Cost to Produce Cellulosic Biomass Feedstock: Four Perennial Grass Species Compared

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Abstract

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Switchgrass has been proposed as a dedicated energy crop to fulfill long-term policy goals. Production costs were determined for switchgrass and three alternative perennial grass species for four levels of nitrogen fertilizer and two harvest systems. For the alternatives evaluated, biomass production cost per ton was lowest for switchgrass.

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One reason often cited to justify subsidies to the U.S. corn-ethanol program is to achieve "energy security". However, if the entire 2005 U.S. corn crop of 11.1 billion bushels had been converted to ethanol, the resulting product would have contained less than nine percent of the energy contained in the 2005 U.S. net crude oil imports. In addition, corn grain production is heavily dependent upon nitrogen fertilizer and in 2005 the U.S. imported a net of 65.7 percent of nitrogen fertilizer used. The argument that the corn-ethanol policies enhance energy security is dampened by the fact that corn production depends on the use of nitrogen fertilizer, two-thirds of which is imported.

If U.S. biofuel policy goals are to be achieved, ethanol from lignin and cellulosic sources will be required. Research and development is ongoing in an attempt to develop economically competitive methods to produce ethanol from cellulose. In February of 2007, the U.S. Department of Energy announced plans to invest up to $385 million in six cellulosic biorefinery projects. Initially these proposed biorefineries are expected to use crop residues (such as corn stover, wheat straw) wood residues, and other waste products as feedstock. However, to achieve long-term policy goals, a dedicated energy crop will be required to provide feedstock. It has been hypothesized that more than 50 million U.S. acres of cropland, idle cropland and cropland pasture could be used to grow crops for the production of cellulose for biorefinery feedstock.

Switchgrass has been proposed as a dedicated energy feedstock. Research sponsored by the Bioenergy Feedstock Development Program at the Oak Ridge National Laboratory identified switchgrass as a model biomass feedstock. Switchgrass is a native "well-behaved" perennial grass species that does not invade cropland. It can develop a deep, vigorous root system to acquire nutrients and water under diverse soil and climate conditions. Switchgrass was one of a group of species that developed and persisted on the Great Plains for centuries without the addition of nitrogen fertilizer. However, nitrogen fertilizer will be required if substantial quantities of biomass are removed annually from pure switchgrass stands. In post establishment years the cost of nitrogen is estimated to be a substantial component of the nonharvest cost of managing and maintaining pure stands of switchgrass.

While a pure stand of switchgrass may be good for producing biomass, it is not an ideal pasture grass. The grazing window during which the forage is palatable and nutritious is relatively narrow. Alternative grasses that provide superior grazing attributes and that could also be used as biomass feedstock are available. However, nitrogen is a major variable cost component of all pasture grasses. Prior to investing in the establishment of pure stands of perennial switchgrass on millions of acres for intended use as a biorefienery feedstock, determining relative nitrogen response and relative yields of switchgrass to nitrogen response and yields of alternative perennial forage grasses would be prudent. If an alternative energy system eliminated the need for cellulosic biorefinery feedstock, the use of switchgrass might be limited; however, traditional pasture grasses would have alternative uses as pasture and hay for livestock.

Alternatives to switchgrass for the Southern Plains include bermudagrass, lovegrass, and flaccidgrass. In pure stand, these grasses have a longer grazing window and superior grazing attributes. Potential cellulosic feedstock producers may be more interested in seeding pasture lands to traditional improved grasses, which would enable an alternative use and provide some protection against a single area cellulosic biorefinery that chose to exercise monopsony power.

Switchgrass is a warm-season perennial and is one of the dominant species of the central North American tallgrass prairie. Switchgrass is defiant to many pests and plant diseases, and capable of producing high yields with low applications of fertilizer. Vogel et al. found that averaged over years, optimum biomass yields were obtained from switchgrass with nitrogen fertilizer application at the rate of 107 pounds of nitrogen per acre. Mulkey et al. evaluated switchgrass stands enrolled in, or managed similarly to, Conservation Reserve Program grasslands. They found that nitrogen applied at 50 pounds per acre per year increased total biomass without affecting switchgrass persistence, but found no additional benefit of nitrogen applied at rates in excess of 50 pounds per acre per year. Grass biomass yield response to nitrogen varies across regions.

Bermudagrass is a warm-season lawn and pasture perennial. It is found in Australia, Africa, India, and South America, and in the Southern region of the United States. Common bermudagrass was introduced into the U.S. during the colonial period from Africa or India (Duble). Janet et al. concluded that a multiple harvest system is suitable for bermudagrass. Overman et al. found that to achieve 50 percent of maximum yield, in their region, the nitrogen requirement was 82 pounds per acre per year. Silveira et al. found that maximum bermudagrass production was achieved with 80 pounds per acre per year of nitrogen fertilizer. Boateng et al. suggest that burmudagrass has potential as an energy crop.

Flaccidgrass is native to Central Asia and a selection, carostan, has been evaluated for its potential as a perennial, warm-season forage grass in the U.S. (North Carolina Agricultural Research Service). Flaccidgrass yields are responsive to nitrogen applications ranging from 160 to 360 pounds per acre per year (North Carolina Agricultural Research Service). Burns et al. found that Carostan flaccidgrass yield was responsive up to 360 pounds of nitrogen per acre.

Weeping lovegrass was imported to the U.S. from South African countries in the late 1920's. Weeping lovegrass responds to nitrogen fertilizer applications. Edwards (2000) hypothesize that lovegrass has the potential biomass production to make it a viable alternative to switchgrass.

Objective

The objective of the research reported in this paper is to determine the cost to produce a ton of cellulosic biomass feedstock from four perennial grass species (bermudagrass, flaccidgrass, lovegrass, and switchgrass) for each of four nitrogen fertilization levels (30, 60, 120, 240 pounds per acre per year) and two harvest systems (one and two harvests per year) and to determine the most economical species, nitrogen level and harvest system.

This study differs from prior studies in several respects. The agronomic study from which the data were obtained included side-by-side comparisons of four alternative perennial grasses that could be used to produce biorefinery feedstock. The study includes four levels of nitrogen fertilizer and two harvest alternatives for each of the four species. The cost to produce and harvest a ton of biomass is computed for each of the 32 alternative systems.

Data and Methods

Data were obtained from a field experiment conducted at the Oklahoma State University Agronomy Research Station in Stillwater (36°10′N, 97°5′W) on a Kirkland silt loam soil; fine, mixed, superactive, and thermic Udertic Paleustolls. The experimental design was a randomized complete block with a split-plot arrangement of treatments and four replications. The plots were 131 feet by 180 feet and separated by a 49 foot alley in the east-west direction and 66 feet in the north-south direction. The four species were switchgrass (S) (*Panicum virgatum*) (selection SL 93-3), weeping lovegrass (L) (*Eragrostis curvula*), bermudagrass (B) (*Cynodon dactylon (l.) Pers.*) (variety midland 99), and carostan flaccidgrass (F) (*Pennisetum flaccidum*). Four nitrogen rates (30, 60, 120, and 240 pounds per acre per year after the establishment year) were assigned to the 33 feet by 180 feet subplots. Two harvest levels (once and twice per year) were assigned to the 33 feet by 66 feet sub-subplots.

Soil testing was done in April of 2002 to ensure adequate pH, phosphorous, and potassium. In May-June 2002, 2, 4-D was applied at 1.5 pounds per acre across all plots. A clean seedbed was prepared, 30 pounds-per-acre nitrogen was applied across all plots, and the four species were planted on July 22-23. Seeds of switchgrass and weeping lovegrass were drilled into the prepared clean seedbed using a Brillion seeder. Bermudagrass sprigs were transplanted in the middle of each assigned 33 feet by 66 feet sub-subplot. Carostan flaccidgrass sprigs were transplanted on 10 foot centers in three rows each in the 33 feet by 66 feet sub-subplots. Among the three rows that were planted, only the center row was harvested for calculation of biomass yield. The plots were not harvested in 2002.

No herbicide or fertilizer other than nitrogen was applied in the second and subsequent years. Nitrogen, in the form of urea (46-0-0), was applied to the subplots at levels of 30, 60, 120, and 240 pounds per acre per year in years after the establishment year. For the two harvests per year sub-subplots, half of the total nitrogen was applied at the beginning of the season and half after the first harvest as a top dressing. The two harvest sub-subplots were harvested in July and October. The single harvest sub-subplots were harvested in October.

A standard enterprise budgeting procedure was used to estimate production costs for each of the four species. One budget was prepared to estimate costs in the year of establishment (Table 1). A second budget was constructed to estimate annual maintenance and harvesting costs for years after stands were established (Table 2). The establishment budget (Table 1) includes cost estimates for tillage operations used to prepare a seedbed. The budgeted tillage operations include plowing, disking twice, and cultipacking. State average custom operation rates were used to estimate the cost of field operations (Doye, Sahs, and Kletke).

Seeding rates of six pounds per acre and two pounds per acre of pure live seed were budgeted for switchgrass and lovegrass, respectively. Regional average seed prices of $7.00 per pound for switchgrass and $11.50 per pound for lovegrass were used. A bermudagrass sprigging rate of 30 bushels per acre was budgeted at a sprig price of $2.75 per bushel. A commercial market for flaccidgrass sprigs is not established in the region, and a market price for commercial quantities of sprigs was not identified. For the budget, it was assumed that sprigs could be obtained or produced at a delivered price of 1.5 times the market price for bermudagrass sprigs. A price of $4.13 per bushel was entered in the establishment budget.

The estimated stand life of each of the species is ten years. The estimated establishment costs were amortized over ten years at a rate of seven percent. These estimates were included as costs in the annual maintenance and harvesting budgets (Table 2). The annual maintenance budgets also include the cost of nitrogen, nitrogen application, and harvest. Budgeted harvest operations include mowing, raking, and baling into large (1,500 pound dry matter) rectangular solid bales. State average custom operation rates were used to estimate harvest costs (Doye, Sahs, and Kletke). The level of nitrogen, and mowing and raking operations varied across treatments. The number of bales produced was a function of yield. The budgets were used to determine the species, nitrogen level, and harvest strategy that would produce biomass for the least cost from among the 32 potential alternatives (four species by four nitrogen levels by two harvest alternatives).

Results

Table 3 includes mean annual yields (tons per acre) for each of the four perennial grasses, for both the one (October) and the two (July and October) harvests per year treatments. Figure 1 contains a chart of the mean annual yields for each grass for each level of nitrogen for the single harvest per year system. Figure 2 contains a chart of the average annual yields for the double harvest system.

For a single harvest system, the switchgrass yields were greater than the yields of each of the three alternative perennial grasses for each level of nitrogen. For the single harvest per year treatments, the switchgrass yields for 30, 60, 120 and 240 pounds of nitrogen per acre per year were 3.86, 5.36, 5.41 and 5.51 (tons per acre) respectively. For the region and switchgrass selection, the single October harvest produced more total annual biomass than a July harvest followed by an October harvest for annual nitrogen levels of 30, 60, and 120 pounds. However for the 240 pounds of nitrogen treatments the double harvest of switchgrass resulted in an additional 0.66 tons per acre of biomass annually. For the two harvest system and an annual nitrogen treatment of 60 pounds per acre, switchgrass yielded more biomass than each of the three alternative perennial grasses.

Table 4 includes estimates of the per-ton cost to produce and harvest each of the four species for each nitrogen treatment and both harvest systems. Figure 3 contains a chart of the estimated cost of producing biomass ($ per ton) for each of the four species for each of the four levels of nitrogen for the single (October) harvest system. Figure 4 contains a similar chart for the twice per year (July and October) harvest system. For both harvest systems the cost to produce a ton of biomass was lower for switchgrass than for any of the alternatives for each level of nitrogen.

The cost to produce and harvest a ton of biomass from switchgrass for 30, 60, 120, and 240 level of nitrogen was $40.42, $35.60, $39.41, and $46.83 respectively for the single harvest. For the alternatives included in the experiments, switchgrass with an annual fertilizer application of 60 pounds per acre of nitrogen and harvested once per year in October, was the lowest cost feedstock. For a yield of 5.36 tons per acre the estimated cost to produce and harvest a ton of switchgrass biomass is $35.60 using 60 pounds of nitrogen. The cost of storing the biomass until required by the biorefinery and the cost of transporting the biomass from the field to the biorefinery is not included in these estimates.

For bermudagrass, lovegrass, and flaccidgrass the two harvests per year (July and October) subplots that received 120 pounds of nitrogen per acre per year produced biomass at the least cost per ton. The least cost systems for bermudagrass, lovegrass, and flaccidgrass produced biomass for $45, $43, and $44 per ton respectively. These costs exceed the least cost switchgrass system (single harvest, 60 pounds of nitrogen per acre per year) by $9, $7, and $8 per ton. For the yields obtained and the prices used in the budgets, biomass produced from the most cost efficient bermudagrass, lovegrass, and flaccidgrass systems would be from 20 to 26 percent more costly than biomass produced from the most cost efficient switchgrass system.

Table 5 includes the annual maintenance and harvesting budget for the least-cost strategy: switchgrass receiving 60 pounds per acre per year of nitrogen fertilizer and harvested once per year. The budget reflects per-acre costs of $23.17 for establishment, $25.47 for nitrogen, $45 for land rental, and $97.16 for harvest. For a yield of 5.36 tons per acre, the estimated cost to produce and harvest one dry ton of switchgrass biomass is $35.60. Twelve percent of the estimated cost to produce and harvest a ton of switchgrass is for establishment, 24 percent for land rental, 13 percent for nitrogen, and 51 percent for harvesting. The annual application of 60 pounds of nitrogen fertilizer accounts for 27 percent of the nonharvest cost.

The estimated cost of $35.60 per ton is similar to that reported by Epplin. He found that for an expected yield of four dry tons per acre, the estimated cost to establish, produce, harvest, load, and transport one dry ton of switchgrass biomass to a conversion facility was $37. Approximately, 14 percent of the estimated cost was for establishment, 22 percent for land rental, 32 percent for standard maintenance and harvesting, and 32 percent for loading and transportation. Epplin's estimated cost would be $25 after subtracting the cost of loading and transportation (the current study does not include the cost of transportation and loading). If adjusted for inflation, his estimated cost would be $34.77 which is close to the estimated cost of $35.60 per ton for the most efficient switchgrass production system.

Discussion

Switchgrass has been proposed as a dedicated energy feedstock. In post establishment years, the cost of nitrogen is estimated to be a substantial component of the nonharvest cost of managing and maintaining pure stands of perennial grasses such as switchgrass. In 2005 the U.S. imported two-thirds of the nitrogen fertilizer used in the country. Prior to investing in the establishment of perennial grasses on millions of acres for intended use as biorefienery feedstock, research is warranted to determine the most cost efficient species and cost efficient level of nitrogen.

The objective of the research reported in this paper was to determine the cost to produce a ton of cellulosic biomass feedstock from four perennial grass species (bermudagrass, flaccidgrass, lovegrass, and switchgrass) for each of four nitrogen fertilization levels (30, 60, 120, 240 pounds per acre per year) and two harvest systems (one and two harvests per year) and to determine the most economical species, nitrogen level and harvest system.

For the alternatives evaluated, switchgrass fertilized (in post-establishment years) with 60 pounds per acre per year of nitrogen and harvested once per year was the least-cost strategy. The estimated per-acre costs per year were $23.17 for establishment, $25.47 for nitrogen, $45 for land rental, and $97.16 for harvest. For the yield obtain in the designed experiment, 5.36 tons per acre per year, the estimated cost to produce and harvest of one dry ton of switchgrass biomass was $35.60. For the yields obtained and the prices used in the budgets, biomass produced from the most cost efficient bermudagrass, lovegrass, and flaccidgrass systems would be from 20 to 26 percent more costly than biomass produced from the most cost efficient switchgrass system.

Additional research is warranted to estimate biomass yield response to nitrogen functions for each of the four species. More precise optimal levels of nitrogen could be determined for a set of relative biomass and nitrogen prices.

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Table 1. Estimated establishment costs for each of four species ($/acre)

				Cost ($/acre)			
Item	Unit	Quantity	Price/unit ($)	Switchgrass	Bermudagrass	Lovegrass	Flaccidgrass
Moldboard plow	acre	1	12.50	12.50	12.50	12.50	12.50
Tandem disk	acre	2	8.75	17.50	17.50	17.50	17.50
Spraying herbicide	acre	1	4.00	4.00	4.00	4.00	4.00
Applying nitrogen	acre	1	3.75	3.75	3.75	3.75	3.75
Cultipack	acre	1	7.00	7.00	7.00	7.00	7.00
Seeder	acre	1	10.00	10.00		10.00	
Sprigger	acre	1	50.00		50.00		50.00
Switchgrass seed	lbs.	6	7.00	42.00			
Bermudagrass sprigs	bu.	30	2.75		82.50		
Weeping lovegrass seed	lbs.	2	11.50			23.00	
Flaccidgrass sprigs	bu.	30	4.13				123.90
Herbicide (2,4-D)	pt.	1.5	1.90	2.85	2.85	2.85	2.85
Nitrogen	lbs.	30	0.35	10.43	10.43	10.43	10.43
Annual operating capital (S)	$	110	0.07	7.98			
Annual operating capital (B)	$	191	0.07		10.78		
Annual operating capital (L)	$	91	0.07			6.65	
Annual operating capital (F)	$	232	0.07				29.89
Total machine operations and operating inputs				118.01	201.31	97.68	261.82
Land rental	acre	1	45.00	45.00	45.00	45.00	45.00
Total machinery, input and land rental cost	$			162.73	248.87	142.40	293.00
Establishment cost, amortized for 10 years at 7%	$		0.07	23.17	35.43	20.27	41.72

Table 2. Estimated annual maintenance and harvesting costs for each of four species after establishment ($/acre)

Items	Unit	Quantity	Price per unit ($)	Cost ($/acre) Switchgrass	Bermudagrass	Lovegrass	Flaccidgrass
Establishment cost amortized over 10 years at 7%	$			23.17	35.43	20.27	41.72
Nitrogen	lbs.	rate	0.35	variable	variable	variable	variable
Fertilizer application	acre	1 or 2	3.75	variable	variable	variable	variable
Annual operating capital	$	variable	0.07	variable	variable	variable	variable
Mowing	acre	1 or 2	8.25	variable	variable	variable	variable
Raking	acre	1 or 2	3.15	variable	variable	variable	variable
Baling 1,500 lb DM rectangular bale	bale	variable	12.00	variable	variable	variable	variable
Land rental	acre	1	45	45.00	45.00	45.00	45.00
Total Production Cost	acre			variable	variable	variable	variable
Average harvested yield	ton			variable	variable	variable	variable
Cost	ton			variable	variable	variable	variable

Table 3. Mean annual yield (dry tons per acre) of four perennial grasses, switchgrass (S), burmudagrass (B), weeping lovegrass (L), and flaccidgrass (F) for one and two harvests per year.

	One Harvest per Year				Two Harvests per Year			
Nitrogen	S	B	L	F	S	B	L	F
Pounds per acre	Tons per acre							
30	3.9	2.2	2.7	3.8	3.7	3.3	2.8	3.8
60	5.4	3.0	3.6	4.4	4.1	4.1	3.6	4.1
120	5.4	3.6	3.7	4.1	5.3	5.3	5.2	5.7
240	5.5	4.7	4.1	4.3	6.2	6.5	5.5	6.3

Table 4. Cost per ton of biomass produced by four perennial grasses, switchgrass (S), burmudagrass (B), weeping lovegrass (L), and flaccidgrass (F) for one and two harvests per year.

	One Harvest per Year				Two Harvests per Year			
Nitrogen	S	B	L	F	S	B	L	F
Pounds per acre	$ per ton							
30	40	64	50	46	46	53	54	50
60	36	55	45	44	45	49	49	50
120	39	54	50	52	43	45	43	44
240	47	55	57	59	46	46	49	49

Table 5. Annual maintenance and harvesting budget for switchgrass fertilized with 60 pounds per acre per year of nitrogen and harvested once per year

Items	Unit	Quantity	Price per unit ($)	Value ($/acre) Switchgrass
Establishment cost amortized over 10 years at 7%	$			23.17
Fertilizer application	acre	1	3.75	3.75
Operating inputs				
Nitrogen	lbs.	60	0.35	20.87
Annual Operating Capital	$	12.31	0.07	0.86
Harvest				
Mowing	acre	1	8.25	8.25
Raking	acre	1	3.15	3.15
Baling 1,500 lb DM rectangular bale	bale	7.14	12.00	85.76
Land rental	acre	1	45	45.00
Total Production Cost	acre			190.81
Average harvested yield	ton	5.36		
Cost	$/ton		35.60	

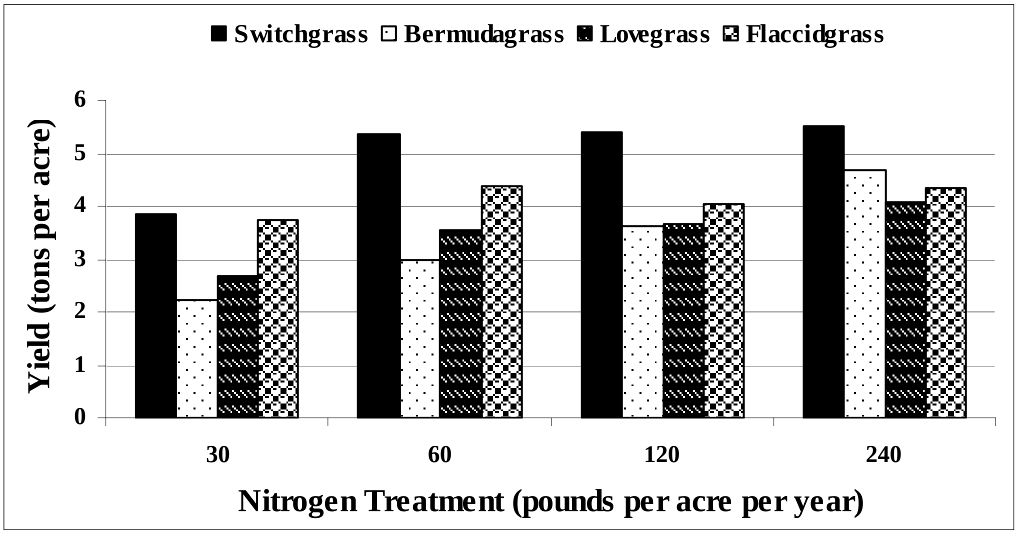

Figure 1. Biomass yield (tons per acre per year) of switchgrass, bermudagrass, weeping lovegrass, and flaccidgrass for 30, 60, 120, and 240 annual pounds of nitrogen and a single harvest per year

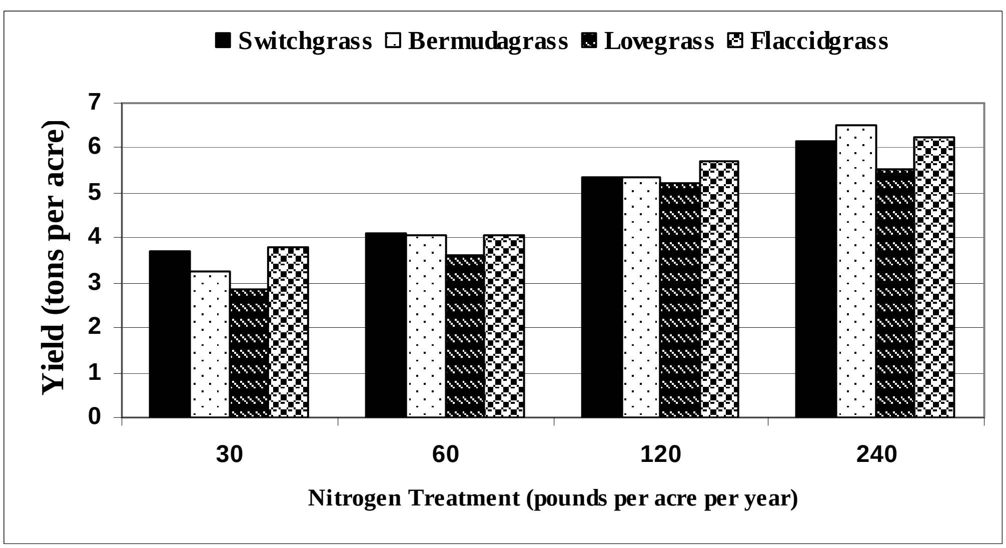

Figure 2. Biomass yield (tons per acre per year) of switchgrass, bermudagrass, weeping lovegrass, and flaccidgrass for 30, 60, 120, and 240 annual pounds of nitrogen and two harvests per year

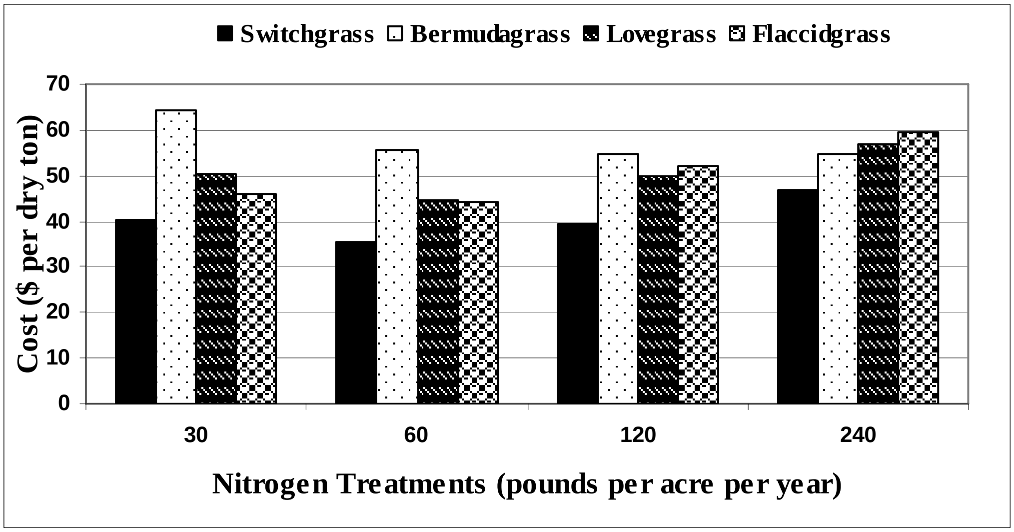

Figure 3. Cost of producing biomass ($ per ton) of switchgrass, bermudagrass, weeping lovegrass, and flaccidgrass for 30, 60, 120, and 240 annual pounds of nitrogen and a single harvest per year

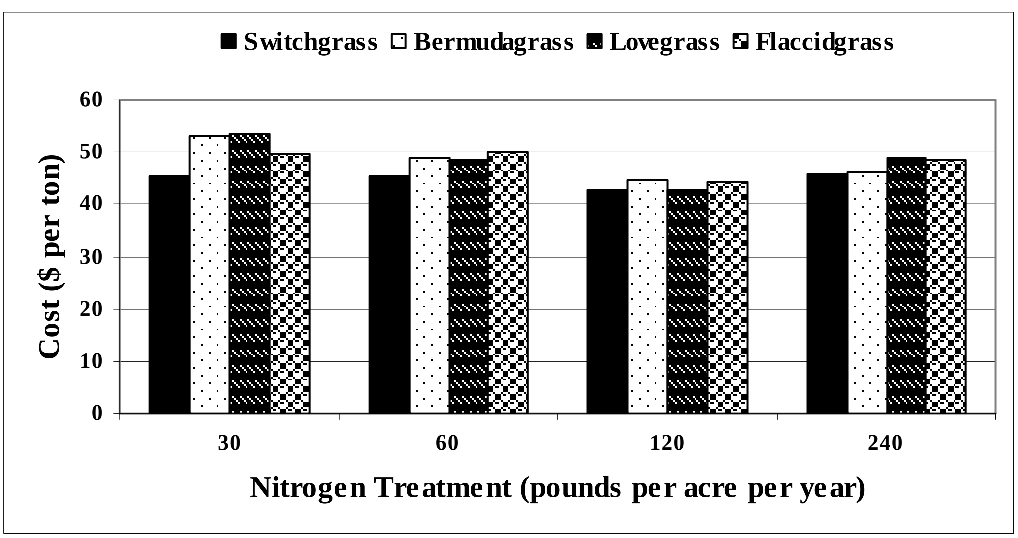

Figure 4. Cost of producing Biomass ($ per ton) of switchgrass, bermudagrass, weeping lovegrass, and flaccidgrass for 30, 60, 120, and 240 annual pounds of nitrogen and two harvests per year