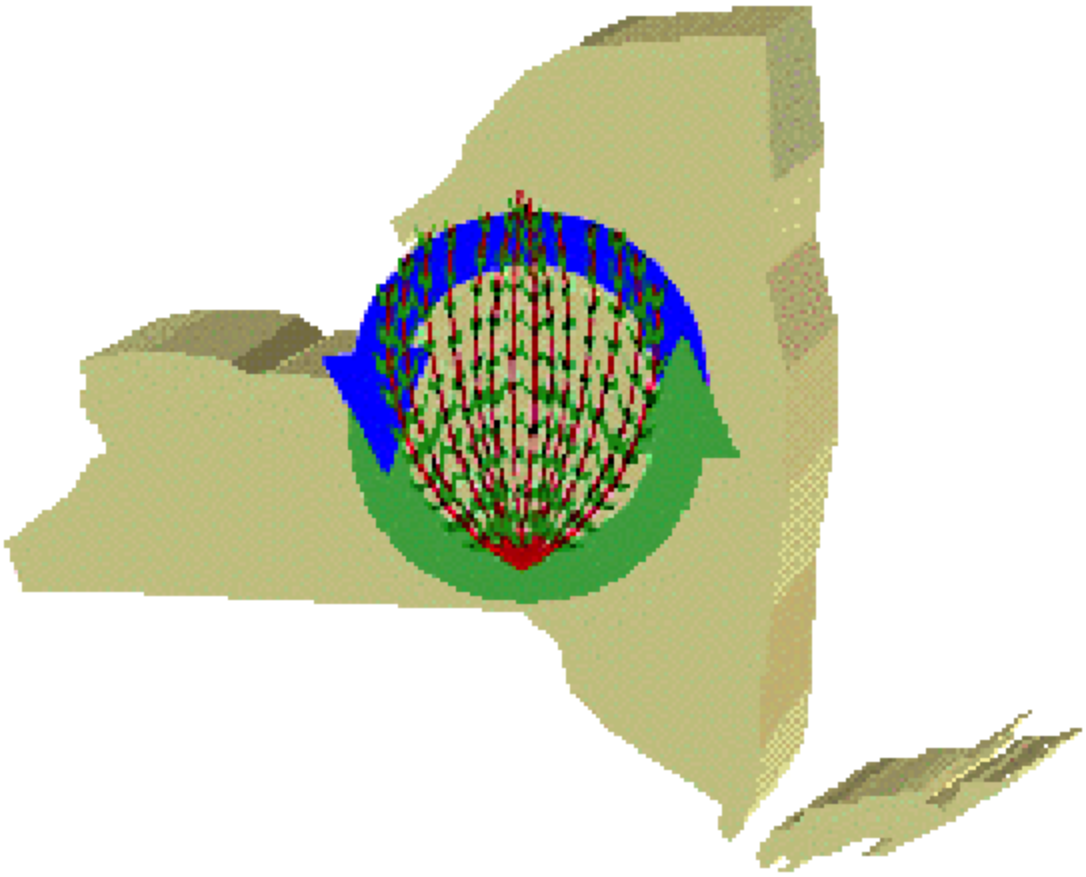
Willow Biomass Producer's Handbook



Syracuse, NY

Revised January 2002

Salix dasyclados

The Willow Biomass Producer's Handbook describes the willow biomass production system, which is based on a combination of agricultural and forestry practices. The system simultaneously produces a renewable cellulosic feedstock and provides a wide range of environmental and rural development benefits. The system described is operational, but is being optimized on more than 500 acres in central and western New York. This revision of the handbook provides information that has been gained from research and operational trials since the first edition of the handbook was produced in 1997. 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.

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Willow coppice

INTRODUCTION

Cultivation of willow in the United States began in the 1840s by immigrants in western 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 the State University of New York College of Environmental Science and Forestry (SUNY-ESF). The focus was research on the production of willow as a locally produced, renewable, cellulosic feedstock for bioproducts and bioenergy. Over 20 organizations have teamed up to form the Salix Consortium, whose goal is to facilitate the commercialization of willow biomass crops in the Northeastern and Midwestern regions of the United States. In 1995, the Salix Consortium was one of three competitively bid national projects selected to develop a dedicated feedstock energy project under the Biomass Power for Rural Development Program supported by the United States Departments of Energy (DOE) and Agriculture (USDA). To reach these goals a series of simultaneous activities, including research, regional clone-site trials, a large-scale demonstration program, and outreach and education efforts, were initiated (Figure 1).

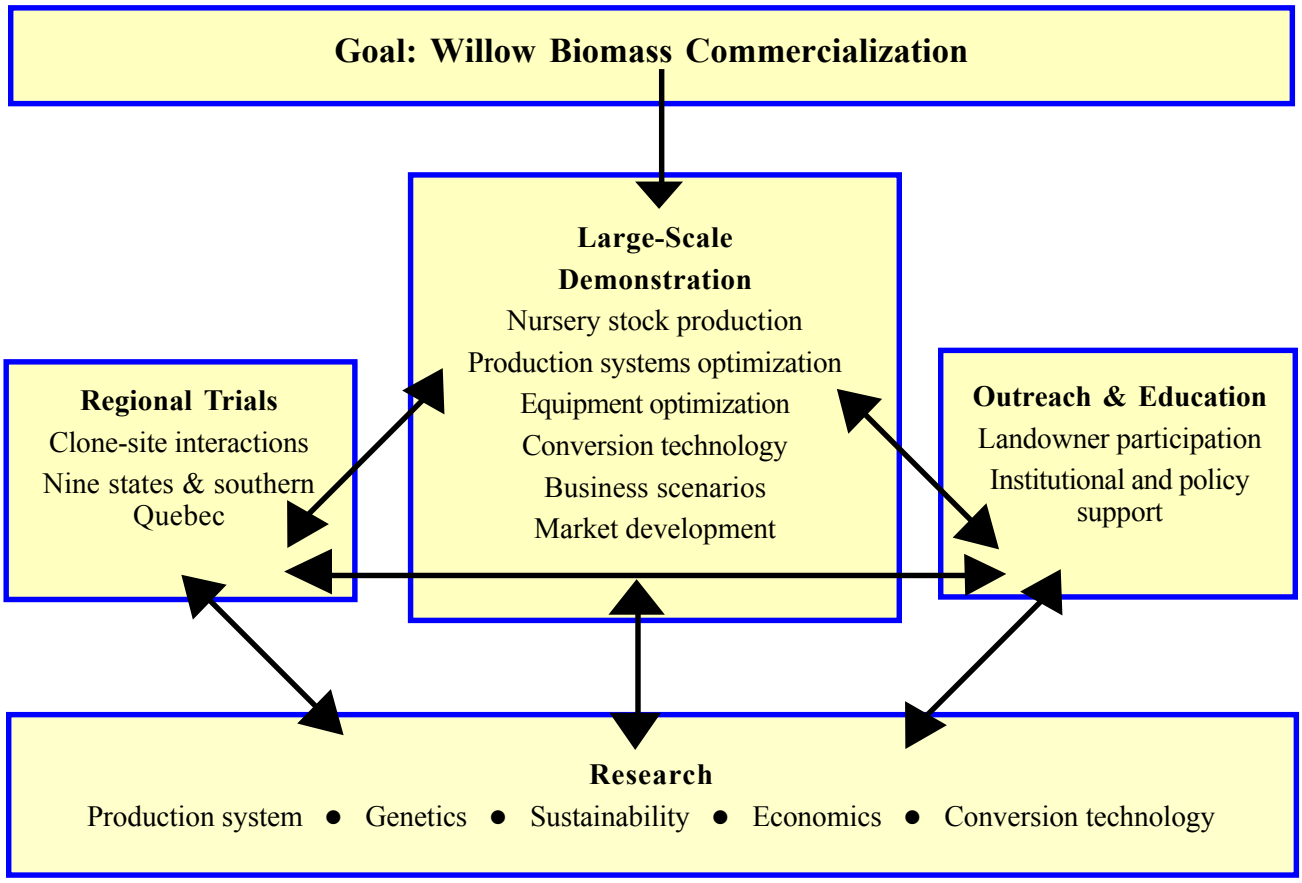


Figure 1. Components of the Salix Consortium's program that are being implemented simultaneously to reach the goal of commercialization.

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.

Between 1998 and 2000 over 500 acres of willow biomass crops were established in western and central New York. Smaller trials have been established in nine states and southern Quebec. First rotation yields of the best clone in the trials that have been harvested to date has ranged from 3.7 oven dried tons per acre per year (odt/A/yr) in Burlington, VT to 5.1 odt/A/yr in Canastota, NY. Second rotation yields have increased by 35 to 100%, depending on the site. Correlation of these research plot yields with commercial harvests will begin in the winter of 2001/2002 with the large-scale harvest of the first 100 operational acres. The biomass will be co-fired with coal at the NRG Dunkirk power plant in western New York, used for gasification tests, and for research on the fabrication of new biobased materials and chemicals as alternatives to products currently derived from non-renewable fossil fuels.

In addition to co-firing and gasification for energy production, willow biomass represents a relatively low cost and locally available feedstock for the production of liquid fuels, chemicals and advanced materials derived from its lignin, cellulose and hemicellulose. Analysis has shown that willow wood derived from three-year old stems is 19% lignin compared to 22 - 30% for mature hardwoods, which will facilitate the pulping process while enhancing the overall product yield for those chemicals derived from the polysaccharide fraction of willow (glucose, ethanol, furfural, and levulinic acid). The dry weight ratio of cellulose to xylan hemicellulose in willow was found to be approximately 3.5:1 based on a new Nuclear Magnetic Resonance (NMR) technique. This ratio is higher than typically observed in most hardwood species, which could enhance the yield of bioproducts from willow biomass.

Studies are in progress utilizing a fungal pre-treatment (biopulping) to optimize the yield of both usable papermaking fiber (cellulose) and water-extractable xylan from willow. Trials at the Empire State Paper Research Institute (ESPRI) at SUNY-ESF have revealed that willow fiber can make paper of equivalent strength and quality to eucalyptus, a "standard" papermaking pulp worldwide, and represents a viable commercial fiber resource. In addition, aqueous liquid crystalline phases of extracted xylan have been produced from willow, which we plan to fabricate into high performance, biodegradable fibers and films, as well as composites with thermoplastic bacterial polyesters. These products represent biodegradable alternatives to petroleum-derived polyethylene and polystyrene. Other "high tech" applications for willow biomass include stimuli responsive elastomers, which could be used in shock absorbers as equipment dampeners, artificial muscles, biomedical equipment; and in the development of micron-sized dispensers for insect pheromones used to control forest and agricultural insect pests. From an economic perspective, it has been estimated that process improvements leading to efficient xylan (hemicellulose) extraction and utilization have the potential to significantly improve the value of a ton of willow biomass. About 275 pounds of xylan (assuming 25% weight xylan and 50% recovery) could be recovered from each ton of willow biomass. This would add $20 to the value of a dry ton of willow biomass.

The ongoing research and large-scale demonstration of willow biomass crops, supported by DOE, USDA and the New York State Energy Research and Development Authority (NYSERDA); developments in the extraction and use of xylan from willow biomass; and the active participation of Salix Consortium partners are creating new opportunities to reach the goal of commercialization of the system. The development of a vibrant willow biomass enterprise can play an important role in bolstering the region's farm and forestry sectors, increasing energy independence, strengthening the protection of the environment, and mitigating pollution problems.

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 2). This manual is based on fifteen years of research at SUNY-ESF, plus information from Sweden, the United Kingdom, and Canada. This is the first update to the Willow Biomass Producer's Handbook, and as new information is gained, recommendations may change. The system described is operational, but it is still in the developmental phase in New York. Feedback from growers and other collaborators is essential for continued improvement.

Figure 2. Willow biomass crops growing on a cooperating landowner's farm in western New York state.

SOIL 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. Studies are underway that will result in soil recommendations for a wide variety of different willow clones. 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 8.0. 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 do not grow at economically acceptable rates under these conditions.

Table 1. Soil characteristics that are suitable for growing willow biomass crops.

Soil Characteristic	Suitable	Unsuitable
Texture	loams, sandy loams, loamy sands, clay loams and silt loams	coarse sand, clay soils
Structure	well developed to single grain structure	massive or lacking structure
Drainage	imperfectly to moderately well drained	excessively well or very poorly drained
pH	5.5 to 8.0	below 5.5, above 8.0
Depth	18 inches or more	less than 18 inches

SITE PREPARATION FOR PLANTING

Effective weed control is critical for the successful establishment of willow biomass plantings. *Weed competition is the most common cause of failure for willow biomass crops.* Currently available willow clones do not compete well with weeds during the establishment year, or during the first part of the second growing season. Once trees close canopy, completely occupying the site, weeds are unable to compete. If weeds are not controlled until the trees fully occupy the site, production will be much lower during the first rotation, or in the worst case scenario, the planting may have low survival and never be productive. Effective weed control techniques, outlined below, have been developed for willows in New York, and research to make weed control methods more efficient continues.

The following site preparation procedure has been used successfully and is recommended until new methods are proven to be economically successful. Alternative methods that minimize tillage and employ sustainable agriculture practices are being developed.

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 should be removed and baled into hay bales. After the vegetation resumes vigorous growth, the site should be sprayed with glyphosate (Figure 4), a broad spectrum post-emergent, translocated herbicide. Site preparation could

Figure 3. Completed fall site preparation ready for planting in the spring.

Figure 4. Application of a post-emergent herbicide on an old-field, as part of fall site preparation.

begin during mid August, but starting this late is riskier because perennial weed regrowth may not be vigorous enough for effective control with herbicides. If difficult to control perennial weeds such as crown vetch, morning glory, or thistle are present, adding 2,4-D 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 kill all weeds. We recommend using higher water spray volumes than normal to insure good spray coverage.

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

Figure 5. Cross discing of planting site after plowing as part of fall site preparation.

Rocks that protrude more than approximately two inches above the soil surface should be removed. Since harvesting machines will cut the stems at a height of two to four inches, rocks can damage harvesting equipment and expensive saw blades.

The following spring, if a winter-hardy cover crop was planted, it must be killed. Just before planting, soil should be cultimulched to kill any germinating weeds and loosen the soil for planting. Willow planting machines function best on freshly cultimulched sites.

PLANTING WILLOW CUTTINGS

The planting design for each field should be carefully thought out before planting begins. Rows should be as long as possible. Very long rows should have a 20 foot break inserted every 500 - 600 feet to allow harvesting equipment to be moved on and off the field. Where possible, the rows should run across slopes, as with conventional crops, to reduce soil erosion. At least 20 feet should be left at row ends to allow turn-around space for harvesting machines and for access with other farm equipment. Once established, willow biomass crops will be productive for about 22 years, so mistakes in the planting design could cause problems for many years.

Willow planting is done by machine in early spring as soon as sites are workable, and within several days following cultimulching. Willow planting material consists of unrooted dormant stem cuttings eight to 10 inches in length and 3/8 to 3/4 inches in diameter, or dormant stem whips > 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 June if necessary. Early May planting is advisable so that soil moisture is sufficient to support young plants and root development, and trees have as much time as possible to grow and develop. Shoots typically sprout 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. 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. 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 25° - 30°F, and should not be shipped to the planting site until just before they are to be planted. Once cuttings or whips are thawed, they should be planted as quickly as possible, and not be re-frozen. Cuttings and whips should be stored in conditions as cool and moist as possible. Under good conditions they can be maintained outside the freezer for approximately one week, 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.

The current willow biomass crop system consists of planting genetically improved willow clones as unrooted hardwood cuttings at densities of about 6,000 plants per acre. Planting is done with mechanized planters specifically designed for dormant hardwood cuttings or 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).

Agriculturally based planting machines have been commercially developed in Europe and are being adapted to conditions in the northeastern United States. The two most common machines used to date are the Fröebbesta planter (Figure 7) and Salix Maskiner's Step planter (Figure 8), both of which were designed and produced in Sweden. The Fröebbesta planter uses 10 inch long hardwood cuttings as the planting stock. The planter opens a slit in the ground to a depth of eight to 10 inches. Cuttings are fed manually into the planting tube and are driven into the open slit by hydraulically powered rubber wheels. A pair of packing wheels closes the slit around the cutting. Staff at Cornell University have modified the Fröebbesta planter to suit local soil conditions and farm machinery.

The Step planter has become the industry standard as the most efficient and effective machine for planting willow biomass crops. 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 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 eight inches, which provides increased flexibility to work on a variety of different soil types. When the

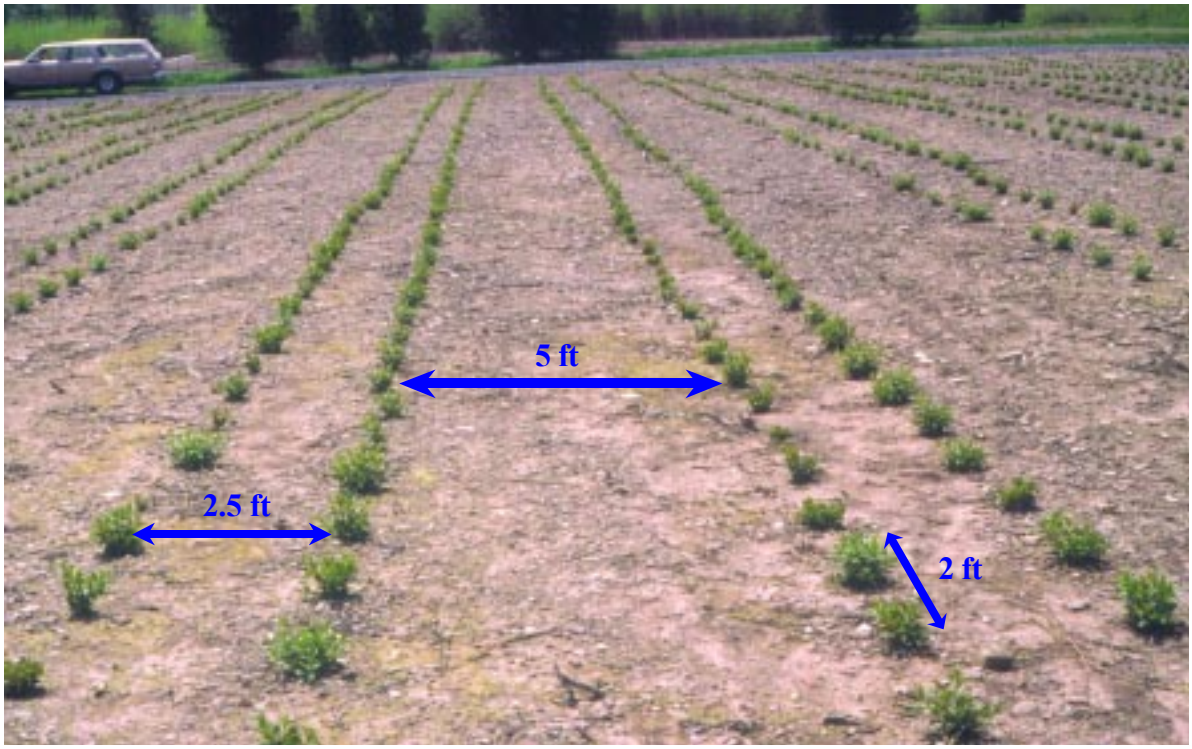


Figure 6. The double-row spacing for willow biomass crops facilitates the use of existing or slightly modified agricultural equipment. This two week old willow crop is at the beginning of the second season following coppicing of the first year's growth.

Figure 7. The Fröebbesta willow planter uses 10 inch long cuttings as planting stock and plants one double-row at a time.

Figure 8. Salix Maskiner's Step planter uses > four foot long willow whips as planting stock and plants two double-rows at once.

plant material 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.

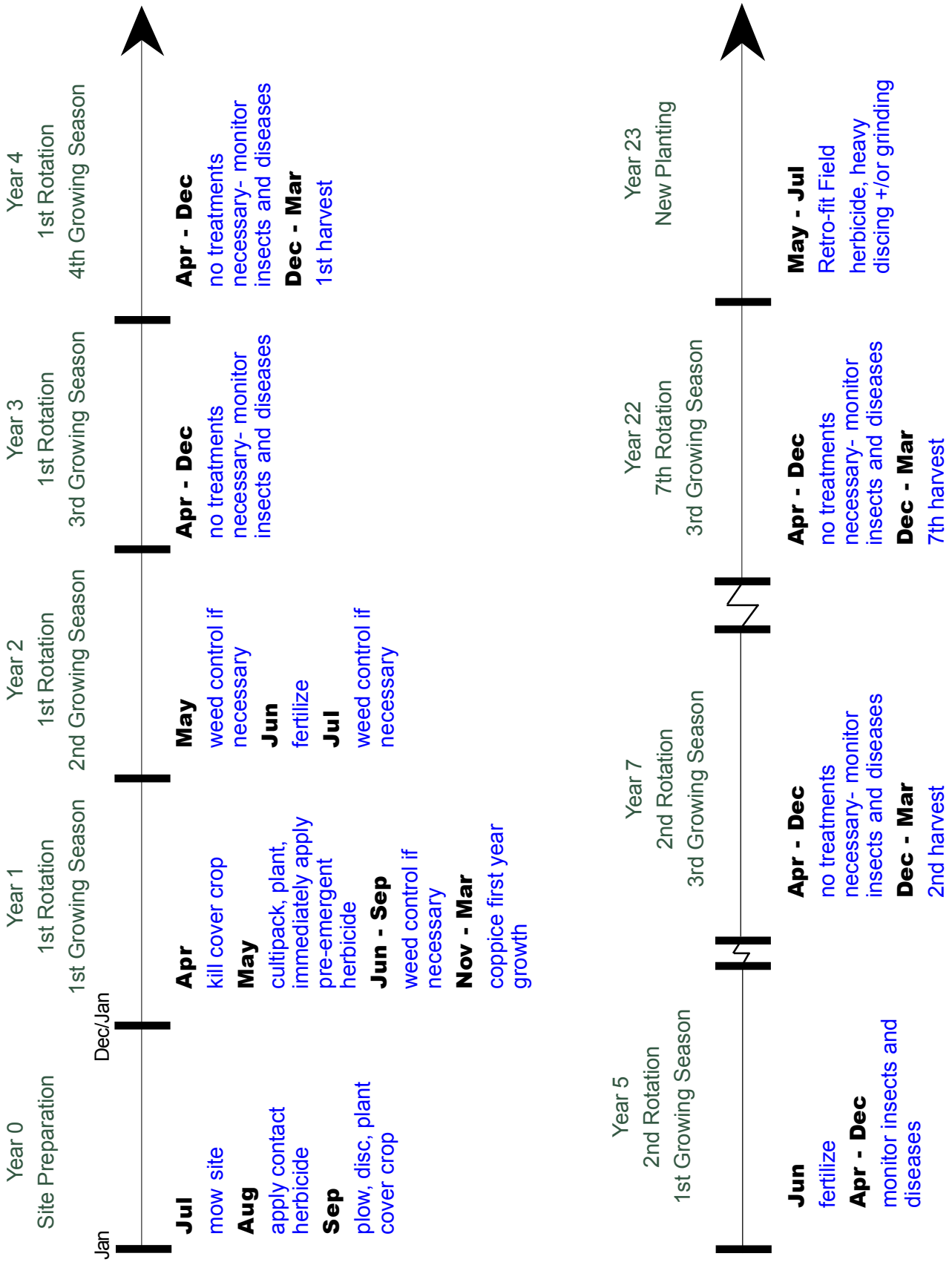
The planter increases the efficiency of planting willow biomass crops compared to the Fröebbesta planter in a number of ways. The use of whips versus cuttings as planting stock results in savings in the cost of planting material production since labor is not required to make the whips into cuttings. The Step planter plants two double-rows (four rows) at once, while the current Fröebbesta machine only plants one double-row (two rows) at a time. Since two people are required to operate both planters, the man-hour requirement for planting a given field is cut in half with the Step planter. The Step planter's output is about two acres per hour while the Fröebbesta planter's output is half an acre per hour. The Fröebbesta is a smaller machine that is easier to operate with a smaller tractor so it will still be used for planting smaller parcels of land and specialized willow plantings such as riparian buffers.

Immediately following planting, a pre-emergent herbicide is applied to provide weed control through the first year (Figure 9). Oxyfluoren and simazine are the two herbicides currently being used, based on the results of previous trials. Directions provided on the label and local regulations for the use of specific herbicides should always be followed. Trials are underway to test other pre-emergent herbicides on willow biomass crops.

Figure 9. Spraying pre-emergent herbicides immediately after planting for weed control.

WILLOW CROP PRODUCTION TIMELINE

Following are key steps in the production of willow biomass crops. (See text for details on year by year activities.)



THE 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 planting should be replanted, has not yet been determined, but we suspect that this value is somewhere around 60 - 70%, depending on the site.

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 annual weed seeds germinate, or if perennial weeds not killed during site preparation begin to compete with trees, 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 accomodate the double-row spacing used in willow plantings have been developed. Contact herbicide application with shielded sprayers has been used successfully, but willows are highly sensitive to post-emergent herbicides, so the risk of damaging trees is high. Grass weeds can be effectively controlled with grass post-emergent herbicides.

Growth during the first growing season (Figure 11) varies by clone, rainfall, and site conditions. Trees should be at least three feet tall at the end of the first growing season, and greater than eight feet of growth has been observed. Most trees will have one to four stems.

At the end of the first growing season and after leaf fall (typically mid November), trees may 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 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 being 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 if additional planting material is desired. Coppicing promotes multiple sprout formation and results in rapid canopy closure the second year.

Figure 10. Mechanical weed control with a Badalini multi-row rototiller.

Figure 11. One and a half month old willow plants are one to two feet tall.

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 about 100 pounds of elemental nitrogen per acre (Figure 12). Potassium or phosphorous addition may be necessary on some sites. Rates may vary depending on the fertility of specific sites and the requirements of different clones. 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, but 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 trees are vigorously growing and have had a chance to produce 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. These organic amendments are ideal for slow release of nutrients over the three to four year growing season.

Weed control may be necessary during the first part of the second growing season, until trees close canopy. If weeds become established during the second season, they should be removed prior to fertilization; otherwise, fertilized weeds may overtop trees.

Willows should close canopy (Figure 13) by mid to late 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 feet or more in height by the end of the second growing season and have multiple stems (Figure 14).

During the third and fourth growing seasons (second and third seasons after coppicing) no tending of the crop should be necessary. Plants should be 10 - 15 feet in height by the end of the third season, and over 15 - 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 12. Nitrogen fertilizer application over new sprouts at the start of the second season.

Yields of fertilized and irrigated willow grown for three years have exceeded 12 odt/A/yr. First rotation, unirrigated trials in central New York have produced yields of four to five odt/A/yr. Unirrigated, second rotation yields increased by 35 - 100% 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 12 - 67%. In addition, yields will be increased by optimizing various components of the production system, such as weed control and fertilization.

Figure 13. Trees generally close canopy by the second growing season, effectively controlling competing vegetation.

Figure 14. At the end of the second growing season, willow plants are one-year old above ground on a two-year old root system.

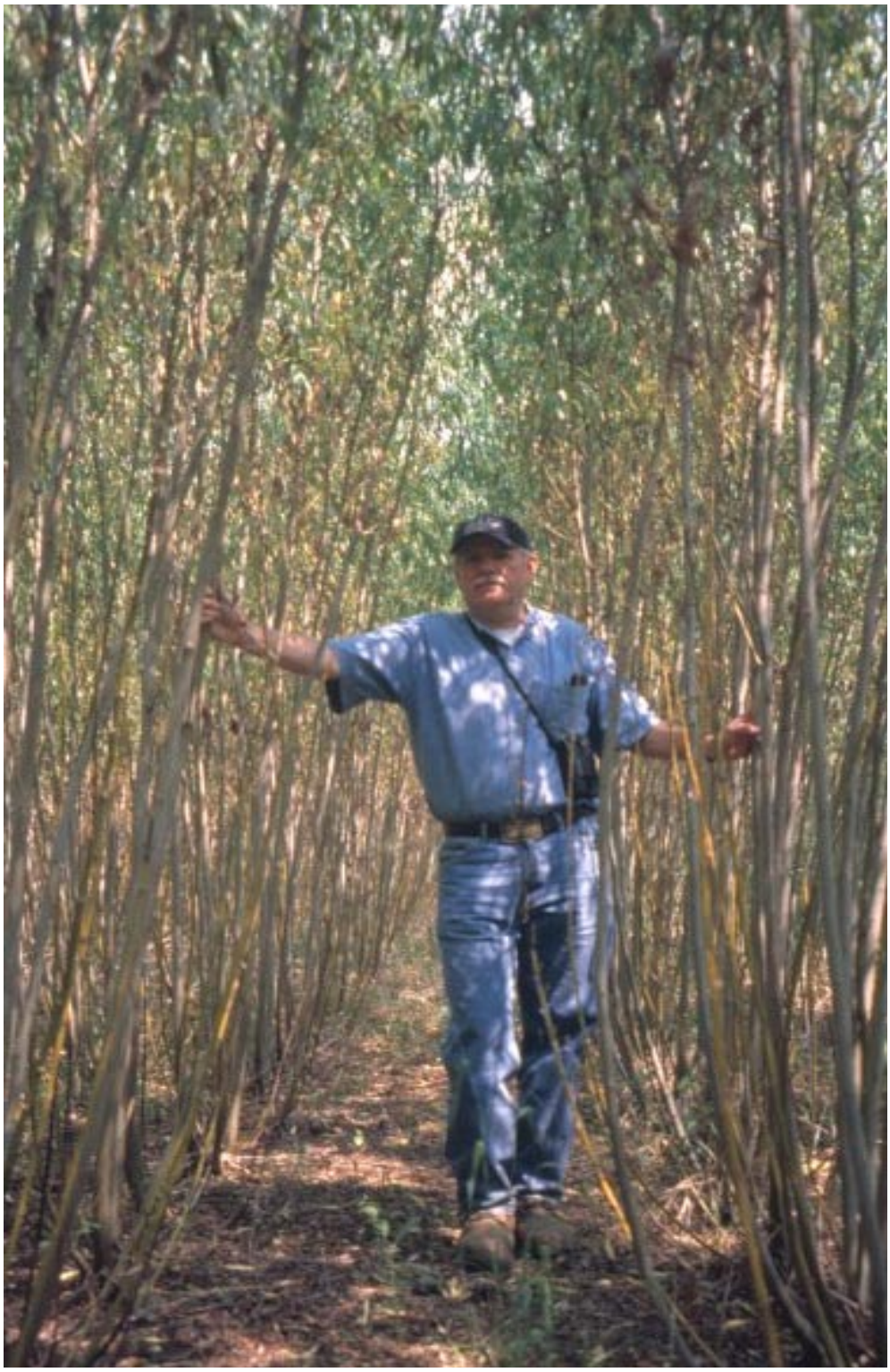


Figure 15. In the fourth growing season, the willows are three-years old above ground on a four-year old root system.

HARVESTING THE WILLOW CROP

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, between leaf fall and bud swell in early spring.

Harvesting equipment has been developed in Europe specifically for willow biomass plantations. The most efficient machines currently are the modified Claas Jaguar corn harvester (Figure 16) and the Bender harvester (Figure 17). The Claas harvester has two large saw blades, one for each row in a double-row that cuts the stems at approximately three to six inches above the ground. In contrast, the Bender uses a single long chain-saw cutting chain to cut the willow stems. This means that the Bender is not restricted by the location of the rows and can be used to cut across rows, if necessary. Both harvesters chip the stems after cutting them (Figure 18) and blow the chips into a wagon towed by the harvester or by a tractor along side of the harvester. Other willow harvesters have been developed in Europe that bundle whole stems, rather than chip them. Advantages of chipping include less handling and more efficient transport. Whole stems can be stored longer than chips, but add to the cost of transport and handling. Harvesting can be completed with 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. Willow harvesting machine improvements continue, and current harvest rates are from 22 to 45 wet tons per hour, or approximately one to two A/hr.

Willows sprout vigorously in the spring following winter harvest, and harvesting can be repeated on a three to five-year cycle. We expect that six to seven harvests 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.

Figure 16. Claas Jaguar corn harvester with a special willow harvesting head, harvesting three-year old willow in Sweden.

Figure 17. Bender harvester harvesting three-year old willow at Tully, NY.

Figure 18. Willow chips from Claas and Bender willow chip-harvesters.

WILLOW CUTTING DEVELOPMENT AND PRODUCTION

The ultimate success of willow biomass crops depends heavily on developing genetically improved willows that are more productive than present clones (Figure 19). SUNY-ESF is developing new 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 cutting orchards so that thousands, or even millions, of genetically identical cuttings are available for sale. A group of genetically identical cuttings is referred to as a "clone". All the individuals in a clone originated from one plant. Cuttings should only be purchased from nurseries that can prove that cuttings being sold are truely from the clone specified.

Willow cuttings and whips are produced in irrigated, fertilized nursery cutting orchards (Figure 20). Plants in cutting orchards are cut annually, so all cuttings and whips are from current year's growth. Cuttings and whips are made during the dormant season, packaged in plastic-lined waxed boxes to prevent moisture loss, and stored at 25 - 30°F. Cuttings should be planted during the spring following production, but cuttings and whips of some clones can be stored for a year under the right conditions.

Testing to identify willow clones that grow well in New York has been in progress for over a decade. Some of the most productive clones identified so far that are being used commercially listed in Table 2. Starting in 1998, SUNY-ESF began producing new clones using traditional breeding methods. Additional clones have been collected across the Northeast. Willow breeding in New York is in its infancy, and large increases in production are anticipated through these breeding efforts. Eventually, we hope to make new improved clones available to producers on an annual basis.

Figure 19. Willow seedlings from genetic crosses in the greenhouse. Willow clones that are more productive, have better form, and are insect and disease resistant are being developed.

Figure 20. An irrigated willow cutting orchard at the New York Department of Environmental Conservation Saratoga Tree Nursery.

Table 2. Promising willow clones available for New York State.

Clone	Species	Description
S25	*Salix eriocephala*	Good growth rate on most sites, favored by deer
S365	*S. discolor*	Moderate to good growth rate, good form, favored by rabbits, not damaged by deer
SA2	*S. alba*	Consistently high survival, moderate growth rate, susceptible to foliage diseases
SX61	*S. sachalinensis*	Native to Japan, grew very well on the few sites where it has been tested - needs more testing
SX64	*S. miyabeana*	Native to Japan, grew very well on the few sites where it has been tested - needs more testing
SX67	*S. miyabeana*	Native to Japan, grew very well on the few sites where it has been tested - needs more testing
SV1	*S. dasyclados*	The most productive clone to date, the current standard for comparison, favored by willow leaf and Japanese beetles
NM6	*Populus nigra x maximowizii*	A hybrid poplar clone that has been tested with the willow crop system, is very productive, grows well on many sites, especially on soils where willow clones are more susceptible to failure due to weeds and frost heaving

At least seven to 10 years are required to screen a willow clone and produce enough planting stock for commercial planting. Original testing requires four years, and consists of planting new clones on various sites, along with "standard" clones for comparison. Clones that are identified as superior are then propagated in a nursery, and approximately three to five years are required to produce enough cuttings for commercial release.

Questions have been raised about how to deploy willow clones. Should one superior clone, or numerous genetically diverse good clones be planted? Rather than planting a single clone over a large area, planting clones in blocks that are a few double-rows to several acres in size is recommended (Figure 21). Planting a number of clones will maximize chances for success. Currently we are developing the expertise to recommend clones for specific sites.

Figure 21. Large clonal blocks of willows are usually planted with four to eight different clones. Differences in foliage color of clonal blocks are obvious in this one-year old crop. Large differences in characteristics, such as yield and pest resistance, are commonly expressed among willow clones.

WILLOW CROP PESTS AND DISEASES

Insects generally have not been a problem in experimental willow plantings in New York. Limited foliage feeding by insects is commonly observed but impacts are not considered severe enough to warrant insecticide application. Foliage feeding insects likely to be observed include Japanese beetles (*Popillia japonica*) (Figure 22), imported willow leaf beetles (*Plagiodera versicolora*), Calligrapha beetles *(Calligrapha multipunctata*), and willow sawflies (*Nematus ventralis*) (Figure 23). Control efforts might be recommended if more than 50% defoliation occurs before August. 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 clones more than others.

Another insect pest observed is the willow shoot sawfly (*Janus abbreviatus*), which damages cutting orchards by killing shoot tips early in the growing season, causing trees to form a "shepherd's crook" at the shoot tip. Upon close inspection, a ring of punctures will be evident just below each crook. The shepherd's crooks die followed by production of multiple shoots below dead shoot tips. These insects have little impact on biomass production, but can reduce cutting yields by production of multiple shoots below the damaged shoot tips.

Fungal pathogens have been observed on willows in New York, but so far, fungal problems have been minimal and restricted to specific clones. A rust *(Melampsora spp.*) is the most serious fungus problem in Sweden, causing premature foliage drop. *Melampsora* has been observed in New York but has not caused a serious problem except on one clone in the western part of New York. This clone 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 clone (SH3 [not a recommended clone]), and two other clones (S365 and SV1) to a lesser extent. Deer appear to have a preference for the native *S. eriocephala* clones. Commercial plantings established in areas with high deer pressure will have to use designs that can minimize browsing by using clones that are unpalatable to deer near the edges of deer habitat.

If defoliation due to insects or disease, or any other problems with willow plantation health are observed, please contact us at the addresses provided at the end of this document so that we can investigate the problem.

Figure 22. Japanese beetle (*Popillia japonica*) adult.

Figure 23. Willow sawfly (*Nematus ventralis*) caterpillars.

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