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Improving the Profitability of Willow Crops—Identifying Opportunities with a Crop Budget Model

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Abstract Short-rotation woody crops like shrub willow are a potential source of biomass for energy generation and bioproducts. However, since willow crops are not widely grown in North America, the economics of this crop and the impacts of key crop production and management components are not well understood. We developed a budget model, EcoWillow v1.4 (Beta), that allows users to analyze the entire production-chain for willow systems from the establishment to the delivery of wood chips to the end-user. EcoWillow was used to analyze how yield, crop management options, land rent, fuel, labor, and other costs influence the Internal Rate of Return (IRR) of willow crop systems in upstate New York. We further identified cost variables with the greatest potential for reducing production and transport costs of willow biomass. Productivity of 12 oven-dried tons (odt) ha^{-1} year^{-1} and a biomass price of $ (US dollars) 60 odt^{-1} results in an IRR of 5.5%. Establishment, harvesting, and transportation operations account for 71% of total costs. Increases in willow yield, rotation length, and truck capacity as well as a reduction in harvester down time, land costs, planting material costs, and planting densities can improve the profitability of the system. Results indicate that planting speed and fuel and labor costs have a minimal effect on the profitability of willow biomass crops. To improve profitability, efforts should concentrate on (1) reducing planting stock costs, (2) increasing yields, (3) optimizing harvesting operations, and (4) co-development of plantation designs with new high-yielding clones to reduce planting density.

Keywords Short-rotation woody crops · Coppice · Willow · Economics · Management · Profitability

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Introduction

Perennial energy crops like short-rotation woody crops (SRWC) are projected to be an essential component of the supply of biomass feedstock around the world in the coming decades [11]. The Billion Ton study [15] indicates that perennial woody and herbaceous crops could annually provide up to 342 million dry metric tons of biomass by 2030, which is about 35% of the total annual agricultural production. Their deployment would put over 24 million ha of land into production, create thousands of rural jobs, and produce an array of environmental benefits. Shrub willow (*Salix* spp.) is one SRWC that has been identified as having potential for large-scale deployment in the USA (e.g., [24]).

Shrub willow as a SRWC has many favorable characteristics: Growth rates of new willow clones exceed 15 oven-dried tons (odt) ha^{-1} year^{-1} on 3- to 4-year rotations [27]. Therefore, large amounts of biomass can be grown on relatively small areas. Transportation costs and emissions are lower for strategically situated willow crops compared to forest harvesting or annual agricultural crops as yields are greater or comparable, but inputs reduced and only a portion of the planted area is harvested annually [23]. Production costs are less affected by natural gas/fertilizer price fluctuations because willow crops recycle nitrogen through leaf litter and nitrogen removal is minimized by harvesting during the dormant season after leaf abscission [8]. The overall net energy balance of chipped willow biomass up to and including harvest is between 1:55 and 1:80 depending on whether commercial fertilizer or organic amendments are used [10]. The overall net energy balance for electricity generation using willow biomass as feedstock for co-firing with coal is around 1:11 [9].

Besides providing a flexible renewable feedstock for an array of bioenergy, biofuels, and bioproducts, the willow crops have the potential to provide a series of environmental benefits related to soil and water quality [18, 28]. The perennial nature and extensive fine-root system of willow crops reduce soil erosion and non-point source pollution relative to annual crops, promote stable nutrient cycling, and enhance soil carbon storage in roots and the soil. Willow crops can be deployed on marginal agricultural land, which reduces the food vs. fuel competition and possible associated indirect land use effects. Bird species richness, nesting density, and reproductive success in willow crops are comparable to natural shrublands and forests [6].

Research and development of willow crops has been occurring since the mid 1980s in the USA and has expanded across the northeast, midwest, and northern parts of the southern USA [26]. After field preparation in fall prior to the planting year, a cover crop is often established and killed the next spring to reduce soil erosion. Willow is typically planted using 20-cm-long dormant cuttings at a density of about 15,000 plants ha^{-1}. The crop is coppiced after the first year to promote the production of multiple stems. Harvest occurs after three to four growing seasons when the mean annual increment culminates [25]. The crop resprouts (coppices) the following spring and is harvested after another 3 to 4 years. Up to seven 3-year harvest cycles can occur from a single planting [1].

During the past few years, infrastructure to support the large-scale deployment of willow crops, such as planting stock nurseries and planting and harvesting systems, has been developed in North America [27]. A limitation to the commercialization of willow crops is the difficulty in assessing the economics of the system in different settings and under different conditions.

Economic analysis of willow in Europe has focused on a financial comparison with other agricultural products in other regions such as Ericsson et al. [7] for Poland, Rosenqvist and Dawson [16] for Ireland, or the Energy Crops Calculator developed by several UK agencies [4]. Rosenqvist and Dawson [17] looked at the financial viability of using shrub willows as a wastewater treatment system in Ireland while Tharakan et al. [21] analyzed the financial impact of incentive programs under New York conditions. Nevertheless, a comprehensive economic analysis of the basic production schemes for willow crops under North American conditions is still lacking. In addition, tools available to conduct this type of analysis in different regions or under various price structures are also unavailable. Using a newly developed willow crop budget model,[1] we examine the economic performance of willow crops under various economic, biophysical, and management conditions. The objectives of this paper are

- To analyze the economics of willow crops under various yield, land rent, biomass price, fuel costs, and labor costs scenarios
- To identify the cost variables associated with different stages of the production cycle that have the greatest potential for improving the economics of willow crops

Material and Methods

Model Description

The budget model EcoWillow v1.4 (Beta) is designed for willow crops using a coppice management system. The model allows users to alter input variables for their specific situations and calculates IRR[2] through the entire production chain from crop establishment to the delivery of wood chips[3] to the end user. The budget model is built in Excel (Microsoft) and consists of a welcome sheet, four calculation sheets, four sheets containing output graphs, and a brief tutorial.

The *Welcome Sheet's* only numerical input is the total area of the willow crop. The Input/Output Sheet asks for general inputs such as rotation length, expected biomass productivity, costs including land rent, insurance, and crop management operations such as site preparation, weed control, and fertilizer applications. Incentive payments such as establishment grants and yearly rental payments can be factored in on this page. The size of and interest rates for loans to cover the establishment and management of willow crops can also be set on this sheet. The other sheets in the model calculate planting, harvesting, and transportation costs, which in turn feed into the Input/Output sheet.

Cost variables in the *Planting Sheet* include site preparation, planting stock, planting and initial weed control using pre-emergence herbicides as well as labor, travel, equipment, and other supply costs. The Harvest Sheet uses input data to calculate harvesting costs. Inputs include field characteristics such as row length, as well as labor, travel, harvester operation costs, and costs for support equipment such as tractors and wagons. The model's default harvesting system is a single-pass cut-and-chip harvester based on a New

[1] The budget model can be downloaded at http://www.esf.edu/willow/.
[2] The Internal Rate of Return (IRR) is the interest rate at which the costs of the investment lead to the benefits of the investment.
[3] Other harvest systems being developed produce billets or bales instead of wood chips. However, cut and chip harvesting systems are currently the only commercially available option in the USA.

Holland forage harvester with a cutting head designed specifically for SRWC. The sheet includes on-field transportation of chips in forage wagons and the costs associated with unloading the material to trucks at the edge of the field using a blower system.

The *Transportation Sheet* calculates the number of on-road trucks required to move the chips and considers general variables as well as labor and equipment costs. The model is based on chips being loaded at the side of the road directly from field equipment and does not allow for on-site storage and loading of trucks at a later date as this is not common practice in North America. The number of tractors and wagons used during harvesting operations depends on the amount of biomass harvested and is automatically calculated based on current experience with the system. Hauling distance can be subdivided into highway and field roads to account for the different travel speeds on each. Truck capacity can be limited by either weight or volume. Final transportation costs are reported in \$ odt^{-1} and feed into the Input/Output sheet.

Outputs of the model (reported on the Input/Output Sheet) include IRR and Net Present Value (NPV) for crop lifetimes of 13 and 22 years as two representative years. The Input/Output sheet also provides summary figures on production costs, revenues, earnings, and profits on a unit and area basis as well as costs of startup, which include all costs up until the first harvest. Results are provided for a best- and worst-case scenario as part of the output to indicate how NPV might vary with changing costs or revenues. The best-case scenario is based on a 10% increase in revenues and a 10% decrease in costs. The worst-case scenario includes a 10% decrease in revenues and a 10% increase in costs.

The *Cash Flow Diagram Sheet* shows the cash flow per hectare and for the entire cropping area over the total project lifetime of 22 years. The input values provided by the user on the input/output sheet and the planting, harvest, and chip transport sheets provide the data that are used to calculate this cash flow diagram.

The *Cost Distribution Sheet* shows the distribution of unadjusted total costs throughout the life of the crop by categories including establishment, harvest, transportation, fertilizer, stock removal, land cost and insurance, administration, and interest payments.

The *Yearly Cash Flow Sheet* shows the yearly balance of revenues and expenses for the life of the project. One graph shows the yearly cash flow per hectare; the second, cash flow for all the land in the project.

The *Accumulated Cash Flow Sheet* shows the accumulated cash flow over the total project period on a per hectare or entire project basis, which allows the payback period to be identified. The best- and worst-case scenarios described above are also included on this output sheet.

Scenario Analysis

As our base-case scenario, we use an isolated 10-ha field, on the presumption that a field of that size can be harvested in an extended 1-day, one-shift operation, thus representing a breaking point in terms of the economy of scale for harvest operations. The budget model uses the necessary 2 years for site preparation and 21 years of production based on seven 3-year rotations. Our scenario assumes that the producer has sufficient capital to pay for the site preparation and establishment costs through to the first harvest. No subsidy programs are included in the scenario.

The main input variables for the scenario, outlined in Table 1, are based on our experience establishing and managing about 400 ha of willow crops in New York State [26]. Costs used in the base-case scenario for standard farming operations such as herbicide applications and plowing and disking are based on current custom rates for central New York State but can easily be adjusted by users of the model.

To compare the output of the budget model for other scenarios, profitability is measured by means of the project's IRR over a 13- and 22-year period.

Establishment procedures are similar in all scenarios. In the base-case scenario, we assume a harvest rotation of 3 years. Costs to remove the crop at the end of the 22-year period are included in the model. When removed, the crop has to be harvested and then sprayed with contact herbicide the following spring, and then the stools are ground up in place.

In a second step, we selected input parameters that have a large influence on the cash flow of the system and modified the base-case scenario across a range of values for each individual parameter to determine its impact on returns from the willow cropping system. The variables that were modified include biomass yields, land rent, biomass price, fuel costs, and labor costs (Table 2).

Establishment, harvest, and transportation costs make up a significant portion of the final cost of SRWC and are influenced by external forces. Therefore, in a third step, these three key cost categories were further analyzed by identifying the two variables assumed to influence the respective cost category the most. By running a range of values, a sensitivity analysis was performed on how these variables influenced each cost category and the overall project IRR calculated by the budget model.

Results and Discussion

Economics of the Base-Case Scenario

The base-case scenario's IRR over the project's lifetime of 22 years is 5.5% (Table 3). Establishment costs from the

Table 1 Selected input variables used for the base-case scenario in the willow crop budget model (EcoWillow)

	Variable description	Unit	
General variables	Project size	ha	10
	Biomass growth rate	Odt[a] ha^{-1} $year^{-1}$	12
	Rotation length	Years	3
	Headlands[b]	% of total field size	8%
	Biomass price incl. transport	$ odt^{-1}	60
Variables influencing land costs	Land costs including tax, lease, and insurance	$ ha $year^{-1}$	85
Variables influencing administration costs	Administration costs	$ ha^{-1} $year^{-1}$	12
Variables influencing establishment costs	Planting stock costs	$ per cutting	0.12
	Planting density	Cuttings ha^{-1}	14,300
	Planting speed	h ha^{-1}	1.5
Variables influencing fertilizer costs	Fertilizer cost (application after every harvest)	$ ha^{-1} $application^{-1}$	85
Variables influencing harvest costs	Harvester speed	km h^{-1}	6.5
	Average row length	m	200
	Turning time	min	0.75
	Maintenance time harvester	% of harvest time	17%
	Harvester costs[c]	$ h^{-1}	180
	On-field transport units		3
	On-field transport unit cost[c]	$ h^{-1}	60
	Fuel costs	$ L^{-1}	0.56[d]
Variables influencing transport costs	Hauling distance (excl. field roads	km	40
	Truck capacity	m^3	108
	Truck capacity	t	35
	Truck costs[c]	$ km^{-1}	0.3
	Fuel costs	$ L^{-1}	0.62[d]
Variables influencing stock removal costs	Stock removal	$ ha^{-1}	740

For an exhaustive list of input variables, see Appendix 2

[a] Oven-dried ton; containing 0% moisture

[b] Open space (6 m) left at row ends and on field sides to allow access with farm equipment

[c] Excluding labor and fuel costs

[d] Reduced tax for fuel used for agricultural production, conventional fuel tax for road transport

start of the project through to the first harvest in year 4 are \$3,097 ha^{-1} for the 10-ha base-case scenario. The first commercial harvest of 10 ha costs \$5,400 (\$16.3 odt^{-1}), and the payback is reached in the 12th year with the revenues from the third harvest neutralizing the project's expenses (Fig. 1). Discontinuing the project after half of its expected lifetime (13 years) would render the venture unprofitable with an IRR of only 1.5%. For the pessimistic scenario which assumes 10% less revenues and 10% more expenses, the payback is not reached within the 22 years of project life. For the best-case scenario, which assumes 10% more revenues and 10% less expenses, the payback is reached at the second harvest in the ninth year. See Appendix 1 for the cash flow data of the base-case scenario.

Harvesting, establishment, and land rent/insurance are the main expenses associated with willow crops over their entire lifespan making up 32%, 23%, and 16% of the total undiscounted costs (Fig. 2). The remaining costs including crop removal, administrative costs, and fertilizer applications account for about 29% of the total costs of the project.

Modifications to the Base-Case Scenario

Biomass Yields and Land Rent Willow biomass yields have a significant impact on the project's profitability. In the base-case scenario, yields are assumed to be 12 odt ha^{-1} $year^{-1}$. Increasing yields by 2 odt ha^{-1} or 17% to 14 odt ha^{-1} $year^{-1}$ increases the IRR by 51% (from 5.5% to 8.3%). This greater profitability is possible because increasing the yield has a disproportionally small change in harvesting costs. For example, increasing yields by 33% (12–16 odt ha^{-1} $year^{-1}$) only increases harvest costs by 13%. Since willow crops are in their infancy in terms of development and deployment, there is significant potential for improving yields through breeding, agronomy, and matching clones to specific site conditions [13, 14, 19, 26]. Yields as high as

Table 2 Willow crop production input variables analyzed on their impact on overall project profitability

	Unit	Range
General variables		
Biomass yield	Odt ha^{-1} $year^{-1}$	7.5–25
Land rent	\$ ha^{-1} $year^{-1}$	20–160
Biomass price	\$ odt^{-1}	40–90
Fuel costs	\$ L^{-1}	0.56/0.62[a]±50%
Labor costs	\$ h^{-1}	10/20[b]±10%
Variables affecting establishment costs		
Price per cutting	\$ per cutting	0.05–0.25
Planting density	Cuttings ha^{-1}	6,000–18,000
Variables affecting harvest costs		
Row length	m	100–800
Rotation length	Years	3–4
Variables affecting transport costs		
Truck capacity	t	5–40
Hauling distance	km	0–100

Ranges show the input numbers used for sensitivity analysis

[a] Off- and on-road fuel costs

[b] \$10 h^{-1} for basic labor, \$20 h^{-1} for skilled labor

22 odt ha^{-1} $year^{-1}$ have been obtained under optimized conditions with unimproved clones [2, 12]. Over a 22-year project lifespan, yields at or below 8 odt ha^{-1} $year^{-1}$ make it difficult to generate any positive return, even if land costs are low or zero (Fig. 3). These results show that the losses occurring when discontinuing a plantation after 13 years are especially high at low productivity sites due to the high unit costs. Marginal agricultural land that has lower yield potential typically has lower land rental rates. For the base-case scenario with yields of 12 odt ha^{-1} $year^{-1}$, an IRR of >5% can be achieved with annual land costs below \$100 ha^{-1}. If yields are increased to 16 odt ha^{-1} $year^{-1}$, an IRR of greater than 10% can be achieved with annual land costs below \$120 ha^{-1}.

Table 3 Key output variables for the financial analysis of the base-case scenario of willow crops in upstate NY

Output variable description	Unit	Over 22years	Over 13years
NPV[a]	\$ ha^{-1}	116[b]	−609
IRR	%	5.5%	1.5%
Average net earning per ha	\$ ha^{-1} $year^{-1}$	101	27
Earnings per ton	\$	10	3
Payback period	Years	13	13
Startup costs including land costs	\$ ha^{-1}	3,097	3,097
Harvest costs per hectare	\$ ha^{-1}	587	587
Harvest costs per ton	\$ odt^{-1}	16.3	16.3
Transportation costs[b]	\$ odt^{-1}	5.1	5.1

For input variables used in the calculation, see Table 1

[a] Using an interest rate of 5%

[b] 40-km highway and 1.5-km field roads

Biomass Price Assuming all other factors are held constant using the base-case scenario inputs, an IRR of more than 5% can be achieved with a delivered biomass price of \$60 odt^{-1} (Fig. 4). No return on investment is made under the base-case scenario conditions if the biomass price drops below \$51 odt^{-1}. A 50% increase in the price of biomass from \$60 to \$90 odt^{-1} more than doubles the IRR. Throughout the biomass price range depicted, a small increase in biomass price results in a large increase in profitability. This impact of biomass price on the IRR is particularly strong in the lower price ranges. The development of wood-based biorefineries that produce multiple products from a single ton of willow or other woody biomass is one way to effectively increase the value of willow biomass [3].

Fuel and Labor Costs Diesel fuel accounts for about one-third of the primary energy required to produce, harvest, and move willow crops to the farm gate over a 22-year period [10]. Nevertheless, we found that fuel prices had a relatively minor impact on the overall profitability of the biomass production system. Increasing or decreasing diesel fuel costs by 50% of the cost in the base-case scenario (\$0.62 L^{-1}, including \$0.06 L^{-1} in taxes for road use), changes planting costs by +\$8 and −\$4 ha^{-1}, harvesting costs by +\$1.4 and −\$0.7 odt^{-1}, and transport costs by +\$1.1 and −\$0.6 odt^{-1}, respectively. However, even these large changes in diesel fuel costs have comparatively little effect on the overall IRR, reducing or increasing it by comparatively low −1.3 and +0.5 percentage points. However, increases in fuel prices will also affect other costs for, e.g., fertilizer, planting stock, and machinery. These indirect effects of fuel price fluctuations were not analyzed but may have a more significant impact on the economics of willow biomass crops.

Compared with the base-case scenario, changing the labor costs[4] by +10% to −10% has an impact on the overall project's IRR of −0.3 and +0.2 percentage points, respectively. In other words, labor costs are of minor significance for the profitability of willow crops plantations.

Harvest, Establishment, and Transportation Cost Variables and Their Impact on Overall Project Profitability

Variables Affecting Harvest Costs Harvesting is the largest cost component for willow crops, accounting for almost a

[4] Base-case scenario: Skilled labor (foremen, truck drivers) rate \$20 h^{-1}, basic labor rate \$10 h^{-1}.

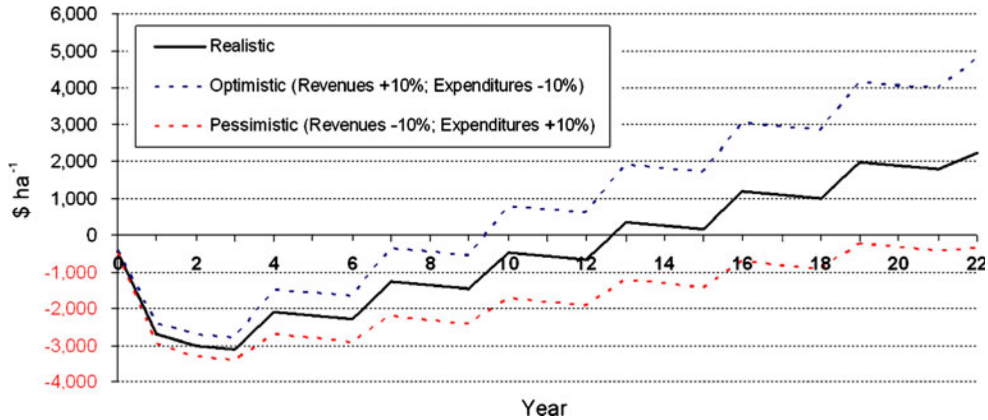


Fig. 1 Undiscounted accumulated cash flow (US dollars per hectare) over the total project life of the base-case scenario for willow crops grown in upstate New York. The payback period is reached in the 12th year. In the best-case scenario, the payback period is reached in the ninth project year while the worst-case scenario does not break even over the 22-year life of the crop

third of all costs over the life of the crop. An important driver for harvesting costs is the working speed of the harvester. Recent trials at SUNY-ESF with a Case New Holland forage harvester and specially designed New Holland cutting head indicate that this speed is fairly constant at around 6 km h^{-1} and is influenced by the diameter distribution of the stems in the stand, stocking density of the crops, soil conditions, and operator's level of experience with the harvesting system and the willow crop. Since operating the harvester is a major cost, maximizing the amount of productive time is essential for reducing costs and increases the IRR [20]. Reducing unproductive time by minimizing turn-around time and down time is important. One way to do this is to plan for harvesting activities at the time of planting to optimize row lengths, leave adequate headland space at the end of the rows to turn equipment around, and minimize time spent waiting for support tractors and wagons.

In the base-case scenario, total harvest time is 11 h or 0.9 h ha^{-1}. Of those 11 h, total turning time accounts for 2.7 h and total maintenance time for another 1.6 h. This is based on a 10-ha field with 219 rows with lengths of 200 m. Increasing row lengths increases the proportion of time the harvester is cutting and processing the crop and reduces the amount of time spent maneuvering equipment at the end of each row, which lowers the cost per ton for harvesting (Fig. 5). Harvesting costs begin to level off when the row length is about 400 m as the proportion of time spent turning reaches an asymptote, suggesting that this is an optimal row length for the harvesting system used in this model. Increasing row length from 200 to 400 m reduces harvest costs by $1.8 odt^{-1} and increases the IRR by 11% (5.5–6.2%). Since field dimensions are set and not easily modified, it is important to think about the entire life span of the willow crop when fields are selected and laid out for planting.

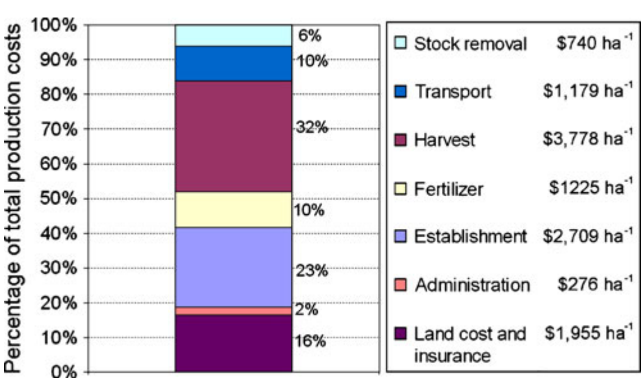


Fig. 2 Distribution of total production costs over the whole project life of 22 years for the base-case scenario for willow crops grown in upstate NY. Land and insurance costs, establishment costs, and harvest costs account for the largest share of total production costs in this scenario

Since harvesting is a major cost component, reducing the frequency of harvesting operations should have an impact on costs. The model allows the user to select either 3- or 4-year coppice rotations over the life of the crop. The 4-year rotation reduces per ton harvesting costs by 14% (from $16.3 to $14.0 odt^{-1}) and increases the IRR by 11% (from 5.5% to 6.2%).[5] This improved profitability is mainly due to a higher biomass density on the field at the time of harvest (44 odt ha^{-1} instead of 33 odt ha^{-1}). These figures assume that annual yields are the same for either 3- or 4-year rotations and that harvesting equipment can handle the larger diameter material in 4-year-old rotations. Reducing planting density, which would also reduce establishment costs, would result in peak mean annual increment occurring later [29]. This combination of lower planting densities (lower establishment costs) and longer rotations (lower harvesting costs) is currently being tested in trials with improved willow clones.

Variables Affecting Establishment Costs The second largest cost component of the willow crop system is establishment, which accounts for 23% of the total costs over the life of the crop. Planting stock accounts for more than 63% of establishment costs in the base-case scenario when planting stock costs

[5] While harvest speed can be changed in the model, our field experience suggests that the actual harvest speed is not limited by higher biomass throughput, so the rate of harvesting (6.5 km/h) was not changed.

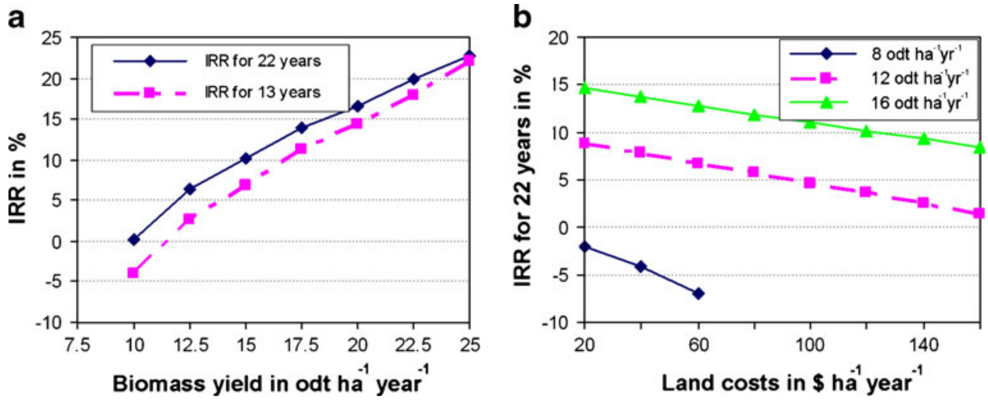


Fig. 3 Increasing the yield willow crops in upstate New York increases **a** the IRR from the crop despite higher harvest costs, particularly if it is grown for the entire 22 years, and **b** increases the price that can be paid for land rent while still generating a reasonable IRR. IRR for a yield below 7.5 odt ha^{-1} $year^{-1}$ was below 0%

are \$0.12 per cutting. As a result, small increases in costs per cutting will result in large increases in establishment costs (Fig. 6a). For instance, increasing cutting costs by \$0.03 per cutting in the base-case scenario increases establishment costs by \$395 ha^{-1}, which are \$2,709 ha^{-1} in the base-case scenario. Since these costs occur at the beginning of the project's life, they have a large effect on the project's total IRR reducing it from 5.5% to 4.1%. Subsidies such as the biomass crop assistance program in the USA[6] or the energy crops scheme in the UK[7] that focus on reducing establishment costs for producers should have a large positive effect on the overall profitability of the crop. For instance, lowering planting stock costs from \$0.12 per cutting to \$0.10 per cutting would reduce establishment costs by 10% and increase the IRR of the system from 5.5% to 6.5%.

Previous studies have shown that increasing planting density raises first rotation yields of willow crops (e.g., [5]). However, increased planting density does reduce the overall profitability of the crop over multiple rotations significantly (Fig. 6b). Increasing planting density to raise yield might therefore not result in an improved profitability of the crops. Therefore, the relationship between increased planting densities and higher yields need to be carefully weighted. As breeding and selection programs develop new willow clones with modified growth characteristics, it may be possible to adjust the planting density and—because reducing planting density has a direct impact on the IRR of the system—reduce establishment costs. For instance, reducing the planting density by 25% in the base-case scenario from 14,300 to 10,750 cuttings ha^{-1} would result in reducing establishment costs from \$2,709 to \$2,315 ha^{-1} and increase the IRR from 5.5% to 7.7%, assuming there is no decrease in yield across this range of densities. While a 25% reduction in planting density should have an impact on yields, especially in the first rotation, the effect is still being determined in trials that are underway.

[6] http://www.fsa.usda.gov/FSA/webapp?area=home&subject=ener&topic=bcap [06/06/2010].

[7] http://www.naturalengland.org.uk/ourwork/farming/funding/ecs/default.aspx [06/06/2010].

Automated planting systems such as the Step and the Egedal planters have been developed in Europe for the establishment of willow crops. Both of these units are capable of planting a hectare in about 1.5 h. While improvements in planting speed would be beneficial from the perspective of getting more hectares planted during the short spring planting season, planting speed has a relatively minor impact on total establishment costs and—as a consequence—project profitability. Doubling planting speed from 1.5 to 0.75 h ha^{-1} would only increase the IRR by around half a percentage point in the base-case scenario.

Variables Affecting Transportation Costs Transportation costs significantly affect the overall economics of biomass because of its relatively low density. This is also true for willow biomass, which has a lower density (0.36–0.47 g cm^{-3} [22]), than other sources of woody biomass. Optimizing transportation operations and minimizing haul distances will impact the overall economics of the system. Increasing truck capacity (in both weight and volume) can reduce transportation costs and therefore improve the project's IRR up to a capacity of around 30 t. Above a truck capacity of 30 t, the model suggests that there seems to be little improvement in terms of profitability. However, using trucks with less than 30 t of willow biomass does

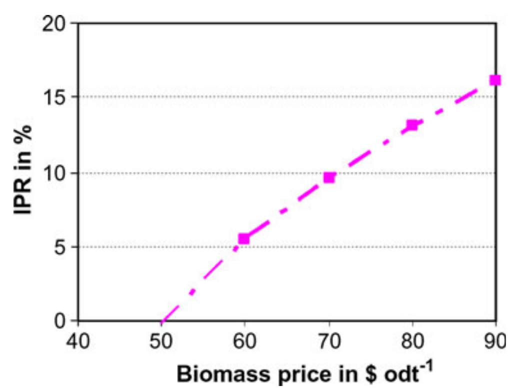


Fig. 4 Based on the analysis from the willow crop budget model EcoWillow, a higher price at the plant gate (delivered) for willow biomass directly affected the producer's internal rate of return

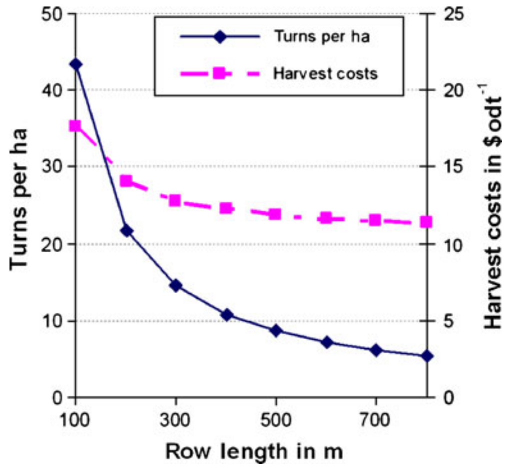


Fig. 5 Increasing row length (and therefore decreasing turning time) up to 400 m reduces harvesting costs for the base-case scenario of willow crops

increase transportation costs and decrease the IRR. As expected, increasing the haul distance for willow crops reduces the IRR from the system in a linear fashion. Minimizing transportation distances and a focused effort on managing the transportation operations will have a direct effect on the viability of these systems.

Conclusions and Recommendations

It is important to understand the interactions between the different components of the willow production system and how they influence each other. The EcoWillow v1.4 (Beta) budget model can demonstrate these interactions and identify parts of the system with the greatest potential for improvements. The model covers the entire production chain from crop establishment to the delivery of woodchips to the end user. The base-case scenario was developed using conditions in upstate New York and is profitable with an IRR of 5.5% during a 22-year project life. The payback for the initial investment in crop establishment is reached in the 13th year.

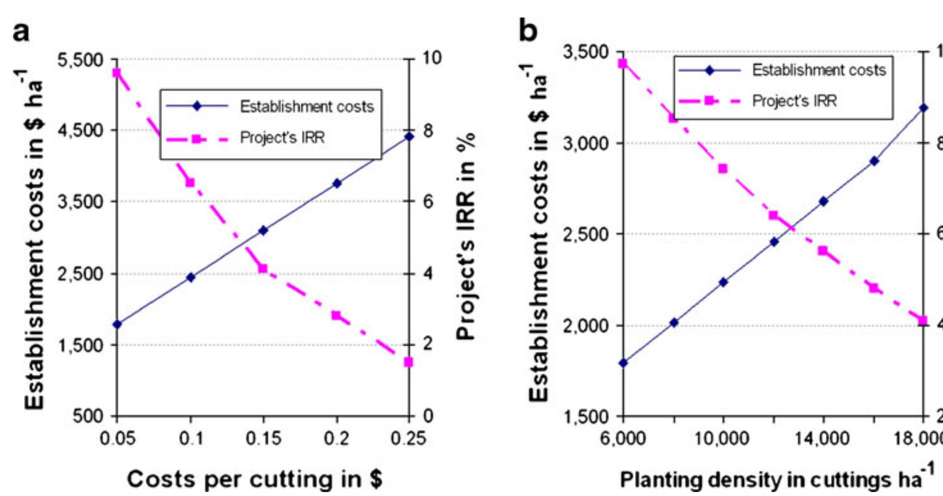
Biomass yields have a major impact on the profitability of the crop. The economics of the base-case scenario would greatly benefit from improved productivity above current 12 odt ha^{-1} year^{-1}. Increasing yields by 2 odt ha^{-1} year^{-1}, through, e.g., new clones or improved agricultural practices, would increase the IRR of the base-case system by 51% to 8.3%. Discontinuing willow crops on less-productive sites after 13 years results in considerable losses compared with the small returns that would occur if the crop was grown for a longer time period.

Land rent has a high impact on the overall project's profitability. In the land rent ranges analyzed (\$20–\$160 ha^{-1}), a biomass productivity of below 8 odt ha^{-1} year^{-1} renders the project unprofitable. Biomass price has a high impact on the project's profitability especially in lower price ranges. Increasing the value of willow biomass by producing multiple products using a biorefinery will assist in making the system more profitable.

Harvest, establishment, and transportation costs combined account for 71% of the total project's costs in the base-case scenario. The cost reduction potential for each of these key cost categories differs. Reducing the cost of planting stock and reducing planting density can reduce establishment costs significantly. In comparison, planting speed has little impact on profitability.

Since the speed of the latest New Holland harvesting system modeled here is not influenced by biomass production under current conditions, a higher biomass density is desired at the time of harvest to reduce harvest costs per ton. As long as stem diameters do not exceed the size that can be managed by this harvesting system, longer rotations are more profitable than shorter rotations. The reduction of harvest costs outweigh the negative economic effects caused by delaying the start of positive cash flow due to a longer rotation.

Fig. 6 Increased cost of **a** the planting stock (cuttings) and **b** increased density of the planted material both increased the cost of establishing the crop and decreased the internal rate of return from the willow crop



Changing the rotation length from 3 to 4 years improves the IRR by 0.7 percentage points. Increasing the productive time of the harvester by increasing row lengths and minimizing the need to turn around equipment can reduce harvesting costs and increase the overall IRR. Results indicate that row lengths approaching around 400 m optimizes harvesting costs. Further increase in profits through economies of scale are expected in reducing the relative share of transport costs of equipment, reduced administration costs, and discounts on supplies and machinery rentals.

Transportation costs influence the profitability of the willow crop system and can be managed by using trucks with a 30-t capacity and keeping the haul distance below 50 km. Results from this study indicate that fuel and labor costs play a minor role in the overall profitability of willow crops, but higher fuel costs will impact the cost of other inputs into the system such as planting stock and machinery that were not assessed.

Other factors not analyzed in this study need to be considered in future studies, such as the impact of loans to finance startup costs or fiscal policies to support willow crops especially under low yielding conditions. The interactions between the different components of the system, such as tradeoffs between site quality and land rent, and initial field lay out and long-term harvesting costs need to be understood and managed as this system is deployed.

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Appendix 1

Table 4 Cash flow diagram (per hectare) as presented in the EcoWillow model

Cash Flow Diagramm (per ha)

EcoWillow v1.3 (Beta)

Year +	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
Field data																								
Activity	Soil prep.	Estab.			Harvest			Harvest			Harvest			Harvest			Harvest			Harvest			Harvest	
Coppice age (yrs)			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Increment (odt*)		0	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	
Stock (odt)			11	22	33	11	22	33	11	22	33	11	22	33	11	22	33	11	22	33	11	22	33	
Use (odt)			0	0	33	0	0	33	0	0	33	0	0	33	0	0	33	0	0	33	0	0	33	
Expenditures																								
Land costs and insurance	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	
Administration	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	
Vegetation removal	50																							
Herbicide	70	110																						
Plow	60																							
Discs	50																							
Plant cover crop	120																							
Kill cover crop		70																						
Planting		1,884																						
Fence installation		0																						
Fence removal				0																				
Mech. or chem. weeding		35	35																					
Back cut		50																						
Fertilizer			175		175			175			175			175			175			175				
Harvest			0	0	540	0	0	540	0	0	540	0	0	540	0	0	540	0	0	540	0	0	540	
Transport			0	0	168	0	0	168	0	0	168	0	0	168	0	0	168	0	0	168	0	0	168	
Stock removal																							740	
Total	447	2,246	307	97	980	97	97	980	97	97	980	97	97	980	97	97	980	97	97	980	97	97	1,545	
Revenues																								
Acreage incentive payments		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Establishment grant	0	0	0																					
Biomass			0	0	1,987	0	0	1,987	0	0	1,987	0	0	1,987	0	0	1,987	0	0	1,987	0	0	1,987	
Total	0	0	0	0	1,987	0	0	1,987	0	0	1,987	0	0	1,987	0	0	1,987	0	0	1,987	0	0	1,987	
Total 1	-447	-2,246	-307	-97	1,007	-97	-97	1,007	-97	-97	1,007	-97	-97	1,007	-97	-97	1,007	-97	-97	1,007	-97	-97	442	
Other costs																								
Loan payments	0	0	0	0	0	0	0	0	0	0	0													
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Sum
Total 2	-447	-2,246	-307	-97	1,007	-97	-97	1,007	-97	-97	1,007	-97	-97	1,007	-97	-97	1,007	-97	-97	1,007	-97	-97	442	2,224
Total 2, equity only	-447	-2,246	-307	-97	1,007	-97	-97	1,007	-97	-97	1,007	-97	-97	1,007	-97	-97	1,007	-97	-97	1,007	-97	-97	442	2,224
Total 2, discounted	-447	-2,139	-278	-84	829	-76	-72	716	-66	-63	618	-57	-54	534	-49	-47	461	-42	-40	399	-37	-35	151	122
Total 2, accumulated	-447	-2,693	-3,000	-3,097	-2,090	-2,187	-2,284	-1,277	-1,374	-1,471	-464	-561	-658	349	252	155	1,162	1,065	968	1,976	1,879	1,782	2,224	-9,791
Total 2, optimistic	-402	-2,022	-276	-87	1,304	-87	-87	1,304	-87	-87	1,304	-87	-87	1,304	-87	-87	1,304	-87	-87	1,304	-87	-87	795	4,783
Total 2, optimistic, equity only	-402	-2,022	-276	-87	1,304	-87	-87	1,304	-87	-87	1,304	-87	-87	1,304	-87	-87	1,304	-87	-87	1,304	-87	-87	795	4,783
Total 2, optimistic, accumulated	-402	-2,424	-2,700	-2,788	-1,484	-1,571	-1,658	-354	-442	-529	775	688	600	1,904	1,817	1,729	3,033	2,946	2,859	4,163	4,075	3,988	4,783	19,009
Total 2, pessimistic	-492	-2,471	-338	-107	710	-107	-107	710	-107	-107	710	-107	-107	710	-107	-107	710	-107	-107	710	-107	-107	89	-336
Total 2, pessimistic, equity only	-492	-2,471	-338	-107	710	-107	-107	710	-107	-107	710	-107	-107	710	-107	-107	710	-107	-107	710	-107	-107	89	-336
Total 2, pessimistic, accumulated	-492	-2,963	-3,300	-3,407	-2,697	-2,803	-2,910	-2,200	-2,306	-2,413	-1,703	-1,809	-1,916	-1,206	-1,312	-1,419	-709	-815	-922	-212	-318	-425	-336	-38,591

* odt: oven-dried ton; containing 0 % moisture

Inputs are for the base-case scenario covering the total project life from site preparation, though planting to removal of the willow plants after seven 3-year harvests

Appendix 2

Table 5 Input variables used in the online EcoWillow v1.4 (Beta) model for the base-case scenario based on data from upstate New York

	Variable description	Unit
General variables		
Interest rate	%	5.00%
Project size	ha	10
Project life	Years	22
Average biomass increment	odt ha^{-1} $year^{-1}$	12
Rotation length	Years	3
Headlands	% of area	8%
Land costs (tax, lease) and insurance	\$ ha^{-1} $year^{-1}$	85
Internal administration costs	\$ ha^{-1} $year^{-1}$	12
Biomass price at plant gate	\$ odt^{-1}	60
Stock removal	\$ ha^{-1} $year^{-1}$	740
Laborer rate	\$ h^{-1}	10
Foreman rate	\$ h^{-1}	20
Indirect labor costs	%	35%
General variables influencing establishment costs		
Vegetation removal	\$ ha^{-1}	50
Contact herbicide	\$ ha^{-1}	70
Plow	\$ ha^{-1}	60
Disk	\$ ha^{-1}	50
Plant cover crop	\$ ha^{-1}	120
Kill cover crop	\$ ha^{-1}	70
Preemergent herbicide	\$ ha^{-1}	110
Mech. or chem. weeding first year	\$ ha^{-1}	35
Cut back	\$ ha^{-1}	50
Mech. or chem. weeding second year	\$ ha^{-1}	35
Fertilizer	\$ ha^{-1}	175
Variables influencing planting costs		
Planter speed	h ha^{-1}	1.5
Labor		
No. crews at site		1
Laborers/crew		4
Foreman/crew		1
Equipment		
No. of planter units		1
Distance	km	80
Planter rental	\$ h^{-1} $unit^{-1}$	70
Tractor rental	\$ h^{-1} $unit^{-1}$	40
Tractor fuel consumption	l h^{-1}	10
Fuel price	\$ L^{-1}	0.56
Maintenance	\$ ha^{-1}	5
Supplies		
Planting stock	\$ $cutting^{-1}$	0.12
Planting density	Cuttings ha^{-1}	14,300
Stock delivery	\$	250
Other supplies	\$ ha^{-1}	5
Variables influencing harvest costs		
Harvester speed	km h^{-1}	6.5
Double row width	m	2.3
Average row length	m	200
Turning time	min row^{-1}	0.75
Maintenance time harvester	% of harvest time	17%
Labor		
No. crews at site		1
Laborer/crew		3
Foreman/crew (harvester driver)		1
Travel costs		
No. of vehicles		1
Vehicle costs	\$ km^{-1}	0.25
Distance	km	80
Equipment		
No. of harvesters		1
Transport harvester	\$ km^{-1}	7
Distance	km	80
Harvester rental	\$ h^{-1} $unit^{-1}$	180
Harvester fuel consumption	l h^{-1}	60
Trailer–tractor units		2
Trailer–tractor rental	\$ h^{-1} $unit^{-1}$	60
Trailer–tractor fuel consumption	l h^{-1}	10
Blower–tractor unit rental	\$ h^{-1} $unit^{-1}$	50
Fuel price	\$ L^{-1}	0.56
Maintenance	\$ ha^{-1}	12
Variables influencing transport costs		
Wet chip density	m^3 t^{-1}	3.4
Highway speed	km h^{-1}	80
Field road speed	km h^{-1}	30
Distance on highway (one way)	km	40
Distance on field road (one way)	km	1.5
Loading time	min	5
Dumping time	min	15
Equipment		
Tractor–trailer costs	\$ km^{-1}	0.3
Fuel consumption	km L^{-1}	3
Fuel price	\$ L^{-1}	0.62
Maximum capacity	m^3	108
Maximum capacity	t	35

References

1. Abrahamson LP, Volk TA, Kopp RF, White EH, Ballard JL (2002) Willow Biomass Producer's Handbook. State University of New York, Syracuse, NY, pp 31. http://www.esf.edu/willow/pdf/2001%20finalhandbook.pdf. Cited 30 June 2010
2. Adegbidi HG, Volk TA, White EH, Abrahamson LP, Briggs RD, Bickelhaupt DH (2001) Biomass and nutrient removal by willow clones in experimental bioenergy plantations in New York State. Biomass Bioenergy 20(6):399–411
3. Amidion T, Wood C, Shupe A, Wang Y, Graves M, Liu S (2008) Biorefinery: conversion of woody biomass to chemicals, energy and materials. J Biobased Mater Bioenergy 2:100–120
4. Areikin E, Laybourn R, Hodsman L (2009) Energy crops calculator. http://www.nnfcc.co.uk/metadot/index.pl?id=10253&isa=DBRow&op=show&dbview_id=2539. Accessed 30 June 2010
5. Bullard MJ, Mustill SJ, Carver P, Nixon PMI (2002) Yield improvements through modification of planting density and harvest frequency in short rotation coppice *Salix* spp.—2. Resource capture and use in two morphologically diverse varieties. Biomass Bioenergy 22(1):27–39
6. Dhondt A, Wrege PH, Cerretani J, Sydenstricker KV (2007) Avian species richness and reproduction in short-rotation coppice habitats in central and western New York: capsule species richness and density increase rapidly with coppice age, and are similar to estimates from early successional habitats. Bird Study 54(1):12–22
7. Ericsson K, Rosenqvist H, Ganko E, Pisarek M, Nilsson L (2006) An agro-economic analysis of willow cultivation in Poland. Biomass Bioenergy 30(1):16–27
8. Ericsson T, Rytter L, Linder S (1992) Nutritional dynamics and requirements of short rotation forests. In: Mitchell CP, Ford-Robertson JB, Hinckley T, Sennerby-Forsse L (eds) Ecophysiology of short rotation crops. Elsevier Applied Science, New York
9. Heller MC, Keoleian GA, Mann MK, Volk TA (2004) Life cycle energy and environmental benefits of generating electricity from willow biomass. Renewable Energy 29(7):1023–1042
10. Heller MC, Keoleian GA, Volk TA (2003) Life cycle assessment of a willow bioenergy cropping system. Biomass Bioenergy 25:147–165
11. Hoogwijk M, Faaij AXE, Eickhout B, de Vries B, Turkenburg W (2005) Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios. Biomass Bioenergy 29(4):225–257
12. Labrecque M, Teodorescu TI (2003) High biomass yield achieved by Salix clones in SRIC following two 3-year coppice rotations on abandoned farmland in southern Quebec, Canada. Biomass Bioenergy 25:135–146
13. Macalpine WJ, Shield IF, Trybush SO, Haynes CM, Karp A (2008) Overcoming barriers to crossing willow (*Salix* spp.) breeding. Asp Appl Biol 90:173–180
14. Pei MH, Lindegaard K, Ruiz C, Bayon C (2008) Rust resistance of some varieties and recently bred genotypes of biomass willows. Biomass Bioenergy 32(5):453–459
15. Perlack RD, Wright LL, Turhollow A, Graham RL, Stokes B, Erbach DC (2005) Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. Study prepared by Oak Ridge National Laboratory for the US Department of Agriculture and the US Department of Energy, pp 78
16. Rosenqvist H, Dawson M (2005) Economics of using wastewater irrigation of willow in Northern Ireland. Biomass Bioenergy 29:83–92
17. Rosenqvist H, Dawson M (2005) Economics of willow growing in Northern Ireland. Biomass Bioenergy 28(1):7–14
18. Rowe R, Street NR, Taylor G (2009) Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. Renewable Sustainable Energy Rev 13(1):271–290
19. Smart LB, Volk TA, Lin J, Kopp RF, Phillips IS, Cameron KD et al (2005) Genetic improvement of shrub willow (*Salix* spp.) crops for bioenergy and environmental applications in the United States. Unasylva 56:51–55
20. Spinelli R, Nati C, Magagnotti N (2009) Using modified foragers to harvest short-rotation poplar plantations. Biomass Bioenergy 33(5):817–821
21. Tharakan PJ, Volk TA, Lindsey CA, Abrahamson LB, White EH (2005) Evaluating the impact of three incentive programs on the economics of cofiring willow biomass with coal in New York State. Energy Policy 33:337–347
22. Tharakan PJ, Volk TA, Nowak CA, Abrahamson LB (2005) Morphological traits of 30 willow clones and their relationship to biomass production. Can J For Res 35(2):421–431
23. Turnbull HJ (1994) Developing an integrated approach to biomass energy systems in the United States. Biomass Bioenergy 6(1–2):151–158
24. US DOE (2006) Breaking the biological barriers to cellulosic ethanol: a joint research agenda. DOE/SC-0095, US Dept. of Energy Office of Science and Office of Energy and Renewable Energy, pp 216. http://genomicscience.energy.gov/biofuels/2005workshop/b2blowres63006.pdf Cited 30 June 2010
25. Volk TA (2002) Alternative methods of site preparation and coppice management during the establishment of short-rotation woody crops. PhD thesis. State Univ. of New York, College of Environmental Science and Forestry, Syracuse, NY
26. Volk TA, Abrahamson LP, Nowak CA (2006) The development of short-rotation willow in the northeastern United States for bioenergy and bioproducts, agroforestry and phytoremediation. Biomass Bioenergy 30(8–9):715–727
27. Volk TA, Luzadis VA (2009) Willow biomass production for bioenergy, biofuels, and bioproducts in New York. Chapter 11. In: Solomon, Luzadis (eds) Renewable energy from forest resources in the United States. London, Routledge, p 321
28. Volk TA, Verwijst T, Tharakan PJ, Abrahamson LP (2004) Growing energy: assessing the sustainability of willow short-rotation woody crops. Front Ecol Environ 2(8):411–418
29. Willebrand E, Ledin S, Verwijst T (1993) Willow coppice systems in short rotation forestry: effects of plant spacing, rotation length and clonal composition on biomass production. Biomass Bioenergy 4(5):323–331