Farm-Scale Production Cost of Switchgrass for Biomass

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Abstract The economic potential of cellulosic biomass from switchgrass has heretofore been evaluated using estimates of farm costs based on extrapolation from experimental data and budget estimates. The objective of the project reported here was to estimate the cost of production that would be experienced by farmers on commercial production situations. Switchgrass was produced as a biomass crop on commercial-scale fields by ten contracting farmers located from northern North Dakota to southern Nebraska. Results showed a wide range of yields and costs across the five production years and ten sites, with an overall average cost of $65.86 Mg^{-1} of biomass dry matter, and annualized yield of 5.0 Mg ha^{-1}. The low-cost half of the producers were able to produce at an average cost of $51.95 Mg^{-1} over the 5-year period. When projected to a full 10-year rotation, their cost fell further to $46.26 Mg^{-1}. We conclude that substantial quantities of biomass feedstock could have been produced in this region at a cost of about $50 Mg^{-1} at the farm gate, which translates to about $0.13/l of ethanol. These results provide a more reliable benchmark for current commercial production costs as compared to other estimates, which range from $25 to $100 Mg^{-1}.

Abbreviations

hectare (ha)	10,000 m^2
megagram (Mg)	1,000 kg
CRP	Conservation Reserve Program

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Introduction

The use of fossil fuels to produce energy has induced both increased CO_2 concentration in the atmosphere and associated climate change and dependencies on politically sensitive international oil markets. These consequences have stimulated both considerable research on alternative energy sources and vigorous policy debates about policies to support them. Meanwhile, grain ethanol production has increased dramatically, raising concerns about unwelcome side effects of that technology, even though it has no promise of replacing more than a small fraction of gasoline for automotive fuel [19]. Ethanol produced from cellulosic sources is thus viewed by many to be a prospective alternative energy source that is both more abundant and more environmentally-friendly than grain ethanol [16]. An estimated 3 to 21 million ha of agricultural land in the USA could be converted to perennial grasses for bioenergy based on theoretical market prices [13]. Land for perennial grass production has been projected to come from the land

currently in crop production, land currently enrolled in the Conservation Reserve Program (CRP), and pastures [27].

Production technology for producing ethanol from cellulose is not yet commercialized, and may not be for several years, but switchgrass is a potential feedstock for the latent commercial conversion processes. An economic evaluation of a cellulosic energy system based on dedicated biomass crops such as switchgrass must include realistic estimates of the cost of producing the feedstock itself. To date, however, all such evaluations have been based on experimental switchgrass plot data extrapolated to commercial fields, using budgeting techniques and guesses about the relevance of the experimental results to farm-level production technology. The present study addresses this gap in information by summarizing actual costs of biomass production on ten cooperating farmers' fields from Nebraska through North Dakota (Fig. 1). Adapted switchgrass cultivars were planted, grown, and managed as biomass crops for a 5 year period beginning in 2000 in Nebraska and 2001 in South and North Dakota using management practices developed in previous small plot research. Net energy and greenhouse gas implications of this study have been reported elsewhere [21].

Cooperating farmers were paid for their work and land use. They documented, and project staff verified, all

Fig. 1 Location of field sites where switchgrass was managed as a bioenergy crop

production operations and field biomass. Production and management information from each farm for the 5 year period was used in the analyses presented here. Fields used in the study had characteristics that would have qualified them for enrollment in the Conservation Reserve Program (CRP) of the US Department of Agriculture which pays farmers and land owners to take erodible land out of production and maintain it as planted grasslands or woodlands. The CRP was authorized by the Food Security Act of 1985 and had a goal of removing highly erodible, marginal cropland from crop production.

Methods

Site Selection The farms in this study were located in a region where previous economic model analyses indicated switchgrass grown as a biomass energy crop would be economically feasible [26]. The cooperating farmers and their farms used in this study were selected based on recommendations of US Department of Agriculture— Natural Resource Conservation Service (USDA-NRCS) staff for the three states and site visits by co-author Vogel. The USDA-NRCS provides technical land eligibility determinations, conservation planning and practice implementation for the Conservation Reserve Program (CRP). Rainfed fields from southern Nebraska to northern North Dakota were selected to represent a range of biomass production environments likely to occur in this large geographical region and the fields had marginal cropland characteristics that would have qualified them for enrollment in the CRP. Sites are identified in this report with the name of the nearest town. Field size ranged from 3 to 9.5 ha and averaged 6.7 ha. Field sizes, crop history and cultivars are reported elsewhere [20].

The Nebraska fields were established in 2000 and grown through 2004, while the South Dakota and North Dakota fields were established in 2001 and grown through 2005. With one exception, the fields were grown for five seasons. The exception was at Atkinson, NE, where a portion of the field was abandoned after two unsuccessful attempts at establishing a switchgrass stand. In this particular location, the fields consisted of two "pivot corners" (the un-irrigated corners of a square field with a center pivot irrigation system), one of which was abandoned after year 2. One other site suffered a failed establishment the first year, and a third required partial re-seeding.

The climatic conditions were in general not favorable during these years, as seven of the ten sites experienced rainfall below the 30-year mean, and all but Munich, ND, experienced temperatures above normal (for weather data by site, see Table 10 which is published as supporting informa-

tion on the BioEnergy Research website.) The Atkinson and Douglas, NE sites were particularly warm and dry.

Management Protocol Farmer cooperators managed all aspects of crop production and harvest except that the Nebraska switchgrass fields were planted by USDA-ARS, Lincoln, personnel. Commercial custom rates were used for the cost of this service. Cooperators contracted to produce the crop following recommended management practices, in exchange for fixed payments plus in most cases a bonus for harvested switchgrass. A general set of recommended management practices, based on previous small plot research, was given to every cooperator. These management practices detailed seedbed preparation, planting depth, planting dates, herbicide use, and harvesting dates. Cultivars selected for each field were based on prior research within respective geographical regions. Seeding rates were 322 pure live seed per square meter. Soil samples were taken on each field before switchgrass establishment to assess soil fertility. No fertilizer was applied the establishment year. Nitrogen fertilizer rates recommended to farmers in this study were 10 kg N per Mg ha^{-1} of expected yield [24] with a recommended maximum of 112 kg ha^{-1} year^{-1}. Nitrogen fertilizer application varied by post-establishment harvest years and locations because of farmer management decisions based on soil moisture or drought conditions. Applied N ranged from 0 to 212 kg ha^{-1} with a mean application rate of 74 kg ha^{-1} year^{-1} across all farms for harvest year 2 to 5 (nitrogen rates and herbicide applied at each site are listed in Tables 8 and 9, published as supporting information on the BioEnergy Research website). A USDA agronomist visited each field at least twice during each growing season to monitor switchgrass management, stands, and biomass yields. In mid-summer, prior to harvest, 1.1 m^2 quadrants were clipped at 16 locations within each field and the harvested samples were dried and weighed to verify subsequent machine harvested yields. Harvests were completed with conventional hay equipment. Harvested bales were stored at the edge of the field, or at an alternate location convenient for the cooperator. Modern balers are engineered to deliver very uniform bales so cooperators weighed a subset of bales for yield determinations and sampled the bales with a provided bale coring probe to obtain bale samples for determining baled biomass dry matter concentration. Bale core samples were sealed in plastic bags and sent to project headquarters for further analysis of moisture content and other characteristics. All yields were adjusted to a dry weight basis.

Cost Assessment Cooperating farmers did not always implement all recommended management practices for a variety of reasons. Management practices and costs reported herein are those actually adopted and incurred.

Farmers chose to perform some field operations with their own equipment, and other times hired custom operators to perform the field work. To establish costs in the former case, farmers reported the type and size of equipment, along with the hours required. Corresponding power and machinery costs per hour were then taken from Selley et al. [22], and labor was charged at $10/h. Services and materials purchased were recorded as the amount actually paid. In a few instances where machinery costs could not be evaluated with these approaches, the average custom rate for the region [11] was used as the cost of the operation. Land rental rates, as estimated by the cooperating farmers for similar land types in their areas, were within the range of rental rates reported in general surveys of rental rates [10]. In the case of the Atkinson site, the costs incurred on the abandoned portion of the field were included in total cost for the crop produced on the surviving portion.

Annualization Special considerations involving the time value of money and goods are required to determine the cost of producing perennial crops such as switchgrass. In this study, this is done by calculating the "annualized cost" of production [3, 17], using a real discount rate of 10%. While the average real prime discount rate in the USA is only about 4%, and the historic real rate of return to land is similar [12], a real rate of 10% is a more conservative estimate of the rate that is appropriate for enterprises with risks comparable to those of a switchgrass crop. To evaluate the sensitivity of results to this assumption, we have calculated that when the interest rate is reduced from 10% to 4%, the average cost per Mg is reduced by 4.1%, with the reduction at individual sites ranging from 2.2% (Huron) to 6.8% (Atkinson.)

To calculate annualized cost per hectare, the present value of the sequence of annual expenditures, E_t, was first calculated using the 10% discount rate as $PV = \Sigma_t (E_t/(1.10)^t)$. Planting expenditures were considered to occur at time $t=0$, and all other expenditures and the harvest itself were considered to occur at the end of the respective crop year, i.e., at $t=1,…, 5$. This present value was converted to an annuity of value A, paid at the end of each year through year 5, such that the present value of the annuity is identical to the present value of the expenditures incurred, viz., $A = PV[0.10/(1-(1.10)^{-5})]$. Thus, actual expenditures over the 5-year period are equivalent in present value to an "annualized" expenditure of A per hectare at the end of each year for the 5 years. To convert this annualized per hectare cost to cost per Mg, the "annualized yield" was calculated in exactly the same manner. Cost per Mg was then obtained by dividing annualized cost by annualized yield.

To provide an estimate of the cost of production for a projected 10-year cropping period, rather than the 5-year

Fig. 2 Average dry weight yields (Mg ha^{-1}) by year of production with first year being the establishment year
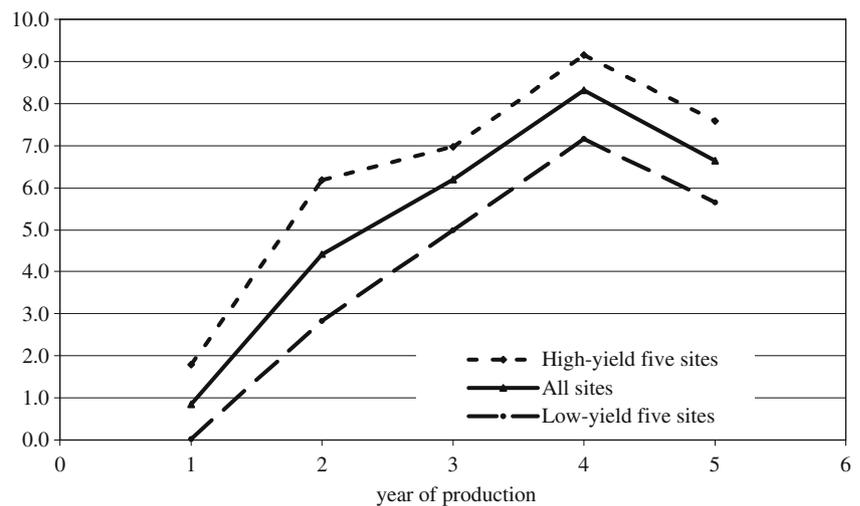
period observed, the average yield and expenditures for the last 4 years at each site were projected to occur at that site for each year from year 6 through year 10. The annualized cost of production over this 10-year period was then calculated as described above.

Results

Yields for the 5-year study period were lower than yields for a fully established crop, because full production may not be achieved until the third growing season for switchgrass. Average yields across these sites continued to increase through the fourth growing season (Fig. 2). The decrease in yield in year 5 is attributed to environmental conditions and farmer deviation from management guidelines. Year 5 was 2004 for the Nebraska sites and 2005 for the South and North Dakota sites. The Nebraska sites had below average growing season precipitation and above average temperatures in 2004. In 2005, Streeter ND had below normal precipitation and had above normal temperatures. Highmore, SD and Munich, ND had reduced N application rates in 2005. Once established, the crop can be expected to persist more or less indefinitely, but a farmer likely would not keep stands for more than 10 years in order to rotate to other crops or to plant improved switchgrass or other grass cultivars. To account for yield variation through this crop production cycle, we annualized yields over the first 5 years to provide an average yield that accounts for the time value of production, at a 10% annual discount rate. To estimate the annualized yield for a 10-year rotation at these sites, we projected yields from year 6 out to year ten at the average level realized during seasons 3–5.

Average annualized dry matter yield across the ten sites for the full 5 years (Table 1) was 5.0 Mg ha^{-1}, or 7.0 Mg ha^{-1}

when extrapolated to a 10-year rotation. Average yields from the five high-yield sites were about 20% higher than this overall average, whereas those from the five low-yield sites were 25% lower. Site-specific annualized yields for the 5-year period ranged widely, from 2.5 to 9.0 Mg ha^{-1} (see Table 5, which is published as supporting information on the BioEnergy Research website).

Cost The average annualized cost for 5 years of production on these sites was $65.86 Mg^{-1} (Table 2), with a range from $41.54 to $107.05 (site specific annualized costs are listed in Table 6, which is published as supporting information on the BioEnergy Research website.) At Atkinson, NE, the high-cost site, establishment failed the first year, and again for the second year on about half the site which was then abandoned. The five low-cost sites averaged about 22% lower costs than the overall average, the same fraction as the yield difference. The five high-cost sites averaged 36% higher than the average, a much higher fraction than the yield difference.

The time period in which a field is kept in switchgrass for biomass production (rotation length) affects the cost of production. We calculated the annualized production cost for various rotation lengths, starting at 3 years, increasing to 5 years and extrapolated to 10 years (Fig. 3; site specific

Table 1 Annualized switchgrass yields on farm fields (Mg ha^{-1})

	Rotation length	
	5 years (observed)	10 years (extrapolated)
Five highest yielding sites	6.0	7.9
All sites	5.0	7.0
Five lowest yielding sites	3.8	5.9

Table 2 Annualized cost of production on farm fields ($ Mg^{-1} DM)

	Rotation length	
	5 years (observed)	10 years (extrapolated)
Five highest cost sites	88.25	78.31
All sites	65.86	59.10
Five lowest cost sites	51.95	46.26

Mg costs are listed in Table 7 which is published online as supporting information on the BioEnergy Research website). Average annualized cost per Mg was $89.02 for a 3-year rotation, $70.64 for a 4-year rotation, and $65.86 for five seasons (as reported above.) We then extrapolated yields and costs to a tenth season, estimating cost and yield as constant for years 6 to 10, at the average of cost and yield for seasons three through five. For this 10-year rotation, average annualized cost per Mg fell to $59.10, $46.26 for the five low-cost sites and $78.31 for the five high-cost sites.

The cost data is broken down by field operation at each site (Table 3). The first three operations, seeding, fertilizing and weed control, each accounted on average for approximately 10% of cost, while harvesting accounted for about 25% and land rent for 45%. Table 4 shows the cost data broken down by category of input. We include machinery and labor expenses together because many operations were performed by custom operators at a single rate per operation, making it impossible to separate the cost into components. Machinery and labor accounted for about a third of cost, materials for about 20%, and land rent for 45%. These results will facilitate reconciliation of these results with other cost estimates and will also allow for adjustment of cost estimates as input prices change, and as input–output ratios change with improved technology.

Discussion

The farm-level production costs from this study provide a benchmark for the cost of commercial production of switchgrass, stored at the farm gate, using technology available in the central and northern Great Plains at the turn of the century. While the average cost experienced over five seasons was $65.86 Mg^{-1}, this cost would have fallen to about $59.10 Mg^{-1} if the rotation period had been extended to 10 years instead of 5. It is reasonable to conclude from this study that substantial quantities of switchgrass could have been produced in the northern Great Plains during this period at a farm-gate cost as low as $50 Mg^{-1}, as half of our producers were able to produce at this cost.

Using a conversion rate of 0.38 l kg^{-1} [7], the farm-gate feedstock cost per liter averaged $0.173 l^{-1} over the 5 years, falling to $0.156 l^{-1} for a simulated 10-year rotation. Comparable figures for the low-cost producers are $0.137 and $.122 l^{-1}, suggesting that substantial quantities of feedstock could have been produced at average costs in the vicinity of $0.13 l^{-1}. The average cost of transporting round bales to a refinery is estimated [12] to be about $13 t^{-1}, or $0.034 l^{-1}, bringing the total cost of switchgrass feedstock delivered to the refinery to about $0.17 l^{-1}. This compares to a net maize feedstock price of $0.13 l^{-1} at $2.00 bu^{-1}, or $0.26 l^{-1} at $4.00 bu^{-1}, the approximate range of maize prices paid by ethanol refineries during 2006 and 2007.

Wide disparities have existed among previous estimates of yield and production cost appropriate to the plains, ranging from $30–100 Mg^{-1}. Estimates from the mid-1990's [8, 25], based on budgeting procedures, ranged from $25 to $30 Mg^{-1} ($31 to $37 in 2003 dollars), but did not include land cost, which is about 45% of cost among our producers. Even as late as 2003, yields were estimated at 7.8 Mg ha^{-1} for the North Central region [27], contrasted with our producers who experienced annual-

Fig. 3 Annualized cost ($ Mg^{-1}) of switchgrass production, by length of rotation
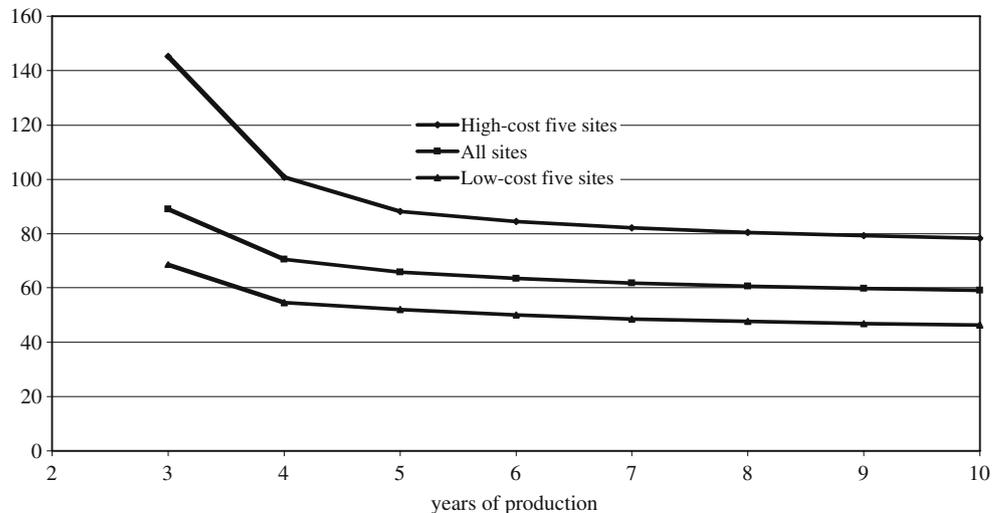
Table 3 Annualized cost per hectare, by farm operation

Site	Seedbed and planting	Fertilizing	Weed control	Harvest	Rent	Total cost
	$ ha^{-1}					
Munich, ND	25.60	33.31	37.05	82.01	98.84	276.80
Streeter, ND	31.86	23.87	40.65	54.02	64.25	214.65
Bristol, SD	34.76	46.48	65.56	107.56	118.61	372.97
Highmore, SD	43.90	22.17	8.80	90.24	86.49	251.59
Huron, SD	37.37	29.26	31.19	105.32	160.62	363.75
Ethan, SD	31.50	54.71	9.43	90.28	197.68	383.61
Crofton, NE	26.61	35.65	34.91	57.74	222.39	377.30
Atkinson, NE	43.02	22.58	34.72	38.24	123.55	262.11
Douglas, NE	22.96	49.84	33.18	79.10	210.04	395.12
Lawrence, NE	21.64	45.23	15.34	98.68	148.26	329.15
Weighted avg	30.21	37.15	33.42	80.25	147.45	328.48

ized yields of 5.0 Mg ha^{-1}, and non-land costs were estimated at $25.62 Mg^{-1} compared with the average $36.29 Mg^{-1} for our producers (Table 4.)

We have made cost comparisons for previous studies that examined all cost components for switchgrass production (see Table 11 in the supporting materials.) To facilitate comparisons, we eliminated interest cost for all these studies as well as our own and calculated cost per Mg based on a 5-year rotation, ignoring any production during the establishment year. The cost estimates per Mg, adjusted to 2003 prices, range from $29.35 by Epplin [6] for the Oklahoma plains, to $72.50 by Hallam et al.[9], and $95.90 by Duffy and Nanhou [5] for Iowa cropland. The comparable number from our study is $63.83 Mg^{-1}. The budgeted cost in Oklahoma is low partly because inputs were minimal, partly because land rent equivalent to $80 ha^{-1} is very low, and partly because postulated yield of 9 Mg ha^{-1} is high relative to the 6.4 Mg ha^{-1} realized by our producers during the 4 maintenance years of the rotation. Costs in Iowa are higher because of higher land rental rates and much higher fertilizer inputs, even though their yield estimates are also considerably higher (11.1 Mg ha^{-1} by Hallam et al. [9]), based on plot data, and 7.6 Mg ha^{-1} postulated by Duffy and Nanhou [5].

More recently, Pimentel and Patzek [18] proposed a yield estimate of 10 Mg ha^{-1} but reported two different cost estimates. In their Table 3 they specify only $23 Mg^{-1} for non-land costs, optimistic relative to the experience of our producers. In their Table 4 they report an extremely high total cost of $100 Mg^{-1}, attributed to an unpublished study that is no longer available at the cited URL. Another recent study [15], based on a 4-year field-scale (8.6 ha) study in northern Italy, reported average yield at 6 Mg ha^{-1} for the last 3 years, annualized cost at about ∈120 Mg^{-1} (approximately $150 Mg^{-1}.) To the authors' knowledge, this is the only other published study of recorded costs on field scale switchgrass production, though it is not very relevant to cost of production in the USA.

In comparison to crops such as maize, only a fraction of the research on developing improved cultivars or hybrids and improved management practices has been conducted for switchgrass. Improved management practices can result in both increased biomass and ethanol yields per hectare and can also result in reduced production costs per Mg of biomass. As an example, the farmers in this study who had the lowest production costs were those that were able to obtain harvestable yields the establishment year because of good weed control by the use of herbicides which controlled both broadleaf and grass annual weeds. Two of these low-cost producers had previous experience with switchgrass, indicating the importance of farmer experience in lowering production cost. They subsequently also had higher than average second year yields.

All the cultivars used in this study [20] were developed primarily for use in pasture production systems and not for

Table 4 Weighted average annualized cost of producing switchgrass as a bioenergy crop by category of input

	Annualized Costs	
	$ ha^{-1}	$ Mg^{-1a}
Machinery and labor		
Seedbed preparation and seeding	13.82	2.77
Herbicide application/weed control	8.60	1.72
Fertilizer application	5.98	1.20
Cut/swath	15.34	3.08
Bale and store	64.91	13.01
Total machinery and labor expenses	108.66	21.78
Materials		
Seed	16.39	3.29
Herbicides and other chemicals	24.82	4.98
Fertilizer	31.17	6.25
Total materials expenses	72.37	14.51
Subtotal	181.03	36.29
Land rent	147.45	29.56
Total cost (b)	328.48	65.86

[a] Calculated at the average annualized yield of 5.0 Mg ha^{-1}

high yield biomass energy production systems. To enhance economic production efficiency of biomass feedstocks for crops such as switchgrass, higher yielding cultivars or hybrids developed specifically for use as biomass energy crops and associated management practices will need to be developed for each major agroecosystem where these crops will be grown. Traditional breeding techniques have increased yield performance of switchgrass by 20 to 30% from existing parent types [13]. It is expected that further improvements in both genetics and breeding technology including the use of molecular markers will result in higher yielding cultivars and hybrids and improved agronomics (production system management practices and inputs) for dedicated energy crops such as switchgrass, which will further improve biomass yields, conversion efficiency, and Net Energy Value [23]. As an indicator of the improvement potential, switchgrass biomass yields in recent yield trials in Nebraska, South Dakota, and North Dakota [1, 2, 4] were 50% greater than achieved in this study.

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