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Impact of Environmental Values on the Breakeven Price of Switchgrass

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Abstract

This study estimates the farm-gate breakeven price of switchgrass relative to wheat in Oklahoma. The breakeven price of switchgrass is determined for two situations: when external consequences are ignored and when the environment costs of changes in soil erosion, fertilizer (nitrogen and phosphorous) runoff, and soil organic carbon are considered. Results suggest that the farm-gate breakeven price of switchgrass from the internal cost only perspective is higher than the cost if the value of the selected external consequences is considered. The potential environmental benefits are greater if highly erodible land is switched from annual cropping to switchgrass.

Key words: Agricultural Runoffs, Farm-gate Breakeven Price, Soil Organic Carbon, Switchgrass Production,

JEL codes: Q24, Q42, Q51

Introduction

With concern over environmental degradation there has been interest in finding alternative sources of energy. Part of this interest has focused on renewable bioenergy, which is expected to have fewer negative environmental consequences than hydrocarbon fuels. Among the many potential dedicated energy crops, switchgrass has promise due to its ability to grow on many different types of soil under diverse climatic conditions. The US-EPA (2010) used the Forestry and Agriculture Optimization Model (FASOM) to predict that by 2022, it would be economically feasible to produce around 0.9 billion gallons of biofuel from switchgrass biomass feedstock. The FASOM model also projected that most of the switchgrass feedstock would be grown in Oklahoma replacing wheat and hay production (U.S. EPA, p. 286-287).

The U.S. Conservation Reserve Program (CRP) was established in 1985. Under the CRP program highly erodible land was removed from agricultural production and planted to trees or

perennial grasses (Mapemba et al., 2007). CRP participants were paid an annual land rental value and half the cost of establishing a permanent land cover in exchange for 10- or 15-year leases on land previously used to grow crops. One of the major goals of the CRP was to reduce soil erosion. As of January 2012, more than 12 million hectares were under USDA CRP contract at an average cost of \$141/ha/year or a total cost of almost \$1.7 billion/year (U.S. Department of Agriculture, Farm Service Agency, 2012). Allowing some of these lands to produce energy crops, would reduce the government CRP expenditure while maintaining at least some of the benefits such as reduced soil erosion, reduced nitrogen and phosphorous loss, and sequester carbon. In anticipation of the establishment of a technology for converting cellulosic biomass into economically competitive bio-products, the CRP was amended by the 2002 Farm Bill to permit biomass harvesting of CRP grassland subject to restrictions (Farm Security and Rural Investment Act (FSRIA) of 2002, U.S. Department of Agriculture, 2003).

The projected potential for switchgrass production in Oklahoma raises several research questions. First, what net price for switchgrass would be required to bid land away from wheat production to switchgrass production? Second, what are the expected changes in soil erosion, fertilizer (nitrogen and phosphorous) runoff, and soil organic carbon from converting wheat production land into switchgrass production and what is the expected economic consequence of these changes?

Several studies have estimated the production costs of switchgrass biomass. Mooney et al. (2009) determined the breakeven price of switchgrass for four different locations in Tennessee. They found that the farm-gate breakeven price of switchgrass based on 10-year production contracts was \$46/Mg for an average yield of 17.7 Mg/ha and \$69/Mg for an average yield of 8.5 Mg/ha. Khanna, Dhungana and Brown (2008) estimated the Illinois farm-gate

breakeven price of switchgrass to be \$98/Mg with average yields of 9.42 Mg/ha. Epplin et al. (2007) found that under a land-lease contract in Oklahoma, the estimated cost of switchgrass production was \$41/Mg under an assumed eight-month harvest window. The cost increased to \$58/Mg when the harvest window was restricted to two months per year. In Tennessee, based on farmer bids, the cost of producing switchgrass ranged from \$40/Mg to \$60/Mg assuming that an average yield of 15.70 Mg/ha could be obtained. McLaughlin and Kszos (2005) estimated U.S. farm-gate prices of switchgrass of \$30/Mg, and \$44/Mg for average yields of 11.4 Mg/ha, and 9.4 Mg/ha, respectively. These studies did not consider the environmental consequences of producing switchgrass relative to existing land use and also did not place any monetary value on those consequences while estimating the farm-gate breakeven price of switchgrass.

Nelson, Ascough II, and Langemeier (2005) discussed the environmental consequences of converting conventional crop land to switchgrass. They used the soil and water assessment tool (SWAT) to determine the environmental outcomes of switchgrass production. They simulated switchgrass yields and other commodity crop yields and estimated the farm-gate breakeven price of switchgrass. Graham, Downing and Walsh (1996) used the environmental policy integrated climate (EPIC) model to predict switchgrass and other alternative crop yields and their associated environmental outcomes. They determined the farm-gate breakeven price of switchgrass by comparing it to the production of other alternative crops. Both of these studies found that switchgrass production reduced soil erosion and nutrient loss compared to annual crops. King, Hannifan, and Nelson (1998) also found that switchgrass production reduced soil erosion and nutrient loss. However, these studies did not attach any monetary value to the environmental benefits derived from converting to switchgrass production while estimating the farm-gate breakeven price of switchgrass.

The primary objective of this study is to determine the site-specific farm-gate breakeven price of switchgrass for two situations: (1) when external consequences are ignored and (2) when the environment costs of changes in soil erosion, fertilizer (nitrogen and phosphorous) runoff, and soil organic carbon are considered. To achieve the objective it is necessary to estimate the expected yield of switchgrass and wheat and the expected differences in nitrogen loss, phosphorous loss, soil loss, and changes in soil organic carbon (SOC) for alternative soil classes over a multi-county area.

Conceptual Framework

The landowners' decision regarding shifting into a long-term investment such as switchgrass by replacing an existing annual crop depends on the relative expected returns. Since no formal market exists for switchgrass biomass, the opportunity cost of producing switchgrass is estimated from the returns of the best alternative crop, which in region of the study is wheat.

This study is divided into three sections: (1) a biophysical simulation model: the EPIC model was used to simulate the expected yield of switchgrass and wheat along with the environmental outcomes including (a) total soil loss (Mg/ha), (b) nitrogen loss (kg/ha), (c) phosphorous loss (kg/ha), and (d) changes in SOC (kg/ha); (2) an economic model is used to estimate the farm-gate breakeven price of switchgrass when external consequences are ignored, and (3) the farm-gate breakeven price of switchgrass is estimated when the environment costs of changes in soil erosion, fertilizer (nitrogen and phosphorous) runoff, and soil organic carbon are considered.

Study Region and Data Requirement

This study examined switchgrass production in counties surrounding a hypothetical potential biorefinery located near Okemah in Okfuskee County, Oklahoma. This plant is

assumed to have an annual switchgrass feedstock requirement of 700,000 Mg. Debnath (2012) previously determined the location and land classes where land would optimally be leased. Farm-gate breakeven prices are determined for each of these counties and land classes (Figure 1).

Data were obtained from several sources. Historical weather information was obtained from NOAA and Mesonet (2011). Soil information for each land class (I, II, and III) for each county was obtained from the USDA, NRCS SSURGO soil database (2011). Universal Soil Loss Equation (USLE) related attributes for each land class of each county was obtained from the USDA-NRCS (2007) report. Production costs of switchgrass were obtained from Turhollow, and Epplin (2012), while cost of wheat production was taken from the Oklahoma State University, enterprise budget data base (2012). The price of wheat was obtained from the FAPRI baseline model (2012). Environmental outcomes were valued based on previously published literature.

EPIC Model Validation and Simulation

The expected yields and the selected environmental outcomes for wheat and switchgrass production is simulated using the Environmental Policy Integrated Climate (EPIC) model (Williams, Jones, and Dyke, 1984). However, prior to simulation the model was calibrated and validated. The switchgrass and wheat yields were validated against results from experimental field trial data, while the EPIC simulated soil loss for both switchgrass and wheat production were validated against the soil loss estimated using the USLE equation (Debnath, 2012).

After the yields and the soil loss for both no-till wheat and switchgrass production are calibrated and validated, the calibrated models were used to simulate wheat and switchgrass yields and environmental outcomes based on 50 years of daily weather information. Each year's data was considered as a state of nature. The EPIC switchgrass simulation was performed under the assumption that crop land was converted from wheat to switchgrass and replanted every tenth

year. Ten different 50 year random weather scenarios were generated based on a unique random number generator seed used in the EPIC control table. Each of these random weather scenarios was used to simulate a 50-year yield distribution along with the selected environmental outcomes for each county and each land class. After each of these 10 random distributions of wheat and switchgrass yields and environmental outcomes are simulated for each county and each land class, the 10 observations for each of the 50 states of nature are averaged to estimate the expected switchgrass and wheat yields and environmental outcomes.

Economic Model

Site-specific enterprise budgets based on the detailed field operations for both crops were prepared for each county and each land class (Turhollow and Epplin, 2012; Oklahoma State University, 2012). The foregone profit from the best alternative use, wheat production, was considered as the opportunity cost of the land for each land class (I, II, and III) and for each county. However, in this study while estimating the farm-gate breakeven price of switchgrass land was valued at a rate well above the revenue lost from not producing wheat. This is based on the assumption that landowner/ farmer required incentive to convert cropland to the perennial switchgrass (Fewell, Bergtold, and Williams, 2011). Therefore, land value is the opportunity costs of the land derived from the forgone wheat production plus the extrapolated USDA (2011) cropland rental rate. Since the switchgrass and wheat production costs were not inflated, a real rate of interest was used as the discount rate with the assumption that all prices will change as per as the general inflation rate (Campbell and Brown, 2009). In the U.S., the average real rate of interest over the last 15 years was 4% (World Bank, 2012). Therefore, a discount rate of 4% was used.

The net present value derived from wheat production in each county for each soil type from the profit maximizing landowners' perspective is estimated using the following equation:

$$E(NPVP_{w,c,s}) = \sum_{i=1}^n \left(\frac{P_{i,w} E(Y_{i,w,c,s}) - VC_{i,w,c,s}}{(1+r)^i} \right) \quad (1)$$

where $E(NPVP_{w,c,s})$ is the expected private profit maximizing landowners' net present value derived from wheat production w for county c and land class type s ; $P_{i,w}$ is the price of wheat w in year i ; $E(Y_{i,w,c,s})$ is the expected wheat yield w for the i^{th} year and for county c and land class type s ; $VC_{i,w,c,s}$ is the entire production cost including the establishment costs, fertilizer costs, and harvesting costs of wheat production w in i^{th} year for county c and land class type s ; and r is the market discount rate.

The net present value derived from switchgrass production in each county for each soil is estimated using the following equation:

$$E(NPVP_{g,c,s}) = \sum_{i=1}^n \left(\frac{BEP_{g,c,s} E(Y_{i,g,c,s}) - VC_{i,g,c,s} - LC_{c,s}}{(1+r)^i} \right) \quad (2)$$

where $E(NPVP_{g,c,s})$ is the expected private profit maximizing land owners' net present value derived from wheat production for county c and land class type s ; $BEP_{g,c,s}$ is the private profit maximizing land owners' farm-gate breakeven price of switchgrass g for county c and land class type s ; $E(Y_{i,g,c,s})$ is the expected wheat yield w for the i^{th} year and for county c and land class type s ; $VC_{i,g,c,s}$ is the entire production cost including the establishment costs, fertilizer costs, and harvesting costs of wheat production w in i^{th} year for county c and land class type s ; $LC_{c,s}$ is the extrapolated USDA (2011) cropland rental rate for county c and land class type s , additional payment made in order to incentivize landowner/ farmer to grow switchgrass.

The landowner/farmer would be indifferent between producing either wheat or switchgrass only when the net present value derived from producing wheat would be identical to the net present value derived from producing switchgrass. Therefore, farm-gate breakeven price of switchgrass derived from private profit maximizing landowners' perspective is estimated by equating equation 1 and equation 2, and solving for $BEP_{g,c,s}$.

Environmental Analysis

The environmental analysis portion of this study deals with determining the differences in soil erosion, nitrogen and phosphorous runoff, and changes in soil organic carbon that would occur from converting traditional wheat production land into switchgrass production. The EPIC model was used to simulate site-specific 50 states of nature distribution of environmental outcomes including nitrogen loss, phosphorous loss, off-site soil erosion, and changes in SOC derived from switchgrass and wheat production for each of the ten different random weather scenarios for each location. Site-specific simulated expected environmental outcomes were then estimated for each of the selected counties and land classes.

Each of the selected environmental variables (soil loss, fertilizer runoff, and soil organic carbon) would impose environmental consequences on the surrounding watershed and the atmospheric carbon cycle. The economic consequences of these environmental outcomes can be modeled either in terms of damage cost or abatement cost. The optimal level of abatement occurs where the marginal damage costs equal marginal treatment costs.

Several previous studies have estimated the costs associated with the abatement of agricultural runoff including nitrogen and phosphorous; and the off-site damage costs of soil erosion. Gerlach and DeSimone (2005) estimated the abatement costs of nitrogen in Maryland to be \$13 kg/ha. Zivojinovich (2010) estimated nitrogen abatement costs of \$55 kg/ha. Ribaud et

al. (2010) estimated a U.S. average nitrogen abatement cost using wetland restoration of \$6.37 kg/ha. Rabotyagov et al. (2010) estimated that an abatement cost of \$6.67kg/ha would be required to reduce nitrogen loading by 30% through the reduction in the nitrogen fertilizer application on fields in the upper Mississippi River basin.

Non-point phosphorous abatement costs were estimated by Johansson and Randell (2003), Johansson et al. (2004), Keplinger et al. (2003), and Ancev et al. (2006). Ancev et al. (2006) estimated marginal phosphorous abatement costs equivalency with marginal damage costs from phosphorous pollution for the Eucha-Spavinaw watershed in Oklahoma to range from \$14.16 to \$70.17 kg/ha. Estimates of off-site damage costs from soil erosion including the non-monetary recreational values have been produced in several previous studies (Pimentel et al., 1995; Ribaud, 1986; and Huszer and Piper, 1986).

In this study, the cost of nitrogen abatement is assumed to be \$6.37/kg/ha; phosphorous abatement costs is assumed at \$25.83/kg/ha; and off-site damage costs of soil erosion is assumed at \$3.15/Mg/ha (all these values are inflated by 2012 CPI, 2012). According to Bloomberg new energy finance (Doan, 2012), carbon credits have been auctioned for \$12 to \$15/Mg CO₂ by the California Air Resources Board. Therefore, the value of sequestering soil organic carbon was assumed to be \$15/Mg CO₂.

The net present value derived from wheat production in each county for each soil type when considering the selected environmental variables is:

$$E(NPVS_{w,c,s}) = \sum_{i=1}^n \left(\frac{p_{i,w} E(Y_{i,w,c,s}) - VC_{i,w,c,s} - \alpha N_{i,w,c,s} - \lambda SL_{i,w,c,s} - \beta P_{i,w,c,s}}{(1+r)^i} \right) \quad (3)$$

where $E(NPVS_{w,c,s})$ is the expected net present value derived from wheat production w for county c and land class type s ; the additional terms $N_{i,w,c,s}$ and $P_{i,w,c,s}$ are the quantity of nitrogen and

phosphorous runoff in kg/ha derived from wheat production for the i^{th} year and for county c and land class type s ; $SL_{i,w,c,s}$ is the quantity of soil loss in Mg/ha derived from wheat production for the i^{th} year and for county c and land class type s ; α , β are the abatement costs of nitrogen and phosphorous runoff respectively; and λ is the damage costs associated with the soil loss.

The net present value derived from switchgrass production in each county for each soil type when considering the selected environmental variables is:

$$E(NPVS_{g,c,s}) = \sum_{i=1}^n \left(\frac{BES_{g,c,s} E(Y_{i,g,c,s}) - VC_{i,g,c,s} - LC_{c,s} - \alpha N_{i,g,c,s} - \beta P_{i,g,c,s} - \lambda SL_{i,g,c,s} + \delta C_{i,g,c,s}}{(1+r)^i} \right) \quad (4)$$

where $E(NPVS_{g,c,s})$ is the net present value derived from switchgrass production for county c and land class type s ; $BES_{g,c,s}$ is farm-gate breakeven price of switchgrass g for county c and land class type s ; $SL_{i,g,c,s}$ is the quantity of soil loss in Mg/ha derived from switchgrass production for the i^{th} year and for county c and land class type s ; $C_{i,g,c,s}$ is the net change in the quantity of soil organic carbon (Mg/ha) derived from switching to switchgrass production from wheat production for the i^{th} year and for county c and land class type s ; λ is the damage costs associated with the soil loss; δ is the assumed carbon credit for sequestering carbon by producing switchgrass; and other variables are previously defined.

Equating equation 3 and equation 4, and solving for $BES_{g,c,s}$ the site-specific farm-gate breakeven price of switchgrass was estimated for the internal plus selected external environmental consequences.

Results

The EPIC model predicts that there will be a significant reduction in nitrogen loss, phosphorous loss, and soil loss if no-till wheat production is replaced by switchgrass production. The site-specific reduction in estimated nitrogen loss ranges from 23.51 kg/ha/year on land class

I in Hughes County to 68.54 kg/ha/year on land class III in Hughes County. The estimated reduction in soil loss ranges from 0.40 Mg/ha/year on land class II in Lincoln County to 2.71 Mg/ha/year on land class III in Hughes County. The estimated reduction in phosphorous loss ranges from 0.02 kg/ha/year on land class II in Latimer County to 1.89 kg/ha/year on land class III in McIntosh County. These are the net changes estimated from replacing no-till wheat production with switchgrass production (Table 1). The potential environmental benefits from converting land from no-till wheat to switchgrass is greater on land more prone to erosion.

The production of switchgrass can also sequester SOC. In an average year the site-specific net increase in soil organic carbon derived from replacing no-till wheat with switchgrass ranges from 122.10 kg/ha on land class III in Hughes County to 531.41 kg/ha also in Hughes County on land class I (Table 1). However, the SOC accumulation are greater on land class I compared to land class II and III, which increase with the plant biomass. The average reduction in soil loss, reduction in nitrogen loss, reduction in phosphorous loss, derived from switchgrass production on land class I is lower compared to the reduction in soil, nitrogen and phosphorous losses on land class II and III (Figure 2). Land class III with slope gradient of 4% in Hughes County, McIntosh County, and Pittsburg County have the greatest environmental benefits derived from replacing no-till wheat production with switchgrass production (Table 1). On the other hand, switchgrass produced on land class I sequesters more carbon than that produced on land class II and class III (Figure 2). Therefore, converting land class III from no-till wheat to switchgrass production is associated with greater reduction in runoff and thus more beneficial to society compared to converting class I, and class II land.

The site-specific farm-gate breakeven price of switchgrass derived from the profit maximizing private landowner's (internal returns and cost) perspective ranges from \$37/Mg

(Pottawatomie County land class I) to \$66/Mg (Johnston County land class I) (Table 2). Switchgrass produced on land class III of each county has a higher farm-gate breakeven price compare to the switchgrass produced on land class I and land class II, due to lower yields. However, when the selected environmental consequences are valued and considered (on-farm plus environmental benefits) the breakeven price reduces and ranges from \$11/Mg (Hughes County land class III) to \$39/Mg (Johnston County land class I). The average farm-gate breakeven price of switchgrass derived from private landowners' perspective increases as the average yields decrease from good quality soil to lower quality soil. However, when selected environmental outcomes are valued then the average farm-gate switchgrass breakeven price decreases from good quality soil to lower quality soil. The selected environmental benefits derived from converting no-till wheat to switchgrass production on lower quality soil offsets the revenue loss due to lower yields on the lower quality soil.

Replacing no-till wheat production in Hughes County on land class III has the greatest reduction in runoff and at the same time has the lowest SOC accumulation (Table 2). However, the benefits derived from reducing runoff exceeded the benefits derived from lower accumulation of SOC in Hughes County land class III compared to land class I and land class II of the same county, resulting in the lowest farm-gate breakeven price of switchgrass in Hughes County on land class III. Land class III of Hughes County, McIntosh County land class III and Pittsburg County land class III with slope gradient of 4% has the highest potential runoff reduction from replacing no-till wheat with switchgrass, and also has the lowest farm-gate breakeven price of switchgrass \$11/Mg, \$13/Mg, and \$13/Mg, respectively (Table 2) if the external costs are considered.

The difference between the farm-gate breakeven prices derived from the internal returns and cost perspective and the on-farm plus selected environmental consequences perspective (Table 2) range from \$13/Mg/year on land class I in Latimer County to \$46/Mg/year on land class III in Pittsburg County. As expected these differences are highest for land class III in Hughes, McIntosh, and Pittsburg counties. When multiplied by the average yield of 9 Mg/ha/year, the environmental benefits derived from replacing no-till wheat with switchgrass on these highly erodible lands for land class III in Hughes, McIntosh, and Pittsburg counties would be on average \$408/ha/year. The potential environmental benefits from converting land from no-till wheat to switchgrass production to produce feedstock for one potential 700,000 Mg/year biorefinery can be estimated by multiplying these differences by the average yields per ha and by the ha of land converted for each land class and in each county (Table 2). The environmental benefit ranges from \$5,652 for 14 ha of McIntosh County land class I to \$3.47 million for 6,368 ha of land class III of Hughes County's. In an average year, around \$26 million of environmental benefits could accrue to society from converting no-till wheat to switchgrass on 65,382 ha to produce feedstock for a single 700,000 Mg/year biorefinery. On average, land class III has the highest environmental benefits (Figure 3). Therefore, converting the most erodible land from wheat to the production of switchgrass has the greatest potential environmental benefits. Therefore, any public policies designed to incentivize feedstock production might best serve the interest of society by including land quality considerations.

A sensitivity analysis of the site-specific breakeven price of switchgrass is also performed (Table 3). It is found that none of the results significantly change when (a) the discount rate is increased from 4% to 8%; (b) when the expected wheat price is doubled; (c) when the land rental values are doubled. The farm-gate breakeven price of switchgrass derived from only internal

costs is greater than the farm-gate breakeven price of switchgrass derived from on-farm plus environmental benefits.

Conclusion and Discussion

This study finds that compared to no-till wheat production, switchgrass production has the potential to reduce nitrogen and phosphorous runoff, reduce soil loss, and increase sequestration of SOC. This study finds that switchgrass production has environmental benefits over no-till wheat production. The economic differences in the environmental benefits between switchgrass production and no-till wheat production were determined by placing monetary values on the environmental benefits which included nitrogen loss, phosphorous loss, soil loss, and changes in SOC. Valuing environmental benefits derived from switchgrass production reduces the site-specific farm-gate breakeven price of switchgrass. The difference between the farm-gate breakeven prices of switchgrass derived from considering only the internal returns and cost and from considering on-farm plus selected environmental consequences was estimated to be greatest at \$46/Mg/year on land class III in Pittsburg County and lowest at \$13/Mg/year on land class I in Latimer County. Switchgrass production results in relatively greater environmental benefits when it is used to replace wheat grown on the most highly erodible land (land class III). These differences in environmental consequences and potential benefits to society should be considered if public policies are used to incentivize switchgrass production.

Sites with a slope gradient of 4% within the study area (Hughes County land class III, McIntosh County land class III and Pittsburg County land class III) have an average annual estimated environmental benefit of \$408/ha for reducing runoff by converting from no-till wheat to switchgrass.

By public policy, land included in the CRP is required to have an erodibility index equal to or greater than eight (USDA-FSA, 2012). According to the estimated erodibility index, Hughes County land class III, McIntosh County land class III, and Pittsburg County land class III would qualify for inclusion in the CRP. Results show that when environmental benefits are considered the farm-gate breakeven price of switchgrass is lowest in those counties.

Accounting for the potential of planting wheat on some other land to offset the wheat production from the land converted to switchgrass further complicates the problem. The worldwide adjustment in land use in response to the conversion of the marginal land from its pre-switchgrass activity needs to be considered. Additional research would be required to consider the indirect land use consequences.

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Table 1. Site-specific soil loss, nitrogen loss, phosphorous loss reduction and accumulation of soil organic carbon (SOC) derived from replacing no-till wheat production with switchgrass production.

County Land Class (LC)	Slope (%)	Soil loss Reduction (Mg/ha/yr)	Nitrogen loss Reduction (kg/ha/yr)	Phosphorous	
				loss Reduction (kg/ha/yr)	Changes in SOC (kg/ha/yr)
Creek LC-I	0.5	1.4	43.6	0.8	158.2
Haskell LC-I	1	1.3	46.4	0.9	390.9
Hughes LC-I	1	0.8	23.5	1.3	531.4
Johnston LC-I	0.5	1.3	38.3	1.0	367.3
Lincoln LC-I	0.5	0.8	33.7	0.7	231.7
McIntosh LC-I	0.5	1.4	41.0	0.4	524.8
Okfuskee LC-I	0.5	1.2	37.8	0.7	156.0
Oklahoma LC-I	0.5	0.4	33.6	0.4	412.3
Okmulgee LC-I	1	1.2	31.4	1.2	467.8
Pittsburg LC-I	1	1.2	34.0	0.4	419.4
Pottawatomie LC-I	0.5	1.1	33.4	0.9	395.1
Seminole LC-I	0.5	2.0	41.0	1.3	241.2
Wagoner LC-I	1	0.8	29.1	0.7	157.8
Coal LC-II	2	2.0	39.8	0.9	302.4
Creek LC-II	2	1.2	43.6	1.0	151.9
Hughes LC-II	2	1.0	36.0	1.3	261.0
Latimer LC-II	1	0.5	25.7	0.0	294.5
Lincoln LC-II	0.5	0.4	25.1	0.6	336.6
McIntosh LC-II	2	3.0	59.5	1.4	404.8
Okfuskee LC-II	0.5	0.6	25.9	0.1	319.9
Oklahoma LC-II	0.5	0.9	44.4	0.7	309.6
Okmulgee LC-II	2	1.7	52.4	1.2	326.4
Pittsburg LC-II	2	2.3	47.7	0.7	209.0
Seminole LC-II	0.5	0.9	41.0	1.3	241.2
Creek LC-III	2.5	3.0	52.2	1.4	210.8
Hughes LC-III	4	5.5	68.5	1.3	122.1
McIntosh LC-III	4	3.4	66.0	1.9	290.2
Muskogee LC-III	2	3.3	29.1	0.7	194.2
Okfuskee LC-III	0.5	0.5	25.9	0.1	279.9
Okmulgee LC-III	1	1.5	31.1	0.5	432.9
Pittsburg LC-III	4	3.7	63.2	1.5	154.1
Seminole LC-III	2	1.9	55.2	1.5	135.9
Wagoner LC-III	1	1.3	56.2	1.1	137.8

Table 2. Site-specific farm-gate breakeven price of switchgrass with and without valuing the selected environmental consequences, the differences between them, hectares of land leased of each land class for each county, and the corresponding environmental benefits.

County Land Class (LC)	Slope (%)	Internal & External breakeven		Diff. (/Mg)	Land (ha)	Env. Benefit
		Internal price (/Mg)	External price (/Mg)			
Creek LC-I	0.5	\$48	\$25	\$23	1,337	\$470,180
Haskell LC-I	1	\$53	\$28	\$24	65	\$28,472
Hughes LC-I	1	\$49	\$30	\$19	329	\$99,123
Johnston LC-I	0.5	\$66	\$39	\$27	107	\$51,403
Lincoln LC-I	0.5	\$53	\$36	\$18	251	\$75,644
McIntosh LC-I	0.5	\$51	\$24	\$26	14	\$5,652
Okfuskee LC-I	0.5	\$50	\$32	\$18	774	\$252,815
Oklahoma LC-I	0.5	\$54	\$36	\$19	590	\$200,654
Okmulgee LC-I	1	\$49	\$27	\$22	544	\$192,701
Pittsburg LC-I	1	\$53	\$33	\$20	142	\$49,768
Pottawatomie LC-I	0.5	\$37	\$20	\$17	669	\$211,861
Seminole LC-I	0.5	\$54	\$32	\$22	120	\$44,981
Wagoner LC-I	1	\$52	\$34	\$18	773	\$252,212
Coal LC-II	2	\$51	\$34	\$16	999	\$275,298
Creek LC-II	2	\$51	\$16	\$34	3,647	\$1,422,695
Hughes LC-II	2	\$50	\$28	\$23	2,645	\$934,153
Latimer LC-II	1	\$50	\$37	\$13	740	\$163,834
Lincoln LC-II	0.5	\$55	\$37	\$18	2,895	\$815,349
McIntosh LC-II	2	\$56	\$18	\$38	1,413	\$743,870
Okfuskee LC-II	0.5	\$52	\$38	\$15	1,057	\$253,309
Oklahoma LC-II	0.5	\$56	\$34	\$22	2,882	\$1,070,551
Okmulgee LC-II	2	\$52	\$19	\$33	3,003	\$1,467,664
Pittsburg LC-II	2	\$55	\$32	\$24	2,774	\$1,065,487
Seminole LC-II	0.5	\$54	\$32	\$22	1,329	\$498,166
Creek LC-III	2.5	\$56	\$12	\$44	3,842	\$1,757,661
Hughes LC-III	4	\$56	\$11	\$45	6,348	\$3,472,148
McIntosh LC-III	4	\$58	\$13	\$45	552	\$290,040
Muskogee LC-III	2	\$54	\$37	\$17	4,623	\$1,181,251
Okfuskee LC-III	0.5	\$53	\$39	\$14	3,154	\$715,647
Okmulgee LC-III	1	\$54	\$30	\$24	5,139	\$1,773,843
Pittsburg LC-III	4	\$58	\$13	\$46	5,938	\$3,056,363
Seminole LC-III	2	\$57	\$26	\$31	2,242	\$898,225
Wagoner LC-III	1	\$55	\$26	\$29	4,445	\$2,075,663
Total						\$25,866,681

Table 3. Sensitivity analysis of the site-specific breakeven price per Mg of switchgrass.

Internal Breakeven Price			
	Land Class I	Land Class II	Land Class III
Discount rates 4%	\$51.47	\$52.96	\$55.76
Discount rate double (8%)	\$53.63	\$55.22	\$57.86
Wheat Price double	\$107.65	\$111.96	\$118.41
Land rent double	\$55.64	\$57.34	\$59.92
Internal and External Breakeven Price			
Discount rates 4%	\$30.45	\$29.54	\$22.87
Discount rates double (8%)	\$29.91	\$29.03	\$22.40
Wheat Price double	\$88.28	\$86.59	\$85.58
Land rent double	\$34.58	\$33.65	\$27.09
Differences between Internal and Internal plus External Breakeven Price			
Discount rates 4%	\$21.03	\$23.41	\$32.89
Discount rates double (8%)	\$23.72	\$26.19	\$35.46
Price double	\$19.37	\$25.37	\$32.83
Land rent double	\$21.06	\$23.69	\$32.83

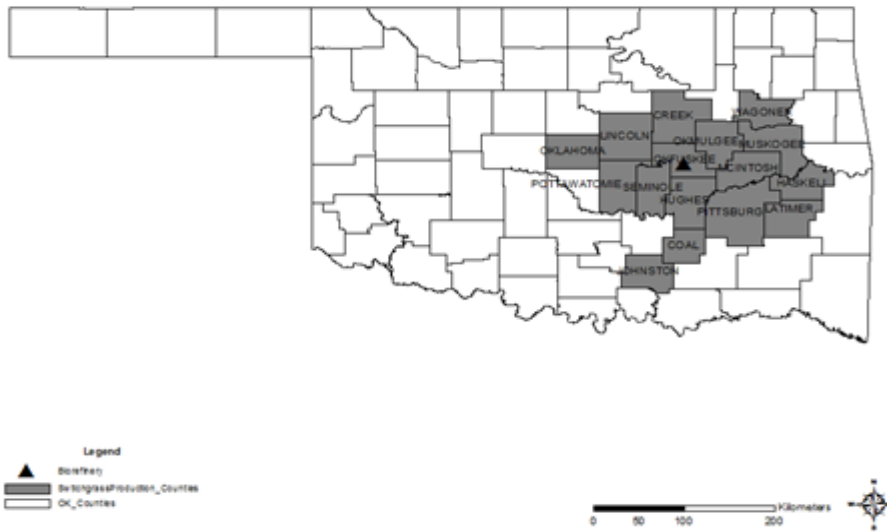


Figure 1. Land to be converted to switchgrass to support a hypothetical biorefinery at Okemah, Oklahoma.

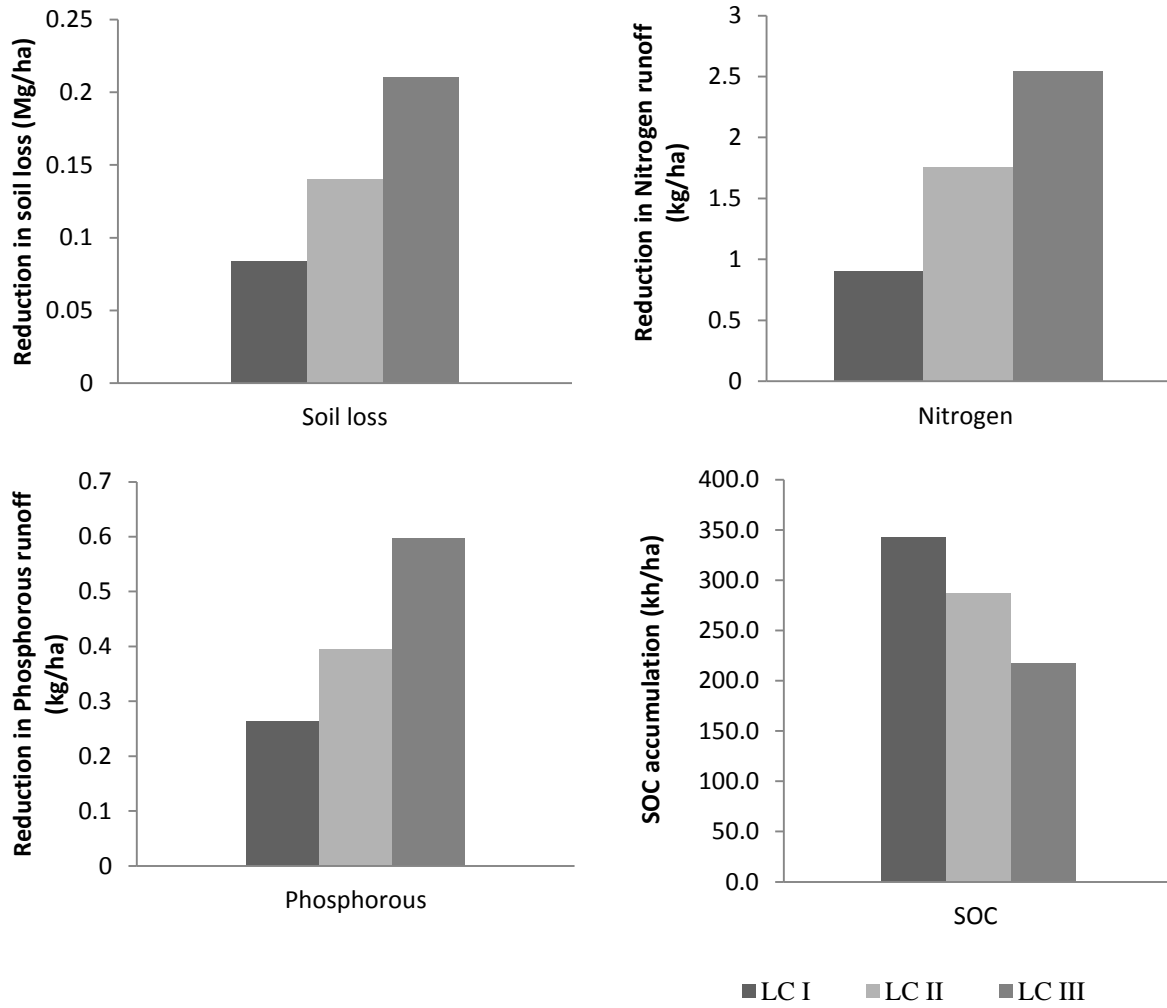


Figure 2. Average per year reduction in soil loss, nitrogen loss, phosphorous loss, and SOC accumulation between land class I (LC I), land class II (LC II), and land class III (LC III).

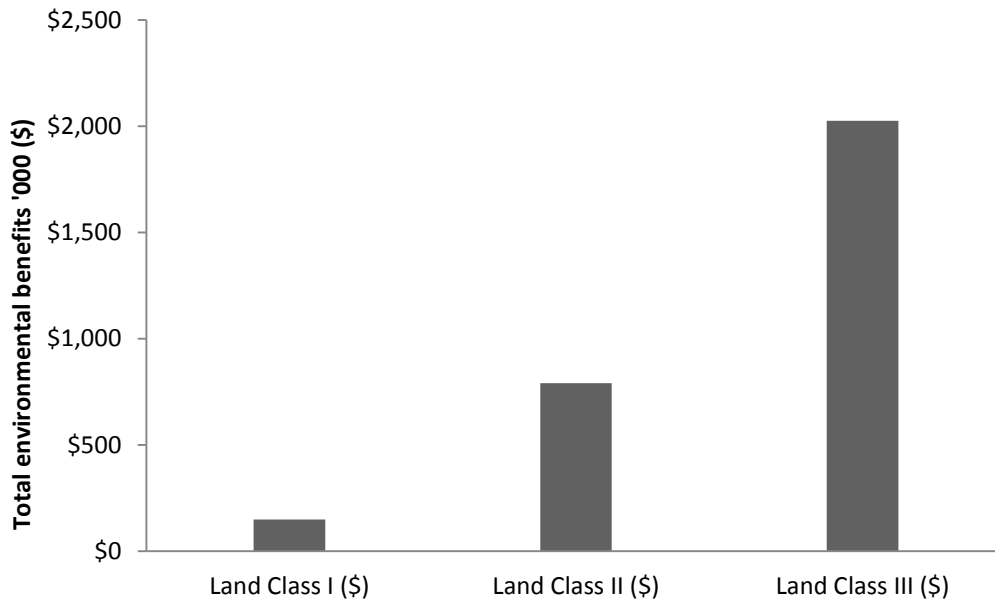


Figure 3. Total environmental benefits derived to society from a potential biorefinery established at Okemah, Okfuskee, Oklahoma.