Shrub Willow Biomass Producer's Handbook

ESF

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Preface

This handbook has been produced by the State University of New York College of Environmental Science and Forestry (SUNY-ESF) to introduce farmers in upstate New York the Northeast, and the Lake States to shrub willow and offer guidelines on how to manage this new crop. The goal is to aid farmers in achieving the best returns in yield and profit. This handbook describes the benefits of growing willow as a bioenergy crop and explains the process of the willow biomass production system, which is based on a combination of agricultural and forestry practices. The system simultaneously produces a renewable lignocellulosic feedstock (woodchips) and provides a wide range of environmental and rural development benefits. Shrub willow is a high-yielding perennial crop with a short harvest cycle of only three to four years which can be grown on underutilized land. Currently in New York State alone there is approximately1.5 million acres of barren or underutilized farm land. Exploiting this resource could improve the farm finances, as well as stimulate the rural economy, by providing a new source of revenue, a new crop market, and environmental benefits. Current updates on research and newly released reports and articles can be found on the following website: www.esf.edu/willow. Feedback from producers and other collaborators is essential for continued improvement. Please send any comments you have to one of the addresses at the end of this handbook.

Introduction

Benefits for Growing Willow

The production of biomass crops, such as shrub willow, will become a major source of renewable energy within the next few decades. Petroleum based energy is becoming more unattractive due to high prices, environmental concerns, and decreasing domestic oil supplies. Locally grown "green-energy", in the form of shrub willow, in the Northeastern United States is a potential solution to help alleviate these problems. While producing a cellulosic feedstock, willow biomass cropping systems simultaneously produce valuable environmental and social benefits. These include reduced SO_2 and NO_x power plant emissions when used as a fuel for co-firing with coal, no net addition of CO_2 to the atmosphere when used to generate electricity, sequestration of carbon in soil, reduced soil erosion and non-point source pollution from agricultural land, and enhanced agricultural landscape diversity. Willow biomass has the potential to play a crucial role in revitalizing the economy of rural communities by making productive use of under utilized cropland. The willow biomass production system is primarily an agricultural based system that is similar to perennial cropping systems currently being used by New York farmers (Figure 1). This manual is based on twenty years of research at SUNY-ESF, plus information from Sweden, the United Kingdom, and Canada. This is the third update to the Willow Biomass Producer's Handbook, and as new information is gained, recommendations may change. Feedback from growers and other collaborators is essential for continued improvement.

Figure 1: Willow biomass farm crop on a farm in western New York.

Harvesting for Sale to the Energy Market – Shrub willow, as a woody feedstock, has the potential to be converted into a wide range of energy products. Heat and electricity can be produced from wood-firing plants through direct combustion, co-fired with coal, or gasification. Liquid transportation fuels, such as, ethanol can be produced through an extraction and fermentation process in a biorefinery. In addition to energy products, willow can also be used to produce biodegradable plastics and other polymers/chemicals normally synthesized from petroleum.

Incentive Programs for Farmers – New policy developments with the federal Conservation Reserve Program (CRP), the Conservation Reserve Enhancement Program (CREP), state Renewable Portfolio Standards (RPS), the USDA Biomass Crop Assistance Program (BCAP), and renewable energy tax credits will aid in the production of willow as an energy crop. New York State* has developed guidelines for the establishment and harvest of willow biomass crops on CRP land. Landowners growing willow on CRP land will receive annual rent payments from the USDA, in addition to incentive payments for establishment costs. These contracts usually last between 10 and 15 years. It is estimated that farmer's could reduce delivery costs from $52 to $33 a ton.

* Farmers outside of New York State must check state guidelines if willow is considered a CRP crop.

Environmental Benefits and Sustainability **–** The predominant environmental benefit from utilizing willow biomass as an energy source is a reduction in greenhouse gas (GHG) emissions. The carbon dioxide (CO_2) emitted by the combustion or conversion of willow biomass to energy is the same CO_2 absorbed by the plant during its growing period, making this a CO_2 neutral process. In addition to reduced GHG emissions, there are other characteristics of the perennial crop that make it environmentally friendly. The bird diversity in a willow field is similar to that of an early-successional forest. Due to its extensive root system, willow crops can help maintain and improve soil conditions in barren fields by reducing erosion, improving nutrient cycling, and in turn, increase soil biodiversity. In addition, these characteristics make shrub willow very useful for phytoremediation, riparian buffers, and stream bank restoration. The energy ratio of willow energy crops at the farm gate is 1:55 or 1:11 to 1:16 as electricity coming from a electric power plant as determined by life cycle assessment (LCA) studies.

The Cultivation of Shrub Willow: History and Current Prospects

Cultivation of willow in the United States began in the 1840s by immigrants in central New York and Pennsylvania. By the late 1800s cultivation of willows for basketry and furniture had spread from the shores of Maryland to the western borders of Wisconsin and Illinois. By the early 1900s, New York State dominated willow cultivation in the United States, with 60% of the total reported area, and about 45% of the income generated from willow products. However, as the demand for willow baskets dropped off rapidly in the 1920s and 1930s, only pockets of willow cultivation remained.

The cultivation of willow was revitalized in upstate New York in the mid 1980s at SUNY-ESF. The focus was research on the production of willow as a locally produced, renewable, lignocellulosic feedstock for bioproducts and bioenergy. Over the last 20 years, numerous organizations have teamed up with the goal of facilitating the commercialization of willow biomass crops in the Northeastern and Midwestern regions of the United States (see Acknowledgements). To reach this goal, a series of simultaneous activities, including research, regional clone-site trials, a large-scale demonstration program, and outreach and education efforts, were initiated (Figure 2).

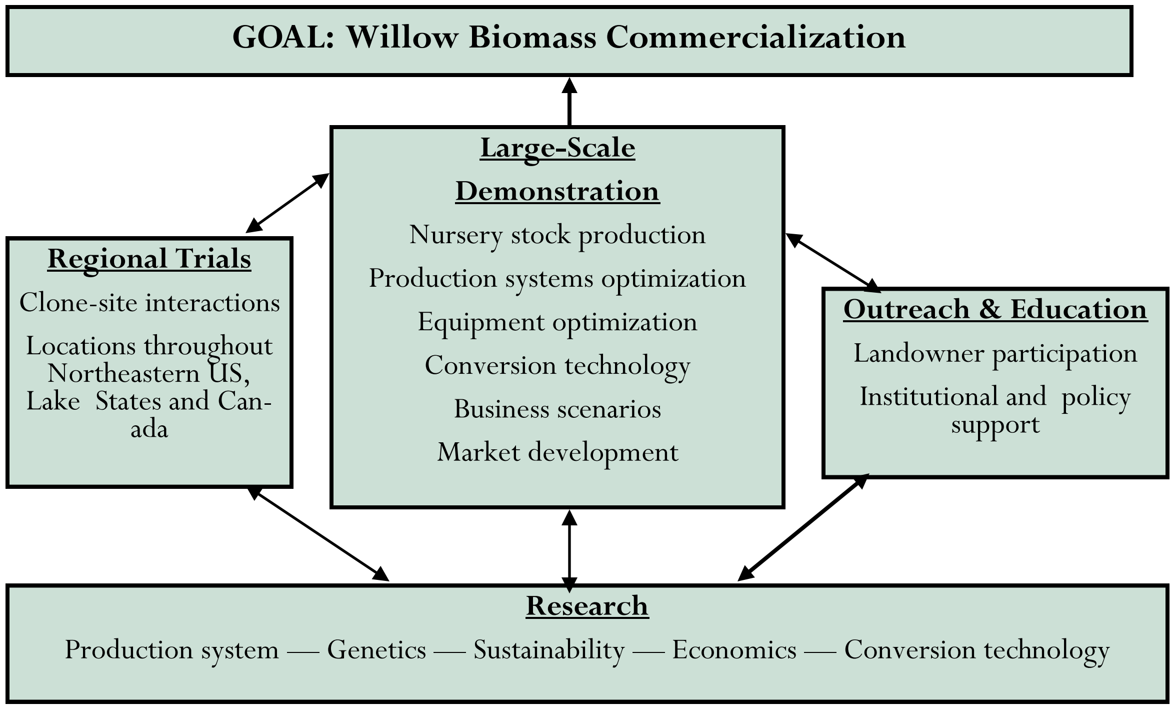

Figure 2: Simultaneous activities initiated by SUNY-ESF to facilitate the commercialization of willow biomass crops in the Northeastern US ands the Lake States.

Currently, in New York State, Lyonsdale Biomass (Lyons Falls, NY) is the only power plant burning willow chips for combined heat and power (CHP) generation. There are other wood-firing plants in the state but they are not burning willow chips at this time. The Chateauguay Power Plant in Franklin County and the Colgate University Steam Heating Plant in Madison County are examples. Other proposed markets for willow chips are the coal-fired power plants retrofitted to co-fire woody biomass: the 104 MW Greenidge pulverized coal power plant owned by AES in Yates County and a 100 MW boiler at the Dunkirk Steam Station owned by NRG Inc. in Chautauqua County. Greenidge has been co-firing wood residues with coal for over a decade. The Dunkirk Steam Station has a capacity to process and co-fire 265 tons of woody biomass on a weekly basis (enough to power 2,000 homes weekly), but is currently not doing so. Within the near future, a number of wood gasifiers, new CHP plants and wood biorefineries will prove to be a major component of the renewable energy industry and a great gateway for shrub willow chips. Consolidated Energy is in the planning stages of a 10-15 MW wood gasifier CHP in Onondaga County. Another small wood gasifier CHP is anticipated to be constructed at the SUNY-Delhi campus in Delaware County. Catalyst Renewables, the owners of Lyonsdale Biomass, will soon be adding a wood biorefinery to their CHP wood burning plant in Lyons Falls, NY. Fulton, NY will soon be the site of Northeast Biofuels for the production of ethanol. At the former Seneca Army Depot in Seneca County, NY there are plans to construct a biomass ethanol plant by Empire Green Biofuels, in addition to a woody biomass

CHP production facility,

Soil & Site Considerations for Willow Biomass Crops

Soil properties are critical to the successful and sustainable production of willow biomass crops. Willows grow best on good agricultural soils, but can also be grown successfully on soils that are marginal for traditional crops (Table 1). Generally, better quality soil will produce greater yields earlier in the rotation. A number of current variety-site trials through out New York, the Lake States and Canada will result in soil/site recommendations for a wide variety of our new willow varieties. The best willow growth occurs on sites with a large rooting volume and good aeration, water, and nutrient availability. Soil pH should be above 5.5 and below 8.5. Soil depth should be at least 18 inches.. Willow has been grown successfully on soils ranging in texture from sandy loam to silt or clay loams. Soils with higher clay content tend to have lower production in the first few years. However, initial results suggest that second rotation yields on these sites may be greater compared to soils with lower clay contents. Although willows grow on poorly drained soils, they will not grow at economically acceptable rates under these conditions. Slopes in the fields should not be greater then 8% to facilitate the harvesting machinery during the dormant season when the fields are wet or snow covered and slippery

Table 1: Soil characteristics suitable and unsuitable for shrub willow agricultural crops

Soil Characteristic	Suitable	Unsuitable
Texture	Loams, sandy loams, clay loams, silt loams and clay	Sandy, course sand & gravel, heavy clay with standing water
Structure	Well developed to single grain structure	Massive or lacking structure
Drainage	Imperfectly to moderately well drained	Excessively well or very poorly drained (standing water)
pH	5.5 to 8.5	Below 5.5, above 8.5
Depth	18 inches or more	Less then 18 inches

Growing Willow

Site Preparation, Weed Control and Cover Crops

Effective site preparation and weed control are critical for the successful establishment of willow biomass plantings. ***Weed competition is the most common cause of failure for willow biomass crops during the first and second years.*** First year willow sprouts are "prima donnas" they do not compete well with weeds. The willow cuttings are producing both roots and sprouts the first year with a lot of energy going into root production. The top sprouts are usually on the "wimpy" side and do not compete well with weeds for light or moisture during the establishment year, or during the first part of the second growing season. Once the willow stand closes canopy during the second year, completely occupying the site, weeds become much less of a problem. If weeds are not controlled until the willow shrubs fully occupy the site, biomass production will be much lower during the first rotation, or in worst case scenarios, the planting may be severely overgrown by weeds and never be economically productive or die out and have to be replanted. Weeds that have shallow roots and are shorter then the willow sprouts may not be as much of a problem if there is enough moisture in the soil. Any tall dense weeds that overtop the willow sprouts during the first or second year will severely damage the planting and kill most of the willow plants. Effective weed control techniques, outlined below, have been developed for willows in New York, and research to make weed control methods more efficient continues. Please contact us with questions and advice on herbicides available in your area.

Effective site preparation (Figure 3) on an old-field or hay-field site must begin the summer before planting, preferably during mid to late July. The site should first be mowed, and if vegetation is excessive the site should be mowed and baled to remove the cut vegetation. After the vegetation resumes vigorous growth (usually 6-8 inches), the site should be sprayed with glyphosate (Figure 4), a broad spectrum post-emergent, translocated herbicide. Site preparation could begin during mid August, but starting this late is riskier because perennial weed regrowth may not be vigorous enough for effective control with glyphosate. If problematic perennial weeds such as crown vetch, morning glory, thistle, etc. are present, adding 2,4-D or a mixture

Figure 3: effective site preparation of an old-field for planting willow biomass crops

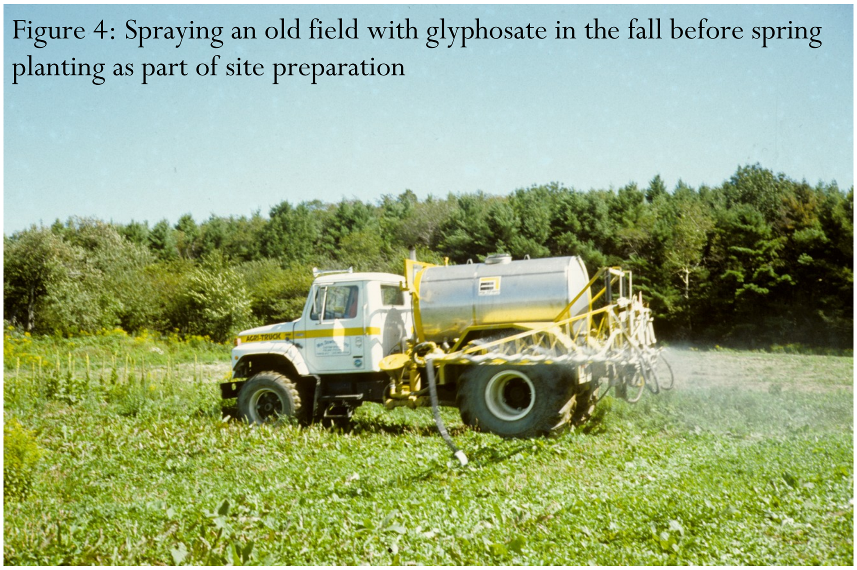

Figure 4: Spraying an old field with glyphosate in the fall before spring planting as part of site preparation

of 2,4-D and triclopyr in a tank mix with glyphosate is advisable. Directions provided on the labels and local regulations on the use of specific herbicides should be followed. At least two to four weeks should be allowed for the herbicide to effectively kill all weeds. We recommend using a higher water spray volume than normal to insure good spray coverage. If there are a number of established woody plants in the field, they should be individually treated with the glyphosate, 2,4-D and triclopyr mixture before the field is mowed to insure a good kill of the woody plants.

Once the effectiveness of the herbicide application is confirmed, the site should be plowed to a depth of 10 inches or more. Plowing can be followed immediately by cross disking (Figure 5). Once disking is completed (probably early to mid September) site preparation of these fields is complete for the fall season. However, on soils with significant erosion potential, a cover crop that provides good ground cover late in the growing season and winter, and is easily killed the following spring, such as winter rye, should be planted. Additional research on incorporating different cover crops into willow cropping systems is underway and additional recommendations will be forth coming.

Figure 5: Cross disking as part of effective site preparation in the fall or spring before planting willow biomass crops.

Rocky or stony fields are not a big problem if the rocks are small and the field is not solid rocks. Large Rocks or stones that protrude more than approximately two inches above the soil surface should be removed. Large rocks or stones will damage planting and harvesting equipment.

The following spring, if a winter-hardy cover crop was planted, it must be killed (using glyphosate or plowed under) and disked. Just before planting, soil must be lightly disked or cultimulched to kill any germinating weeds and loosen the top soil for planting. Willow planting machines function best on freshly cultimulched sites and any germinating weeds need to be killed before pre-emergent herbicides are applied right after planting.

If the field to be planted to willow was in a annual agricultural crop the year before the field can be sprayed (if necessary) with glyphosate, plowed and disked just before planting in the spring.

Planting

The current willow biomass crop system is based on a planting density of about 6,000 plants per acre. Planting is done with mechanized planters specifically designed to use dormant stem whips. To facilitate the management of the site with farm machinery, willows are planted in a double-row system with five feet between double-rows, two and a half feet between rows, and two feet between plants within rows (Figure 6).

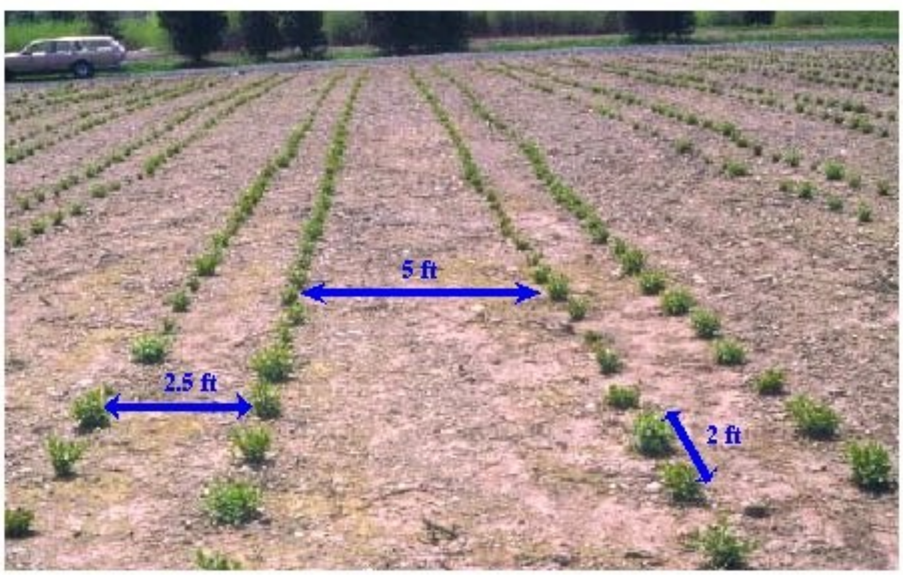

Figure 6: Double row planting scheme used for willow biomass crops in the United States and Northern Europe to facilitate the use of farm machinery and willow forage harvesters—We now recommend 6 ft between the double rows instead of 5 ft and 20-21 inches along the row in instead of 2 ft to facilitate harvesting equipment and maintain planting density.

The planting design for each field should be carefully thought out before planting begins. Rows should be as long as possible with turn around areas for the willow harvesters and chip wagons pulled by tractors at the row ends and plans for a staging area large enough for chip truck loading operations should be strongly considered. Once established, willow biomass crops will be in production for over 20 years, so mistakes in the planting design and staging areas could cause problems for many years.

Willow planting is done using dormant un-rooted cuttings of 6 – 10 inches in length in early spring as soon as sites are workable. The cuttings are usually cut and planted in one step from 4-7 foot long willow "whips" using the willow Step planter (figure 7) or the willow Egedal Energy planter (figure 8), and within several days following disking and/or


Figure 7: Salix Maskiner's willow energy crop Step Planter built in Sweden

cultimulching. Willow "whips" consist of unrooted dormant stems that are a minimum of four feet to approximately seven feet in length and 3/8 to 3/4 inches in diameter (these limits are based on planting machine design and storage box length). Cuttings will produce both roots and shoots after planting. Ideally, planting would take place in late April to late May, but it can be completed as late as mid to late June if necessary. Early spring planting is advisable so that soil moisture is sufficient to support young shoot and root development, and plants have as much time as possible to grow and develop. Buds break and shoots typically emerge one to two weeks after planting under typical New York field conditions in May, and can occur as quickly as 3 days after planting if soil and air temperatures are warm. Some willow varieties are not damaged by late spring frosts, but young shoots of other varieties may be killed back, but the cutting will usually resprout without any lasting damage. There is little advantage to planting earlier than late April because low soil and air temperatures typically result in slow sprouting and growth, and early planting increases the chance of frost damage to young, recently sprouted cuttings. Late planting (June) is risky because soil moisture may become limiting for root development. If willow cuttings do not establish good root systems during the first growing season, they are prone to frost heave during their first winter and weed control will be very important the first part of

Figure 8: Egedal Energy willow energy crop planter built in Denmark

the second year.. The more time they have to grow during the first season, the more extensive the root systems will be. In a wet, warm summer, late plantings may be successful. Willows grow best with warm temperatures and moist, but not saturated, soils.

Willow cuttings and whips are stored at 28° - 30°F, and should not be shipped to the planting site until the day they are to be planted, if possible. Once whips are thawed, they should be planted as quickly as possible, and not be re-frozen. Whips and cuttings may be stored for a few days under cool and moist conditions. Under good conditions they can be maintained outside the freezer for approximately one week before they start sprouting, provided they are in their original containers, are not overheated, and do not dry out. They should never be stored in direct sunlight or under conditions that promote drying. Cuttings that have started to grow before planting should not be planted because their chances for survival are low.

Willow planting machines have been commercially developed in Europe and are being adapted to conditions in the northeastern United States. The machine that has been most successful to date is the Salix Maskiner's Step planter (Figure 7), which was designed in Sweden. The Step planter uses willow whips as planting material. The whips are fed into the machine between two belts that guide the whip into the planting mechanism. The whip is automatically cut to the desired cutting length and simultaneously inserted into a slit in the ground made by a coulter. The length of the cutting can be varied from six to ten inches, which provides increased flexibility to work on a variety of different soil types. When the cutting is inserted into the ground, the planting portion of the machine is held stationary. Designing the machine with this temporary, stationary moment at planting was inspired by the pattern of people walking - hence the name of the machine- Step planter. The Egedal Energy planter (Figure 8) designed in Denmark is newer on the scene, but also has been very successfully used by commercial willow planters here in New York. It also uses the same willow whips as does the Step planter with the advantage of handling whips that are bigger in diameter, more curved and with more cut branch ends. The disadvantage of the Egedal is that it does not place the cuttings in the ground as straight as the Step planter and in wet heavy clay soils may have trouble closing the planting slit with the cuttings in them.

The Step and Egedal willow planters increase the efficiency of planting willow biomass crops compared to the older willow planters that placed pre-cut 10 inch willow cuttings in a slit cut in the ground, such as the Fröebbesta planter in a number of ways. The use of whips versus cuttings as planting stock results in savings in the cost of planting material production since labor is not required to make the whips into cuttings. The Step and Egedal planters plants two double-rows (four rows) at once, while the older Fröebbesta machine only planted one double-row (two rows) at a time. The Step planter is best operated with a four person crew managing the feeding of whips into the planting mechanism. With experience, the crew may be reduced to two (plus a tractor driver). The Egedal planter require a two person crew with the tractor driver. Both the Step and Egedal planters requires a tractor with at least 140 hp with sufficient weight to handle the 3500lb Step planter and/or the 6000lb Egedal Energy planter on the 3-point hitch The Step and Egedal planters's output is about two acres per hour.

Immediately following planting, a pre-emergent herbicide is applied to provide weed control through the first year (Figure 9). Oxyfluorfen and simizine or pendimethalin (depending on soil type) are the herbicides currently being used; usually in a tank mixture of oxyfluorfen with either simizine or pendimethalin, based on the soil type and weed spectrum in the surrounding fields and what was in the field at time of site preparation.. Directions provided on

Figure 9: Applying pre-emergent herbicide immediately after planting willow cuttings for best control of first-year weeds.

the label and local regulations for the use of specific herbicides should always be followed. Trials are underway to test other pre-emergent herbicides for use on willow biomass crops.

First Growing Season

Cuttings should sprout shoots within two weeks of planting. Roots are being produced underground at the same time. Typically 90% or more of the cuttings survive. A minimum survival percentage, below which the field should be replanted, has not yet been determined, but we suspect that this value is approximately 60 - 70%, depending on the site.

Figure 10: Mechanical weed control during the first-year with a shielded Bandalini multi-row rototiller

If survival and weed control are acceptable during the first growing season, no further effort is required until leaf fall. If the pre-emergence herbicide cap fails and weed seeds germinate, or if perennial weeds not killed during site preparation begin to compete with willow plants, mechanical cultivation (Figure 10) will be necessary. Annual weeds are generally easily controlled mechanically when they are small. If perennial weeds become established, two to three cultivations may be necessary. Cultivators and rototillers designed to accommodate the double-row spacing used in willow plantings have been developed. Contact herbicide (paraquat or Gramoxone) application with shielded sprayers has been used successfully, but willows are highly sensitive to systemic post-emergent herbicides, so the risk of damaging foliage is high if glyphosate is used. Grass weeds can be effectively controlled with grass post-emergent herbicides, such as Fusillade, sprayed over the top of the willow plants.

Growth during the first growing season (Figure 11) varies by variety, rainfall, temperature, and soil conditions. Shoots should be at least three feet tall at the end of the first growing season, and stem heights greater than eight feet of growth have been observed. Most plants will have one to four stems.


Figure 11: first-season growth

At the end of the first growing season and after leaf fall (typically mid November), plants should be cut back (coppiced). This operation could be completed any time between two weeks after leaf fall and when buds begin to swell in spring (typically early March). Coppicing can be completed with a sickle bar mower equipped with sharp blades and long guides so that a clean cut is produced. The stems should be cut at a height of about one to two inches. The forward speed of the tractor should be such that stems are cut cleanly, without tearing, and the willow's root system is not being ripped from the soil. Any machine that pulls up on the plant before cutting would not be suitable since the plant's root system would be damaged. Cut stems can be left in the field, or made into cuttings and stored if additional planting material is desired. Coppicing promotes multiple sprout formation and results in rapid canopy closure the second year. Under sever weed conditions, where good weed control does not seem possible, coppicing of the first-year plants should not be done so the willow plants can stay above of the weeds the second year and be able to compete for light. Under these conditions this may be the only way this crop will survive with a high enough density to be profitable. If the weeds get over the top of the willow they will not survive!!!

Second Through Fourth Growing Seasons

After the willows resprout and resume growth during the second season, and assuming weeds are under control, nitrogen fertilizer is applied at the rate of 100 pounds of elemental nitrogen per acre (Figure 12). Potassium or phosphorous addition may be necessary on some very soil depleted sites. Rates will vary depending on the fertility of specific sites and the requirements of different willow varieties. Timing of fertilizer application depends on spreading equipment available and the growth rate of the plants. Machinery must not damage the plants as it passes over them, young willow stems can be bent over without damage provided the object causing the bend (e.g., a tractor axle) pushes on the top third of the stem. Ideally, application would be during mid to late June so that plants are vigorously growing, have captured the site and are producing new roots that can absorb the fertilizer. Experiments have shown that a wide range of organic wastes, including sewage biosolids and composted poultry manure, can be used to supply nutrients to the willow crops. These organic amendments are ideal for slow release of nutrients over the three to four year growing harvest rotation with one application.

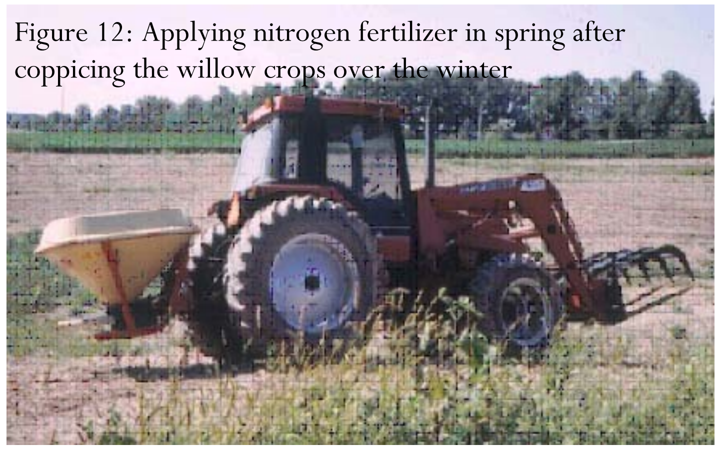
Figure 12: Applying nitrogen fertilizer in spring after coppicing the willow crops over the winter

Weed control may be necessary during the first part of the second growing season, until the stand closes canopy. If weeds are established at the start of the second season, they should be removed prior to fertilization if they are dense and of the type that will overtop the willow; otherwise, fertilized weeds may overtop the emerging willow shoots. It is better not to fertilize if weeds are a problem and they cannot be satisfactory controlled. Fertilization can be started at the start of the second rotation.

Willows should close canopy (Figure 13) by early to mid July of the second growing season. Once the canopy is closed, weeds will be suppressed and no further weed control efforts are necessary. Each willow plant should be six -eight feet or more in height by the end of the second growing season and have multiple stems (Figure 14).


Figure 13: first-year growth after coppice during early July the second growing season

Figure 14: multiple stem produced after coppicing

During the third and fourth growing seasons (second and third seasons after coppicing) no tending of the crop should be necessary. Plants should be 12 - 18 feet in height by the end of the third season, and over 20 feet by the end of the fourth season (Figure 15). The third, and particularly the fourth growing seasons are when the above ground growth is most rapid, assuming growing conditions are similar each year.

Figure 15: Three-year old willow stems ready for harvest

Yields of fertilized and irrigated willow grown for three years have exceeded 12 odt/A/yr. First rotation, un-irrigated trials in central New York have produced yields of four to five odt/A/yr. Un-irrigated, second rotation yields increased by 35 - 50% compared to the first rotation. It is anticipated that commercial yields will be slightly lower due to variability in field conditions. Efforts are underway to improve the yields and form of willow biomass crops. Traditional breeding efforts have been conducted at SUNY-ESF since 1998. Over the last three years over 250 controlled crosses have been made. In Sweden, yields of commercial varieties generated from traditional breeding efforts increased by over 100% from the original "standard" variety. In addition, yields will be increased by optimizing various components of the production system, such as weed control, plant density and fertilization.

Harvesting, Consolidation, and Delivery

Willows should be ready for their first harvest three years after the first coppice (four years after planting). If growth was poor due to weather conditions such as drought or problems with weed competition, harvesting can be delayed a year or two, before annual biomass production begins to decline. As with the first coppice, harvesting can be completed any time during the winter, after leaf fall and before bud swell in early spring.

Figure 16: Hydraulic CRL willow cutting head on a New Holland FX45 forage harvester harvesting 3-year old willow in spring 2007.

SUNY-ESF researchers have worked with engineers at Case New Holland America (CNH) and Coppice Resources Ltd. (CRL) to design a hydraulically driven willow cutting head that attaches to a New Holland FX-series forage harvester (Figure 16). The CRL willow cutting head has two large saw blades, one for each row in a double-row system that cuts the stems at approximately four to six inches above the ground. The stems are directed to the harvester feed rollers by the high speed saw blades spinning in towards the center of the cutting head. The harvester chops the stems and blows the chips out the shoot and into a wagon or forage box pulled in the back or along side by a tending tractor. Class forage harvesters with mechanically driven willow cutting heads have been used successfully in Europe were the willow crop is shorter and the stems not as big. Although other willow harvesters have been developed in Europe that bundle whole stems, rather than chip them, they have not been commercially developed. Advantages of chipping the willow stems include less handling and more efficient transport of the willow chips. Whole stems can be stored longer than chips, but add significantly to the cost of transport and handling.

Figure 17: New Holland SRWC header on a New Holland FR series forage harvester harvesting willow during March 2009.

During 2008-2009 CNH developed a new willow cutting head to fit there FR series forage harvesters (figure 17) that works better then the hydraulic CRL head developed earlier. The "new" New Holland SRWC header is more aggressive and able to handle larger diameter/ older willow very easily and should become the "standard" for harvesting

Figure 18: Forage wagons being used to remove willow chips from the willow harvester

willow and other short rotation hardwoods.

SUNY-ESF has been working with farmers and custom harvesters to developed a system of moving the willow chips off the field and into large (36 ton) chip trailers for haling over the road to the end user. The object is to keep the harvester moving and harvesting the willow crop on a continuing basis. The willow chips are blown from the harvester in large self-unloading forage wagons pulled by tractors, which move the willow chips from the harvester to the loading-staging area where large chip trailers are parked and the self-unloading forage wagon can off-load the willow chips into a forage blower powered by a smaller tractor's PTO. The forage blower can blow the chips into the trailer as fast as the forage wagons can off-load, usually about 5-8 minutes per load of 7-10 tons (the blower can be modified for either covered, (figure 20) or open top chip trailers). Usually two self-unloading forage wagon tractor combos are all that is needed in most fields, however if the run of the loaded wagons to the loading area is fairly long it may be necessary to be running 3 forage wagon tractor combos per harvester. Since each chip over-road trailer can only carry a maximum of 36 tons you will need to make sure that there are a number of

Figure 19: willow chips being unloaded from the forage wagons and blown into an over-the-road chip trailer with a forage blower

Figure20: Close up of willow chips being blown into an over-the-road covered chip trailer for hauling to the end user.

chip trailers ready to make this operation run smoothly. Figures 18-20 show the willow harvesting system developed by SUNY-ESF. In 2008 we worked with another custom operator in western New York that used another system for removing the willow chips from the field and loaded into an open top chip trailer. This system (figures 21-23) used one, two or three smaller dump forage wagons (number depending on length of run to dump into the large dump wagon) that fit over the double willow rows being harvested and they dumped into a large dump forage wagon that was capable of dumping the willow chips into over-the-road open top chip trailers.

Both of these systems worked and will be improved upon as we harvest more and more willow crops over the coming years, especially with continued input form the farmer and custom harvester. The cost of both systems is comparable, and which system works best for you will depend on what kind of over-the-road chip trailers you are using and which equipment you have on hand or is easy to get hold of.

Figure 21: Harvesting willow with the FX45 forage harvester blowing the willow chips into a forage dump wagon in western NY during April 2008.

Figure 22: Dumping willow chips from a smaller forage dump wagon into a large forage dump wagon.

Harvesting can be completed with up to approximately one foot of snow on the ground provided it is not packed or crusty. Large tires or tracks on harvesting machines minimize soil damage when harvesting in wet conditions, harvesting is suspended when it gets too wet and the machinery starts cutting deep ruts, it is best to harvest under dry or frozen ground conditions. Night harvesting may be necessary to be able to get into the fields under frozen ground conditions. Willow harvesting machine improvements continue, and target harvest rates are from 50 to 60 wet tons per hour, or

Figure 23: Dumping the willow chips from the large forage dump wagon into the open top chip trailer to be hauled to the power plant.

approximately 2 ac per hr.

Willows sprout vigorously in the spring following winter harvest, and harvesting can be repeated on a three to four-year cycle. We expect that six to seven harvest rotations can be obtained from a single planting before replanting. The fact that multiple harvests can be obtained from one planting with only a minimal amount of work once the crop is established is an attractive feature for the grower.

Table 2: Commercially available willow varieties

Variety	Species	Diversity Group
SV1	*Salix × dasyclados*	1
S365	*Salix caprea* hybrid	3
S25	*Salix eriocephala*	4
SX67	*Salix miyabeana*	5
SX61	*Salix sachalinensis*	2
SX64	*Salix miyabeana*	5
Fish Creek	*Salix purpurea*	6A
Onondaga	*Salix purpurea*	6B
Allegany	*Salix purpurea*	6B
Sherburne	*Salix sachalinensis* x *S. miyabeana*	7
Canastota	*Salix sachalinensis × S. miyabeana*	7
Tully Champion	*Salix viminalis × S. miyabeana*	8
Owasco	*Salix viminalis × S. miyabeana*	8
Otisco	*Salix viminalis × S. miyabeana*	8
Fabius	*Salix viminslis x S. miysbeana*	8
Truxton	*Salix viminalis x S. miyabeana*	8
Oneida	*Salix purpurea × S. miyabeana*	9
Millbrook	*Salix purpurea × S. miyabeana*	9
Preble	*Salix viminalis x (S. sachalinensis x S. miyabeana)*	10

Willow Varieties Bred for Biomass Production

Commercial Varieties for Biomass

Testing to identify willow varieties that grow well in New York has been in progress for over a decade. Some of the most productive varieties identified so far that are available commercially are listed in Table 2. Starting in 1998, SUNY-ESF began producing new varieties using traditional breeding methods. Additional willow species/ varieties have been collected from natural stands across the Northeast. Although willow breeding in New York is in its infancy, increases in production of 20-25% are expected from each generation of breeding.

At least seven to 10 years are required to select and test new willow varieties and then scale-up planting stock for commercial planting. Original testing requires four years, and consists of planting new varieties on various sites, along with "standard" varieties for comparison. Superior varieties are then propagated in nursery beds, and approximately three to five years are required to produce varieties for commercial release, Tables 2&3.

Rather than planting a single variety of willow over a large area, willow varieties should be arranged in random blocs that are a few double-rows to several acres in size (Figure 21). In any one field (20 ac) four to six genetically diverse (Diversity Group—Table 2) varieties should be planted in random blocks to maximize chances for success and minimize risk from disease and pests. Currently we are continually developing the expertise to recommend different willow varieties for specific sites.

Table 3: Applications for willow varieties commercially available

Variety	Bioenergy Crop*	Living Snow-Fence*	Privacy Hedge*	Stream banks*	Riparian Buffer*	Basket Making*	Ornamental*
SV1	+++		+++				+
S365	+	+	++	+++	+++		+++
S25	++		++	+++	+++	++	++
SX61	+++	+	+++				+
SX64	+++	+	+++				+
SX67	+++	+	+++				+
Fish Creek	+++	+++	+	+++	+++	+++	++
Onondaga	+++	+++	+	+++	+++	+++	++
Allegany	+++	+++	+	+++	+++	+++	++
Sherburne	+++	+	+++				+
Canastota	+++	+	+++				+
Tully Champion	+++	+	+++				+
Owasco	+++	+	+++				+
Otisco	+++	+	+++				+
Fabius	+++	+	+++				+
Truxton	+++	+	+++				+
Oneida	+++	+	+++				+
Millbrook	+++	+	+++				+
Preble	+++	+	+++				+

*Rated on a scale of "+" to "+++"

Double A Willow

The ultimate success of willow biomass crops depends heavily on developing genetically improved varieties that produce high yield reliably over time (Figure 20). SUNY-ESF and the New York State Agricultural Experiment Station in Geneva, NY (Cornell) have developed and are continually developing new willow varieties that have improved biomass production, more upright form, and are resistant to insect and disease pests. When a productive variety is identified, it is propagated in nursery beds at SUNY-ESF and/or at Cornell so that genetically identical cuttings can be transferred to a commercial nursery for scale up and sale to the public. Currently, SUNY-ESF/Cornell shrub willow varieties are licensed for sale by Double A Willow in Fredonia, NY through their web site (www.doubleawillow.com). Willow varieties should only be purchased from a nursery that has been licensed to sale willow varieties from SUNY-ESF/Cornell

Willow whips are produced in irrigated, fertilized nursery beds (Figure 24). Plants in nursery cutting beds are cut annually, so all whips are from current year's growth. Whips are made during the dormant season, packaged in plastic-lined waxed boxes or plastic bags to prevent moisture loss, and stored at 28 - 30°F. Planting is best done during the spring following production, but whips of some willow varieties can be stored for a year under the right conditions.

Figure 24: Double A Willow commercial nursery in western New York. Dennis Rak owner, standing in raising one-year old willow whips on older root stock and newly planted willow to his right.

Willow Crop Pests and Diseases

Insects generally have not been a serious problem in experimental willow plantings in New York. Limited foliage feeding by insects is commonly observed but impacts have not considered severe enough to warrant control. Foliage feeding insects likely to be observed include adult Japanese beetles (*Popillia japonica*), adults and larvae of the imported willow leaf beetles (*Plagiodera versicolora*), Calligrapha beetles (*Calligrapha multipunctata*), and larvae of the willow sawfly (*Nematus ventralis*) (Figure 25). Control efforts might be recommended if more than 50% defoliation occurs before August, especially on first or second year plants. Late season defoliation has been observed with no apparent long-term effects, so no control efforts are recommended when defoliation occurs late in the growing season. Foliage feeding insects typically damage some willow varieties more than others. Sever foliage loss by larvae of the Gypsy moth (*Lymantria dispar*) and/or the forest tent caterpillar (*Malacosoma disstria*) could be a serious problem on first year growth at establishment and/or after harvest as the damage is done in May and June when the new sprouts are trying to get established. and control of these insects may be necessary for survival of the planting.


Figure 25: Larva of willow saw-fly, *Nematus ventralis*.

Potato leafhopper *Empoasca fabae* (Harris) (Figure 26) can be a serious pest of many of the European willow species, mainly *S. viminalis* and its hybrids. Damage from direct feeding is a result of not only adults, but also the tiny nymphs. What makes this pest especially dangerous is that early symptoms are very subtle and can easily be missed. Another concern is that once the leafhoppers arrive, they continue to feed and reproduce until killed by fall frosts. The feeding of both immature and adult leafhoppers is damaging to willow leaves. Potato leafhoppers inject saliva into plants as they feed, resulting in abnormal cell growth and interference with transport of fluids in the leaves. A visible result of this damage is the characteristic "hopperburn," which is a yellowing of the leaves and eventually a stunting and curling of leaves occurs (Figure 27). Since it is a major pest of alfalfa, soybean, apples and potatoes, willow grown near such crops may be more susceptible to injury. Damaged willow plants may be stunted with distorted and dwarfed leaves, with heavily infested fields experiencing a growth loss for that year.

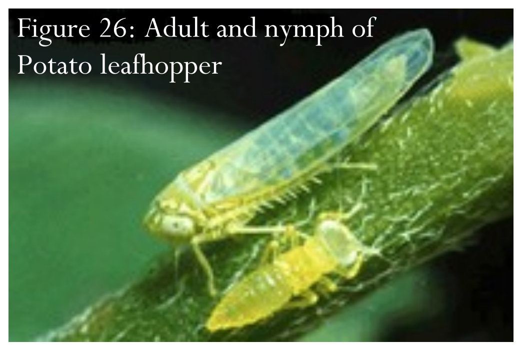
Figure 26: Adult and nymph of Potato leafhopper

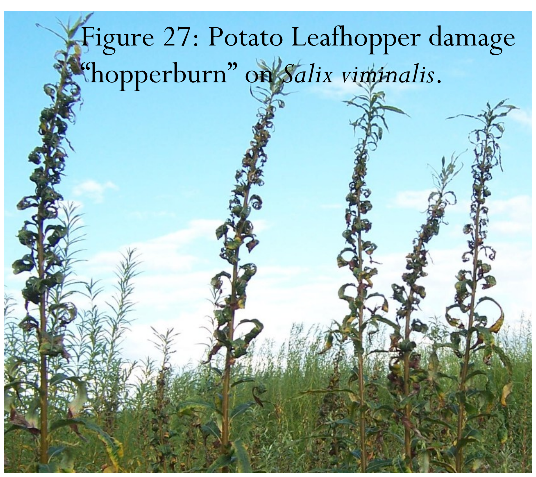
Figure 27: Potato Leafhopper damage "hopperburn" on *Salix viminalis*.

Another insect pest observed is the willow shoot sawfly (Janus abbreviatus), which damages nursery beds by killing shoot tips early in the growing season, causing stems to form a "shepherd's crook" at the shoot tip and usually results in a multi-forked stem. Upon close inspection, a ring of punctures will be evident just below each crook. These insects have little impact on biomass production, but can reduce willow whip yields by production of multiple forked stems above.

Fungal pathogens have been observed on willows in New York, but so far, fungal problems have been minimal and restricted to specific varieties. Rust (*Melampsora* spp.) is the most serious fungus problem on willow crops in Europe, causing premature foliage drop and loss of yield during that year and in sever cases killing the plant. Melampsora has been observed in New York but has not caused a serious problem except on one willow variety in the western part of New York. This variety is no longer being used in large-scale plantings. Planting clones resistant to pathogens is the best method for managing diseases.

Browse by rabbits in research plantings has severely damaged one variety (SH3 [not a recommended variety]), and two other varieties to a lesser extent. Deer appear to have a preference for the native *S. eriocephala* varieties. Commercial plantings established in areas with high deer pressure will have to use designs that minimize browsing by using varieties that are unpalatable to deer, such as Fish Creek, near the edges of field near the deer habitat.

If any damage is noticed due to insects or disease, or any other problems with willow health are observed, please contact us at the addresses, phone numbers and /or email addresses provided at the end of this document so that we can investigate the problem.

Attaining Profitability

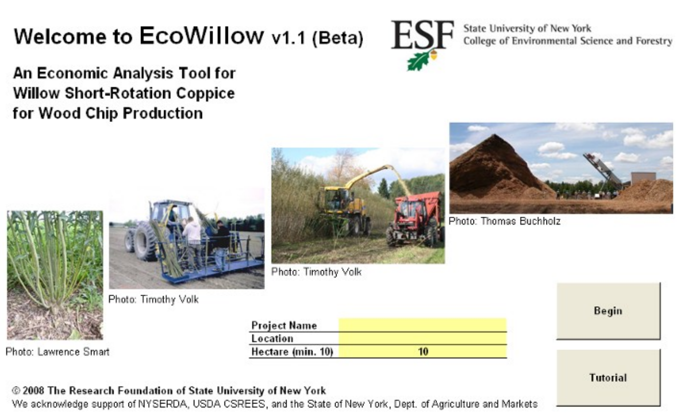

Figure 28: Welcome Sheet of the EcoWillow v 1.0 (Beta) economic model.

The economic performance of SRWC is a key to their widespread deployment. In order to facilitate assessments of the economic potential of shrub willow crops, SUNY-ESF has developed the EcoWillow v1.2 (Beta) budget model (Figure 28).

EcoWillow v1.2 (Beta) can be downloaded free-of-charge from the internet (www.esf.edu/willow) and should be useful for farmers, land owners, agricultural extension workers, or project developers. The model allows users to calculate how yield, management options, and a variety of cost factors influence the cash flow and internal rate of return of willow biomass crops. The budget model is designed based on experience establishing and maintaining over 500 acres of willow biomass crops in Upstate New York. The model is flexible enough so it can be applied across the range of sites where shrub willow might be grown. EcoWillow v1.2 (Beta) allows the user to vary input variables and to calculate cash flow and profits throughout the entire production chain from site preparation and crop establishment

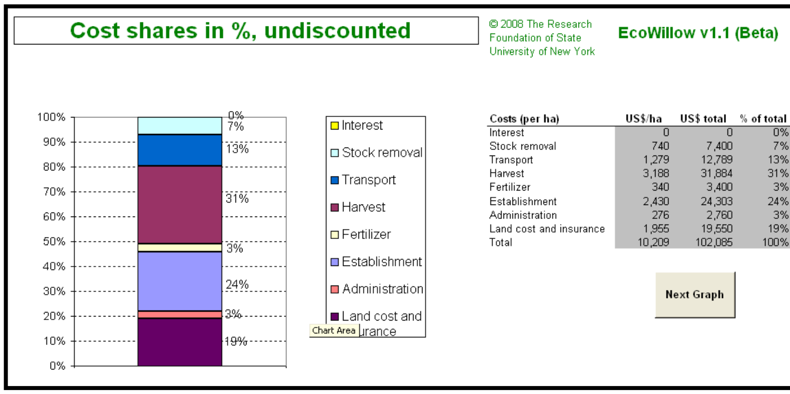

Figure 29: Cost share sheet from the model showing cost share summaries visually and numerically how costs are allocated to different parts of the willow production system

to the delivery of wood chips to an end user. EcoWillow v1.2 (Beta) runs in Microsoft Excel 2003 and consists of a tutorial sheet explaining the use of the model and nine other worksheets including a Welcome sheet, Input/Output sheet, four sheets with output graphs, and three sheets with submodels on planting, harvesting, and transportation costs (figure 29).

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