties and among land classes) and temporal (among years) switchgrass yield variability are developed. The first model does not envision storage across feedstock production seasons. It is designed to maximize expected net returns for the life of the biorefinery. The model solution produces an estimate of the optimal quantity, quality, and location of land to lease. An explicit feature of the model is that it enables shutting down the biorefinery when switchgrass yields are low, if it is economically optimal to do so, and leaving excess biomass unharvested in years when yields across the leased area exceed processing capacity. The second model enhances the first by enabling interyear storage at a given storage cost and accounts for expected interyear storage losses. Both models are presented and solved with switchgrass biomass yield data simulated from 50 years of weather data for each of the four land classes for each of 30 counties in the case study region. Solutions provided by both models are used to determine the economic consequences of restricting switchgrass production to marginal land.

<u>Model 1</u>: <u>No interyear Storage</u>

A biorefinery with a processing capacity of 2,000 Mg of feedstock per day is considered (Debnath et al., 2014; 2015). The biorefinery is expected to have a nameplate capacity to operate 350 days in a given year with an annual feedstock requirement of 700,000 Mg. In model 1 the objective is to maximize the annual expected net returns while allowing for some idle days when it is economical to do so in years of insufficient feedstock production. The objective function is specified as follows:

$$\max_{AP_t, XL_{cl}, XR_{tcl}, AT_{tcl}} E(NR) = \theta\rho\left(\sum_{t=1}^{T} AP_t\right)/T - \sum_{c=1}^{C}\sum_{l=1}^{L} \lambda_{cl}\, XL_{cl} - \alpha\left(\sum_{t=1}^{T}\sum_{c=1}^{C}\sum_{l=1}^{L} XR_{tcl}\right)/T - \left(\sum_{t=1}^{T}\sum_{c=1}^{C}\sum_{l=1}^{L} \gamma_{cl}\, AT_{tcl}\right)/T - \delta\left(\sum_{t=1}^{T} AP_t\right)/T - OPC - ANFC \tag{1}$$

where $E(NR)$ are the annual expected net returns to be maximized, t is year (year 1 to year 50); c is the county (1, 2,…, 30), l is the land class (Class I, II, III, and IV); AP_t is the quantity of biomass processed in year t (Mg); θ is the price of biofuel (\$ L^{-1}); ρ is the bioconversion rate (L Mg^{-1}); λ_{cl} is the production cost including amortized switchgrass establishment cost, land rent, switchgrass stand maintenance fertilizer and mowing costs in county c for land class l (\$ ha^{-1}); XL_{cl} is land leased from land class l, in county c for the life time of the project (ha); α is the raking cost (\$ ha^{-1}); XR_{tcl} is the quantity of class l land raked in year t, in county c (ha); γ_{cl} is the biomass baling, stacking, and transportation cost from the centroid of land class l in county c to the biorefinery (\$ Mg^{-1}); AT_{tcl} is the quantity of biomass baled and transported in year t from land class l in county c to the biorefinery (Mg); δ is the variable plant operation and maintenance cost that depends on the quantity of biomass processed (\$ Mg^{-1}); OPC is the annual fixed plant operation and maintenance cost (\$); $ANFC$ is the annualized cost of the initial biorefinery investment (\$).

Equation (1) is optimized subject to the following constraints:

$$XL_{cl} \leq \bar{X}_{cl} \qquad \forall \ \ c, l \tag{2}$$

Equation (2) restricts the quantity of land of class *l* leased in county *c* to not exceed the total land available from that land class in county *c*.

$$XR_{tcl} \leq \ XL_{cl} \qquad \forall \ \ t, c, l \tag{3}$$

In equation (3) the land raked from land class *l*, in each year *t*, in each county *c*, cannot exceed the land of class *l* leased in the corresponding county.

$$AP_t \leq \ \Psi \qquad \forall \ \ t \tag{4}$$

Equation (4) recognizes that the quantity of biomass processed may be less than the plant processing capacity (Ψ) during the years of insufficient feedstock production.

$$AT_{tcl} \ \leq \ \ \eta_{tcl} XL_{cl} \ \forall \, t, c, l \tag{5}$$

In equation (5) the quantity of biomass baled and transported from each county *c*, on land class *l*, in year *t*, cannot exceed the biomass produced in county *c* on land class *l*. η_{tcl} is the annual switchgrass biomass yield in county *c*, on land class *l*, in year *t*.

$$AP_t \leq \sum_{c=1}^{C}\sum_{l=1}^{L} AT_{tcl} \quad \forall \ t \tag{6}$$

The quantity of biomass processed in each year t cannot exceed the quantity transported to the processing plant in equation (6).

$$XL_{cl}, AP_t \, , AT_{tcl}, XR_{tcl} \geq 0 \tag{7}$$

Equation (7) restricts the choice variables to be nonnegative.

Model 2: Facilitating interyear Storage

Model 2 enhances model 1 by allowing interyear storage. The objective is:

$$\begin{aligned}\max_{AP_t, XL_{cl}, AB_{tcl}, XR_{tcl}, AT_{tcl}, AS_{tcl}} E(NR) = {} & \theta\rho\left(\sum_{t=1}^{T} AP_t\right)/T - \sum_{c=1}^{C}\sum_{l=1}^{L} \lambda_{cl} XL_{cl} - \alpha\left(\sum_{t=1}^{T}\sum_{c=1}^{C}\sum_{l=1}^{L} XR_{tcl}\right)/T - B\left(\sum_{t=1}^{T}\sum_{c=1}^{C}\sum_{l=1}^{L} AB_{tcl}\right)/T \\ & - \left(\sum_{t=1}^{T}\sum_{c=1}^{C}\sum_{l=1}^{L} \tau_{cl} AT_{tcl}\right)/T - S\left(\sum_{t=1}^{T}\sum_{c=1}^{C}\sum_{l=1}^{L} AS_{tcl}\right)/T - \delta\left(\sum_{t=1}^{T} AP_t\right)/T - OPC - ANFC\end{aligned} \tag{8}$$

where B is the baling and stacking cost (\$ Mg^{-1}); AB_{tcl} is the quantity of biomass baled on land class l in year t and in county c (Mg); τ_{cl} is the biomass transportation cost from the centroid of land class l in county c to the biorefinery plant location (\$ Mg^{-1}) (γ_{cl} in model 1 is the sum of B and τ_{cl} in model 2); AT_{tcl} is the quantity of biomass transported in year t from land class l in county c to the biorefinery (Mg), S is the switchgrass biomass interyear storage cost (\$ Mg^{-1}y^{-1}), AS_{tcl} is the quantity of biomass (Mg) stored in county c from land class l in year t (interyear storage is assumed to be in production fields with access to all weather roads), the other variables and parameters are as defined in model 1.

In addition to the constraints in model 1, model 2 includes additional constraints:

$$AS_{t+1\,cl} = AB_{tcl} + AS_{tcl} - AT_{tcl} \quad \forall \, t, c, l \tag{9}$$

In (9), the quantity of biomass in interyear storage for year $t+1$ in county c, and on land class l, is equal to the biomass baled in year t, from the same county and same land class plus the quantity in storage in year t, minus the quantity transported to the biorefinery.

$$AS_{tcl} \leq AB_{tcl} \quad \forall\, t, c, l \tag{10}$$

The biomass quantity stored during year t, in county c, and land Class l, cannot exceed the biomass baled.

$$ASuse_{tcl} = (1 - \emptyset) AS_{tcl} \;\; \forall\, t, c, l \tag{11}$$

The usable biomass quantity from storage is equal to the quantity stored minus the storage loss.

$$AB_{tcl}, AT_{tcl}, AS_{tcl},\; ASuse_{tcl} \;\geq 0 \tag{12}$$

Equation (12) imposes the nonnegativity of the decision variables. In both models the set of land classes, l, collapses to one element for the scenario with land Class IV alone.

Data

Transportation and Land Rental Costs

Spatial soil data from the USDA SSURGO data base (USDA NRCS, 2014) are used to determine the land area for land Classes I-IV in each of the 30 counties. Additionally, it is assumed that no more than 20% of the total land in each land class can be bid from current uses for switchgrass production. The distance between the centroid of each land class and the potential biorefinery location near Okemah, Oklahoma, was determined using the geographical coordinates (latitude and longitude) of the two points. Transportation costs from the centroid of each land class in each county to the biorefinery are calculated using a modified version of a biomass transportation cost as a function of distance framework presented by Wang (2009).

The land rental cost for each land class in each county is estimated using the 2013 revealed CRP rental rates reported by the USDA, FSA (2014). The revealed CRP rental rates are adjusted using the expected wheat grain yield on each land class as reported in the USDA NRCS SSURGO data base (USDA NRCS, 2014) because wheat is the predominate crop within the case study region. By this measure, the wheat yield is used as a measure of land productivity for each land class in each county.

The average SSURGO wheat yield across the 30 counties in the case study region is 2.32 2.11, 1.63, and 1.31 Mg ha^{-1} for Class I, II, III, and IV, respectively. Based on the USDA wheat production cost estimates (USDA, ERS, 2015) for 2012 and 2013, a yield of 2.11 Mg ha^{-1} would have been required to cover production costs for wheat produced in the region. Given the expected wheat yields as reported in the USDA SSURGO data base (USDA NRCS, 2014), the expected returns from growing wheat on Class III and IV lands in the region is negative. The negative expected returns from crop production are consistent with the vast majority of Class III and IV lands in the region being used for pasture. Based on average productivity differences among land classes, the average estimated rental costs, based on the revealed CRP rates for Classes II, III and IV are 89, 67 and 55% of those of Class I, respectively.

Switchgrass Biomass Yield Distributions

Historical switchgrass yield data are not available for each land class and county. Soils data were obtained from the USDA SSURGO soil datamart (USDA NRCS, 2014). Weather data, including solar radiation, maximum temperature, minimum temperature, relative humidity, wind velocity, and daily precipitation were gathered from the Oklahoma Mesonet (Oklahoma Climatological Survey, 2014) and the National Oceanic and Atmospheric

Administration (2014). The soils and weather data were used in combination with the Environmental Policy Integrated Climate (EPIC) model to simulate historical switchgrass yields (Williams et al., 1984; Egbendewe-Mondzozo, 2011; Debnath et al., 2014; 2015). The model was calibrated and validated with observed yield from three experimental sites (Haque et al., 2009; Fuentes and Taliaferro, 2002) within the study region.

The EPIC model was used to simulate switchgrass yields (η_{tcl} in equation (5)) for each of the four land classes, for each of 50 years of weather data (1962-2011), for each of 30 Oklahoma counties. The simulated annual yields are ordered based on the historical weather data series. On average the simulated yield on land Class II, III, and IV are 93, 77, and 59% of the Class I simulated yield, respectively.

Biorefinery Data

The 2,000 Mg per day biorefinery is assumed to process only switchgrass biomass with a biochemical conversion system using enzymatic hydrolysis. The projected biorefinery initial investment cost is estimated at \$220 M for a project life of 20 years (US EPA, 2010). The total investment cost is amortized over the 20-year expected project life with a discount rate at 6.5% to calculate the annualized investment cost ($ANFC$ in equations (1) and (8)). The biomass to biofuel conversion rate (ρ in equations (1) and (8)) is assumed to be 375 L Mg^{-1} (US EPA, 2010). The base biofuel price (θ in equations (1) and (8)) is set at \$0.50 L^{-1}. Assuming the biofuel is ethanol, this is roughly equivalent to a crude oil price of \$80 barrel^{-1} as projected by the USA EIA (2015) for 2022. The models are also solved with ethanol prices of \$0.75 L^{-1} and \$1.00 L^{-1}, equivalent to crude oil prices, based on energy equivalence, of \$131 and \$182 barrel^{-1}, respectively.

The annual operation and maintenance cost was estimated at \$57 M (US EPA, 2010). The annual variable operation and maintenance cost (δ in equations (1) and (8)) including enzyme cost, enzyme nutrients cost, other raw material cost, and waste disposal cost is \$9 M, which is equivalent to \$12.85 Mg^{-1} of feedstock processed. The fixed operation and maintenance cost (OPC in equations (1) and (8)) is \$48 M y^{-1}. Since the feedstock production, harvest, and transportation costs are endogenous, the biomass procurement cost as estimated by EPA (US EPA, 2010) is not included in the operation and maintenance cost parameter.

Interyear Storage Cost and Storage Loss

Several studies have estimated region specific storage loss and storage cost. For the case study region, switchgrass harvest can extend from July through March of the following calendar year (Haque and Epplin, 2012). Over these nine months, it is assumed that switchgrass can be harvested and delivered to a biorefinery just-in-time, requiring minimal intrayear storage, the estimated cost of which is assumed to be non-significant in model 1. However, based on our conceptual framework, interyear storage is incorporated in model 2 necessitating estimates for cost parameter s in equation (8) and interyear storage loss parameter $\emptyset$ in equation (11). Based on estimates from previous studies, model 2 is solved for a storage loss estimate of 15% y^{-1} and for three levels of storage cost, \$6, \$12, and \$18 $Mg^{-1}y^{-1}$ (Larson et al., 2010; Sanderson et al., 1997; Turhollow et al., 2009; Cundiff and Marsh, 1996).

Results

Model 1: Optimal Land Lease with no Interyear Storage

For the levels of biofuel price considered (\$0.50, \$0.75 and \$1.00 L^{-1}), restricting land use to Class IV increases the quantity of land optimally leased by 42 to 52% (Table IV-1); increases biomass trucking total transportation distance by 115 to 140%; and reduces the expected net returns by \$7 to \$16 M y^{-1} for the 262.5 M L y^{-1} nameplate capacity biorefinery compared to when land use is unrestricted.

If land use is restricted to Class IV, for an ethanol price of \$0.50 L^{-1}, it is economically optimal to lease and establish switchgrass on 73,856 ha (Table IV-1). The average annual quantity of biomass transported to the 700,000 Mg nameplate capacity biorefinery is 683,797 Mg. The feedstock production and transportation cost is \$63 Mg^{-1} with average expected net returns of \$6.80 M y^{-1} (Table IV-1). The base assumption is that 15 d y^{-1} would be required for maintenance. If 73,856 ha are leased, the biorefinery would be shut down for an additional average of 8.1 d y^{-1}. Thus, the total average down time is estimated to be 23.1 d y^{-1}. Given the empirical yield distributions based on 50 years of historical weather, expected biomass yield on the land selected by model 1 for leasing and seeding to switchgrass in year zero would exceed 700,000 Mg in 22 of the 50 years. In these 22 years, biomass production would be sufficient to provide 2,000 Mg for each of the assumed 350 working days. Excess production is assumed to be mowed and left on the soil surface to decompose. However, in 28 of the 50 years, biomass production on the 73,856 ha leased would not be sufficient. Thus, on average, based on the parameter levels, it is not economically optimal to lease sufficient land to insure that biomass production in each year is sufficient to prevent shut downs beyond those required for maintenance.

For a biofuel price of \$0.50 L^{-1}, if Class I-IV land may be used, 52,085 ha would be optimally leased to produce an average feedstock quantity of 692,209 Mg y^{-1}. If land use is unrestricted, the average biorefinery downtime is 3.9 d y^{-1}. If 52,085 ha are leased, it costs \$58 to produce and transport one Mg of feedstock to the processing plant and the expected net returns are estimated at \$13.73 M y^{-1} (Table IV-1).

When land use is restricted to Classes III and IV, for a biofuel price of \$0.50 L^{-1}, 59,459 ha (Table IV-1) would be optimally leased. Most of the land leased is Class III with Class IV used in the county where the biorefinery is located taking advantage of the shorter field to biorefinery transportation distances. The land requirement is 12% greater than the quantity of land optimally leased when land from Classes I-IV can be leased. The average annual quantity of feedstock delivered is 692,355 Mg. This results in an average 3.8 d y^{-1} of plant downtime (Table IV-1).

The model is based on the assumption that land to be leased is identified in year zero based on an expected price. If in subsequent years the price is other than the original expectation, the quantity of land leased will either be more or less than optimal. For example, if the area leased is based on a price expectation of \$0.50 L^{-1}, and the actual price is \$1.00 L^{-1}, leased land would be 10,396 ha less than optimal and the expected net returns would be \$2 M y^{-1} less than optimal (Table IV-2). If on the other hand the area leased is based on a price expectation of \$1.00 L^{-1}, and the actual price is \$0.50 L^{-1}, leased land would be 10,396 ha more than optimal and the expected net returns would be \$5 M y^{-1} less than optimal (Table IV-2). If the land lease decision is based on a relatively high expected ethanol price, and if additionally the actual biofuel price was less than projected, the expected annual net returns decrease because of the additional cost associated with the greater quantity of land initially selected and seeded to switchgrass.

The results from model 1 are used to calculate the biorefinery investment payback period and the rate of return on invested capital, for each of the three land availability scenarios, using the expected annual net returns at each biofuel price. The payback period is the length of time required to recover the total initial investment cost, calculated as the ratio of the initial investment to the annual expected net cash flow of the project. The project net cash flow is estimated using the expected annual after tax net returns. The total initial investment cost includes the biorefinery investment cost, the investment in harvest machines, the investment in transportation trucks, and the switchgrass establishment cost. The biorefinery investment cost is estimated at \$220 M (EPA, 2010), the investment in harvest machines is estimated at \$30 M (Haque and Epplin, 2012). The number of trucks necessary to transport 2,000 Mg d^{-1} from the field to the biorefinery in each operating day is function of the average hauling distance, which depends on the location of the land leased. The optimal number of trucks is calculated following Wang (2009) and Kumar and Sokhansanj (2009) using the average transportation distance in each land use scenario. The purchase price of a class 8 truck with day cab and a 16 m flatbed trailer is budgeted at \$146,012 (USEPA, 2010). Depending on the biofuel price and the land use assumption, the estimated number of trucks necessary to transport 2,000 Mg d^{-1} ranges from 13 to 31.

Because the quantity of land optimally leased increases as land use is restricted, the switchgrass establishment cost as well as the average transportation distance and the number of trucks that would be required to haul the feedstock from field to the biorefinery vary across land use scenarios. As a consequence, for a given level of biofuel price, the biorefinery investment payback period increases and the project's rate of return on investment decreases as land use is restricted (Table IV-3). At lower ethanol prices ($0.50 L^{-1} or less), the 20-year period, projected in EPA (USEPA, 2010) as the biorefinery project life, would not be long enough for the biorefinery to breakeven, even if land use is unrestricted. For an ethanol price at $0.50 L^{-1} which is equivalent to an expected crude oil price of $80 barrel^{-1}, the investment payback period is 64 years if only land of Class IV could be leased and the expected rate of return on investment is 2% per year (Table IV-3). If land of Classes III and IV could be leased, the payback period is 38 years and the investment expected annual rate of return is 3% per year. When land use is unrestricted the project's payback period is 31 years with a 3% annual rate of return on investment (Table IV-3). For a biofuel price at $1.00 L^{-1} the investment payback period is constant at 3 years and the investment rate of return ranges from 30 to 35% (Table IV-3). These results suggest that with the USA Energy Information Administration's (EIA, 2015A) crude oil price projections between $81 and $141 barrel^{-1} for the period 2022 - 2040, it would be difficult for the biorefinery investment as modeled for the region to result in a payback period of less than 20 years.

Model 2: Optimal Land Lease with Interyear Storage

Model 2 is solved to identify the tradeoff between leasing enough land, storing biomass from year-to-year, and allowing some biorefinery downtime days in some years. The model is solved for a biofuel price at $0.75 L^{-1} ($131 barrel^{-1}), for three levels of estimated interyear storage cost and storage loss estimated to be 15% y^{-1}. If land lease is restricted to land Class IV, it is optimal to allow some downtime for the three levels of storage cost considered (Table IV-4). For the scenarios with land Classes III and IV, and Classes I-IV, model 2 selects enough land such that biomass produced when supplemented with interyear storage is sufficient to meet the biorefinery processing capacity in every year (Table IV-4).

If land use is restricted to Class IV, for a storage cost of \$6 Mg^{-1}, 76,786 ha are optimally leased and the average annual quantity of biomass delivered is 699,839 Mg. The expected annual net returns are estimated at \$66.8 M. If the storage cost is \$12 Mg^{-1}, 77,192 ha are optimally leased and the quantity of feedstock produced is 699,484 Mg. The annual expected net returns are estimated at \$66.5 M. For the storage cost of \$18 Mg^{-1}, 77,130 ha are optimally leased to deliver an average 698,921 Mg y^{-1}(Table IV-4). The expected net returns are \$66.2 M.

If land use is restricted to Classes III and IV, the quantity of land optimally leased is on average 27% less than that of the land leased when land use is restricted to Class IV (Table IV-4). For interyear storage cost of \$6 Mg^{-1}, it is optimal to lease 55,743 ha and deliver the 700,000 Mg of feedstock required by the biorefinery in every year. The expected annual net returns increase by 15% relative to when land use is restricted to Class IV. The quantity of land optimally leased is insensitive to the cost of interyear storage (Table IV-4).

If land use is unrestricted such that Classes I-IV can be leased, for storage cost of \$6 $\mathrm{Mg}^{-1}\ \mathrm{y}^{-1}$, 51,420 ha are optimally leased to deliver the annual 700,000 Mg of feedstock required by the biorefinery. The optimal land leased is 52,015 and 52,436 ha for storage costs of \$12 and \$18 Mg^{-1}, respectively. The expected annual net returns are estimated at \$79.5 M and \$79.4 M for storage cost of \$12 and \$18 Mg^{-1}, respectively (Table IV-4).

The total annual feedstock trucking distance from the field to the processing plant more than doubles when land use is restricted to Class IV compared to when land use is unrestricted (Table IV-4). For a storage cost of \$6 $\mathrm{Mg}^{-1}\ \mathrm{y}^{-1}$, the transportation distance increases from 2.6 M km y^{-1} to 5.8 M km y^{-1} (223% greater) when land use is restricted to Class IV. If the storage cost is \$18 Mg^{-1} y^{-1}, the trucking distance decreases from 5.8 M km y^{-1} when land use is restricted to Class IV, to 2.7 M km y^{-1} when land use is unrestricted (Table IV-4). The difference in the total travel distances across land use scenarios are nearly the same with model 1 as with model 2.

Discussion and Conclusion

The USA Department of Energy has proposed that dedicated energy crops such as switchgrass produced on marginal lands could provide a significant quantity of feedstock at low cost (USEPA, 2010). Additionally, the production of switchgrass on marginal land has been proposed as a way to produce something of value on millions of ha of policy idled land. The construction of a switchgrass biomass to biofuel biorefinery requires an investor, or group of investors, to provide the capital necessary to build a facility. Due diligence would require that investors be provided a business plan for providing a daily flow of switchgrass biomass throughout the year for the expected life of the biorefinery. To achieve cost economies a biorefinery may require 2,000 Mg d^{-1}, which would require production from thousands of hectares, and long-term lease contracts with hundreds of private landowners.

Conceptually, the expected objective of the investors would be to maximize expected net returns or to maximize the return on their investment. Based on this conceptual framework, the land area selected, leased, and seeded to switchgrass, would be determined and fixed in year zero, simultaneous with construction of the biorefinery. In year one and subsequent years, biomass production on the fixed land area would vary depending on soil characteristics and environmental conditions. The leased and planted land area may produce more biomass than can be processed in some years and insufficient biomass in others. Given the expected yield and variability across years, determining the optimal quantity of land to bid from current use and convert to switchgrass is not a trivial matter. Prudent investors would expect a reasonable plan to facilitate a flow of feedstock for the expected life of the biorefinery. Failure to provide feedstock would result in costly disruptions of biorefinery operations. Therefore, a management plan to secure a continuous feedstock supply would be required.

The present study determines the optimal land leased for an assumed biorefinery capacity, for a strategy that allows downtime days in those years when it is economical to do so, and a strategy that incorporates a storage capacity for three land availability scenarios when: (a) land use is restricted to Class IV; (b) land use is restricted to Classes III and IV; and (c) land use is unrestricted. The current study finds that restricting switchgrass production to less productive marginal land increases the land requirement, increases total biomass transportation distance, increases investment payback period, and reduces profitability. Ultimately, the specific land converted from existing use to the production of dedicated energy crops, will be determined by land owners and biomass businesses. Therefore, in the absence of government restrictions, it is unlikely that land use would be limited to marginal land. Public policies that impose restrictions on the type of land that may be converted from current use for energy crop production would increase biofuel production cost and reduce the likelihood of cellulosic biorefineries being built.

The modeling approach presents two main advantages. First, the model includes a strategy that enables idling the biorefinery in years of insufficient feedstock production due to switchgrass yield variability if it is economically optimal to do so. Second, the model endogenously integrates the penalty cost that would be incurred, when the processing plant is idled, due to insufficient feedstock. The approach captures the relative difference between the marginal cost of idling the processing plant and the marginal cost of leasing an additional unit of land to produce feedstock and avoid idling the plant. Also, even though the results are presented for a case study region, the model is highly applicable to other regions.

References for Chapter IV

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Table IV-1. Expected Annual Net Revenue, Average Number of Days of Biorefinery Downtime per Year, Average Feedstock Cost, Optimal Quantity of Land to Lease, and Total Trucking Distances for three Land Use and three Biofuel Price Scenarios

Land Classes permitted	Biofuel Price (\$ L^{-1})	Crude Oil Price (\$ barrel^{-1})[a]	Expected Net Revenue (M \$ y^{-1})	Land Leased (ha)	Class IV Land Leased[b] (ha)	Average Annual Feedstock Delivered (Mg)	Average Annual Feedstock Shortage (Mg)	Average Annual Downtime (d y^{-1})	Total Biomass Trucking Distance (000 km y^{-1})[c]
Class IV	0.50	80	6.80	73,856	73,856	683,797	16,203	8.1	5,752
Class III & IV			11.14	59,459	4,049	692,355	7,645	3.8	3,824
Class I, II, III, & IV			13.73	52,085	4,049	692,209	7,791	3.9	2,394
Class IV	0.75	131	64.80	80,605	80,605	693,698	6,302	3.2	5,832
Class III & IV			74.73	59,813	4,049	695,575	4,425	2.2	3,754
Class I, II, III, & IV			78.22	54,957	4,049	697,741	2,259	1.1	2,670
Class IV	1.00	182	126.55	84,252	84,252	696,408	3,592	1.8	5,842
Class III & IV			137.93	64,264	6,890	697,218	2,782	1.4	3,639
Class I, II, III, & IV			142.19	55,572	4,049	698,206	1,794	0.9	2,714

[a] The crude oil price is determined based on a linear regression (OLS) of the annual price of gasoline (1995-2013) on the annual crude oil price (1995- 2013) (EIA, 2015, B).

[b] For the case study region, 6% of the total land (713,716 ha) is Class I, 23% is Class II, 48% is Class III and 23% is Class IV.

[c] The transportation distance is calculated assuming that a truck can haul 16 Mg per load, and each load necessitates a roundtrip.

[d] The delivered feedstock cost includes the field production cost and the transportation cost.

Table IV-2. Expected Consequences of Underestimating and Overestimating the Long Run Expected Price of Ethanol if Land Use is Restricted to Class IV

Ethanol Price ($ L^{-1})	Actual Land Leased (ha)[a]	Expected Net Revenue (M $ y^{-1})[b]	Optimal Land Leased (ha)	Optimal Expected Net Revenue (M $ y^{-1})	Difference in Land Leased (ha)	Difference in Expected Net Returns (M $ y^{-1})[c]
Land leased based on an expected price of $0.50 L^{-1}						
0.50	73,856	6.8	73,856			
Outcome if actual price is $1.00 L^{-1}						
1.00	73,856	124.6	84,252	126.6	-10,396	-2.00
Land leased based on an expected price of $1.00 L^{-1}.						
1.00	84,252	126.6	84,252			
Outcome if actual price is $0.50 L^{-1}						
0.50	84,252	2.02	73,856	6.8	10,396	-4.78

[a] Quantity of land actually leased based on expectations in year zero.

[b] Expected net returns based on land actually leased with actual ethanol price.

[c] Expected cost of underestimating and overestimating the long run price of ethanol if land use is restricted to Class IV.

Table IV-3. Total Investment Requirement, Expected Annual Net Returns and Payback Period of the Biorefinery Investment for three Levels of Biofuel Price and three Land Use Scenarios

Land Classes Permitted	Biofuel Price ($ L^{-1})	Crude Oil Price ($ barrel^{-1}) [a]	Expected Net Revenue (M $ y^{-1})	Estimated Taxes[b] (M $ y^{-1})	Expected Net Revenue After Tax (M $ y^{-1})	Assumed Total Investment[c] (M $)	Expected Annual Rate of Return on Invested Capital (%)	Payback Period[d] (years)
Class IV	0.50	80	6.80	2.31	4.49	288.60	2%	64
Class III & IV			11.14	3.80	7.34	280.70	3%	38
Class I, II, III, & IV			13.73	4.71	9.03	277.70	3%	31
Class IV	0.75	131	64.80	16.26	48.53	291.10	17%	6
Class III & IV			74.73	20.58	56.54	281.00	20%	5
Class I, II, III, & IV			78.22	20.96	57.26	279.50	20%	5
Class IV	1.00	182	126.55	37.88	88.68	294.10	30%	3
Class III & IV			137.93	41.86	96.07	281.90	34%	3
Class I, II, III, & IV			142.19	43.35	98.84	280.30	35%	3

[a] The crude oil price is determined based on a linear regression (OLS) of the annual price of gasoline (1995-2013) on the annual crude oil price (1995- 2013) (EIA, 2015, B).

[b] The estimated taxes are calculated using the federal and the Oklahoma state corporate income tax rates. The federal income tax rate varies with the level of taxable income while the Oklahoma corporate tax rate is flat at 6%.

[c] The total investment cost includes the initial biorefinery investment for a plant with a processing capacity of 262.5 M L y^{-1}, the investment in harvest machines, the investment in transportation trucks, and the switchgrass establishment cost.

[d] The payback period is the length of time required to recover the total initial investment cost with the corresponding expected annual net returns.

Table IV-4. Optimal Land Leased, Feedstock Storage and Shortage, and Feedstock Cost for three Land Use Scenarios and three Levels of Storage Cost[a]

Land Classes Permitted	Storage Cost ($ Mg^{-1})	Expected Net Revenue (M $ y^{-1})	Land Leased (ha)	Average Annual Feedstock Shortage (Mg)	Average Annual Feedstock Delivered (Mg)	Average Annual Feedstock Stored (Mg)	Total Biomass Trucking Distance (000 km y^{-1})[b]	Delivered Feedstock Cost ($ Mg^{-1})
Class IV	6	66.8	76,786	161	699,839	44,445	5,844	64
Class III & IV		76.9	55,743	0	700,000	31,347	3,786	64
Class I, II, III, & IV		79.7	51,420	0	700,000	31,796	2,621	60
Class IV	12	66.5	77,192	516	699,484	35,080	5,835	68
Class III & IV		74.7	55,926	0	700,000	28,419	3,783	64
Class I, II, III, & IV		79.5	52,015	0	700,000	20,977	2,638	60
Class IV	18	66.3	77,130	1,079	698,921	29,943	5,813	68
Class III & IV		76.5	56,488	0	700,000	22,875	3,776	64
Class I, II, III, & IV		79.4	52,436	0	700,000	15,310	2,659	60

[a] A biofuel price at $ 0.75 L^{-1} ($131 barrel^{-1}) is assumed to solve model 2 for different storage costs and 15% annual dry matter storage loss.

[b] The transportation distance is calculated assuming that a truck can haul 16 Mg per load, and each load necessitates a roundtrip

Appendix for Chapter IV: GAMS Code for Model 1 with Unrestricted Land Use

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$OFFUPPER OFFSYMXREF OFFSYMLIST OFFUELLIST OFFUELXREF
OPTIONS LIMROW=0, LIMCOL=0;
OPTION OPTCR = 0.0000;
option lp=minos;
OPTION RESLIM=1000000;
OPTION ITERLIM=5000000;
SETS
C Counties
/ATOK, CANA, CLEV, COAL, CREK, GARV, GRAD, HASK, HUGH, JOHN,
LOGN,  LINC,  McCL,  McIN, MURR, MUSK, NOBL, OKFU, OKLA, OKMU
OSAG,  PAWN,  PYNE,  PITS, PONT, POTT, LATI, SEMI, TULS, WAGN/
L land class
/CLS1, CLS2, CLS3, CLS4/
T Time periods
/1*50/
;
PARAMETER Yr(T);
Yr(T) = ORD(T);
TABLE LandRent(C, L) Rental costs of land $ per hectare 'No Class1 type soil for ATOK
                     COAl & LATI'
              CLS1          CLS2           CLS3           CLS4
ATOK        000.00        062.92        057.79        041.01
CANA        139.81        131.89        101.16        071.05
CLEV        137.22        121.81        080.88        067.32
COAL        000.00        119.84        098.27        096.86
CREK        053.98        048.49        041.47        027.69
GARV        123.56        113.35        079.40        061.49
GRAD        123.04        108.98        081.42        063.28
HASK        144.91        126.80        094.92        072.75
HUGH        146.10        127.83        103.33        091.31
JOHN        079.50        067.08        052.61        043.72
LATI        000.00        105.05        091.40        076.27
LINC        135.43        122.54        090.62        077.39
LOGN        173.44        149.11        111.27        074.67
McCL        145.71        137.05        092.88        094.84
McIN        062.22        052.20        045.11        033.93
MURR        077.37        068.25        050.94        045.39
MUSK        153.21        138.16        106.53        090.53
NOBL        165.19        150.09        106.62        084.95
OKFU        129.54        113.17        085.41        067.68
OKLA        136.12        120.98        086.41        064.26
OKMU        127.28        117.29        091.63        081.46
OSAG        166.46        154.76        110.97        094.93
PAWN        130.46        122.37        085.02        063.18
PYNE        164.57        149.28        105.79        074.67
PITS        055.96        048.53        037.73        028.96
PONT        105.38        099.90        077.56        063.23
POTT        153.62        137.16        102.01        093.27
SEMI        115.77        110.50        079.34        069.11
TULS        143.65        135.84        102.43        085.93
WAGN        149.89        137.16        114.02        090.39
;
SCALAR LF                  Standard Life/20/;
SCALAR EST                 Establishment costs without land rent/394.45/;
*/Turhollow, A.F. and F.M. Epplin.  "Estimating Region Specific Costs to Produce and
Deliver Switchgrass."
*/Chapter 8 in Switchgrass: A Valuable Biomass Crop for Energy.  ed. Andrea Monti, New
York: Springer Publishing Co. 2012
PARAMETER ESTCST(C,L)      Total amortization costs per hectare land;
ESTCST(C,L)= LandRent(C,L)+ EST;
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SCALAR R "Amortization Rate"/0.065/;
SCALAR req                    Total biomass requirement (Mg per year)/700000/;
SCALAR D                      Discount rate/0.065/;
SCALAR TP                     Project life in years/20/;
PARAMETER BETA                Discount Factor;
BETA = 1+R;
PARAMETER PVAF               Present value of an annuity factor;
PVAF= [POWER{(1+D),TP}-1]/[D*POWER{(1+D),TP}];
PARAMETER AMORTCOST(C,L) Total amortization costs per hectare land;
AMORTCOST(C,L)=((LandRent(C,L)+ EST)*((1+R)**LF*R))/((1+R)**LF-1);
SCALAR NIT                   Nitrogen applied Kg per hectare/78/;
SCALAR PN                    Price of Nitrogen $ per Kg/1.23/;
SCALAR AM                    Annual maintainence cost per hectare/9.63/
SCALAR MOW                   Cost of Mowing per hectare/30.97/;
SCALAR RAK                   Cost of Raking per hectare/18.89/;
*/Turhollow, A.F. and F.M. Epplin.  "Estimating Region Specific Costs to Produce and
Deliver Switchgrass." */Chapter 8 in Switchgrass: A Valuable Biomass Crop for Energy.
ed. Andrea Monti, New York: Springer Publishing Co. 2012
PARAMETER LNDCST(C,L)        Total production costs per hectare;
LNDCST(C,L)= AMORTCOST(C,L) + PN*NIT+AM+MOW;
PARAMETER PRODCST(C,L)       Total production costs per hectare;
PRODCST(C,L) = AMORTCOST(C,L) + LandRent(C,L)+PN*NIT+AM+MOW;
SCALAR  Bal                 Cost of Baling per Mg/28.89/;
SCALAR  Invest              Capital investment for the processing plant In 2013 US $
/19966406.98/;
SCALAR  Investstor          storage Capital Investment for the stotage facilty/0/;
scalar  opcost              Annual Biorefinery Operation and maintenance cost
/48000000/;
SCALAR  conv                convertion factor (Gallons of biofuel per MG of
feedstock)/100/;
SCALAR  VPCST               variable processing cost excluding feedstock /12.86/;
TABLE   DIS(C, L)           Distance form Centroid of Soil Class in County C Soil class
                            L  to the biorefinery location in Km 'No Class1 type soil
                            for ATOK COAl & LATI'
             CLS1           CLS2          CLS3          CLS4
ATOK        000.00         099.93        104.00        114.12
CANA        247.35         267.64        258.65        219.88
CLEV        165.93         146.02        167.48        137.31
COAL        000.00         037.25        073.64        077.07
CREK        044.43         047.05        045.27        057.69
GARV        185.10         162.31        181.20        164.78
GRAD        260.56         233.89        255.90        274.69
HASK        163.82         190.09        188.06        193.77
HUGH        039.72         025.73        030.38        030.46
JOHN        135.27         093.26        065.82        096.98
LATI        000.00         172.89        164.57        189.26
LOGN        060.97         119.10        090.22        098.26
LINC        157.90         173.23        175.13        169.75
McCL        211.61         150.59        157.95        135.23
McIN        054.01         100.00        074.59        098.46
MURR        140.83         133.04        143.21        134.63
MUSK        165.22         132.42        145.03        128.49
NOBL        172.83         188.31        154.69        164.95
OKFU        011.98         015.94        012.82        015.87
OKLA        202.34         174.05        186.53        140.31
OKMU        055.46         056.58        060.08        062.52
OSAG        134.19         092.53        114.38        041.05
PAWN        092.41         118.35        145.65        117.34
PYNE        152.19         097.77        113.23        103.30
PITS        075.19         088.77        091.72        106.52
PONT        093.78         088.64        090.99        095.48
POTT        103.36         105.15        111.85        100.41
SEMI        037.92         045.99        066.29        060.00
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TULS        100.73        094.35        079.62        087.89
WAGN        121.87        151.99        121.84        137.74
;
SCALAR FXCT                Fixed cost of transportation $ per Mg/0.879856/;
SCALAR VRCT                Variable cost of transportation $ per Mg"/0.284941/;
PARAMETER TRNSCST(C,L)     Transportation cost in $ per dry Mg truck;
TRNSCST(C,L) = (FXCT + VRCT*DIS(C,L));
TABLE TOTLAND(C, L)        Hectare of land class capability IV by county and land
                           class 'No Class1 type soil for ATOK COAl & LATI'
                           */20 percent of the total land of capability class III is
                           assumed to be available for lease
             CLS1            CLS2           CLS3            CLS4
ATOK        0000.00       05054.40        11718.80        8633.40
CANA        9254.60       11441.00        12761.20        5656.60
CLEV        1320.00        4172.40         6490.60       11858.80
COAL        0000.00        1996.00         9960.40        3165.80
CREK        2666.00        7171.00         8007.20        7444.60
GARV        3387.80        7585.40        15682.00        1966.40
GRAD        3975.00       10712.60        21739.60        6320.00
HASK        0129.40        2137.00        11145.40        2171.80
HUGH        0657.60        5212.80        12149.60        2841.60
JOHN        0213.20        7075.60         9098.20        8409.80
LATI        0000.00        1478.20         4789.80        2401.00
LOGN        0430.40        4720.60        12728.40        9074.40
LINC        0502.00        5786.20        8839.80         3918.60
McCL        1283.20        4734.20        11359.60        1567.00
McIN        0027.20        3434.80        12114.40        5203.60
MURR        0359.20        1849.20        4671.80         1706.00
MUSK        1090.60        9697.60        18483.40        3119.20
NOBL        1288.60       10504.00        13176.40        3585.40
OKFU        1544.00        2303.00         7395.20        4048.80
OKLA        1185.80        5605.20        12223.00        9766.80
OKMU        1086.60        6769.00         9829.40         848.60
OSAG        3188.40        9264.20        33822.20       23300.00
PAWN        1297.60        3473.40         9188.40        2731.20
PYNE        0570.80        4840.00        10266.00        7139.20
PITS        0284.00        5480.40        11844.80        3203.40
PONT        093.20         5035.20        10884.40        4631.20
POTT        1335.80        5822.00        10492.40        4160.80
SEMI        0240.40        2756.80         5174.00        3604.00
TULS        4553.60        5460.20         4138.20        5666.60
WAGN        1545.40        4586.40         8879.60        6847.60
;

TABLE AvgYld(C,L)        Average biomass yield by county and land class (Mg per ha)
                         'No Class1 type soil for ATOK COAl & LATI'
            CLS1         CLS2         CLS3          CLS4
ATOK        00.00        16.90        12.84        10.56
CANA        16.43        14.71        11.55        09.15
CLEV        18.32        16.32        13.85        11.01
COAL        00.00        16.45        11.94        08.68
CREK        16.24        11.53        10.56        08.23
GARV        15.39        15.39        13.38        11.06
GRAD        15.53        15.53        14.74        11.23
HASK        17.77        14.95        14.81        11.13
HUGH        16.01        15.46        13.39        08.64
JOHN        17.92        15.53        11.75        08.54
LATI        00.00        16.57        12.47        09.40
LOGN        17.28        15.45        12.18        07.65
LINC        16.47        14.79        13.38        11.23
McCL        16.96        15.04        11.83        08.40
McIN        15.74        15.74        13.70        10.17
MURR        17.66        15.72        12.22        09.53
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MUSK        16.14        15.61        14.94        13.72
NOBL        15.76        13.98        11.20        07.94
OKFU        17.72        16.04        15.97        12.12
OKLA        17.67        17.17        14.90        11.27
OKMU        16.24        15.57        13.02        09.90
OSAG        16.71        15.12        12.05        09.98
PAWN        16.80        15.11        12.18        09.51
PYNE        15.91        15.91        11.60        10.08
PITS        17.45        16.46        12.13        09.05
PONT        16.62        14.80        11.65        09.05
POTT        17.92        15.96        12.54        08.51
SEMI        17.28        17.28        12.21        10.16
TULS        15.93        15.94        12.73        09.19
WAGN        18.27        17.71        17.00        11.61
;
TABLE AnYld (T,C,L) Annual EPIC simulated biomass yield by county and land class

    ATOK.CLS1  ATOK.CLS2  ATOK.CLS3  ATOK.CLS4  CANA.CLS1  CANA.CLS2  CANA.CLS3  CANA.CLS4
 1     00.00      19.20      16.08      11.80      18.58      17.59      11.52      09.88
 2     00.00      15.67      12.66      08.80      13.31      10.12      09.85      06.24
 3     00.00      17.03      15.72      11.90      15.75      15.12      12.94      09.49
 4     00.00      19.38      17.10      13.47      17.53      16.47      14.80      08.59
 5     00.00      20.78      16.30      11.18      16.95      16.64      12.95      09.02
 6     00.00      15.89      13.47      12.56      17.34      14.92      14.50      12.02
 7     00.00      16.20      12.29      12.20      17.87      16.57      14.25      11.54
 8     00.00      18.33      11.73      09.76      14.12      13.03      10.11      08.27
 9     00.00      15.94      13.98      12.89      14.14      12.28      12.24      07.71
10     00.00      20.19      17.44      12.36      15.75      13.33      11.39      10.31
11     00.00      17.02      13.92      11.80      11.47      10.58      10.07      07.64
12     00.00      20.15      14.21      11.14      17.50      17.48      12.51      09.49
13     00.00      19.15      16.44      14.15      17.77      15.52      12.66      10.81
14     00.00      20.20      14.46      09.98      18.11      16.52      12.50      10.03
15     00.00      17.20      14.51      09.72      17.71      10.96      09.76      09.22
16     00.00      12.56      11.18      06.58      16.81      15.22      13.11      11.11
17     00.00      12.57      11.87      07.97      12.97      11.21      09.75      05.99
18     00.00      18.66      14.62      09.20      16.74      15.71      12.76      09.78
19     00.00      11.66      10.21      09.95      12.65      11.13      07.92      07.45
20     00.00      16.73      15.69      12.73      16.60      15.44      13.56      07.98
21     00.00      15.86      13.20      13.10      17.42      15.68      11.04      09.67
22     00.00      13.54      12.50      09.28      14.90      14.67      10.59      08.22
23     00.00      15.74      12.16      07.35      17.33      13.37      08.75      06.91
24     00.00      15.83      11.03      10.97      18.77      16.14      10.60      09.09
25     00.00      16.05      12.39      09.30      18.40      16.89      13.18      12.70
26     00.00      17.47      13.21      12.54      18.06      16.36      12.49      11.08
27     00.00      11.76      08.64      06.98      17.40      12.50      07.08      06.97
28     00.00      20.82      14.14      12.11      19.31      18.31      16.89      11.86
29     00.00      14.35      08.14      07.95      16.77      14.06      07.91      07.72
30     00.00      18.15      10.63      10.36      18.97      16.84      14.43      09.50
31     00.00      19.20      12.85      11.85      18.25      18.16      14.02      13.46
32     00.00      18.15      14.70      13.68      16.96      16.10      13.69      07.75
33     00.00      19.57      12.03      11.98      18.07      16.81      09.59      08.49
34     00.00      15.49      10.93      10.64      14.44      14.09      13.48      09.26
35     00.00      19.22      12.63      11.52      16.80      16.80      13.19      11.55
36     00.00      16.85      08.40      08.20      14.48      13.36      12.34      09.74
37     00.00      11.26      06.85      05.76      15.99      11.15      05.93      05.75
38     00.00      16.67      12.99      09.77      16.60      16.18      10.61      10.46
39     00.00      13.13      11.79      10.69      16.27      13.40      09.20      09.15
40     00.00      18.70      11.95      12.11      18.46      16.56      12.06      11.85
41     00.00      18.77      11.06      10.59      13.02      11.12      10.08      09.17
42     00.00      17.20      15.37      11.88      14.25      12.82      09.82      08.37
43     00.00      19.98      15.79      10.94      13.47      12.57      10.35      07.07
44     00.00      15.84      11.46      11.28      17.16      17.14      14.75      07.62
45     00.00      13.40      09.62      09.32      17.40      14.36      09.90      05.49
```

46	00.00	17.66	11.32	10.92	18.25	18.06	13.97	12.80
47	00.00	21.12	12.86	10.66	19.53	18.12	12.53	09.35
48	00.00	18.22	11.99	09.52	14.79	14.69	11.96	08.63
49	00.00	17.63	16.57	08.46	18.41	15.52	10.46	08.65
50	00.00	12.91	11.05	07.94	11.66	07.68	07.40	04.96
+	CLEV.CLS1	CLEV.CLS2	CLEV.CLS3	CLEV.CLS4	COAL.CLS1	COAL.CLS2	COAL.CLS3	COAL.CLS4
1	17.91	17.56	14.74	11.37	00.00	16.83	11.63	10.66
2	14.61	12.36	09.78	08.96	00.00	18.01	09.96	06.51
3	16.67	15.79	13.52	12.50	00.00	16.59	11.87	07.12
4	19.07	18.83	16.46	11.60	00.00	17.66	09.82	05.58
5	20.83	19.77	17.23	13.26	00.00	19.78	11.88	10.22
6	20.03	17.60	15.35	07.72	00.00	14.32	13.11	08.44
7	19.52	19.48	17.64	12.03	00.00	14.97	14.01	09.16
8	18.90	17.97	15.22	11.45	00.00	15.63	12.21	09.94
9	16.87	15.36	12.98	11.02	00.00	16.29	11.72	09.39
10	18.19	16.77	13.95	12.44	00.00	18.50	15.00	08.78
11	14.90	13.36	11.20	10.72	00.00	18.23	11.19	07.93
12	20.68	20.57	18.51	11.47	00.00	12.88	11.53	09.51
13	19.48	18.51	15.45	11.38	00.00	17.58	15.68	09.63
14	19.76	19.74	14.99	11.85	00.00	18.02	15.73	09.63
15	19.55	17.14	13.66	11.31	00.00	17.72	13.04	10.05
16	20.01	13.51	10.65	10.37	00.00	16.69	11.10	11.04
17	19.75	17.36	14.79	11.71	00.00	19.58	09.55	08.18
18	18.16	18.12	13.43	09.99	00.00	17.60	12.45	10.43
19	19.98	17.25	13.38	11.48	00.00	19.13	12.85	09.41
20	16.32	15.65	12.51	12.46	00.00	14.58	11.60	10.08
21	18.04	16.81	10.48	10.37	00.00	12.98	11.76	09.77
22	17.25	17.20	13.71	11.52	00.00	18.89	10.29	06.02
23	19.29	18.55	15.18	11.79	00.00	17.40	09.92	05.57
24	19.18	18.87	16.74	11.03	00.00	18.36	14.02	10.71
25	18.41	17.48	15.64	11.12	00.00	14.87	13.54	11.13
26	18.10	17.09	15.36	11.83	00.00	15.05	12.37	10.13
27	18.92	16.38	12.32	10.97	00.00	18.47	08.10	06.12
28	17.29	16.82	14.09	11.61	00.00	15.01	13.40	11.10
29	17.03	16.78	12.67	09.39	00.00	12.84	08.90	09.46
30	17.32	16.40	15.49	11.55	00.00	12.97	10.18	10.06
31	19.40	18.28	17.90	11.25	00.00	13.30	12.55	08.82
32	16.89	16.39	15.46	11.96	00.00	13.87	13.36	10.13
33	18.62	17.25	14.90	11.82	00.00	13.50	12.69	08.33
34	15.54	12.11	11.72	11.09	00.00	16.63	13.44	09.23
35	18.74	18.62	17.65	11.56	00.00	15.90	14.22	09.05
36	16.26	15.63	14.41	11.13	00.00	17.02	11.58	08.74
37	16.70	11.62	09.01	08.48	00.00	14.92	07.04	06.37
38	19.36	18.13	14.93	11.33	00.00	17.32	13.38	08.52
39	17.84	12.73	11.84	09.83	00.00	15.45	09.70	05.54
40	19.92	18.29	16.75	12.86	00.00	18.89	12.38	09.32
41	19.91	16.80	16.13	11.56	00.00	17.97	11.59	09.12
42	19.53	13.63	10.56	10.40	00.00	18.00	13.03	07.11
43	20.67	13.43	10.79	10.47	00.00	17.67	11.75	05.99
44	20.03	13.66	12.94	11.52	00.00	18.95	12.20	08.25
45	16.14	14.65	12.27	10.10	00.00	14.33	08.30	04.95
46	18.15	17.55	13.77	11.13	00.00	18.23	13.28	10.40
47	19.15	16.30	14.78	10.71	00.00	19.77	13.81	09.69
48	17.29	13.50	11.21	10.06	00.00	12.86	12.21	08.82
49	18.91	12.90	10.39	09.41	00.00	15.72	12.56	09.33
50	15.13	09.51	07.80	07.67	00.00	14.66	09.48	04.33
+	CREK.CLS1	CREK.CLS2	CREK.CLS3	CREK.CLS4	GRAD.CLS1	GRAD.CLS2	GRAD.CLS3	GRAD.CLS4
1	14.99	11.89	08.89	08.57	18.76	18.76	18.16	13.89
2	16.22	10.44	09.95	07.49	14.04	14.04	09.32	09.42
3	16.52	12.42	12.10	08.50	13.98	13.98	12.81	13.23
4	17.92	11.07	10.80	08.71	17.56	17.56	16.23	13.21
5	18.67	13.50	13.04	08.62	17.04	17.04	15.71	14.27
6	18.68	13.91	12.45	10.70	15.46	15.46	13.46	12.82

7	17.35	12.65	11.17	10.03	13.70	13.70	12.69	12.91
8	17.82	10.58	10.25	08.16	13.98	13.98	12.88	11.14
9	13.57	10.15	09.61	09.49	07.59	07.59	06.12	06.10
10	19.09	14.86	11.13	08.04	10.86	10.86	09.31	11.92
11	16.90	08.04	07.62	07.46	12.17	12.17	10.79	07.86
12	14.69	12.14	11.61	08.17	17.39	17.39	15.84	15.54
13	15.30	14.58	13.27	07.52	16.08	16.08	13.61	10.44
14	16.41	13.93	13.90	11.62	17.34	17.34	17.22	12.24
15	17.42	11.20	10.71	07.62	18.53	18.53	13.16	14.04
16	15.23	09.28	07.73	07.25	14.36	14.36	12.44	11.80
17	14.46	08.80	07.70	05.72	13.66	13.66	12.14	09.27
18	18.61	11.77	11.42	09.81	16.11	16.11	14.54	12.65
19	12.60	09.33	09.01	06.66	11.41	11.41	10.32	09.33
20	14.11	10.54	10.00	09.54	15.87	15.87	14.49	14.04
21	16.70	10.58	08.92	07.97	18.77	18.77	17.83	13.69
22	15.92	08.55	08.16	08.15	14.46	14.46	11.60	10.62
23	17.03	10.43	09.81	07.62	17.05	17.05	12.52	09.69
24	15.92	09.89	09.45	08.78	15.13	15.13	14.80	11.36
25	15.34	10.55	10.38	09.18	15.50	15.50	13.92	10.98
26	15.53	10.50	09.98	09.72	16.90	16.90	15.31	14.78
27	16.52	06.32	06.21	07.60	18.17	18.17	12.70	09.63
28	17.83	14.38	14.06	08.80	16.45	16.45	16.41	14.62
29	14.23	06.25	05.66	05.49	14.80	14.80	14.54	10.14
30	17.22	13.37	12.41	09.72	17.12	17.12	15.38	12.58
31	14.91	14.11	13.31	09.49	16.99	16.99	13.00	15.65
32	15.78	10.58	08.93	05.67	15.17	15.17	12.04	13.21
33	18.98	15.16	14.89	10.66	17.76	17.76	13.27	11.07
34	13.64	13.19	09.41	08.41	12.71	12.71	10.35	10.96
35	17.88	11.72	10.52	06.21	16.18	16.18	15.77	08.25
36	17.34	12.42	12.37	10.52	16.25	16.25	14.35	10.09
37	12.64	05.77	04.73	04.63	14.40	14.40	10.86	07.57
38	16.73	13.13	11.57	08.07	16.04	16.04	13.84	09.26
39	15.35	10.17	09.74	08.36	12.05	12.05	09.48	09.69
40	16.28	11.31	10.94	09.40	16.65	16.65	13.01	09.61
41	16.18	11.76	11.09	07.51	14.49	14.49	11.13	10.63
42	18.40	16.52	14.68	07.45	15.87	15.87	13.82	10.15
43	18.09	10.65	10.11	07.45	14.83	14.83	12.75	09.63
44	17.44	15.58	11.23	07.66	15.83	15.83	14.46	09.19
45	17.09	09.80	09.07	06.60	13.64	13.64	12.21	07.46
46	15.73	15.47	13.66	07.02	17.13	17.13	15.99	11.12
47	15.45	12.86	12.04	09.59	19.08	19.08	18.47	10.03
48	14.21	10.99	10.27	07.00	16.56	16.56	15.58	07.57
49	16.87	14.72	14.37	10.07	16.04	16.04	14.12	08.19
50	14.14	08.46	07.86	05.70	11.38	11.38	08.31	07.63
+	GARV.CLS1	GARV.CLS2	GARV.CLS3	GRAV.CLS4	HASK.CLS1	HASK.CLS2	HASK.CLS3	HASK.CLS4
1	14.70	14.70	14.54	08.70	19.16	17.95	17.95	13.55
2	13.41	13.41	12.71	11.19	17.34	08.71	08.71	07.69
3	12.04	12.04	11.59	10.79	18.11	12.56	12.56	09.71
4	14.10	14.10	13.63	11.33	20.76	15.82	15.82	14.86
5	13.13	13.13	12.77	11.36	19.92	14.49	14.49	11.41
6	13.79	13.79	12.66	11.80	20.95	17.87	17.87	13.25
7	17.21	17.21	17.16	11.63	17.38	16.09	16.09	13.01
8	16.94	16.94	16.82	11.26	18.91	12.53	12.53	11.62
9	13.65	13.65	12.36	10.42	15.54	13.87	13.87	10.49
10	17.23	17.23	16.68	12.03	19.16	18.40	18.40	13.55
11	16.18	16.18	13.10	13.04	18.77	13.73	11.13	08.72
12	16.71	16.71	16.01	10.17	18.68	13.48	13.48	12.80
13	16.23	16.23	16.21	11.56	17.09	14.87	14.87	11.81
14	13.67	13.67	12.35	07.48	17.71	16.54	16.54	13.73
15	17.27	17.27	17.27	11.76	19.06	17.21	17.21	13.20
16	15.67	15.67	15.50	11.79	17.64	14.02	14.02	13.38
17	12.73	12.73	11.86	11.35	17.47	11.70	11.70	10.03
18	16.38	16.38	15.13	10.92	17.10	14.97	14.97	12.77

19	13.54	13.54	12.63	12.08	15.71	12.37	12.37	09.95
20	16.67	16.67	16.49	11.35	15.94	15.64	15.64	13.20
21	16.40	16.40	15.41	12.11	17.82	17.07	17.07	12.90
22	16.20	16.20	14.01	10.85	16.81	13.64	12.09	08.14
23	16.96	16.96	15.19	11.67	18.61	17.59	17.59	13.02
24	14.62	14.62	14.30	11.29	17.30	15.99	15.99	11.27
25	14.38	14.38	13.55	11.47	16.31	13.49	13.49	12.68
26	15.30	15.30	14.69	10.76	16.95	15.82	15.82	12.25
27	14.86	14.86	14.31	11.88	18.52	14.42	14.42	09.23
28	17.46	17.46	17.42	13.05	18.16	16.33	16.33	11.72
29	13.87	13.87	12.05	08.57	14.36	10.83	10.83	10.73
30	16.79	16.79	15.83	11.61	18.55	14.73	14.73	11.04
31	17.71	17.71	16.90	13.05	19.75	18.16	18.16	14.47
32	16.49	16.49	16.00	10.59	15.06	14.80	14.80	11.01
33	17.52	17.52	15.66	10.96	19.86	19.01	18.17	14.01
34	11.85	11.85	10.47	10.29	12.31	10.68	10.68	09.74
35	15.69	15.69	15.36	11.02	19.20	14.17	14.17	11.65
36	16.42	16.42	15.51	12.59	18.37	16.10	16.10	12.96
37	12.31	12.31	11.71	10.86	16.89	13.06	13.06	09.53
38	17.92	17.92	17.86	11.07	16.53	16.16	16.16	12.02
39	13.14	13.14	13.02	10.67	18.00	14.11	14.11	08.29
40	17.72	17.72	17.61	12.18	18.42	15.47	15.47	09.68
41	17.05	17.05	16.98	11.48	18.73	15.84	15.84	09.57
42	17.14	17.14	17.09	11.20	18.34	16.38	16.38	10.83
43	19.51	19.51	19.51	11.95	18.35	16.09	16.09	08.82
44	17.13	17.13	15.00	11.64	18.67	16.71	15.02	09.23
45	13.06	13.06	12.24	10.85	17.67	14.37	14.37	07.75
46	16.06	16.06	13.24	10.84	18.74	17.82	17.82	11.20
47	16.88	16.88	16.46	12.15	17.80	17.26	17.26	11.45
48	16.49	16.49	16.24	11.53	16.12	11.80	11.80	06.67
49	16.19	16.19	15.57	11.22	18.31	16.62	16.62	09.10
50	12.05	12.05	10.24	10.05	15.53	10.06	10.06	06.60

+	HUGH.CLS1	HUGH.CLS2	HUGH.CLS3	HUGH.CLS4	JOHN.CLS1	JOHN.CLS2	JOHN.CLS3	JOHN.CLS4
1	16.54	16.37	15.29	09.35	17.06	16.35	10.49	08.79
2	16.50	16.07	11.77	05.55	18.52	12.01	07.88	06.83
3	15.47	15.26	13.01	05.90	15.52	13.79	11.18	07.23
4	16.27	16.16	14.15	07.85	16.87	15.69	11.71	09.70
5	16.04	15.93	13.18	08.99	18.64	17.12	11.41	08.39
6	16.86	16.01	14.28	07.31	18.22	16.16	10.25	08.85
7	16.57	15.45	13.17	10.90	16.58	14.60	13.80	11.42
8	18.26	17.74	16.08	10.40	19.10	17.82	12.14	10.08
9	16.54	16.38	14.85	07.93	17.34	15.41	10.48	07.60
10	18.47	18.17	16.65	10.59	19.25	18.91	13.73	09.14
11	17.15	17.13	13.22	06.06	18.53	15.35	11.49	06.57
12	17.00	16.36	14.39	10.21	16.11	14.42	13.59	10.02
13	15.17	14.57	13.64	11.90	16.93	16.90	14.01	10.71
14	14.88	12.58	10.61	10.23	20.05	18.08	15.03	08.70
15	19.21	17.07	11.80	04.94	16.34	14.61	10.70	09.23
16	17.26	17.00	15.46	09.81	17.55	14.71	11.04	08.16
17	14.94	14.61	12.57	07.41	21.02	15.15	13.10	08.36
18	15.13	14.92	13.15	10.38	19.56	19.03	12.36	09.30
19	09.88	09.67	08.97	05.95	19.55	12.16	09.72	05.35
20	15.75	15.41	14.46	10.69	15.27	15.21	14.06	12.36
21	13.71	12.75	10.16	09.03	19.99	16.88	11.85	11.60
22	16.76	16.47	15.13	08.77	18.55	13.76	10.95	07.24
23	17.65	17.61	14.99	04.23	18.25	15.70	11.30	10.23
24	14.54	14.53	12.86	09.13	17.37	14.20	12.68	09.80
25	16.42	16.28	14.48	08.22	17.30	16.95	12.86	08.04
26	17.15	16.92	15.52	10.16	17.16	16.24	13.97	09.59
27	17.07	17.06	12.44	04.71	19.43	15.11	08.91	05.54
28	17.82	17.63	17.60	08.75	17.58	15.61	12.01	06.73
29	12.79	11.24	10.35	09.50	13.83	13.23	06.34	06.51
30	14.09	13.48	12.07	10.32	17.53	16.06	13.56	10.74

31	12.63	11.66	10.08	09.68	20.79	17.33	11.10	10.34
32	14.33	13.58	12.42	09.08	16.88	15.34	13.26	09.54
33	19.00	18.82	16.19	10.80	17.57	17.37	11.92	08.26
34	16.02	15.37	13.15	08.60	16.41	13.28	12.36	07.49
35	15.43	14.32	12.60	10.49	20.76	15.23	11.51	10.10
36	17.36	17.27	15.88	09.01	18.59	15.05	09.70	07.30
37	15.79	15.22	09.67	06.21	16.35	11.40	07.06	05.50
38	16.00	14.45	12.21	10.33	17.87	14.59	11.79	07.81
39	16.43	16.03	12.83	06.44	16.86	11.19	10.06	06.98
40	16.40	16.02	13.48	07.51	19.16	17.76	12.89	08.25
41	16.63	16.61	15.30	10.22	17.79	16.59	15.23	10.31
42	17.72	17.71	15.36	08.94	19.05	16.68	11.62	07.13
43	16.86	15.01	12.77	10.10	21.14	18.38	14.29	10.40
44	16.62	16.55	16.18	09.20	18.89	17.40	13.52	07.99
45	13.48	13.38	11.11	02.51	15.52	13.32	08.01	05.19
46	16.38	16.29	11.50	10.31	18.86	18.32	11.84	08.94
47	17.32	16.97	15.01	09.84	20.05	17.54	14.44	09.36
48	15.76	14.65	12.63	10.25	15.38	13.95	11.67	08.60
49	16.20	15.78	15.09	10.52	17.39	16.57	12.42	09.11
50	12.14	10.48	09.84	06.96	15.66	11.89	10.10	05.71

+	LATI.CLS1	LATI.CLS2	LATI.CLS3	LATI.CLS4	LINC.CLS1	LINC.CLS2	LINC.CLS3	LINC.CLS4
1	00.00	17.10	12.82	10.82	18.49	16.96	11.26	10.01
2	00.00	13.37	08.35	05.76	15.38	10.90	09.77	04.50
3	00.00	15.72	11.01	09.99	18.68	18.41	15.55	08.68
4	00.00	18.80	13.19	08.85	19.90	18.90	13.73	08.66
5	00.00	19.32	09.24	11.24	17.58	13.82	10.80	07.88
6	00.00	18.67	14.36	09.99	19.99	18.85	13.85	07.15
7	00.00	18.34	14.00	11.40	18.20	15.00	12.11	06.23
8	00.00	19.27	13.64	10.18	17.71	15.52	11.66	07.12
9	00.00	18.68	13.16	09.75	13.17	12.44	10.77	03.66
10	00.00	18.80	13.89	09.36	18.83	17.98	12.58	06.51
11	00.00	15.85	08.93	07.81	15.21	12.37	07.84	03.86
12	00.00	17.97	16.84	12.51	17.24	15.57	13.52	07.50
13	00.00	19.42	17.44	13.61	19.35	16.20	15.24	07.81
14	00.00	19.02	13.53	09.78	19.52	17.00	11.36	06.43
15	00.00	17.66	14.49	08.89	20.22	15.11	12.23	07.98
16	00.00	18.04	14.23	10.22	14.65	12.78	10.77	04.25
17	00.00	17.00	13.62	08.75	15.96	14.74	12.22	05.62
18	00.00	17.74	13.21	10.70	18.91	16.91	14.00	08.43
19	00.00	15.89	12.49	07.79	12.70	11.64	09.20	04.42
20	00.00	16.01	14.09	08.97	14.67	13.74	12.17	06.22
21	00.00	16.50	12.24	09.10	09.62	09.61	08.58	04.87
22	00.00	12.45	09.12	06.52	17.54	16.95	11.28	09.36
23	00.00	09.03	08.84	05.97	17.18	16.88	11.72	07.79
24	00.00	19.87	14.22	08.61	15.75	12.58	11.15	10.01
25	00.00	18.87	13.48	12.46	17.85	17.21	13.87	08.61
26	00.00	09.14	08.05	07.40	19.95	18.40	13.86	10.08
27	00.00	10.15	09.87	08.06	19.55	12.06	07.15	05.74
28	00.00	12.19	09.17	06.78	20.06	20.04	17.97	08.40
29	00.00	17.70	11.63	10.44	14.99	12.52	08.35	08.89
30	00.00	17.94	12.96	09.38	19.44	18.58	16.57	09.98
31	00.00	17.49	15.24	14.86	15.04	14.36	13.59	07.59
32	00.00	17.68	13.61	09.07	13.47	12.78	12.71	07.22
33	00.00	15.87	10.58	07.30	18.74	16.16	15.32	09.86
34	00.00	16.91	13.24	08.88	11.85	10.87	10.20	08.20
35	00.00	18.86	15.33	11.19	19.49	19.40	13.61	09.58
36	00.00	17.18	14.00	09.06	18.46	18.37	13.99	08.69
37	00.00	13.06	09.05	08.61	15.66	14.56	07.79	08.79
38	00.00	16.07	11.60	11.32	18.68	16.68	12.83	08.45
39	00.00	13.62	11.05	08.29	18.61	14.44	09.95	08.96
40	00.00	18.33	13.97	10.58	18.89	16.32	15.30	09.90
41	00.00	17.21	10.02	08.32	19.43	18.16	14.21	09.17
42	00.00	18.44	15.69	08.16	18.65	17.95	16.17	08.71

43	00.00	18.51	13.64	09.80	18.76	16.80	11.34	09.35
44	00.00	14.30	08.87	06.11	20.11	19.53	13.84	07.83
45	00.00	15.69	10.00	08.07	16.71	14.56	10.22	04.10
46	00.00	18.08	14.39	11.22	16.27	12.23	10.41	09.40
47	00.00	20.23	16.22	10.41	18.87	17.54	12.18	09.24
48	00.00	17.31	14.52	11.62	16.32	16.09	13.01	08.38
49	00.00	14.20	10.60	07.37	18.69	17.21	13.05	09.70
50	00.00	12.74	09.94	08.55	13.02	08.65	08.35	02.65
+	LOGN.CLS1	LOGN.CLS2	LOGN.CLS3	LOGN.CLS4	McCL.CLS1	McCL.CLS2	McCL.CLS3	McCL.CLS4
1	18.38	17.95	15.95	14.38	17.68	15.66	11.84	08.22
2	15.88	15.04	14.86	14.47	16.91	11.89	08.79	07.22
3	16.90	13.64	10.80	10.56	15.58	13.98	12.01	06.94
4	15.94	12.60	10.36	10.20	18.40	17.59	12.72	08.54
5	17.99	15.73	13.03	10.21	17.38	13.65	12.16	10.36
6	19.24	18.16	17.96	14.43	17.29	16.80	15.28	10.03
7	14.14	12.98	12.86	10.32	19.67	19.58	16.51	09.71
8	17.91	16.95	15.91	11.32	18.02	17.74	12.67	08.92
9	13.08	10.58	10.01	09.97	16.17	13.45	10.58	06.66
10	15.84	14.85	14.42	11.49	18.29	16.85	13.18	08.97
11	12.96	12.52	12.18	09.77	17.62	11.92	07.72	06.52
12	19.37	18.44	16.32	12.17	18.92	17.22	14.93	09.09
13	18.88	18.69	18.07	13.26	18.02	17.94	13.66	07.95
14	18.85	18.39	15.70	13.17	14.75	12.77	12.10	08.62
15	15.77	10.84	10.08	09.45	19.65	15.92	11.63	10.00
16	14.76	12.53	11.60	10.13	14.74	10.22	09.67	07.08
17	13.85	12.66	12.03	10.18	13.58	12.97	10.73	07.64
18	17.64	15.70	14.74	13.37	12.85	12.29	09.29	10.67
19	12.62	11.71	10.12	08.48	12.53	10.46	07.53	05.63
20	14.65	12.04	11.05	10.48	16.68	15.04	12.47	09.55
21	16.66	14.86	10.63	09.23	19.43	18.89	13.80	09.27
22	11.80	11.00	10.81	09.50	14.51	11.60	09.23	09.20
23	16.05	11.34	09.37	08.10	10.45	10.27	07.76	06.72
24	17.07	16.89	15.30	14.29	14.11	12.74	10.72	07.36
25	15.63	14.90	11.90	11.70	16.52	14.20	12.54	08.88
26	16.67	16.03	14.63	14.27	16.70	15.78	12.89	08.06
27	14.88	10.81	08.95	08.61	16.78	11.28	05.33	05.04
28	19.64	19.60	18.54	15.48	20.55	20.24	18.12	09.69
29	15.10	13.51	08.93	07.82	17.49	16.64	08.87	07.99
30	13.33	11.63	11.46	12.55	19.46	17.45	14.35	09.28
31	19.62	17.32	15.15	17.02	20.20	18.44	13.74	10.34
32	16.27	15.52	12.65	09.50	17.78	15.18	14.68	09.03
33	17.78	14.69	13.72	09.66	12.77	12.72	10.46	05.81
34	13.48	10.49	09.07	08.95	13.94	12.71	10.03	08.77
35	18.68	18.38	17.35	10.68	18.26	18.24	14.29	08.45
36	17.87	15.02	14.70	10.43	17.40	16.44	13.67	09.56
37	14.55	12.84	10.45	10.00	14.83	10.96	06.98	05.56
38	17.47	15.10	15.01	12.03	18.63	16.68	12.87	09.12
39	16.87	14.14	12.32	10.85	15.54	12.91	09.29	07.13
40	17.15	16.58	14.06	12.80	19.67	18.60	13.10	09.04
41	18.49	17.37	16.58	09.50	19.12	18.80	15.02	09.29
42	18.59	16.18	15.16	10.58	19.48	17.99	14.72	09.88
43	18.93	17.90	17.34	14.85	19.24	17.92	13.55	10.29
44	18.44	17.46	17.18	09.73	19.45	15.11	10.87	09.30
45	15.71	14.51	13.94	08.81	16.73	14.06	10.49	06.68
46	15.52	14.91	12.91	11.75	14.59	12.40	11.08	08.55
47	19.79	19.68	16.45	10.03	20.67	18.81	14.44	09.46
48	17.17	16.50	15.75	10.09	16.77	15.27	12.80	09.80
49	17.24	13.31	12.51	10.25	17.68	17.00	11.65	08.06
50	12.56	08.87	08.14	07.81	14.29	08.59	08.50	06.19
+	McIN.CLS1	McIN.CLS2	McIN.CLS3	McIN.CLS4	MURR.CLS1	MURR.CLS2	MURR.CLS3	MURR.CLS4
1	16.32	16.32	14.01	11.53	17.75	17.68	12.37	08.86
2	16.70	16.70	10.67	07.31	17.47	11.79	08.28	06.02
3	14.53	14.53	13.40	10.92	15.52	14.86	12.96	09.20

4	15.15	15.15	13.48	11.07	16.98	15.14	10.64	09.17
5	17.42	17.42	16.06	08.63	18.06	14.75	13.17	09.79
6	15.37	15.37	14.83	11.29	19.23	17.32	11.88	11.28
7	14.65	14.65	12.05	10.32	18.10	17.36	14.70	12.18
8	16.40	16.40	14.32	10.83	18.18	16.09	10.78	07.88
9	15.28	15.28	10.97	09.60	17.22	14.39	10.53	07.61
10	15.80	15.80	14.96	12.78	19.64	18.77	12.69	09.46
11	15.69	15.69	10.51	09.21	18.85	15.79	11.63	07.08
12	16.23	16.23	14.64	09.41	17.81	16.72	16.28	09.66
13	15.58	15.58	15.14	12.42	18.00	16.22	14.25	11.61
14	16.57	16.57	15.98	10.58	19.51	16.54	14.46	10.69
15	16.73	16.73	14.84	11.05	18.28	13.25	11.07	09.69
16	15.77	15.77	15.27	11.58	16.44	13.28	11.51	11.74
17	15.70	15.70	11.93	08.40	16.53	15.14	12.71	06.55
18	18.93	18.93	15.58	09.11	20.32	17.56	14.49	09.71
19	15.48	15.48	12.83	08.61	12.83	11.59	09.85	08.57
20	15.93	15.93	13.14	10.03	17.46	16.31	13.56	09.11
21	14.38	14.38	13.46	11.81	14.49	14.06	12.17	09.54
22	15.75	15.75	13.97	13.45	15.65	13.13	11.74	08.74
23	14.24	14.24	12.44	08.95	18.79	15.83	10.72	07.05
24	18.36	18.36	14.61	11.48	16.45	16.09	10.40	08.74
25	15.43	15.43	15.03	12.44	17.53	15.06	11.71	11.68
26	16.90	16.90	16.21	07.11	17.60	16.85	12.90	11.00
27	17.66	17.66	12.19	09.47	18.38	13.49	08.05	07.82
28	17.86	17.86	14.57	11.11	18.97	18.92	15.46	11.71
29	13.43	13.43	12.79	10.30	16.03	15.31	08.62	08.56
30	15.85	15.85	13.35	09.84	16.03	15.52	15.24	10.22
31	13.07	13.07	10.53	13.58	20.11	19.84	13.82	13.58
32	16.21	16.21	13.25	08.74	17.71	16.89	14.34	07.63
33	15.45	15.45	13.39	12.41	18.39	16.82	14.14	09.35
34	14.22	14.22	14.11	11.06	15.93	14.01	12.91	09.23
35	17.12	17.12	15.15	07.90	19.03	18.88	15.23	13.49
36	18.35	18.35	17.77	12.74	18.28	18.16	11.85	10.45
37	14.59	14.59	10.79	08.20	14.90	11.69	07.77	07.26
38	13.32	13.32	12.37	11.86	18.97	18.84	14.77	11.32
39	13.86	13.86	13.75	08.77	17.71	11.76	08.73	10.82
40	13.31	13.31	13.03	07.13	19.12	17.29	12.15	11.46
41	16.11	16.11	12.48	11.01	18.49	17.03	15.48	09.64
42	18.09	18.09	16.34	12.93	19.64	19.25	15.23	09.10
43	17.96	17.96	14.22	08.19	20.45	16.40	09.80	08.27
44	17.85	17.85	14.36	08.15	18.88	16.96	14.34	07.38
45	11.83	11.83	09.79	07.37	15.58	13.03	07.58	05.98
46	16.54	16.54	15.31	10.87	17.40	14.60	13.01	12.77
47	16.34	16.34	16.07	08.57	21.07	16.62	13.90	10.39
48	16.43	16.43	16.29	11.47	17.09	16.98	12.32	10.58
49	14.79	14.79	11.92	09.72	17.37	15.33	09.98	08.01
50	11.40	11.40	10.65	07.05	12.70	10.84	09.07	07.43

+	MUSK.CLS1	MUSK.CLS2	MUSK.CLS3	MUSK.CLS4	NOBL.CLS1	NOBL.CLS2	NOBL.CLS3	NOBL.CLS4
1	15.90	15.89	15.83	13.52	16.92	16.23	10.65	10.05
2	14.94	14.64	14.02	12.69	15.88	13.77	12.55	08.13
3	16.27	16.10	16.04	12.78	15.61	13.73	12.25	08.05
4	17.31	17.31	17.30	13.78	14.39	12.13	09.54	05.47
5	18.30	16.89	16.13	15.87	14.09	13.15	10.50	06.57
6	18.77	18.24	17.37	16.07	16.55	15.52	14.17	09.02
7	16.40	14.82	13.70	13.43	14.42	13.14	12.32	06.88
8	17.62	17.53	17.43	15.82	18.80	18.80	16.56	10.33
9	17.47	17.29	16.95	13.67	13.18	11.17	08.05	05.10
10	17.97	17.95	17.59	15.81	16.86	15.83	13.08	08.55
11	18.48	17.85	17.79	14.33	14.55	13.04	09.54	07.17
12	13.83	12.47	11.45	11.23	17.31	17.22	12.20	08.91
13	15.26	15.04	13.73	13.45	16.83	16.61	14.94	10.30
14	17.84	17.58	17.16	16.57	15.98	14.09	13.47	09.70
15	16.18	15.88	14.91	15.01	16.39	10.26	09.41	04.66

16	17.76	17.58	17.41	14.24	15.68	15.08	11.56	07.48
17	18.31	17.66	17.66	14.65	12.85	10.74	08.65	03.77
18	16.48	15.87	15.77	15.87	16.32	14.06	11.09	08.18
19	15.21	13.35	13.04	11.67	14.93	14.00	10.23	07.17
20	16.94	16.33	14.71	14.42	15.70	13.57	12.71	07.73
21	15.07	14.66	14.15	14.09	14.50	12.67	08.33	06.11
22	08.75	08.46	08.04	07.94	15.99	13.58	08.37	06.18
23	14.98	14.79	14.70	13.84	15.44	10.41	05.15	05.08
24	18.39	17.75	17.62	14.48	16.43	15.74	11.97	08.78
25	16.83	15.13	13.73	13.55	17.99	15.97	13.54	08.85
26	16.44	16.17	15.60	13.90	13.88	12.69	08.45	09.44
27	17.19	17.06	16.24	15.23	15.81	11.59	07.35	07.08
28	14.41	12.73	11.40	11.23	15.40	15.37	14.95	08.14
29	15.27	15.10	12.68	13.01	15.17	13.21	08.39	06.54
30	17.12	16.96	15.76	13.73	14.31	10.96	10.67	05.24
31	11.86	10.12	08.42	08.34	18.83	18.64	15.35	09.44
32	15.09	14.70	14.00	12.63	15.67	14.82	11.86	09.51
33	18.14	17.77	16.35	15.06	16.69	16.34	10.60	07.34
34	11.50	10.63	10.59	10.36	14.88	12.81	12.04	10.06
35	17.74	17.65	17.01	14.12	16.87	14.24	13.75	09.73
36	16.56	16.56	16.29	13.80	18.34	16.58	12.92	10.49
37	15.40	15.33	14.89	12.30	11.89	10.15	06.63	05.85
38	13.50	12.21	10.95	10.24	14.92	13.60	13.53	09.96
39	16.25	16.05	15.42	13.98	13.77	13.22	09.68	07.27
40	16.82	16.74	16.45	14.42	15.16	13.69	10.58	07.83
41	16.43	16.07	15.86	14.65	17.48	16.90	15.16	10.44
42	16.46	16.42	15.97	14.39	18.10	15.66	12.93	09.08
43	17.48	17.32	14.77	14.52	19.34	16.11	09.84	09.85
44	17.06	17.05	16.23	13.88	16.73	15.33	12.61	09.60
45	16.17	15.99	15.81	12.66	15.05	12.87	07.98	04.53
46	17.71	15.78	15.30	12.96	15.08	13.54	12.75	09.85
47	15.91	14.47	13.36	13.20	17.56	14.94	13.02	08.67
48	14.35	14.09	13.86	13.31	16.25	13.67	11.13	08.93
49	16.76	16.73	16.03	12.97	18.11	15.45	11.36	08.59
50	14.05	13.89	13.75	11.66	09.13	05.89	05.60	05.50
+	OKFU.CLS1	OKFU.CLS2	OKFU.CLS3	OKFU.CLS4	OKLA.CLS1	OKLA.CLS2	OKLA.CLS3	OKLA.CLS4
1	20.30	19.12	19.12	11.91	18.57	18.13	17.88	12.57
2	19.18	16.51	16.51	12.67	18.01	17.88	12.24	10.19
3	20.19	20.01	20.01	10.70	17.87	17.74	15.72	11.93
4	22.00	16.42	16.42	12.01	15.84	15.61	13.61	09.99
5	21.83	17.36	17.36	12.94	18.26	17.83	17.19	13.57
6	21.95	19.49	19.49	09.46	16.43	16.28	14.42	11.64
7	19.10	18.85	18.85	10.55	18.45	18.22	17.03	14.53
8	20.56	16.48	16.48	10.56	19.33	19.21	18.45	14.51
9	18.41	18.38	18.38	10.07	16.88	16.33	14.16	09.54
10	20.60	20.55	20.55	13.86	17.80	16.63	15.41	12.90
11	19.41	16.47	16.14	10.81	14.16	13.59	12.52	09.97
12	18.14	16.84	16.84	10.72	17.06	16.14	15.78	14.91
13	20.07	20.01	20.01	13.69	19.16	18.48	17.12	15.47
14	17.81	16.75	16.75	10.62	16.45	14.61	12.78	12.12
15	21.03	14.91	14.91	12.52	16.99	16.80	09.47	09.33
16	18.96	18.57	18.57	11.17	17.50	16.97	15.13	12.34
17	15.60	13.28	13.28	11.43	16.61	16.05	14.21	10.30
18	20.74	19.88	19.88	11.04	18.76	18.74	17.14	13.33
19	14.64	11.90	11.90	10.19	14.86	14.62	11.88	07.88
20	19.22	18.27	18.27	12.33	18.17	17.27	15.14	13.20
21	19.83	18.40	18.40	11.24	19.41	19.01	17.72	12.74
22	15.35	14.85	13.79	09.08	18.15	18.05	14.31	12.20
23	17.75	16.49	16.49	10.48	18.22	18.09	11.81	08.72
24	16.69	14.73	14.73	10.17	18.08	17.61	14.61	12.58
25	19.81	15.23	15.23	12.46	16.51	15.67	13.70	11.92
26	19.46	18.42	18.42	13.67	17.96	17.38	17.07	11.65
27	16.68	16.58	16.58	11.53	18.86	18.63	12.99	08.41

28	18.19	17.21	17.21	14.71	20.78	20.09	19.09	15.38
29	15.14	14.47	14.47	12.12	16.49	15.23	14.63	09.54
30	17.46	17.23	17.23	14.58	17.94	17.76	16.91	11.97
31	12.82	11.04	11.04	10.85	19.51	17.99	16.18	14.22
32	14.52	12.39	12.39	12.35	16.14	15.05	13.60	10.77
33	15.41	13.83	12.96	14.88	18.70	18.46	13.68	11.23
34	10.99	10.12	10.12	10.08	14.37	13.40	10.22	10.12
35	17.08	16.95	16.95	14.88	18.09	17.22	14.22	13.57
36	18.40	17.56	17.56	13.07	18.61	18.53	15.16	11.03
37	13.85	12.31	12.31	11.15	15.32	15.15	09.62	06.33
38	14.65	13.34	13.34	13.30	17.64	17.59	17.35	11.84
39	15.85	15.49	15.49	13.35	18.09	17.93	13.25	08.28
40	19.29	17.72	17.72	13.79	19.83	19.64	18.08	11.41
41	16.63	15.86	15.86	11.82	19.63	18.25	17.22	11.49
42	18.77	18.68	18.68	13.35	19.43	19.31	15.66	12.38
43	17.83	15.77	15.77	14.25	17.15	16.62	14.64	08.43
44	18.47	18.00	16.96	15.68	19.54	19.03	15.90	10.09
45	17.36	15.22	15.22	13.17	15.89	15.87	13.30	07.96
46	17.81	15.41	15.41	15.25	18.38	17.15	15.68	10.78
47	15.83	12.51	12.51	12.05	17.68	17.32	16.35	10.23
48	14.02	11.67	11.67	10.87	17.78	17.47	17.20	09.95
49	16.62	14.10	14.10	13.60	17.14	16.55	15.90	07.44
50	13.93	10.23	10.23	09.01	15.15	15.14	11.78	08.01

+	OKMU.CLS1	OKMU.CLS2	OKMU.CLS3	OKMU.CLS4	OSAG.CLS1	OSAG.CLS2	OSAG.CLS3	OSAG.CLS4
1	17.49	17.06	17.04	10.95	18.42	18.38	12.82	10.43
2	16.43	16.14	11.24	08.73	18.42	12.36	09.05	07.00
3	16.99	16.39	10.77	08.47	16.46	15.15	13.93	10.99
4	18.53	18.46	15.54	12.48	20.32	17.94	15.39	09.89
5	14.83	13.39	10.29	09.96	16.09	13.13	12.86	11.59
6	18.53	18.49	14.26	11.60	17.00	16.96	15.80	13.05
7	18.18	17.22	15.33	10.76	16.07	15.13	13.95	12.08
8	19.17	19.10	11.62	06.46	20.15	18.70	14.07	10.58
9	15.10	15.03	13.22	10.33	17.43	15.45	12.26	08.40
10	17.75	17.61	16.62	13.39	17.05	16.19	12.24	12.19
11	16.67	16.54	09.58	09.33	19.31	18.61	13.82	09.58
12	12.65	10.45	10.32	09.64	17.98	17.86	12.09	11.11
13	16.95	16.79	15.65	12.73	19.38	19.00	15.00	11.34
14	17.97	17.61	16.87	11.54	14.53	13.30	11.74	11.25
15	17.25	17.25	11.91	10.23	17.99	14.79	12.24	08.74
16	16.51	16.22	12.86	10.22	17.88	16.69	12.67	10.89
17	16.84	14.39	11.56	08.56	18.46	14.53	10.92	07.48
18	18.86	18.83	15.11	09.58	17.73	17.40	14.61	10.88
19	14.77	14.76	11.55	07.85	15.93	13.22	09.55	06.07
20	17.76	17.69	16.13	12.27	16.12	13.97	12.50	09.29
21	16.77	15.44	12.23	09.09	18.67	15.81	09.22	08.72
22	14.67	13.14	10.67	06.75	15.99	15.64	10.40	09.65
23	17.97	17.96	11.55	08.69	17.25	14.40	09.85	08.45
24	17.22	15.43	11.06	10.27	18.08	16.24	10.75	09.13
25	13.58	11.80	10.08	12.46	19.46	18.62	12.85	10.13
26	17.30	17.16	15.09	11.93	17.49	16.46	14.88	11.62
27	18.41	18.31	12.69	07.51	15.21	13.87	07.93	07.65
28	20.24	17.83	15.30	10.57	11.61	10.71	10.42	10.20
29	16.33	14.73	12.14	07.96	13.74	12.52	11.54	08.75
30	17.50	17.24	15.32	11.46	17.02	15.79	13.53	11.18
31	19.25	17.61	15.37	12.79	15.05	13.48	12.57	11.25
32	16.41	14.67	12.85	07.76	12.13	11.83	10.13	10.12
33	16.91	16.71	15.42	11.63	16.46	15.21	14.11	11.63
34	10.92	10.34	10.32	09.79	16.84	15.93	10.83	10.81
35	16.15	15.90	15.71	10.23	19.67	15.15	12.45	11.86
36	13.92	13.74	12.56	12.15	13.89	12.76	11.84	10.28
37	14.90	14.61	10.34	10.32	14.60	13.30	11.06	07.05
38	10.85	09.98	09.48	09.35	14.38	13.72	12.38	11.05
39	13.05	13.00	11.84	10.36	11.31	10.07	07.99	07.73

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 40    16.02      14.72      14.14      09.11      19.85      16.10      11.89       08.57
 41    14.97      13.88      13.55      08.33      16.91      16.01      15.19       11.95
 42    15.93      15.63      15.20      07.89      15.98      14.98      12.34       12.20
 43    15.41      15.21      11.14      08.67      14.75      12.66      10.02       09.87
 44    17.68      17.59      17.01      11.52      17.86      17.17      12.68       09.62
 45    15.63      15.57      10.62      07.16      17.18      15.21      09.20       06.39
 46    17.11      15.50      12.06      10.58      16.33      15.50      11.35       10.68
 47    11.53      10.14      09.72      10.73      16.19      15.14      13.03       11.63
 48    15.03      14.52      14.37      07.92      15.42      15.18      12.15       10.67
 49    17.84      17.40      16.03      11.92      20.00      18.88      14.16       10.80
 50    13.45      13.36      09.75      05.19      13.69      08.90      08.35       06.67
 +   PAWN.CLS1  PAWN.CLS2  PAWN.CLS3  PAWN.CLS4  PITS.CLS1  PITS.CLS2  PITS.CLS3   PITS.CLS4
 1     18.67      18.66      13.70      10.53      18.66      18.44      14.31       10.20
 2     16.57      10.46      09.70      07.90      17.56      17.55      09.26       05.37
 3     14.75      13.20      12.73      08.07      16.25      16.20      12.01       09.05
 4     17.32      16.05      14.05      09.90      18.61      18.60      14.59       09.48
 5     13.24      12.25      10.58      10.03      20.04      18.90      11.25       07.81
 6     19.06      18.43      15.80      12.55      17.94      17.80      14.77       10.97
 7     17.61      15.36      12.59      10.52      16.92      15.00      14.72       14.27
 8     19.64      18.14      15.58      10.88      19.07      17.74      10.84       07.61
 9     14.46      11.93      09.39      07.06      16.90      15.93      12.56       09.11
 10    17.15      16.85      15.36      11.06      15.86      13.34      10.18       10.10
 11    16.43      14.45      12.29      09.60      19.36      19.19      11.48       07.99
 12    17.35      17.03      12.82      11.02      16.96      14.30      12.18       11.01
 13    19.68      18.01      14.65      11.22      15.12      13.80      11.95       11.46
 14    16.31      16.25      13.08      11.23      17.71      16.16      14.10       12.23
 15    17.19      12.13      10.31      09.12      17.83      16.17      14.52       09.50
 16    16.32      14.98      11.98      08.52      17.23      16.23      10.75       10.21
 17    15.71      14.30      12.08      08.38      17.34      16.64      09.40       06.65
 18    15.28      12.85      10.50      09.54      17.35      16.63      13.24       09.51
 19    15.84      13.85      09.61      06.74      14.80      14.01      09.18       05.69
 20    14.26      12.53      11.01      09.59      18.67      18.63      13.97       10.59
 21    17.93      15.73      12.18      08.51      15.58      13.98      12.21       08.79
 22    15.83      15.78      10.79      09.61      16.34      15.93      09.13       06.49
 23    16.45      13.58      08.95      07.47      17.71      17.54      10.14       06.02
 24    18.44      18.06      13.72      09.71      17.89      17.48      13.75       09.93
 25    18.78      16.79      13.72      09.78      16.91      15.33      13.91       10.64
 26    16.90      15.32      11.96      08.69      17.55      16.51      15.46       12.22
 27    17.53      14.04      07.95      07.16      18.14      17.47      06.95       05.03
 28    17.33      15.17      12.00      10.85      17.07      16.21      15.88       09.96
 29    19.99      16.22      11.05      07.54      14.65      11.11      10.51       09.82
 30    16.42      12.82      11.25      07.33      18.95      18.23      13.56       08.92
 31    18.74      18.69      15.22      11.52      15.18      13.31      11.83       11.45
 32    16.00      15.25      13.89      10.58      16.22      15.57      11.84       08.94
 33    18.40      17.76      13.10      11.96      20.12      18.09      14.83       09.10
 34    17.93      17.22      14.36      11.63      15.73      15.11      12.50       10.30
 35    18.06      15.19      12.56      10.17      17.77      17.26      12.14       11.08
 36    14.47      13.93      12.46      10.89      19.20      18.31      12.54       07.02
 37    15.50      13.05      07.06      06.42      15.30      14.28      07.79       06.53
 38    14.74      13.96      13.37      10.61      16.97      16.31      13.62       11.26
 39    16.58      15.00      10.41      07.06      17.88      17.85      11.03       08.88
 40    17.93      14.98      11.25      08.38      18.74      17.36      14.28       10.13
 41    18.26      16.84      16.62      10.58      18.75      16.83      08.64       06.44
 42    16.85      16.37      13.29      11.04      20.55      20.01      13.44       08.04
 43    15.91      13.76      11.99      10.20      18.26      17.47      11.77       06.65
 44    17.62      17.14      15.29      10.84      19.46      17.83      09.99       05.78
 45    17.31      16.63      11.63      09.00      15.11      14.62      08.36       06.33
 46    14.85      12.60      10.18      09.77      17.40      16.94      16.08       11.41
 47    13.11      12.17      11.68      10.10      20.60      19.29      11.40       09.04
 48    16.06      15.79      11.06      09.35      16.50      14.86      14.76       10.42
 49    19.56      18.40      15.25      09.69      17.27      16.38      12.61       09.72
 50    13.74      09.45      07.05      05.66      14.43      14.33      10.47       07.59
 +   PONT.CLS1  PONT.CLS2  PONT.CLS3  PONT.CLS4  POTT.CLS1  POTT.CLS2  POTT.CLS3   POTT.CLS4
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 1    15.75      15.61      11.11      11.05      17.94      15.85      11.18       08.07
 2    15.81      13.98      09.44      07.80      17.79      12.63      10.35       05.74
 3    15.29      12.36      11.29      09.26      18.59      18.22      14.84       10.53
 4    16.91      14.19      10.68      07.41      20.34      17.87      13.01       08.15
 5    17.82      15.61      13.01      09.34      20.73      17.71      13.97       09.08
 6    15.34      14.06      12.28      10.13      19.06      16.21      12.88       08.95
 7    18.17      18.15      15.55      14.07      19.57      18.76      14.17       10.21
 8    21.40      19.66      13.42      10.37      19.53      15.83      10.33       05.27
 9    16.67      15.62      10.34      08.56      16.77      13.86      11.29       08.08
10    17.93      16.37      14.82      09.59      19.98      17.87      13.02       07.68
11    18.12      14.01      10.52      08.20      17.79      13.01      09.84       06.07
12    13.64      12.93      10.11      09.97      18.74      17.57      16.32       09.59
13    17.59      15.41      13.94      10.80      19.25      18.26      13.23       09.30
14    17.81      14.19      13.49      09.60      15.85      14.40      13.79       09.42
15    18.70      12.78      10.60      06.73      20.55      16.18      12.98       08.46
16    17.39      16.64      14.35      09.34      17.84      15.21      12.52       08.14
17    16.75      13.95      10.43      07.84      18.87      15.72      12.15       07.15
18    20.03      17.48      14.23      09.97      18.59      18.55      13.31       11.08
19    11.27      10.76      09.98      05.10      20.03      19.11      12.60       08.64
20    17.96      16.87      15.95      10.53      16.92      16.04      13.51       10.46
21    13.32      11.16      10.75      08.00      13.82      11.29      10.70       09.36
22    17.69      16.07      11.20      07.81      16.98      16.80      11.14       07.81
23    17.66      12.59      07.56      04.46      18.65      17.30      11.90       07.22
24    16.29      16.18      11.63      08.99      20.13      17.76      14.07       09.63
25    16.80      15.13      11.10      08.64      15.18      14.12      13.67       07.92
26    18.20      17.13      10.93      09.33      18.93      16.14      15.14       10.47
27    16.24      10.29      04.72      04.62      16.83      14.58      07.46       04.91
28    18.01      17.15      15.68      11.22      18.19      15.16      13.88       10.36
29    15.26      14.49      06.90      06.53      13.06      12.69      08.97       08.14
30    18.60      18.58      15.99      11.04      17.33      15.07      14.30       09.87
31    14.04      13.88      11.64      13.64      19.39      17.35      15.74       11.61
32    16.64      15.90      12.09      08.28      16.47      15.64      14.93       10.12
33    17.82      15.58      14.82      09.40      17.89      16.96      12.41       08.79
34    14.35      12.80      10.19      10.07      16.28      14.46      12.11       09.80
35    15.73      15.46      13.18      11.58      19.46      17.75      15.80       11.14
36    17.96      16.48      12.09      07.85      16.22      15.35      14.02       08.45
37    15.17      12.93      07.64      06.86      14.71      11.72      06.08       04.91
38    18.81      18.72      15.20      11.14      18.41      18.22      13.12       09.60
39    15.32      11.64      08.28      06.26      16.28      13.14      10.65       07.91
40    17.05      14.24      09.17      07.43      18.66      17.79      12.98       07.85
41    17.74      15.57      13.97      12.56      18.02      15.49      10.94       06.70
42    18.04      14.94      11.40      07.60      18.29      17.16      14.33       07.61
43    19.02      16.68      11.31      10.39      19.40      19.04      14.76       09.80
44    17.30      16.37      12.12      08.73      19.39      19.32      12.92       08.40
45    12.38      10.65      07.75      05.31      16.24      14.03      09.39       06.72
46    15.83      13.04      12.16      10.96      17.35      16.80      12.92       10.46
47    16.99      15.80      13.57      09.47      20.57      18.93      14.59       08.07
48    14.01      13.79      12.55      09.40      17.86      13.71      12.46       08.25
49    16.47      15.89      12.57      11.02      17.83      17.46      13.30       08.87
50    11.94      10.02      08.70      04.35      13.43      08.07      07.14       04.85
 +  PYNE.CLS1  PYNE.CLS2  PYNE.CLS3  PYNE.CLS4  SEMI.CLS1  SEMI.CLS2  SEMI.CLS3  SEMI.CLS4
 1    17.51      17.51      12.13      12.05      18.85      18.85      14.01       11.29
 2    16.77      16.77      12.63      10.12      19.81      19.81      12.56       09.03
 3    15.68      15.68      11.58      10.03      17.98      17.98      12.18       09.66
 4    15.00      15.00      12.29      11.62      18.14      18.14      12.32       10.11
 5    16.94      16.94      12.55      08.88      20.50      20.50      13.96       08.82
 6    18.06      18.06      15.74      13.86      21.29      21.29      14.60       10.71
 7    14.61      14.61      10.90      09.42      18.55      18.55      14.25       12.09
 8    17.75      17.75      13.21      11.47      20.51      20.51      13.08       09.78
 9    12.59      12.59      08.97      08.25      18.12      18.12      13.77       10.97
10    15.49      15.49      12.42      10.63      19.09      19.09      16.17       11.70
11    13.83      13.83      10.03      09.85      18.86      18.86      10.57       09.06
12    13.33      13.33      12.52      10.75      18.38      18.38      14.44       11.23
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13    16.85       16.85       15.59       10.98       18.94       18.94       13.75        10.41
14    13.20       13.20       12.01       10.25       16.60       16.60       14.21        11.84
15    16.72       16.72       08.67       07.93       19.78       19.78       11.86        07.34
16    17.03       17.03       14.33       10.34       15.91       15.91       11.64        07.90
17    12.78       12.78       10.60       09.47       13.79       13.79       09.60        07.47
18    16.99       16.99       11.77       09.60       19.16       19.16       14.80        10.89
19    16.14       16.14       09.19       07.29       13.71       13.71       10.67        07.27
20    18.40       18.40       13.54       10.82       18.06       18.06       14.82        12.12
21    16.39       16.39       10.94       09.63       14.80       14.80       10.96        10.37
22    15.98       15.98       08.80       08.64       16.40       16.40       08.79        08.68
23    16.52       16.52       08.98       07.74       16.58       16.58       08.78        08.77
24    16.49       16.49       12.83       10.93       14.60       14.60       10.72        10.65
25    16.24       16.24       11.60       11.02       14.01       14.01       11.84        11.64
26    16.60       16.60       11.87       11.56       16.58       16.58       10.34        14.09
27    17.13       17.13       07.80       07.42       15.35       15.35       04.50        04.32
28    17.04       17.04       15.46       11.95       18.82       18.82       15.97        11.90
29    15.01       15.01       10.22       09.82       12.56       12.56       09.23        09.05
30    17.54       17.54       12.95       09.32       17.27       17.27       13.47        11.64
31    16.02       16.02       14.08       13.69       16.28       16.28       16.01        12.07
32    14.37       14.37       10.10       09.94       16.15       16.15       10.68        10.12
33    18.76       18.76       12.85       12.12       18.74       18.74       11.67        09.87
34    12.13       12.13       10.06       09.85       13.75       13.75       12.91        11.03
35    18.44       18.44       13.04       10.21       18.37       18.37       14.18        11.44
36    17.46       17.46       11.99       11.85       18.20       18.20       13.57        10.65
37    14.21       14.21       05.97       05.56       15.68       15.68       07.26        07.06
38    16.19       16.19       12.47       12.00       17.93       17.93       12.86        11.98
39    15.11       15.11       09.97       08.32       17.92       17.92       10.90        08.76
40    17.68       17.68       12.23       08.50       18.89       18.89       13.41        10.70
41    17.84       17.84       14.55       12.92       17.60       17.60       13.29        11.33
42    16.29       16.29       12.17       10.44       18.76       18.76       15.92        10.86
43    17.11       17.11       10.20       10.15       18.65       18.65       11.16        10.93
44    17.52       17.52       14.47       09.99       17.83       17.83       11.88        11.07
45    13.38       13.38       07.14       07.07       16.29       16.29       07.58        06.81
46    13.25       13.25       12.73       12.15       16.57       16.57       12.66        11.67
47    16.31       16.31       10.30       09.15       18.96       18.96       12.73        11.27
48    16.70       16.70       12.72       10.56       16.04       16.04       12.63        10.01
49    14.93       14.93       13.18       12.08       14.90       14.90       12.12        10.93
50    11.07       11.07       07.68       05.72       13.48       13.48       09.41        05.67
 +  TULS.CLS1   TULS.CLS2   TULS.CLS3   TULS.CLS4   WAGN.CLS1   WAGN.CLS2   WAGN.CLS3    WAGN.CLS4
1     18.26       18.26       16.96       16.83       18.01       17.63       17.56        12.73
2     14.45       14.45       14.37       09.01       17.49       17.49       17.48        09.54
3     15.37       15.37       14.60       10.31       17.74       17.62       17.54        11.88
4     17.16       17.16       14.30       08.46       18.84       18.77       18.67        11.13
5     18.60       18.60       14.24       07.78       21.43       21.14       20.85        11.28
6     18.02       18.02       15.26       10.31       22.50       22.50       22.50        14.18
7     17.39       17.40       13.00       07.28       19.46       18.71       17.69        11.11
8     18.45       18.46       14.33       08.05       20.58       20.53       20.51        09.12
9     14.77       14.74       12.63       08.41       18.82       18.17       18.09        12.21
10    14.57       14.58       13.98       08.98       19.76       19.74       19.45        13.65
11    16.13       16.13       14.54       08.81       18.44       18.07       18.02        10.94
12    18.27       18.27       17.13       13.41       20.07       19.81       18.78        14.26
13    19.71       19.71       15.96       13.22       19.44       19.11       18.93        12.04
14    15.53       15.54       14.97       12.08       17.47       17.00       16.45        11.94
15    16.21       16.21       15.85       10.76       19.39       19.02       18.74        11.18
16    15.50       15.50       13.98       11.23       17.44       17.38       17.09        13.83
17    13.55       13.54       11.76       08.36       15.46       14.97       14.74        09.20
18    16.69       16.70       16.52       10.02       19.21       19.02       17.97        12.01
19    12.05       12.05       11.99       08.20       17.41       17.21       16.92        10.23
20    17.34       17.34       15.55       10.02       19.52       19.51       19.23        15.27
21    13.52       13.53       12.16       09.04       17.48       17.13       16.54        12.21
22    13.28       13.28       11.32       05.87       17.68       17.17       15.86        09.89
23    15.43       15.43       14.22       07.23       18.47       18.37       18.21        09.18
24    18.00       18.00       15.56       10.82       20.38       16.95       15.80        14.23
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25    15.26      15.26      14.49      10.90      16.45      15.96      15.41       14.88
26    18.93      18.93      14.61      10.73      18.70      18.61      18.15       12.50
27    17.23      17.23      12.74      07.03      18.14      18.04      16.02       11.05
28    17.26      17.26      17.22      11.13      19.52      18.46      17.21       10.14
29    13.34      13.40      09.88      06.41      18.96      15.86      12.29       09.44
30    12.39      12.42      11.24      07.85      19.27      19.08      19.05       13.16
31    18.08      18.17      17.99      12.02      18.22      16.21      14.04       15.05
32    14.39      14.38      11.15      08.62      16.03      15.85      15.61       09.85
33    17.24      17.24      11.23      12.15      19.88      19.08      17.42       12.54
34    17.29      17.29      15.74      11.23      15.67      13.97      12.23       12.16
35    17.89      17.91      11.56      05.44      19.29      19.19      19.05       11.32
36    16.06      16.06      10.35      10.25      16.16      16.09      15.80       11.87
37    14.01      14.01      07.56      07.46      16.91      16.79      15.65       09.52
38    14.47      14.46      12.64      10.09      15.27      14.73      14.68       11.46
39    13.68      13.68      09.24      08.87      12.79      12.66      12.23       10.44
40    15.35      15.35      08.59      08.00      20.34      19.96      19.69       09.56
41    16.89      16.89      09.23      08.38      19.19      19.09      17.54       11.76
42    16.49      16.49      09.07      08.97      18.49      18.32      16.79       11.94
43    16.83      16.83      08.32      08.12      17.92      17.01      15.53       12.94
44    15.87      15.87      13.80      08.79      18.93      18.87      18.27       10.12
45    16.09      16.09      16.22      09.38      18.47      18.17      17.58       08.27
46    15.61      15.61      09.46      09.16      18.22      18.08      18.08       12.96
47    13.97      13.96      08.20      05.12      17.56      15.33      12.93       11.01
48    13.08      13.08      06.82      06.36      15.79      13.79      12.48       12.26
49    16.75      16.82      07.15      06.82      19.08      18.99      18.50       11.80
50    14.02      14.02      06.77      05.57      15.69      14.39      14.14       09.17
;
SCALAR P                             "Output price for biofuel per gallon" /2.84/;
VARIABLES
OBJ                                  Objective Function
X(C, L)                              Hectares of land by county and land class
RAKING(T, C,L)                       Hectares of land Raked
BALING(T, C, L)                      Megagram Baled
TRANSPORT(T,C,L)                     Megagram Transportated
COSTLAND                             Determines the cost of land per Mg
POSITIVE VARIABLES
X(C, L),RAKING(T,C, L), BALING(T,C,L), TRANSPORT(T,C, L);
EQUATIONS
NETR                                 Annual net returns
LANDCOST                             Land Cost
LAND(C,L)                            Resource Constraints
AvgTARGET(T)                         Average Target Constraints
RAKACTIVITY1(T,C,L)                  Raking activity
BALACTIVITY(T,C,L)                   Baling Constraints
TRANSPORTACTIVITY(T,C,L)             Transportation Constraints
AvgYield                             Arbitrary to determine total prod if average yield
                                     was obtained on each leased ha
YearProd(T)                          Arbitrary to show production in each state of nature
;
NETR..OBJ =E= -invest- opcost + P*conv*(sum((T,C,L), TRANSPORT(T,C,L)/50)) -
[(SUM((C,L), PRODCST(C,L)*X(C,L))+ BAL*SUM((T,C,L),BALING(T,C,L)/50)+(RAK*SUM((T,C,L),
RAKING(T,C,L))/50)+(sum ((T, C,l), VPCST*TRANSPORT(T,C,L)/50)) +
SUM((T,C,L),TRNSCST(C,L)*TRANSPORT(T,C,L)/50))];
LANDCOST..          CostLand      =E=  (SUM( (C,L), LandRent(C,L) * X(C,L)));
LAND(C, L)..        X(C,L)               =L= TOTLAND(C,L);
AvgTARGET(T)..      SUM((C, L),TRANSPORT(T,C,L)       =L=  700000;
RAKACTIVITY1(T,C,L).. RAKING(T,C,L) -  X(C,L)         =L=0;
BALACTIVITY(T,C,L)..  BALING(T,C,L)  -  AnYld(T,C,L)*RAKING(T,C,L)    =L=0;
TRANSPORTACTIVITY(T,C,L)..TRANSPORT(T,C,L)- BALING(T,C,L)           =L=0;
AvgYield..     SUM((T,C,L), AvgYld(C,L)*X(C,L))                     =G=0;
YearProd(T)..  SUM((C,L),   AnYld(T,C,L)*X(C,L))                    =G=0;
MODEL   RETURNS/ALL/;
SOLVE   RETURNS USING LP Maximizing OBJ;
```

```
DISPLAY X.L;
DISPLAY Raking.L;
DISPLAY Baling.L;
DISPLAY Transport.L;
DISPLAY Obj.L;
PARAMETER  Landleased            Total hectares of land leased;
Landleased = SUM((C,L),X.L(C,L));
DISPLAY Landleased;
PARAMETER Raked                  Average hectares of land raked;
Raked = SUM((T,C,L),Raking.L(T,C,L))/50;
DISPLAY Raked;
PARAMETER Transported            Average Mg of switchgrass transported;
Transported= SUM((T,C,L),Transport.L (T,C,L))/50;
DISPLAY Transported;
PARAMETER cost                   Feedstock production per year in $;
cost= SUM((C,L),PRODCST(C,L)*X.l(C,L))+ RAK*SUM((T,C,L), RAKING.L(T,C,L)/50)+
SUM((T,C,L), (Bal+ TRNSCST(C,L))*TRANSPORT.l(T,C,L)/50);
PARAMETER CostPerYr              Feedstock production cost $ per Mg;
CostPerYr  =  cost/SUM((T,C,L), TRANSPORT.L(T,C,L)/50);
DISPLAY cost;
DISPLAY CostPerYr ;
PARAMETER ProdCost               Anuual Field feedstock production cost per year;
ProdCost = SUM((C,L),PRODCST(C,L) * X.L(C,L)) + (RAK*SUM((T,C,L), RAKING.L(T,C,L)/50)+
BAL*SUM((T,C,L),TRANSPORT.L(T,C,L)/50));
DISPLAY ProdCost;
PARAMETER  PRODCOSTPerMg         FIELD PRODUCTION COST PER Mg;
PRODCOSTPerMg = ProdCost/Transported;
DISPLAY PRODCOSTPerMg;
PARAMETER TRANSPORTCOST          TRANSPORTATION COST PER MG;
TRANSPORTCOST = SUM((T,C,L), TRNSCST(C,L)*TRANSPORT.l(T,C,L)/50)/Transported;
DISPLAY TRANSPORTCOST;
PARAMETER LandCostPerMg     Average Land cost per Mg of feedstock;
LandCostPerMg  = (CostLand.L)/Transported;
DISPLAY LandCostPerMg;
DISPLAY AvgYield.L;
DISPLAY YearProd.L;
PARAMETER IDLECOST        Unavoidable fixed cost of schuting the plant perday;
IDLECOST =  ((invest + opcost)/360)* ((700000-transported)/2000);
DISPLAY IDLECOST;
PARAMETER Totest           Total estbalishment cost;
 Totest = sum ((C,L), ESTCST(C,L)*X.L(C,L));
Display Totest ;
PARAMETER Frak             Fixed raking cost;
Frak = 1.889*(SUM((T,C,L), RAKING.L(T,C,L))/50);
DISPLAY Frak;
PARAMETER FbaL             Fixed baling cost;
FbaL  =0.1*Bal*(SUM((T,C,L), BALING.L(T,C,L))/50);
DISPLAY FbaL;
PARAMETER Ftransp          Fixed transportation cost;
Ftransp = FXCT * (SUM((T,C,L),Transport.L(T,C,L))/50);
DISPLAY Ftransp;
PARAMETER Fixed            Total fixed cost per day;
Fixed  = (Ftransp + Totest  +  Frak  + CostLand.L + FbaL)/360;
DISPLAY Fixed;
PARAMETER AFIXE            Annual fixed cost;
AFIXE =  Fixed *((700000-transported)/2000);
DISPLAY  AFIXE;
```

VITA

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