Restricting Switchgrass Biomass Feedstock Production to Marginal Land to Limit Competition with Food Production

Amadou Gouzaye and Francis M. Epplin

Contact information:

Amadou Gouzaye
Department of Agricultural Economics
Oklahoma State University
Stillwater, OK 74078-6026

405-744-6161 (phone)
405-744-8210 (fax)
amadou.gouzaye@okstate.edu

Francis M. Epplin
Department of Agricultural Economics
Oklahoma State University
Stillwater, OK 74078-6026

405-744-6156 (phone)
405-744-8210 (fax)
f.epplin@okstate.edu

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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 acres 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 mathematical programming model was 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 44% and increases the cost to deliver feedstock by 32% compared to when switchgrass production is permitted on land classes I-IV.

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

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). 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. Development of dedicated energy crops such as switchgrass was envisioned as a way to mitigate the “excess capacity” problem (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 anticipation of an economically viable feedstock production and conversion system (Pacheco, 2006), the U.S. Energy Independence and Security Act (EISA) was passed by Congress and signed by President Bush in 2007. 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. Researchers have evaluated 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).

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. For details of the model, see Gouzaye (2015).

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.

Land Area and Transportation Distances

The quantity of land in each county is determined for land capability classes I–IV from the USDA SSURGO (USDA NRCS, 2014) soil database. For each land capability class in each county, the soil with the most acres 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 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).

Transportation cost is assumed to be a function of the distance between the feedstock production site and the biorefinery location (Griffith, Haque and Epplin, 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™ 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.

Switchgrass Biomass Yield Distribution

Soils (USDA NRCS, 2014) and historical weather (Oklahoma Climatological Survey, 2014; NOAA, 2014) data were used in combination with crop management data to simulate historical switchgrass yields using the Environmental Policy Integrated Climate (EPIC) model. EPIC was calibrated using 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.

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 1). Land is leased in 12 counties within the potential biorefinery supply shed (Figure 1). If 176,784 acres of land of capability class IV are leased, it costs $62.31 to produce and deliver one ton of feedstock to the biorefinery (Table 2). 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 2). 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 $48.08 million. For an investment capital cost of $220 million, a price of biofuel of $2.38 per gallon is necessary for the biorefinery to breakeven (Table 2).

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, 130,75 acres would be leased to produce enough feedstock to meet the biorefinery requirement (Table 1). The land requirement in this scenario is 26% 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 2) 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 $51.15 which is 18% 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 $5.07 per ton (7%) for land cost (Table 2). The annual feedstock cost is $39.47 million (Table 2). 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 11% lower compared to the breakeven price in the scenario with only land class IV (Table 2). 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 acres (Table 1) would optimally be leased across seven counties (Figure 3) 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 $47.27 (Table 2). The average field operation cost for feedstock production is $40.63. Estimated transportation cost is $6.65 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 $62.31 per ton when only land class IV is assumed to be available for lease.

The breakeven biofuel price in the third scenario is $2.08 per gallon, and the average annual feedstock cost is $36.48 million. The breakeven price is lower than the breakeven price in the first scenario, which reflects the lower cost of delivered feedstock. At $47.27 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".

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 2). With increased acres, the land rental cost increases from $6.54 to $6.97 per ton. However, the feedstock production cost decreases from $62.31 to $60.88 per ton (Table 2). 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 miles 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.

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 of 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 2). Biomass transportation cost increases from $15.92 per ton to $17.74 per ton.

Discussion

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 44% and the cost to deliver feedstock increases by 32% compared to when switchgrass production is permitted on land classes I-IV. 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 acre 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. 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 not 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.

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Table 1. 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 2. 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.

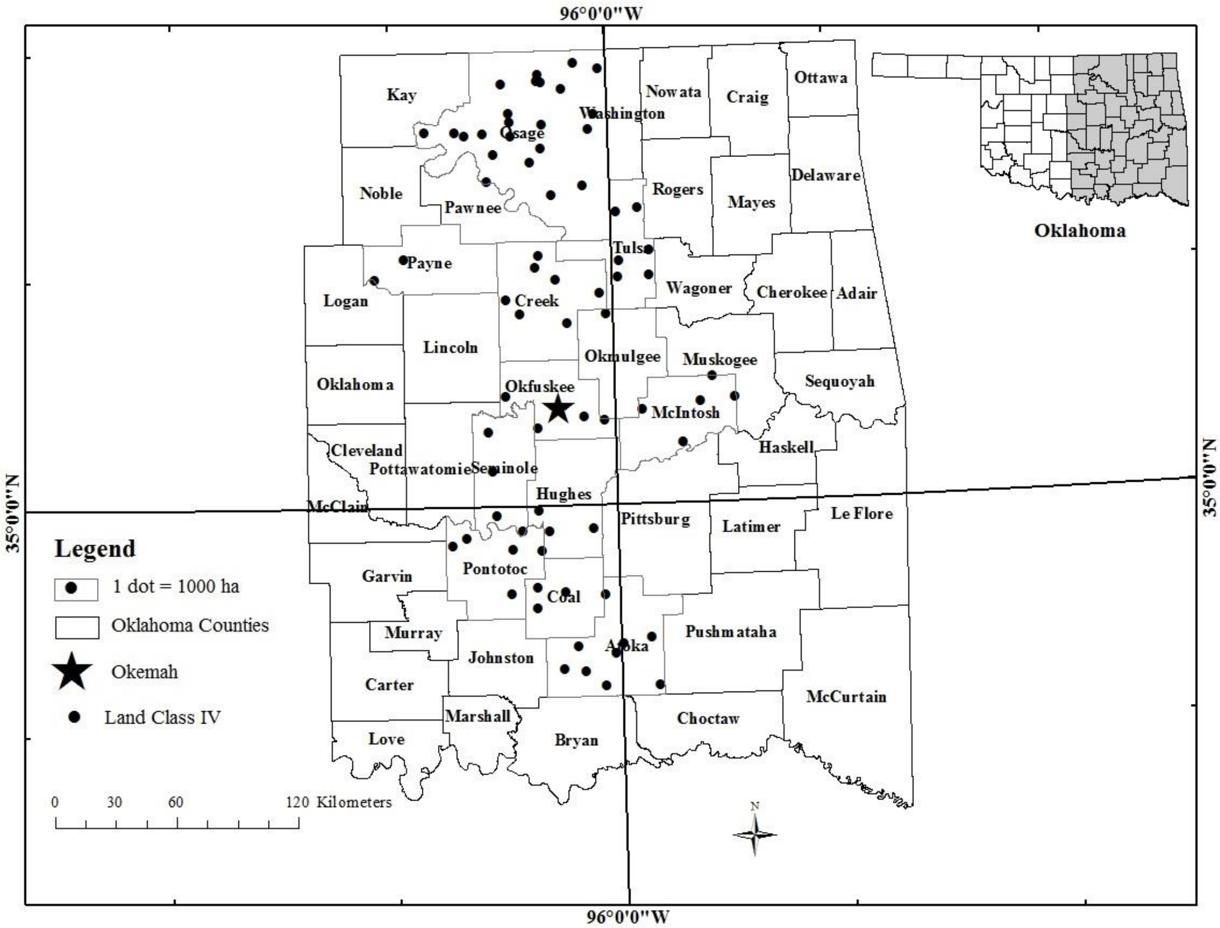

Figure 1. Land optimally selected in 12 Oklahoma counties when lease is restricted to land of Capability Class IV

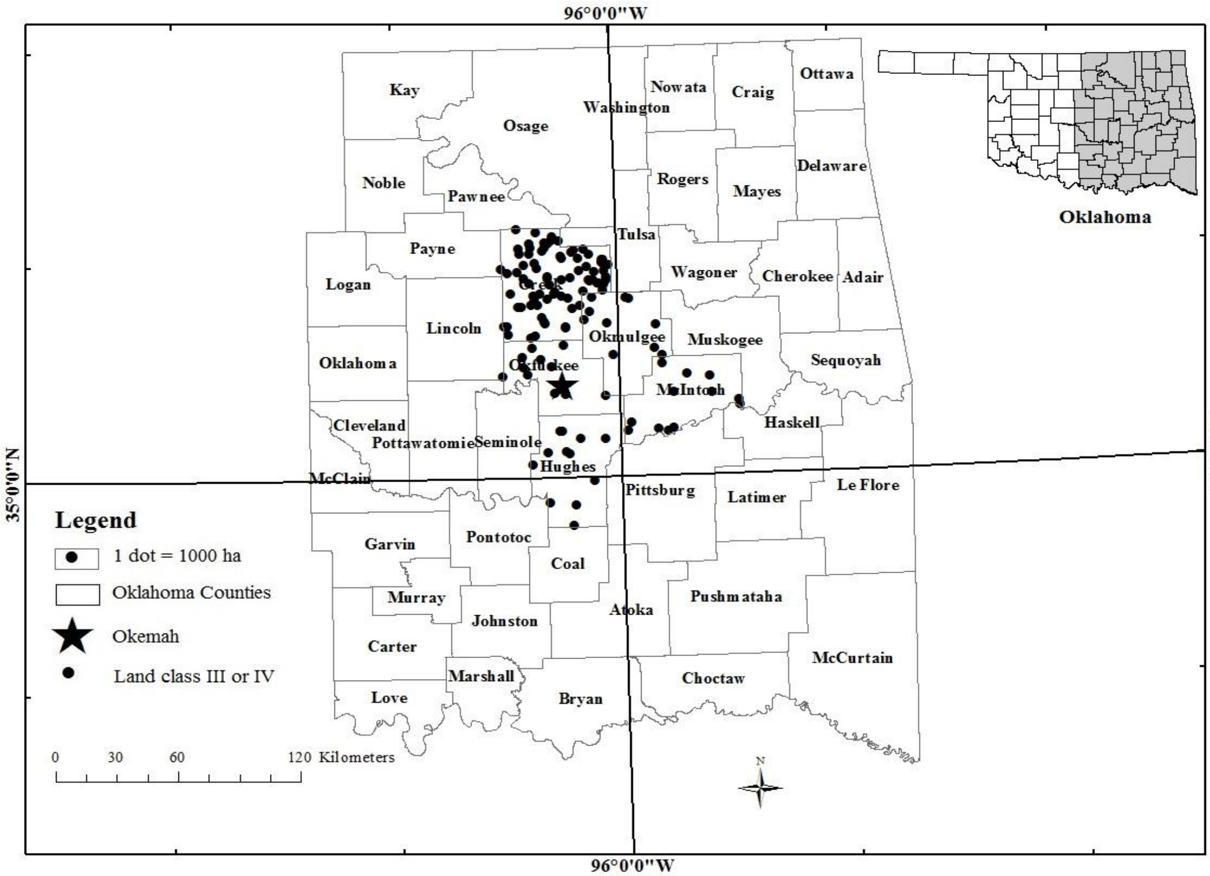

Figure 2. Land optimally selected in five Oklahoma counties when lease is restricted to land of Capability Classes III and IV

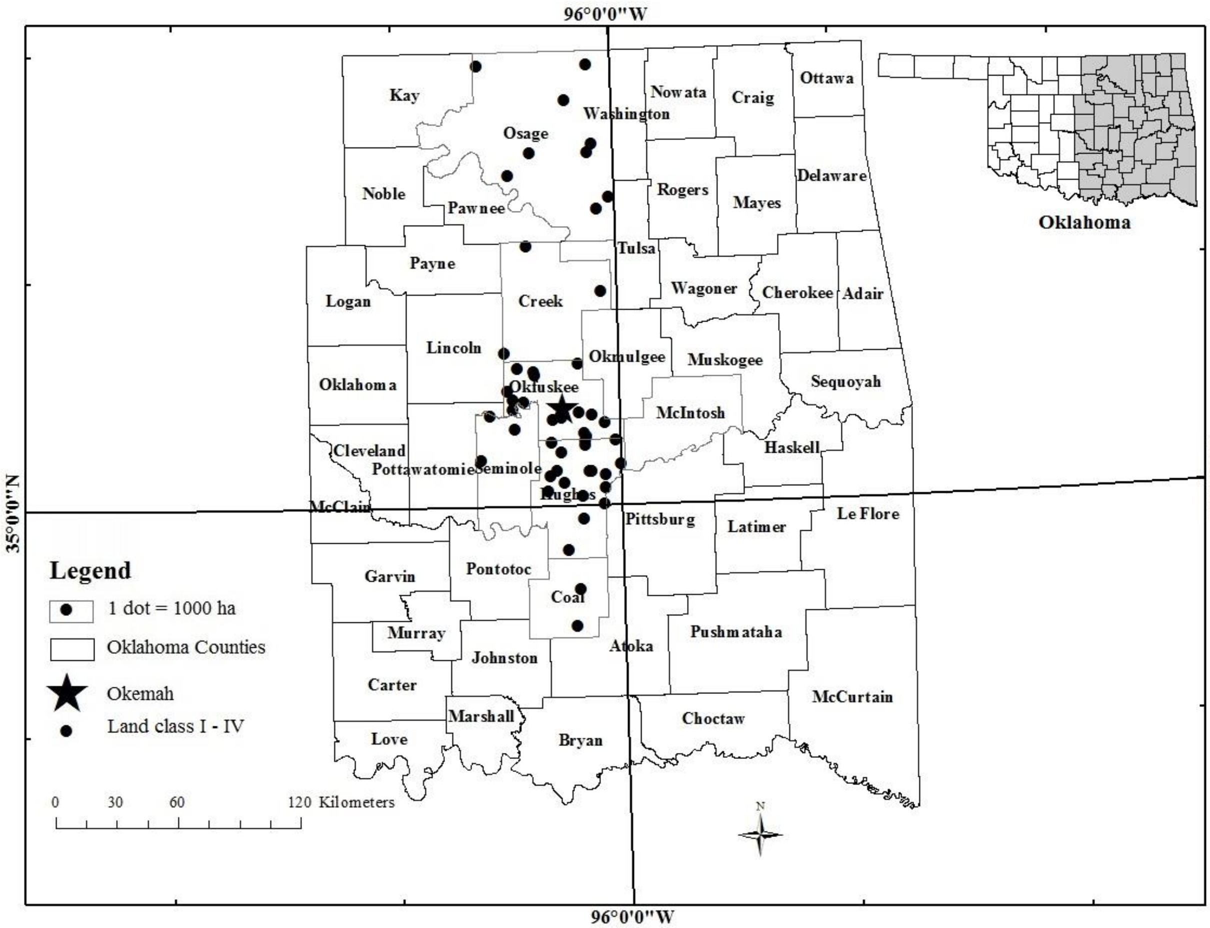

Figure 3. Land optimally selected in seven Oklahoma counties when lease is unrestricted