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ALTERNATIVE METHODS OF SITE PREPARATION FOR SHORT-ROTATION WILLOW AND POPLAR BIOMASS CROPS

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Edward Neuhauser, Project Manager

Niagara Mohawk: A National Grid Company

Syracuse, New York

by:

T.A. Volk, L.P. Abrahamson, E.H. White, D.J. Robison

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Alternative Methods of Site Preparation for Short-Rotation Willow and Poplar Biomass Crops

By

T.A. Volk, L.P. Abrahamson, E.H. White and D.J. Robison

Executive Summary

The proper application of site preparation techniques is essential to the biological and economic success of short rotation woody crops (SRWC). The recommended site preparation technique involves the application of mechanical and chemical weed control in the late summer or fall the year prior to planting. It typically includes a late summer application of post-emergence herbicides, followed by plowing and disking before winter. A final cultivation is conducted the following spring, immediately prior to planting, which is followed immediately with the application of pre-emergence herbicides.

While the fall tillage site preparation approach is effective for establishing SRWC, it creates the potential for significant soil erosion. If conducted properly, the fall tillage technique results in limited vegetation cover for over one and a half years, from the time of plowing until the canopy begins to close in the summer of the second year of growth. Under these conditions, soil erosion rates could equal or exceed those recorded for annual agricultural crops. The soil erosion issue is important because of the increasing concern surrounding non-point source pollution from agriculture lands; the detrimental effect it could have on long-term sustainability of the production system; and the negative impact it could have on the public perception of SRWC.

The easiest and most effective approach to reduce soil erosion on a site is to provide vegetative cover that will disperse rainfall energy. A variety of conservation tillage and other ground cover management techniques have been developed to address soil erosion concerns without adversely affecting crop yields for annual agriculture and orchard systems. Some of the more successful approaches include no-till and strip tillage. In addition, the use of cover crops and altering the timing of different tillage operations have been shown to reduce soil erosion. However, little work has been done on establishing SRWC using any conversation tillage and/or alternative ground cover management techniques, especially for SRWC systems with densities greater than 10,000 plants ha^{-1}. These experiments examined the effects of different methods of site preparation on SRWC biomass production and other plant and soil characteristics.

The alternative site preparation and rye cover crop studies indicated that concerns about soil erosion during the establishment phase could effectively be addressed without compromising, and in some cases increasing, aboveground biomass production. First rotation aboveground biomass production in the spring tillage and cover crop treatments was similar to or greater than the currently recommended fall tillage approach for both willow and hybrid poplar. Poplar biomass production in the strip tillage treatment was similar to the fall tillage treatment. Poplar production was greater than 12.0 odt ha^{-1} yr^{-1} for all four of these treatments. Willow biomass production on the spring tillage, cover crop and fall tillage treatments were not significantly different and ranged from 3.7 to 8.0 odt ha^{-1} yr^{-1}. These alternatives (spring tillage, cover crop and strip tillage) to the standard fall tillage approach will help reduce soil erosion during the establishment phase.

The approach to managing cover crops during the establishment of SRWC requires balancing three critical factors, aboveground biomass production, weed control, and residue cover. In the alternative site preparation experiment, biomass production was good in the cover crop treatment, but the rye cover crop was disked under during the spring. This reduced the length of time that the rye provided cover for the soil. In the rye cover crop experiment, the most effective management system that balanced these three

critical factors was the Spray (P) treatment, where the rye cover crop was killed with a post-emergence herbicide in the spring, the SRWC was planted and the site was immediately sprayed with pre-emergence herbicides. Biomass production was similar to or greater than the Control (P), which had no cover crop planted on it but did have pre-emergence herbicides applied. Recent developments in mechanically controlling cover crops, such as rolling, roll-chopping, undercutting or partial rototilling have been more effective than mowing in some annual cropping systems and should be studied as options for using cover crops during the establishment phase of SRWC. Further research is required to determine the most effective combinations of cover crop species to use, methods and timing of cover crop control, and applications rates for pre-emergence herbicides for SRWC that are grown across a range of site conditions.

Weed control is the primary factor limiting the successful establishment and production of SRWC. While the importance of effective weed control during establishment of SRWC has repeatedly been emphasized, it is still often neglected. There were drastic differences in first rotation biomass production in the alternative site preparation experiment between the no weed control treatment and the rest of the treatments. In the rye cover crop experiment, the amount of weed cover had an effect on aboveground biomass production, particularly in those treatments where pre-emergence herbicides were not used. These results once again emphasize the need to effectively control weed competition during the establishment phase. An acceptable level of weed control was not obtained in the rye cover crop experiment by using cover crop residue alone without pre-emergence herbicides. Combining the proper management of cover crops and pre-emergence herbicides enhanced weed control and needs to be developed further as part of an integrated weed control strategy for SRWC.

Concern has been expressed that the intensive production methods associated with SRWC will have detrimental impacts on soil fertility and productivity. There were only a few detectable changes in soil characteristics three years after the conversion of the site from a fallow condition to SRWC in the alternative site preparation experiment, regardless of the type of site preparation. Soil carbon levels in the surface 15 cm, which were high at the beginning of the experiment (62.7 – 77.5 Mg C ha^{-1}), were maintained. In the 15 – 30 cm layer, soil carbon levels were maintained or increased in some treatments by 12 to 24 Mg ha^{-1}. There were decreases in Mg concentrations over the first three years of the experiment, particularly at the 0 - 15 cm depth. These changes were related more to site conversion than SRWC production since the amount of Mg accumulated in aboveground and root biomass accounted for less than 5% of the estimated change in Mg content. The changes in Mg concentrations were similar across treatments whether the SRWC grew well or poorly, providing further indication that the changes were not primarily due to the growth of the SRWC. These changes are only for one site over a three-year period. The impacts of SRWC on soil quality over a longer period across a range of sites still needs to be assessed.

These experiments indicate that changes can be made to the current recommendations for site preparation and establishment of SRWC. A wide range of factors including field history, soil characteristics, and climate affected these results. Further research needs to be conducted to develop these approaches for a wider range of conditions. In the mean time, caution must be taken when transferring these results to other sites that have different soil, climate and site history characteristics.

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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

Introduction

Growing concerns about national energy security, environmental impacts associated with the use of fossil fuels, sustainability of natural resources, an increasing demand for biodegradable products, and need to revitalize rural economies has made the development of biomass for bioproducts and bioenergy a critical national priority (National Research Council 2000). Biomass can come from a number of different sources including forests, agricultural crops, various residue streams, and short-rotation woody crops (SRWC). Interest in the development of SRWC has grown over the past few decades because of the multiple environmental and rural development benefits associated with their production and use (Abrahamson et al. 1998, Börjesson 1999). Shrub willows grown at densities of 10,000 – 20,000 plants ha^{-1}, are appealing as a SRWC because of the high yields that can be obtained in just a few years, ease of propagation from dormant hardwood cuttings, broad genetic base and ease of breeding, and ability to resprout after multiple harvests (Christersson et al. 1993, Mitchell 1995, Volk et al. 1999). Willow biomass crops have been studied in Europe since the early 1970's (Verwijst 2001) and in North America since the mid 1980's (Volk et al. 2001a). Over 17,000 ha of willow biomass crops have been established in Sweden (Verwijst 2000). In the United Kingdom an eight MW gasifier that will be fueled primarily by short-rotation willow coppice is due to come on line in 2002. Several other countries, including the United States, have ongoing research and demonstration projects underway with SRWC.

SRWC are being developed as a sustainable system that simultaneously produces a renewable feedstock for bioenergy and bioproducts and a suite of environmental and rural development benefits. After planting, the crop is harvested on three-to-four year rotations, resprouting after each cut (Volk et al. 1999). Six or seven harvests are expected before replanting. Therefore, the site is only tilled and planted once every 19 - 29 years. Established SRWC have little soil erosion potential because of their perennial nature, and extensive branch and root systems (Ranney and Mann 1994, Mann and Tolbert 2000). Field studies indicate that there is negligible N leaching from established willow plantings, even with annual applications of nitrogen fertilizer (Mortensen et al. 1998, Aronsson et al. 2000). However, N leaching can occur during the establishment year when the plants' requirement for N is low and the plants have not fully occupied the site (Mortensen et al. 1998, Aronsson et al. 2000). The amount of herbicide used in growing SRWC is lower than conventional agriculture since herbicides are only used during the first one or two growing seasons until the woody crop fully occupies the site. Willow biomass crops in New York have been shown to support over 30 species of birds, including neotropical migrants. The level of avian diversity is similar to or greater than what is found in natural shrub lands in upstate New York (Dhondt and Sydenstricker 2001). Belowground, soil microarthropods have been used as an indicator of soil health because they are essential in the decomposition of organic matter and hence nutrient cycling. The diversity and density of soil microarthropods in willow crops is similar to that found in fields that have been fallow for the same length of time (M. Minor, personal communication, 2002). Soil carbon levels are maintained or increased several years after converting agricultural land to SRWC (Hansen 1993, Grigal and Berguson 1998, Tolbert et al. 2002, Ulzen Appiah 2002).

There are a variety of environmental benefits associated with the use of SRWC for energy production. Co-firing woody biomass with coal at a 10:1 coal: biomass mixture by heat input to generate electricity reduces SO_2 by 9.8% and NO_x by 5 - 15%, depending on firing and fuel conditions (Tillman 2000). Woody crops like willow and poplar dedicated to bioenergy production are considered CO_2 neutral (Mann and Spath 1999, Matthews 2001, Heller et al. 2001). As a result, a 10% replacement of coal with biomass can offset the release of CO_2 from the combustion of fossil fuels. This is an important consideration with the increased concern about global warming and the search for cleaner sources of fuel. The net energy ratio from the production and harvest of SRWC ranges from 1:29 to 1:55. This means that for every unit of nonrenewable fossil fuel energy used to grow and harvest SRWC, between 29 and 55 units of biomass energy are produced (Matthews 2001, Heller et al. 2001). In essence, SRWC are large solar collectors that capture solar energy and store it as woody biomass. If this biomass is then transported to a power plant and used to generate electricity, the net energy ratio is 1:10 to 1:16 depending on the conversion system used (Mann and Spath 1999, M. Heller, personal communication, 2002). In contrast, the net energy ratio for ethanol produced from corn is 1: 1.3 (Shapouri et al. 2002). The net energy ratio of fossil fuels such as coal and natural gas that are currently used for electricity generation are around 1: 0.4 (Mann and Spath 1999). From an energy balance perspective SRWC are clearly sustainable and provide a wide range of valuable environmental benefits.

As an alternative farm crop, SRWC will help to revitalize rural economies. Estimates are that for each 4,000 hectares of willow biomass crops established, 75 rural based jobs would be created and over $520,000 per year in state and local government revenue would be generated (Proakis et al. 1999). This would be a welcome development in New York State where the $2.6 billion agriculture industry has been in decline since the 1950's (New York State Dep. of Agriculture and Markets 1998).

Despite the numerous environmental and rural development benefits associated with SRWC, their use as a feedstock for bioenergy and/or bioproducts has not yet been widely adopted in the United States. The primary reason is the high cost of producing SRWC relative to the value of the bioenergy and/or bioproducts produced. Current costs to produce and deliver SRWC to an end user are in the range of \$43 – 50 odt^{-1} (Welsh et al. 1998, Tharakan et al. 2002). On a energy unit basis, these prices are greater than commonly used fossil fuels like coal or wood residuals from wood processing industries.

Costs associated with the establishment of SRWC accounts for about a quarter of their costs over the lifespan of the crop (White et al. 1995, Van Den Broek 1997, Danfors et al. 1998, Mitchell et al. 1999, Goor et al. 2000). These costs are a barrier to the deployment of SRWC, especially since a return on these investments is not realized until the first harvest, which typically occurs four years after planting (Abrahamson et al. 2002). Any efforts to reduce establishment costs, without compromising high survival rates and early rapid growth of the crop would be beneficial to the overall economics of the system. One point in the current establishment system where this may be possible is the elimination of the coppicing operation in the winter after the first year of growth (Danfors et al. 1998, Armstrong 1999).

A concern during the establishment of SRWC is the potential for soil erosion and the impact it can have on the long-term production and sustainability of SRWC (Lal 1998, Mann and Tolbert 2000, Vance 2000) and the public perception of the renewable nature of the system (Tolbert and Wright 1998, Tolbert et al. 2002). The current system of site preparation results in little vegetation cover on the soil for over a year and a half.

Estimated soil erosion rates during that period range from 40 – 130 t ha^{-1} (White et al. 1991, Ranney and Mann 1994). A limited amount of work has been done in the past on establishing SRWC using conservation tillage or cover crops (Aird 1962, Hansen 1984a, 1984b, McLaughlin 1985, McKittrick 1990, Malik et al. 2000, Malik et al. 2001). As a result, establishment of SRWC is primarily done with a combination of mechanical tillage and chemical weed control that leaves the soil bare (Danfors et al. 1998, Mitchell et al. 1999, Abrahamson et al. 2002). In contrast, research on alternative ground cover management systems in orchard and vineyard crops over the years has resulted in the adoption of systems that leave a portion of the soil covered during establishment and throughout the life of the crop (Pool et al. 1990, Merwin et al. 1994). Additional research on alternative methods of site preparation needs to be conducted in order to reduce the negative biological and social impacts associated with the establishment of SRWC. This is especially true in the Northeastern United States where the initial deployment of SRWC will occur on marginal agricultural land that is usually prone to erosion.

Objectives

Research was undertaken to study the impact of different methods of establishment on the survival and growth of SRWC. Two different experiments were conducted. The objective of the first experiment was to assess the impact of six different methods of site preparation for SRWC on survival, aboveground biomass production, foliar nitrogen concentrations and soil characteristics. The six site preparation treatments studied were 1) the standard fall tillage system, 2) fall tillage followed by establishment of a winter rye cover crop, 3) a no-till system, 4) strip tillage applied in the spring, 5) spring tillage, and 6) control (no weed control applied after the application of herbicide and mechanical tillage in the fall prior to planting). The objective of the second experiment was to assess the impact of different approaches to managing a winter rye cover crop on the survival and aboveground biomass production of SRWC.

Literature Review

SRWC Establishment and Yields

The willow biomass system being developed in New York State is based on years of research and operational experience in the United States, Canada, Sweden and the United Kingdom. The system combines knowledge and experience from the fields of agriculture and forestry. The current system consists of a double-row planting of approximately 14,300 plants ha^{-1}, following agricultural type site preparation using a combination of mechanical tillage and chemical weed control. Under current recommendations, the plants are cutback (coppiced) following the first growing season (Abrahamson et al. 2002) and then harvested on three to four year coppice cycles. Nitrogen fertilizer is applied after cutback and following each harvest (Volk et al. 1999), with current recommended rates being 100 kg N ha^{-1} (Adegbidi 1999, Ballard et al. 2000). Experimental willow biomass crops in New York State have produced up to 27 odt ha^{-1} yr^{-1} under irrigated and fertilized conditions (Adegbidi et al. 2001). First-rotation, unirrigated trials in central New York have produced yields of 9 to 11 odt ha^{-1} yr^{-1} (Adegbidi 1999). Second rotation yields of the five best producing willow clones increased by 18 - 62% (Volk et al. 2001b). Recent breeding efforts with both native and introduced willow species are expected to result in yield increases > 20% compared to the current standard clone SV1 (Kopp et al. 2001a).

Experimental yields of short-rotation willow in Sweden have ranged from 10 to 12 odt $ha^{-1}yr^{-1}$, which is the equivalent of four to five m^3 (0.6 – 0.8 standard barrels) of oil. Peak production of over 30 odt $ha^{-1}yr^{-1}$ has been obtained in irrigated and fertilized plots (Christersson et al. 1993). Commercial yields have been considerably lower, about four odt $ha^{-1}yr^{-1}$, across almost 2,000 ha harvested over a three year period (Larsson et al. 1998). Low yields were impacted by poor establishment, use of unimproved clones, ineffective weed control and improper nutrient management. Larson et al. (1998) predict that future commercial yields in Sweden should be above 7.5 odt $ha^{-1}yr^{-1}$ if these issues are addressed according to current management recommendations. New willow clones produced in breeding programs in Sweden and the United Kingdom respectively have produced yields that are 112 – 167% (Larsson 2001) and 108 – 243% (Lindegaard et al. 2001) of the reference clone.

The establishment phase, which lasts from the beginning of site preparation until the site is fully occupied, is critical to both the economic and biological success of SRWC. Establishment accounts for 20 - 25% of total production costs for willow (White et al. 1995, Van Den Broek 1997, Danfors et al. 1998, Mitchell et al. 1999, Goor et al. 2000). In contrast to traditional agricultural crops, the first harvest of SRWC does not typically occur for four years, so the time to recover these investment costs is lengthy, which further increases the cost of establishment and risk associated with the crop. Any reductions in the costs of establishment that do not compromise initial survival and growth can be beneficial to the overall economics of the system.

Initial survival and early rapid aboveground biomass production of SRWC are important to their long-term production and sustainability. Survival rates at the end of the establishment year of less than 80% are considered unsuccessful (Bergkvist et al. 1996). Interplanting fields with low survival is costly and can be ineffective since replanted cuttings are easily out competed by adjacent established plants (Verwijst 1996, Armstrong 1999). Weed competition is the primary factor limiting the successful establishment of SRWC because willow and poplar are susceptible to competition during establishment (Barkley 1983, Labrecque et al. 1994). Poorly established SRWC with low biomass production in their first year will have a negative effect on production over the entire first rotation (Willebrand et al.1993, Harrington and DeBell 1984, Hytönen 1995a) and possibly in subsequent rotations. One poor year of production in SRWC harvested on an annual rotation has been shown to reduce production in subsequent harvests and in some cases resulted in the steady decline of the crop's production (Willebrand and Verwijst 1993, Willebrand et al. 1993, Kopp et al. 2001b). Since SRWC in the current system are expected to be harvested six or seven times before they are replanted, efficient and effective establishment of the crop is essential.

Alternative Methods of Site Preparation

Current site preparation recommendations for SRWC involve a combination of mechanical tillage and chemical weed control (Boysen and Strobl 1991, Mitchell 1995, Danfors et al. 1998, Armstrong 1999, Abrahamson et al. 2002), but the specific steps vary depending on field history, site conditions and surrounding land use. The majority of sites in New York that have been used for willow biomass production were in hay, used for pasture, or fallow for one to three years prior to planting. Beginning site preparation in the late summer or early fall the year prior to planting is the standard approach for these sites (Boysen and Strobl 1991, Danfors et al. 1998, Abrahamson et al. 2002). If vegetation on the site is dense and tall, it is cut and allowed to regrow to a height of 15 – 25 cm. Contact herbicides are then applied when the vegetation is actively growing. Glyphosate is typically applied, but other contact herbicides or mixtures can be used. The choice of herbicides and their rates will depend on labeling guidelines, the vegetation present, and any local restrictions. When the existing vegetation is clearly dead, the site is plowed to a depth of 25 cm or more and then cross disked. The next spring the site is disked again followed by a pass with a cultipacker just before planting. Dormant hardwood cuttings are planted in the spring, as soon as the site is accessible by agricultural equipment, at a density of 14,300 cuttings ha^{-1}. Pre-emergent herbicides, typically oxyflourfen and/or simazine, are applied at the labeled rates over the top of cuttings immediately after planting. If the application of pre-emergent herbicide is delayed so that buds are beginning to open, then the herbicides used should be chosen carefully since some pre-emergent herbicides can damage the plants after bud break (Wagner 2000). Additional mechanical and/or chemical weed control is applied during the first year if weed competition becomes severe enough to warrant it. The effectiveness of initiating site preparation the fall prior to planting is evidenced by good weed control, survival rates greater than 80%, and rapid aboveground biomass production of the crop.

If conducted properly, the fall tillage technique results in limited vegetation cover on the site for over a year and a half, from the time of plowing until the crop canopy begins to close in the summer of the second year of growth. During the first growing season, crop canopy development is slow and a limited number of stems per plant are produced. Leaf area index (LAI) in the establishment year averaged 0.1 (mid July) and 0.5 (mid September) for four willow clones grown at 18,000 plants ha^{-1} in central NY. LAI values for the hybrid poplar clone NM6 planted at the same density averaged 0.3 and 1.7 in mid July and mid September respectively (Tharakan 1999). At the end of the first growing season, the four willow clones had an average of 2.2 stems per plant while NM6 had 1.6 stems per plant. As a result, the site was not fully occupied at the end of the first growing season. The current practice is to coppice the plants during the first dormant season so that multiple shoots are produced the next growing season, which contributes to rapid canopy cover. At the end of the first growing season following coppicing, the average number of stems on the four willow clones was 11.1 per plant while NM6 had 7.1 stems per plant (Tharakan 1999). LAI of the four willow clones averaged 1.8 by mid July and peaked at 2.2 in mid September of the first growing season after coppicing. LAI for poplar clone NM6 at the same time was 5.9 and 8.3 respectively (Tharakan 1999). Cannell et al. (1988) and Chapman (1992) reported that LAI is typically greater than or equal to one by late June or early July in the first growing season after coppice if weed control has been successful during the establishment year. LAI typically peaks in the second or third year after coppicing or harvest (Hytönen 1995a, Ceulemans et al. 1996, Ross and Ross 1998, Bullard et al. 2002a). LAI values of 2.6 to 6.7 have been reported for established willow (Cannel et al. 1987, Hytönen 1995a, Ceulemans et al. 1996, Ross and Ross 1998, Ross et al. 2000, Bullard et al. 2002a, Proe et al. in press). Hybrid poplar

LAI has reached 6 in the first few years of growth and has been reported to be as high as 11 (Ceulemans 1990, Ceulemans et al. 1996).

While the fall tillage site preparation approach is effective for establishing willow and poplar biomass crops, the lack of vegetation cover creates the potential for significant soil erosion and non-point source pollution for the first one or two years. Under these conditions, soil erosion rates on sites with certain topographic and soil characteristics could be substantial (Kort et al. 1998, Mann and Tolbert 2000). Ranney and Mann (1994) reported that soil erosion rates up to 40 t ha^{-1} yr^{-1} could occur during the establishment of SRWC. In one study, White et al. (1991) estimated that about 130 t ha^{-1} of soil were lost during the establishment year in a hybrid poplar trial on a Mardin silt loam soil with a 13% slope. In the second year of growth of a sweetgum plantation in the southeastern United States with no ground cover, soil erosion was just over nine tonnes per hectare (Malik et al. 2000). Soil erosion was not measured during the spring of the establishment year, but was probably even greater.

The potential for soil erosion during the establishment of SRWC is a concern for a number of different reasons. There is increasing attention surrounding non-point source pollution from agriculture lands and the potential detrimental effect it is having on surface water supplies (Welsh 1991). Non-point source pollution as one of major environmental concerns related to SRWC (Heilman and Norby 1998). Erosion could have a detrimental effect on long-term sustainability of the production system (Lal 1998, Mann and Tolbert 2000, Vance 2000). Finally, erosion during establishment could have a negative impact on the public perception and acceptance of SRWC (Tolbert et al. 2002). The majority of land that will initially become available for SRWC production in the Northeastern and Midwestern United States is agricultural land that is prone to soil erosion, so attention needs to be given to establishment practices that reduce erosion potential.

The easiest and most effective approach to reducing soil erosion on a site is to provide vegetative cover for the soil that will disperse rainfall energy (Hudson 1981, Ranney and Mann 1994, Kort et al. 1998, Lal, 1998). If SRWC could be established successfully with some ground cover through the middle of the second growing season then the erosion potential during the establishment phase would be reduced. A variety of conservation tillage and other ground cover management techniques have been developed to address soil erosion concerns without adversely affecting annual agriculture and orchard systems crop yields. Conservation tillage is any reduced tillage system that leaves >30% of the residue from the previous crop on the soil surface after planting (Lal et al. 1990). Some of the more successful approaches include no-till and strip tillage. In addition, use of cover crops and altering the timing of different tillage operations has been shown to reduce soil erosion (Lal et al. 1990).

Little work has been done on establishing SRWC, especially with densities greater than 10,000 plants ha^{-1}, using any conservation tillage and/or alternative ground cover management techniques. Five different site preparation techniques, using a combination of mechanical and chemical weed control techniques, were tested on hybrid poplar planted at 10,000 plants ha^{-1} (Hansen et al. 1984b). Treatments ranged from no-till preparation to using both post emergent and pre-emergent herbicides and several tillage operations. Hansen et al. (1984b) concluded that as the number of chemical and mechanical weed control operations increased, both weed control and height growth improved over the first two growing seasons. Survival was not affected by the site preparation treatments. Eighteen different site preparation treatments including no weed control, no-till, various cover crops and pre-emergent herbicides were tested on high density willow and poplar plantings in the United Kingdom (Clay and Dixon 1996). Plots where ground cover – either weeds or cover crops – was not controlled until one to two months after establishment produced 30 – 50% less biomass than treatments where weeds were controlled immediately following planting with pre-emergent herbicides. Following cutback, weeds were aggressively controlled using post-emergent herbicides. By the end of the first year of growth after cutback differences between the treatments had decreased. Clay and Dixon (1996) concluded that the willows and poplars have an ability to recover from vegetation competition in the establishment year. Therefore, allowing some undetermined level of ground cover during some periods in the first year may not have a detrimental effect on the first rotation yield of the planting.

The benefits of no-till site preparation methods in annual agricultural production systems include earlier access to the site in the spring, higher soil moisture in the plant root zone, reduced erosion, greater soil organic matter levels, elevated levels of soil nitrogen and exchangeable bases compared to cultivated soils, and reduced site preparation costs. Drawbacks of no-till methods include lower spring soil temperatures, increased weed populations, and increased soil bulk density (Lal et al. 1990). Reduced soil temperatures in the spring have been suggested as a factor reducing growth in hybrid poplar plantations (Hansen et al. 1986). Weeds, which can compete for moisture, nutrients and in some cases light, have been frequently identified as one of the most important factors limiting successful establishment of willow biomass crops (Labrecque et al. 1994, Danfors et al. 1998, Volk et al. 1999).

While the few studies that have tested no-till site preparation techniques in SRWC have produced mixed results, the numerous benefits associated with no-till systems make them worth further testing. McKittrick (1990) compared no-till and complete tillage site preparation methods for the establishment of hybrid poplar with 1,111 plants ha^{-1} on an alluvial silt loam. He found that the total volume of clone DN-55 was similar on the no-till and cultivated plots after three years, despite the fact that no-till plots had a significantly lower survival rate. Arid (1962) reported that first year height growth of hybrid poplar was similar between no-till and tillage treatments when chemical weed control was used on both treatments. However, when chemical weed control was not used, height growth on the no-till plots was significantly less than on tillage treatments. Dickman and Stuart (1983) noted that no-till approaches have been used to successfully establish hybrid poplar plantations, but did not cite specific data. In the United Kingdom the use of no-till site preparation to establish SRWC has been recommended on well drained sites that are susceptible to soil erosion (Mitchell 1995). In contrast, Hansen et al. (1986) found that height growth of two hybrid poplar clones established at 1,388 plants ha^{-1} using conventional cultivation was 18 to 96% greater than sites prepared with no-till techniques. The difference was greatest on a poorly drained loam soil and smallest on an excessively drained sandy soil. No-till techniques resulted in higher moisture in the plant root zone and reduced soil temperatures in the spring. Hansen et al. (1986) suggested that these factors, especially reduced spring soil temperatures, would limit the usefulness of no-till practices for establishing hybrid poplar in northern latitudes. No-till plots of 14 clones of willow planted at a high density (15,300 plants ha^{-1}) on an alluvial soil in northern New York produced between 2.4 – 9.2 odt ha^{-1} yr^{-1} in the first rotation. In the second rotation, production increased significantly to 7.30 - 19.8 odt ha^{-1} yr^{-1} with the best clones exceeding yields on sites established using fall site preparation techniques (Volk et al. 2001b).

Various ground cover management systems have been tested and developed for woody fruit crops to address concerns of potential soil erosion and long-term sustainability of the systems. Welker and Glenn (1988) compared four systems (cultivated, herbicide, mowed sod, and killed sod) during the establishment phase of peach trees and found that the growth and fruit yield was greatest under the killed sod management system. This system included the establishment of a sod cover that was killed with herbicide prior to planting and left on the soil surface. The mowed sod treatment consistently had the lowest growth rates. Soil organic matter levels were highest under the killed sod treatment and there was a positive linear relationship between soil organic matter levels and tree growth after three years. Infiltration rates were four to eleven times greater under the killed sod compared to the other systems. In established vineyards, Pool et al. (1990) found that over a four year period there were no differences in yield between various ground cover management systems, which included regular cultivation, permanent mowed sod cover and various herbicide treatments. They recommended the use of no-till management systems in non-irrigated vineyards because of the additional benefits of reduced soil erosion and compaction.

Maintaining strips of vegetation cover between established trees or vines has been tested in various agricultural and forestry systems. If strips are established along the contour then the length of the slope that water can flow is reduced, minimizing soil erosion. Malik et al (2000) found that strips of living cover crops between rows of sweetgum reduced erosion during establishment by 38 – 74% depending on the cover crops used. Doubling the width of the strips from 1.22 m to 2.44 m had little or no effect on erosion control. However, increasing the width of the strips did significantly reduce the volume growth of the sweetgum over the first two years (Malik et al. 2001). Similarly, Welker and Glen (1989) found that peach tree cross sectional area growth was directly related to the vegetation free area maintained around the tree up to 9.0 m^2. In contrast, doubling the width of the vegetation free zone from 1.25 m to 2.5 m around apple trees did not affect the cross sectional growth or yield of apple trees (Merwin and Stiles 1994). Some studies have shown that later in the growing season, apple tree roots concentrate under the untilled portion of the field where the soil moisture content is higher (Atkinson 1980), which may have been a factor in the study by Merwin and Stiles (1994).

The integration of cover crops into agricultural production systems has been developed to reduce runoff and soil erosion, and improve infiltration, soil moisture availability, nutrient availability, and weed control (Teasdale 1996). However, only a limited amount of work has been done on integrating cover crops during the establishment of perennial woody crops and trees. Living cover crops have been shown to compete strongly for water with a variety of trees and woody crops during establishment resulting in reduced growth (Hansen et al. 1984a, Shribbs and Skroch 1986, Cogliastro et al. 1990, Ferm et al. 1994, Merwin and Stiles 1994, Malik et al. 2001). Living cover crops have not been recommended in high density SRWC because of the potential for serious competition for moisture and possibly light. However, a viable alternative is to establish cover crops in the fall after site preparation and kill them just prior to planting in the spring or establish a fall cover crop that produces a significant amount of biomass and then dies over the winter. This would provide ground cover during the late fall, winter and early spring prior to planting, which would reduce soil erosion during that time. If the cover crop is killed just prior to planting then a protective mulch could be left on the soil surface during the first growing season. This mulch has the potential to reduce erosion and weed growth while maintaining soil moisture and soil organic matter. This approach has been successful in vineyards (Pool et al. 1990) and orchards (Shribbs and Skroch 1986), and shown some potential in short-rotation sweetgum plantations (Malik et al. 2001). To date only a limited amount of testing of this approach has been completed in high density SRWC plantations (Clay and Dixon 1996).

CHAPTER 2: ALTERNATIVE METHODS OF SITE PREPARATION FOR SRWC

Introduction

The proper application of site preparation techniques is essential to the biological and economic success of SRWC. Failure to control weeds during site preparation and through the establishment year causes competition for water, light and nutrients resulting in decreased survival and production, and potentially the failure of the crop (Barkley 1983, Labrecque et al. 1994). The recommended site preparation technique involves the application of mechanical and chemical weed control in the late summer or fall the year prior to planting (Danfors et al. 1998, Mitchell et al. 1999, Abrahamson et al. 2002). It typically includes a late summer application of contact herbicides, followed by plowing and disking before winter. A final cultivation is conducted the following spring, immediately prior to planting, which is followed immediately with the application of a pre-emergent herbicide.

While the fall tillage site preparation approach is effective for establishing willow and poplar biomass crops, it creates the potential for significant soil erosion. If conducted properly, the fall tillage technique results in limited vegetation cover for over one and a half years, from the time of plowing until the canopy begins to close in the summer of the second year of growth. Under these conditions, soil erosion rates could equal or exceed those recorded for annual agricultural crops (Ranney and Mann 1994). The majority of land that will initially become available for willow and poplar biomass crop production in the northeastern and Midwestern United States is marginal agricultural land that has characteristics that make it prone to soil erosion. In one study, White et al. (1991) estimated that about 130 MT ha^{-1} of soil were lost during the establishment year in a hybrid poplar trial on a Mardin silt loam soil with a 13% slope. The soil erosion issue is important because of the increasing concern surrounding non-point source pollution from agriculture lands (Welsh 1991); the detrimental effect it could have on long-term sustainability of the production system (Lal 1998, Mann and Tolbert 2000, Vance 2000); and the negative impact it could have on the public perception of SRWC (Tolbert and Wright 1998, Tolbert et al. 2002).

The easiest and most effective approach to reducing soil erosion on a site is to provide vegetative cover that will disperse rainfall energy (Hudson 1981, Ranney and Mann 1994, Kort et al. 1998, Lal, 1998). A variety of conservation tillage and other ground cover management techniques have been developed to address soil erosion concerns without adversely affecting crop yields for annual agriculture and orchard systems (Lal et al. 1990, Pool et al. 1990, Merwin et al. 1994). Some of the more successful approaches include no-till and strip tillage. In addition, use of cover crops and altering the timing of different tillage operations has been shown to reduce soil erosion. However, little work has been done on establishing SRWC using any conversation tillage and/or alternative ground cover management techniques, especially for systems with densities greater than 10,000 plants ha^{-1}.

This study assessed the impact of six different site preparation methods on SRWC survival, aboveground biomass production, foliar nitrogen concentrations, and soil characteristics. The following hypotheses were tested.

1. Different site preparation methods would have no affect on survival, aboveground biomass production or foliar N, P, K, Ca or Mg concentrations of willow and poplar SRWC during the first rotation.

2. Different site preparation methods will not affect soil characteristics, including bulk density, pH, soil carbon, and N, P, K, Ca, and Mg concentrations, under willow and poplar SRWC over the first rotation.

Materials and Methods

Site Description

The study was located in Lafayette, NY on the High Meadows farm (48° 52' 42" N, 76° 06' 45" W), which has an elevation of 298 m. The soil is mapped as a Honeoye, which is a deep, well drained, silt loam soil, with a high available water capacity in the upper 60 – 90 cm that has formed on calcareous glacial till (Hutton and Rice 1977). The study site was used for corn production in the summer of 1994 and was left fallow in 1995. Vegetation on the site was brush hogged once in late summer 1995. Site preparation for this trial began in August 1996 when vegetation on the site was mowed, baled and removed from the field. Glyphosate (2.25 kg ai ha^{-1}) was applied three weeks after the site was mowed.

The climate is temperate humid and cold. Thirty-year average for annual precipitation is 973.1 mm (NOAA 2002). Precipitation was below normal in all four years of this study. The lack of precipitation was the most severe in 1999 when the annual total was 828.5 mm, 20% below normal. From April through August 1999, precipitation was only 44% of normal (Figure 2.1). The long-term average for growing degree-days (base 10°C) during the growing season (April 1 – October 30) is 1440. Growing degree-days in 1997 – 2000 were 1306, 1607, 1637, and 1332, respectively.

Experimental Design and Site Preparation Methods

A two by six factorial treatment experiment was laid out using a randomized complete block design with four blocks. Plots were 11.9 x 11.4 m in size. The six site preparation methods studied were 1) the currently recommended fall tillage system, 2) fall tillage followed by the establishment of a winter rye cover crop, 3) no-till system, 4) strip tillage applied in the spring, 5) spring tillage, and 6) no weed control following fall site preparation (Table 2.1). Two clones, one willow (SV1 - *Salix dasyclados*) and one hybrid poplar (NM6 - *Populus nigra* x *maximowiczii*), were used in each treatment. Each plot contained 240 plants established in six double rows. Rows within the double row are 0.7 m apart and 1.5 m to the next double row. Plants are 0.6 m apart within the double row resulting in a final plant density of 14, 376 plants ha^{-1}. Measurement plots consisted of the 32 plants in the middle of two double rows, resulting in buffer areas of 2.6 m (six plants) along the row and 3.4 m (four plants) across the rows.

The steps taken following the application of glyphosate (2.25 kg ai ha^{-1}) across the entire site in the fall of 1996 for the different site preparation treatments are outlined in Table 2.1. Moldboard plowing to a depth of 20 to 25 cm occurred on the appropriate plots 10 - 12 days after contact herbicide was applied, followed immediately by cross disking. Aroostook winter rye *(Secale cereale L.*) was planted the first week in October for the cover crop treatment with a Brillion seeder at 124 kg ha^{-1}. Prior to planting in the spring of 1997, some perennial weeds were developing on the site so glyphosate (2% concentration) was spot sprayed on all plots except the no weed control treatment. Five to seven days after herbicide application, spring plowing and cross disking of the

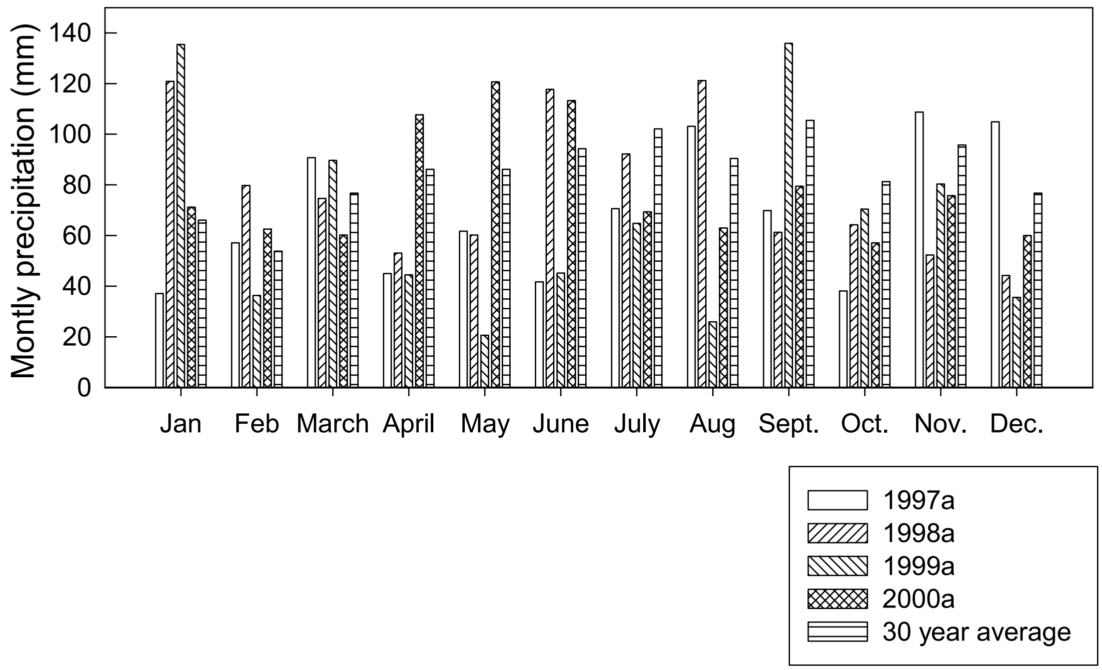

Figure 2.1. Monthly precipitation for 1997 – 2000 and the 30 year average at Syracuse, NY.

Table 2.1. Timeline of field activities for six different site preparation treatments for poplar (NM6) and willow (SV1) biomass crops in Lafayette, NY.

Field activity	Site Preparation Treatment					
	Fall tillage (1) †	Cover crop (2)	No till (3)	Strip tillage (4)	Spring tillage (5)	No weed control (6)
Mow (summer 1996)	**X**	**X**	**X**	**X**	**X**	**X**
Post emergent herbicide (glyphosate at 2.25 kg ai ha^{-1}) (summer 1996)	**X**		**X**	**X**	**X**	**X**
Moldboard plow (fall 1996)	**X**	**X**				**X**
Disk (fall 1996)	**X**	**X**				**X**
Plant cover crop (fall 1996)		**X**				
Post emergent herbicide (glyphosate at 2% concentration) (Spring 1997)	**X**	**X**	**X**	**X**	**X**	
Plow (spring 1997)					**X**	
Disk (spring 1997)	**X**	**X**			**X**	
Rototill 1.2 m wide strip (spring 1997)				**X**		
Plant willow (SV1) and poplar (NM6) cuttings (spring 1997)	**X**	**X**	**X**	**X**	**X**	**X**
Pre emergent herbicide (oxyflourfen at 1.1 kg ai ha^{-1}) (spring 1997)	**X**	**X**	**X**	**X**	**X**	

† Treatment numbers were assigned to facilitate the explanation of linear contrasts.

appropriate treatments occurred. Strips 1.2 m wide were rototilled in the strip tillage treatments. Dormant hardwood cuttings 25 cm in length were removed from frozen storage (-4^{o}C) two days prior to planting and soaked in water. All the treatments were hand planted using dibbles. Two days after planting oxyflourfen (1.1 kg ai ha^{-1}) was applied on all but the no weed control plots. Spot applications of glyphosate (2% concentration) and hand weeding of plots were conducted during the first and second growing seasons to reduce weed competition on all but the no weed control plots.

Plant survival was assessed in all the plots on December 5, 1997. All the plants were cutback at between two to four centimeters height on December 6 - 8. The aboveground biomass of each measurement plot was weighed, dried at 65^{o} C to a constant weight and weighed again to determine moisture concentration. At the end of the first (1998) and second (1999) growing seasons after cutback, the diameter of all stems was measured at a height of 30 cm above the soil. The maximum height of each stool was measured. The aboveground biomass was estimated for each measurement plot using allometric equations developed by Ballard et al. (2000). At the end of the third (2000) growing season after cutback, the measurement plots were harvested after complete leaf fall, and aboveground biomass was measured. A subsample of one small, one medium, and one large stem per plot was selected and used to determine moisture concentration of the harvested material.

Weed biomass has harvested in mid-July 1999 and 2000 in each plot from four 60 cm x 60 cm square quadrats evenly spaced along a diagonal line that ran across the measurement plot. Weed biomass was dried at 65^{o} C to a constant weight and weighed.

To determine bulk density, three undisturbed soil core samples were collected from two depths (0 - 15 and 15 – 30 cm) in each measurement plot using a bulk density corer (15 cm long x 7.4 cm in diameter) in May 1997 and May 2000. Soil samples were collected at the same two depths from four locations in each plot in May 1997 and May 2000. Soil from the four sample points was combined into one sample per plot in the field. Litter and other organic material were removed from the soil surface before sampling. Soil organic matter was determined by loss on ignition. Bulk density measurements and a conversion factor (0.58) were used to convert soil organic matter to soil carbon content (Post et al. 1999). The macro-Kjeldhal method was used to determine nitrogen concentration. Soil samples were extracted with ammonium acetate (pH 7.0) to determine K, Ca, Mg and analyzed by atomic absorption spectrophotometry. Phosphorus was determined by the Truog method and concentrations were determined using a spectrophotometer. Soil reaction (pH) was measured in a soil: water (1:2) solution (Bickelhaupt and White 1982).

Fully expanded, mature leaves were sampled from the top third of the crown from plants in the buffer area of each plot between August 15 and September 15 each year for nutrient analysis. Leaf samples were dried at 65^{o}C to a constant weight and ground in a Wiley mill to pass through a 2 mm screen. The macro-Kjeldhal method was used to determine N concentration. Phosphorous concentration was determined using the ammonium molybdate vandate method and a mass spectrometer. Potassium, Ca and Mg concentrations were determined using the dry ashing procedure with 6 N HCl and atomic absorption spectroscopy (Bickelhaupt and White 1982).

Statistical Analysis

The data were analyzed as a completely randomized block design. Analysis of variance was used to assess treatment effects on plant survival, biomass production, foliar nutrient concentrations and soil characteristics using the following model.

$y_{ijk} = \mu + b_i + t_j + c_k + t*c_{jk} + \varepsilon_{ijk}$

Where:

y_{ijk} = i^{th} observation of the j^{th} treatment of the k^{th} clone

μ = overall mean of the observations

b_i = added effect of the i^{th} block

t_j = added effect of the t^{th} treatment

c_k = added effect of the c^{th} clone

$t*c_{jk}$ = interaction effect between the t^{th} treatment and the c^{th} clone

ε_{ijk} = random effect associated with the y_{ijk}, ε_{ijk} NID(0, σ^2)

Significance of hypothesis for the interaction effect was assessed at $\alpha = 0.20$ (Stehman and Meredith 1995). The following set of orthogonal linear contrasts were used to test simple effects for SV1 and NM6 separately when the interaction term was significant:

a. weed control – no weed control (average of treatments 1 through 5 minus treatment 6 (see Table 2.1 for treatment numbers))
b. tillage – no-till (average of treatments 1, 2, 4 and 5 minus treatment 3)
c. fall tillage – spring tillage (average of treatment 1 and 2 minus the average of treatment 4 and 5)
d. fall tillage – cover crop (treatment 1 minus treatment 2)
e. spring tillage – strip tillage (treatment 5 minus treatment 4)

A paired t-test was used to determine if changes in survival and soil characteristics were significant over the first rotation. All statistical analyses were conducted using SAS (SAS 1999).

Results

Survival

The interaction of treatment and species had an effect on plant survival in all four years (Table 2.2). Linear contrasts for simple effects were examined for poplar and willow separately.

Hybrid Poplar (NM6)

Establishment year (1997) survival for poplar was greater than 84% for all site preparation treatments (Figure 2.2), and greater than 96% in five of the six treatments. In the first year of growth after cutback (1998), survival decreased by 2 – 6%, with thelargest changes occurring in the strip tillage and no weed control plots. The largest decrease in poplar survival from the end of the establishment year (1997) until harvest in 2000 was 6% in the strip tillage and no weed control plots (Table 2.3). A paired t-test indicated that none of the decreases in survival were significant at $\alpha = 0.05$. Survival in the no weed control treatment was significantly lower in each of the four years compared

Table 2.2. Mean square and p-values from ANOVAs for survival over four years for six different site preparation treatments for poplar (NM6) and willow (SV1) biomass crops in Lafayette, NY.

Source	df	1997		1998		1999		2000	
		Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value
Block	3	18.717	0.6462	99.614	0.4704	164.087	0.4616	128.694	0.5229
Treatment	5	108.398	0.0174	583.083	0.0015	1020.626	0.0009	1594.685	<0.001
Species	1	208.333	0.0178	1104.001	0.0040	3035.310	0.0003	5088.201	<0.001
Treatment x species	5	53.548	0.1881	279.791	0.0563	443.394	0.0601	933.736	0.0008
Error	33	33.513		115.531		186.517		168.672	

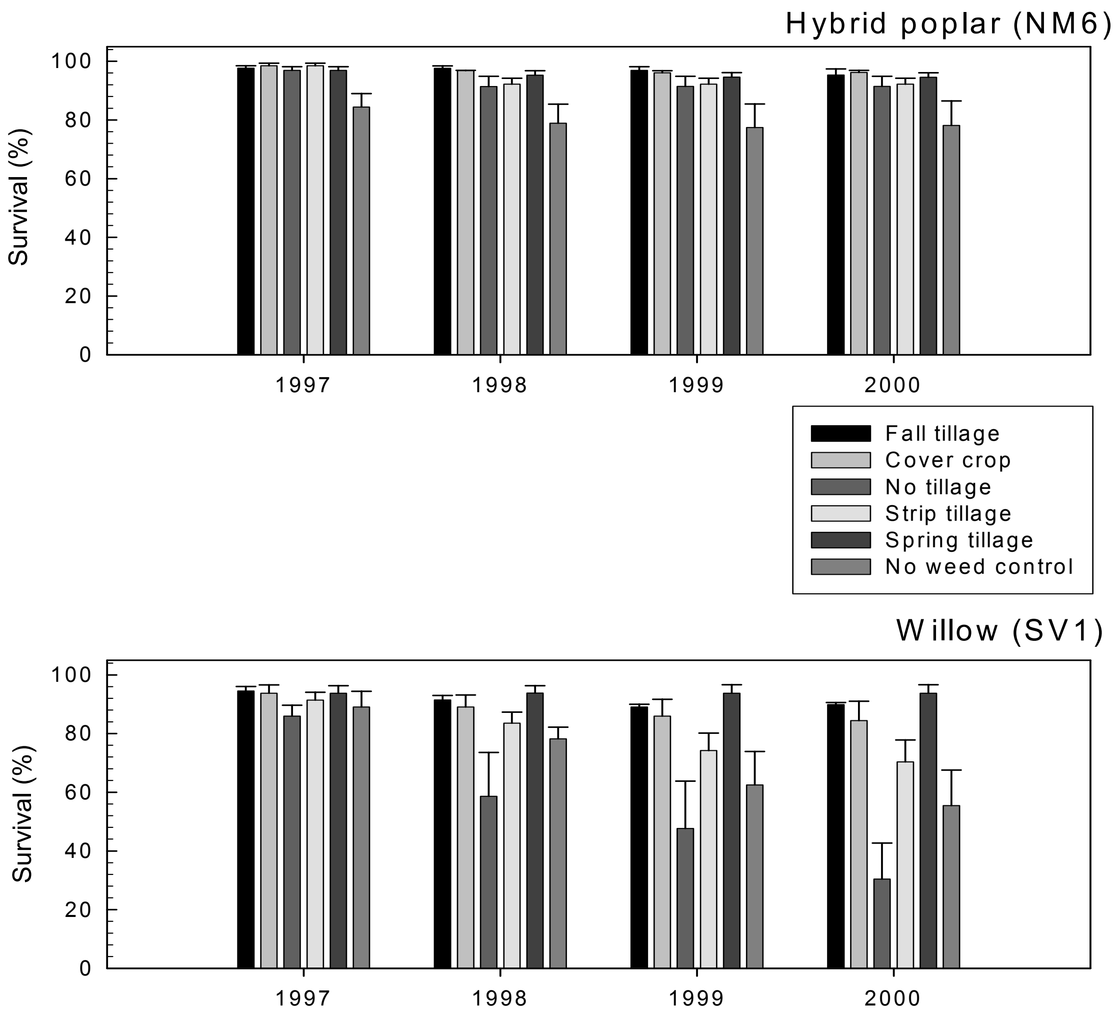

Figure 2.2. Survival (mean + SE) from 1997 – 2000 for hybrid poplar (NM6) and willow (SV1) established using six different site preparation treatments.

Table 2.3. Changes in survival from the end of the establishment year (1997) through the end of the first rotation (2000) for six different site preparation treatments for poplar (NM6) and willow (SV1) biomass crops in Lafayette, NY.

	Change in survival from 1997 to 2000		
Treatment	Mean (%)	SE	p-value of paired T-test
	Poplar (NM6)		
Fall tillage	2.33	1.50	0.2186
Cover crop	2.31	1.49	0.2186
No-till	5.45	2.34	0.1027
Strip tillage	6.23	2.56	0.0925
Spring tillage	2.33	1.49	0.2172
No weed control	6.25	4.43	0.2530
	Willow (SV1)		
Fall tillage	4.71	0.91	0.0138
Cover crop	9.38	5.56	0.1901
No-till	55.49	9.50	0.0100
Strip tillage	21.08	7.89	0.0756
Spring tillage	0.78	0.79	0.3910
No weed control	33.59	12.12	0.0695

to treatments with weed control (Table 2.4). There were no differences in poplar survival in the no-till plots compared to the average of the tillage treatments in any year. Conducting tillage operations in the fall versus the spring did not have any effect on poplar survival.

Willow (SV1)

Willow (SV1) survival at the end of the establishment year ranged from 84 to 95% (Figure 2.2). Survival decreased by 0 – 27% between the end of the establishment year (1997) and the end of the first year of coppice growth after cutback (1998). The greatest decreases were in the no-till (27%) and no weed control (11%) treatments. Over the next two years willow survival continued to decline in the no-till, no weed control, and strip tillage treatments, so that by the fall of 2000 survival on these plots was 31%, 56% and 70%, respectively (Figure 2.2). Not using tillage on this site significantly decreased the survival of the willow in the establishment year (Table 2.4). This difference was maintained throughout the first rotation. Weed control after fall site preparation did not significantly effect survival in the establishment year or the first year after coppice. However, a continual decline in survival in the no weed control treatment resulted in significantly lower survival by the end of 1999 and 2000 compared to the treatments where weed control was applied. By the end of the first rotation survival on the strip tillage treatment was significantly less than on the spring tillage plots. The application of complete tillage in the fall versus the spring did not effect survival over the first rotation.

<u>Aboveground Biomass Production</u>

For aboveground biomass, the interaction between species and site preparation treatment was significant in all four years (Table 2.5). Simple effects for willow and poplar aboveground biomass production were examined separately.

Table 2.4 Linear contrast estimates and p-values for survival over four years for poplar (NM6) and willow (SV1) biomass crops for six different site preparation treatments in Lafayette, NY.

Linear contrast	1997 Estimate (%)	1997 p-value	1998 Estimate (%)	1998 p-value	1999 Estimate (%)	1999 p-value	2000 Estimate (%)	2000 p-value
				Poplar (NM6)				
Weed control – no weed control	13.3	0.0001	15.8	0.0106	16.8	0.0298	15.8	0.0310
Tillage – no-till	1.0	0.7555	4.1	0.5002	3.5	0.6474	3.1	0.6660
(Fall tillage + cover crop) – spring tillage	1.2	0.7330	2.0	0.7660	1.9	0.8182	1.2	0.8821
Fall tillage – cover crop	- 0.8	0.8438	0.8	0.9189	0.9	0.9299	- 0.8	0.9303
Spring tillage – strip tillage	- 1.6	0.6938	3.1	0.6889	2.4	0.8080	2.4	0.7973
				Willow (SV1)				
Weed control – no weed control	2.8	0.3621	5.1	0.3884	15.5	0.0447	18.1	0.0143
Tillage – no-till	7.4	0.0224	30.9	<0.0001	37.9	<0.0001	53.9	<0.0001
(Fall tillage + cover crop) – spring tillage	0.4	0.9123	- 3.5	0.5921	- 5.5	0.5134	- 5.9	0.4600
Fall tillage – cover crop	0.8	0.8438	2.4	0.7551	3.1	0.7467	5.4	0.5522
Spring tillage – strip tillage	2.4	0.5532	10.2	0.1855	18.8	0.0586	22.7	0.0174

Table 2.5. Mean square and p-values from ANOVAs for aboveground biomass production over four years for poplar (NM6) and willow (SV1) biomass crops for six different site preparation treatments in Lafayette, NY.

Source	df	1997 Mean square	1997 p-value	1998 Mean square	1998 p-value	1999 Mean square	1999 p-value	2000 Mean square	2000 p-value
Block	3	0.021	0.2539	2.456	0.2556	17.413	0.0063	53.751	0.0358
Treatment	5	0.746	<0.0001	18.615	<0.0001	80.593	<0.0001	415.540	<0.0001
Species	1	12.568	<0.0001	272.987	<0.0001	723.077	<0.0001	1603.834	<0.0001
Treatment x species	5	0.691	<0.0001	12.369	0.0001	18.879	0.0011	67.257	0.0060
Error	33	0.0151		1.735		3.551		16.784	

Hybrid Poplar (NM6)

Hybrid poplar aboveground biomass in the establishment year was affected by site preparation treatments. Production ranged from 0.2 – 1.5 odt ha^{-1} (Figure 2.3). The difference between the no weed control treatment and the average of the weed control treatments (1.0 odt ha^{-1}) was significant (Table 2.6). Biomass production on the no-till treatment was 1.0 odt ha^{-1} less than the average of the tilled treatments. Spring cultivated treatments produced significantly more biomass (0.2 odt ha^{-1}) than the treatments that were tilled in the fall. The cover crop treatment produced 0.2 odt ha^{-1} more biomass than the fall tillage treatment. The strip tillage treatment produced 0.4 odt ha^{-1} less biomass than the full spring tillage treatment during the establishment year.

Estimated aboveground biomass after the first and second year of coppice growth respectively ranged from 0.7 to 7.7 odt ha^{-1} and 2.1 to 12.6 odt ha^{-1}. The no weed control treatment had significantly less aboveground biomass at the end of each year compared to plots with weed control. Tillage significantly increased the amount of aboveground biomass at the end of both years. Aboveground biomass production at the end of the first three-year coppice rotation ranged from 12.0 odt ha^{-1} in the no weed control treatment to 37.6 odt ha^{-1} in the strip tillage treatment. The cover crop, fall tillage, and spring tillage treatments all produced more than 36 odt ha^{-1} of aboveground biomass. At the end of the first coppice rotation the weed control treatments produced 22.1 odt ha^{-1} more biomass than the no weed control treatments and the tilled treatments produced 8.4 odt ha^{-1} more biomass than the no-till treatment.

Throughout the study, the no-till and no weed control treatments were consistently ranked fifth and sixth in terms of aboveground biomass production. The ranking of the remaining four treatments changed over the rotation. In 1997 the strip tillage treatment was ranked fourth and had significantly less aboveground biomass than the spring tillage treatment. However, by the end of the first coppice rotation the strip tillage treatment had the same amount of aboveground biomass as the fall tillage, spring tillage, and cover crop treatments.

Willow (SV1)

Willow (SV1) aboveground biomass in the establishment year ranged from 0.01 to 0.04 odt ha^{-1} and was not different among the site preparation treatments (Figure 2.3, Table 2.6). Estimated aboveground biomass in the first (1998) and second year (1999) of coppice growth after cutback ranged from 0.02 to 1.0 odt ha^{-1} and 0.1 to 3.9 odt ha^{-1} respectively. Treatment effects on aboveground biomass production were evident beginning the first year after cutback (1998). The average production of treatments with weed control was 0.5 odt ha^{-1} greater than treatments without weed control. This difference expanded to 2.7 odt ha^{-1} in 1999, the second year of coppice growth. In 1999, the tilled treatments had 2.3 odt ha^{-1} more aboveground biomass than the no-till treatment and the spring tillage treatment had 2.6 odt ha^{-1} more aboveground biomass than the strip tillage treatment.

Willow aboveground biomass at the end of the first three-year coppice rotation ranged from 0.4 odt ha^{-1} in the no-till and no weed control treatment to 23.0 odt ha^{-1} in the spring tillage treatment. The difference in aboveground biomass production between the weed control and no weed control treatments was 12.2 odt ha^{-1}. The tilled treatments produced 16.9 odt ha^{-1} more aboveground biomass than the no-till treatment. The spring tillage treatment produced 13.6 odt ha^{-1} more aboveground biomass than the strip tillage treatment. Aboveground biomass production was 7.6 odt ha^{-1} higher in the cover crop treatment compared to the fall tillage treatment.

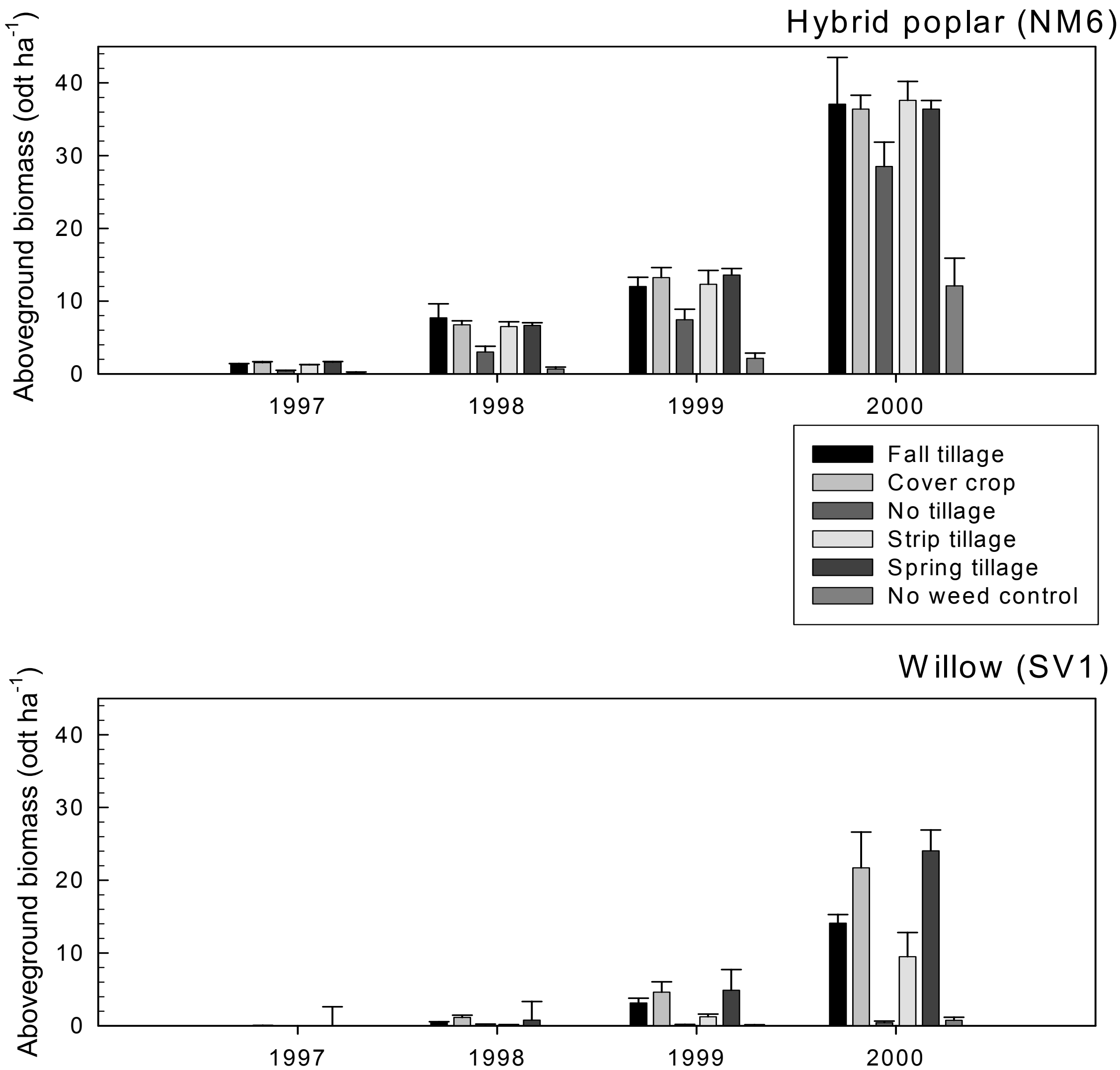

Figure 2.3. Aboveground biomass (mean + SE) from 1997 – 2000 for hybrid poplar (NM6)) and willow (SV1) established using six different site preparation treatments.

Table 2.6. Linear contrast estimates and p-values for aboveground biomass production over four years for poplar (NM6) and willow (SV1) biomass crops for six different site preparation treatments in Lafayette, NY.

	1997		1998		1999		2000	
Linear contrast	Estimate (odt ha^{-1})	p-value	Estimate (odt ha^{-1})	p-value	Estimate (odt ha^{-1})	p-value	Estimate (odt ha^{-1})	p-value
	Poplar (NM6)							
Weed control – no weed control	1.02	<0.0001	5.45	<0.0001	9.58	<0.0001	23.09	<0.0001
Tillage – no-till	1.02	<0.0001	3.89	<0.0001	5.34	<0.0001	8.35	0.0240
(Fall + cover crop) – spring	-0.16	0.0392	0.56	0.5002	-0.95	0.4792	0.32	0.9340
Fall – cover crop	-0.21	0.0205	0.98	0.3114	-1.24	0.4242	0.67	0.8824
Spring – strip tillage	0.36	0.0002	0.17	0.8627	1.24	0.4233	-1.21	0.7890
	Willow (SV1)							
Weed control – no weed control	0.02	0.8224	0.51	.04915	2.68	0.0304	13.19	0.0005
Tillage – no-till	0.02	0.7798	0.52	0.4904	3.34	0.0091	16.90	<0.0001
(Fall + cover crop) – spring	0.0	0.9786	0.04	0.9590	-0.99	0.4627	- 6.14	0.1225
Fall – cover crop	-0.02	0.8474	-0.65	0.4970	-1.47	0.3451	-7.61	0.0981
Spring – strip tillage	0.02	0.8392	0.63	0.5119	3.64	0.0230	14.55	0.0025

The ranking of the treatments in terms of aboveground biomass changed little from the establishment year to the end of the first rotation. The cover crop and spring tillage treatments were consistently ranked first or second out of six treatments. The fall tillage treatment and strip tillage treatments were consistently ranked third and fourth respectively. The no-till and no weed control treatments consistently had the lowest biomass production and were ranked fifth or sixth.

Weed Biomass

The interaction between treatment and species for weed biomass was not significant in 1999, but was significant in 2000 (Table 2.7). Across all treatments in 1999, weed biomass was less under poplar compared to willow (Table 2.8, Figure 2.4). The no weed control treatments had 3.0 odt ha^{-1} more weed biomass than the weed control treatments. Weed biomass in 1999 had a significant negative correlation with 1999

Table 2.7. Mean square and p-values from ANOVAs for weed biomass in 1999 and 2000 under poplar (NM6) and willow (SV1) biomass crops for six different site preparation treatments in Lafayette, NY.

		1999		2000	
Source	df	Mean square	p-value	Mean square	p-value
Block	3	12.38	0.1787	2.31	0.5018
Treatment	5	109.97	<0.0001	116.01	<0.0001
Species	1	31.60	0.0009	39.43	<0.0001
Treatment x species	5	5.99	0.7710	28.17	0.0006
Error	33	78.47		31.69	

Table 2.8. Linear contrast estimates and p-values for weed biomass in 1999 and 2000 under one willow (SV1) and one poplar (NM6) clone grown using six different site preparation treatments.

	1999		2000	
Linear contrast	Estimate (odt ha^{-1})	p-value	Estimate (odt ha^{-1})	p-value
	Main Effects		**Simple Effects Poplar (NM6)**	
Weed control – no weed control	-3.96	<0.0001	-3.26	<0.0001
Tillage – no-till	0.31	0.6275	-0.19	0.7255
(Fall + cover crop) – spring	0.17	0.8116	-0.01	0.9951
Fall – cover crop	0.83	0.3016	0.01	0.9928
Spring – strip	0.42	0.5975	-0.01	0.9993
Willow - poplar	1.62	0.0011		
			Willow (SV1)	
Weed control – no weed control			-3.83	<0.0001
Tillage – no-till			-3.57	<0.0001
(Fall + cover crop) – spring			0.20	0.7355
Fall – cover crop			-0.77	0.2645
Spring – strip			-2.54	0.0007

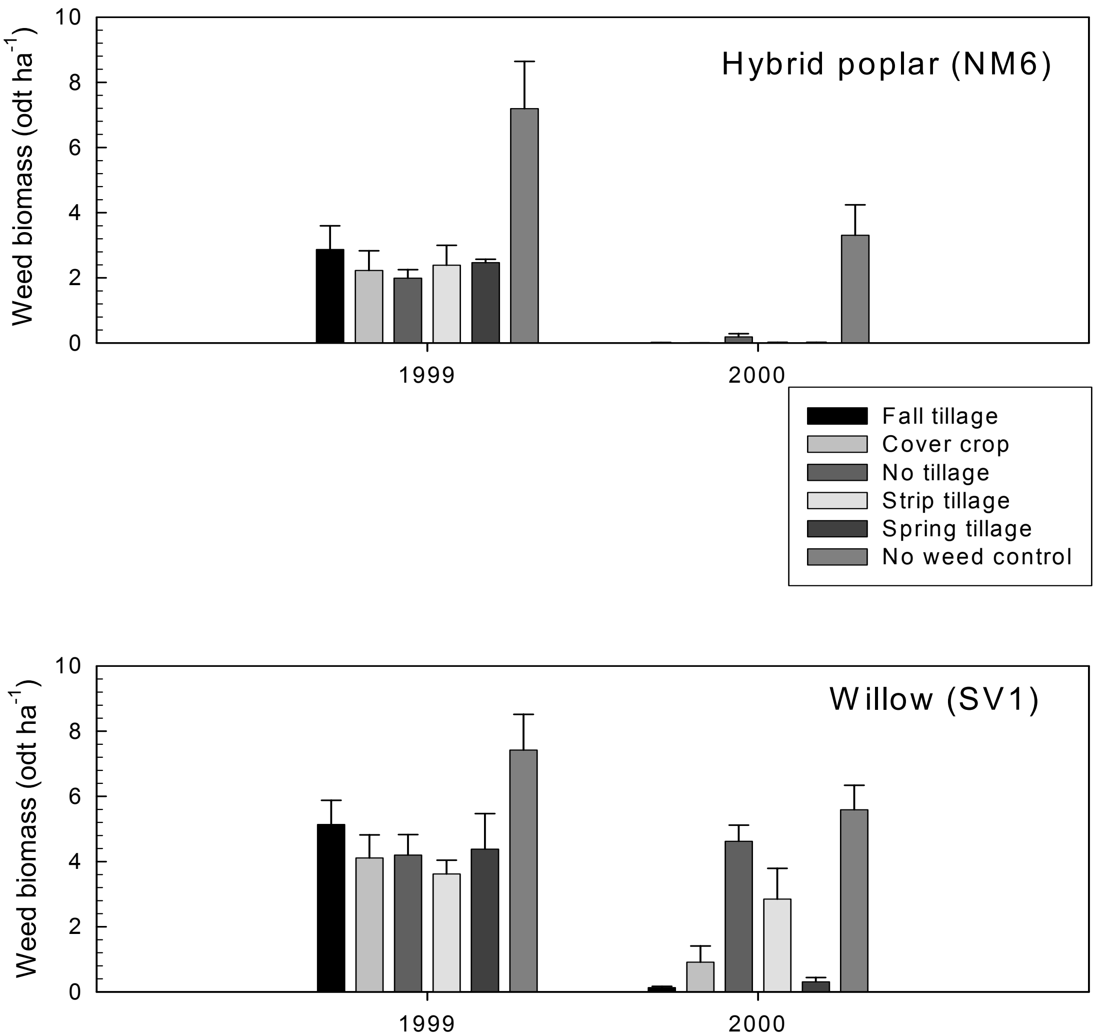

Figure 2.4. Weed biomass (mean + SE) in 1999 and 2000 under hybrid poplar (NM6) and willow SV1).

aboveground biomass for poplar ($r = -0.65$, $p = 0.0007$), but not for willow ($r = -0.25$, $p = 0.2269$).

As the canopy closed and the SRWC occupied the site, weed biomass declined in most treatments. In the third year of coppice growth (2000) weed biomass under poplar was less than one dry tonne per hectare on all but the no weed control treatments. The only significant difference in weed biomass under poplar was between the no weed control and weed control treatments. Under willow, the fall tillage, cover crop and spring tillage treatments all had less than one dry ton per hectare of weed biomass in 2000. Weed biomass was greater on the no weed control and no-till treatments respectively compared to treatments with weed control and tillage. Weed biomass had a significant negative correlation with 2000 aboveground biomass for both poplar ($r = -0.80$, $p = <0.0001$) and willow ($r = -0.83$, $p = <0.0001$).

Foliar Nitrogen Concentration

Poplar foliar nitrogen concentrations in the establishment year ranged from 20 g kg^{-1} in the no weed control treatment to 33 g kg^{-1} in the cover crop treatment (Figure 2.5). Willow values ranged from 19 g kg^{-1} in the no weed control treatment to 31g kg^{-1} in the cover crop treatment. Foliar nitrogen concentrations were lower in the first year after coppice (1998), ranging from 16 to 22 g kg^{-1} in poplar and 21 to 26 g kg^{-1} in willow. After the plots were fertilized with 100 kg N ha^{-1} in the spring of 1999, foliar nitrogen concentrations increased to 20 – 26 g kg^{-1} for poplar and 25 – 30 g kg^{-1} for willow. Foliar nitrogen concentrations dropped again in 2000 to 18 – 24 g kg^{-1} for poplar and 21 – 23 g kg^{-1} for willow.

In the establishment year (1997), and the first (1998) and second (1999) years of coppice growth the interaction between treatments and species was not significant for foliar nitrogen concentration (Table 2.9). However, the interaction was significant in the third year of coppice growth (2000). In the establishment year, the average foliar nitrogen concentration was 2.2 g kg^{-1} greater in the poplar compared to the willow across all the treatments (Table 2.10). This pattern changed following cutback. The foliar nitrogen concentrations in willow were significantly greater than in poplar in both 1998 (3.4 g kg^{-1}) and 1999 (2.3 g kg^{-1}).

There were significant differences in foliar N concentrations among site preparation treatments in all four years. In 1997, 1998 and 1999 foliar N concentrations were significantly greater in the weed control treatments versus the no weed control treatment. In 2000, this comparison was not significant for either the poplar or the willow. Tillage treatments had significantly higher concentrations of foliar N versus the no-till treatment in both 1997 and 1998. This comparison was not significant in 1999 following the application of 100 kg N ha^{-1}. In 2000, poplar foliar N concentrations in theno-till treatment were significantly higher versus the tillage treatments. Conducting tillage operations in the fall (fall and cover crop treatments) versus the spring had no significant effect on foliar N concentration, except for the willow plots in 2000. Foliar N concentrations in the spring tillage treatment were greater than the strip tillage treatment in the establishment year (1997) and the first year after cutback (1998). The comparison was no longer significant for poplar or willow in 1999 or for poplar in 2000. The spring tillage treatment for willow had higher foliar N concentrations in 2000 compared to the strip tillage treatment.

There was a strong correlation for poplar between 1997 foliar N concentrations and aboveground biomass in 1997, 1998, 1999 and 2000 (Table 2.11, Figure 2.6). The relationship was strong between 1998 foliar N concentrations and aboveground biomass in 1998, 1999 and 2000. However, following fertilization with 100 kg N ha^{-1} in the spring of 1999, the relationship between foliar N concentrations and aboveground biomass for both 1999 and 2000 was still significant but was weak, with $r < 0.43$ in all cases.

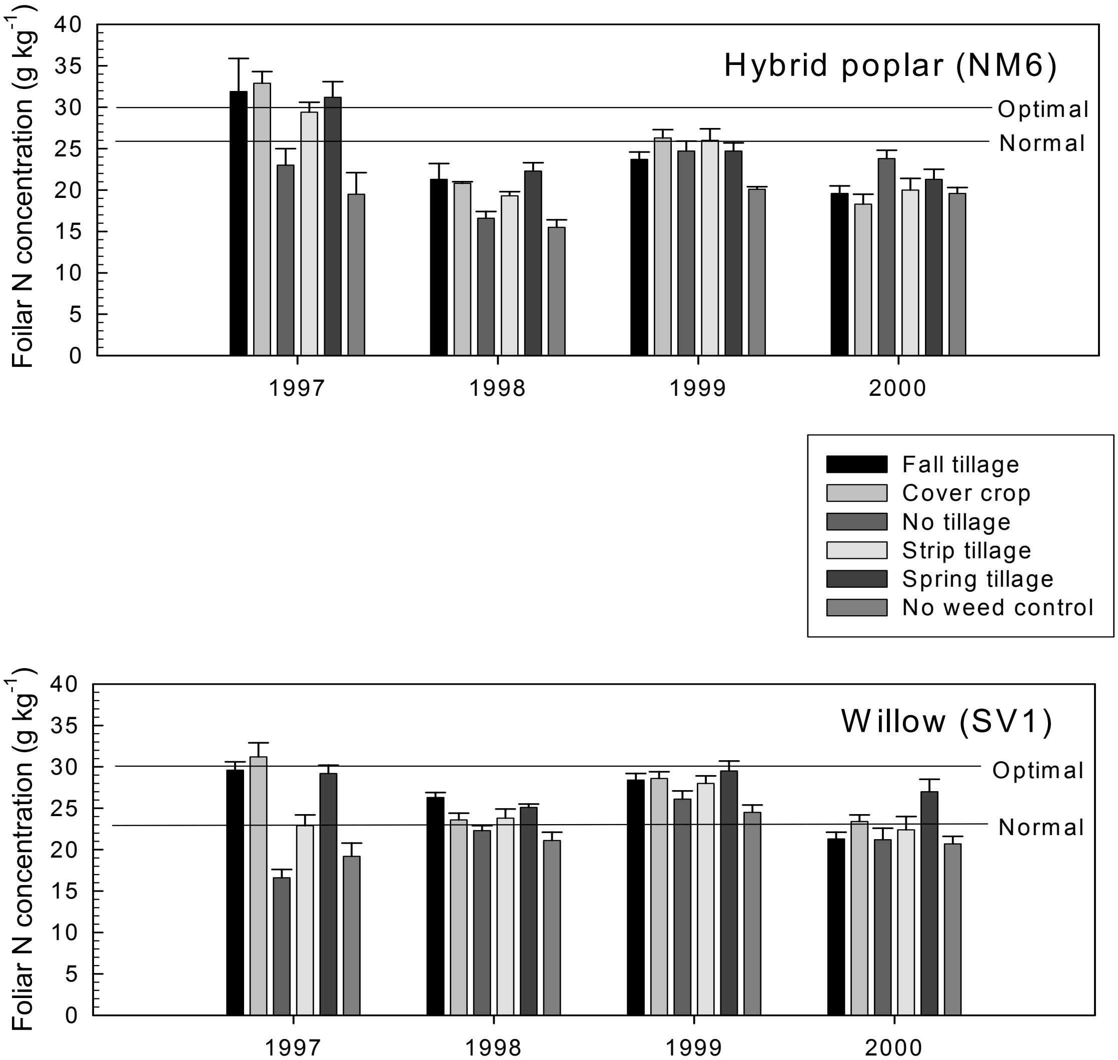

Figure 2.5. Foliar N concentrations (mean +SE) from 1997 – 2000 for hybrid poplar (NM6) and willow (SV1) established using six different site preparation treatments.
Normal and optimal levels for willow are from Ericsson et al. (1992), Rytter and Ericsson (1993), Kopinga and van den Burg (1995), Labrecque et al. (1995), von Fircks et al. (2001). Values for poplar are from Carter and White (1971), Blackmon and White (1972), Hansen (1994), Kopinga and van den Burg (1995), Hansen et al. (1998).

Table 2.9. Mean square and p-values from ANOVAs for foliar N concentrations over four years for poplar (NM6) and willow (SV1) biomass crops for six different site preparation treatments in Lafayette, NY.

		1997		1998		1999		2000	
Source	df	Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value
Block	3	0.3768	0.0418	0.0463	0.2598	0.0076	0.9072	0.0106	0.9075
Treatment	5	2.5413	<0.0001	0.4024	<0.0001	0.2936	0.0001	0.1830	0.0198
Species	1	1.2442	0.0032	2.3259	<0.0001	1.2787	<0.0001	0.5904	0.0032
Treatment x species	5	0.1310	0.3983	0.0339	0.4179	0.0467	0.3664	0.1767	0.0231
Error	33	4.0654		0.0330		0.0415		0.0582	

Table 2.10. Linear contrast estimates and p-values for foliar nitrogen concentrations over four years for one willow (SV1) and one poplar (NM6) clone grown using six different site preparation treatments.

	1997		1998		1999		2000	
Linear contrast	Estimate (g kg^{-1})	p-value	Estimate (g kg^{-1})	p-value	Estimate (g kg^{-1})	p-value	Estimate (g kg^{-1})	p-value
	Main Effects						**Simple Effects Poplar (NM6)**	
Weed control – no weed control	8.44	<0.0001	3.84	<0.0001	4.32	<0.0001	0.10	0.4465
Tillage – no-till	9.99	<0.0001	3.36	<0.0001	1.47	0.0669	-4.01	0.0039
(Fall + cover crop) – spring	1.21	0.4683	-0.701	0.3870	-0.33	0.7014	-2.35	0.1087
Fall – cover crop	-1.32	0.4917	1.63	0.0870	-1.37	0.1713	1.28	0.4423
Spring – strip tillage	4.06	0.0394	2.16	0.0251	0.05	0.9605	1.33	0.4236
Willow - poplar	-3.22	0.0058	4.40	0.0533	3.26	<0.0001		
							Willow (SV1)	
Weed control – no weed control							2.35	0.0739
Tillage – no-till							2.25	0.0925
(Fall + cover crop) – spring							-4.65	0.0024
Fall – cover crop							-2.07	0.2154
Spring – strip tillage							4.52	0.0093

Table 2.11. Pearson correlation coefficients (r) and p-values between foliar N concentrations and aboveground biomass from 1997 – 2000 for one willow (SV1) and one poplar (NM6) clone grown using six different site preparation treatments.

	1997 aboveground biomass	1998 aboveground biomass	1999 aboveground biomass	2000 aboveground biomass
Hybrid Poplar NM6				
1997 foliar N concentration	0.7366	0.6688	0.7235	0.7718
	<0.0001	0.0004	<0.0001	<0.0001
1998 foliar N concentration		0.6913	0.7397	0.8001
		0.0002	<0.0001	<0.0001
1999 foliar N concentration			0.4201	0.4234
			0.0409	0.0392
2000 foliar N concentration				0.0465
				0.8293
Willow SV1				
1997 foliar N concentration	0.7695	0.7557	0.8357	0.8564
	<0.0001	<0.0001	<0.0001	<0.0001
1998 foliar N concentration		0.3632	0.4896	0.4956
		0.0811	0.0152	0.0138
1999 foliar N concentration			0.5631	0.6828
			0.0042	0.0002
2000 foliar N concentration				0.6042
				0.0018

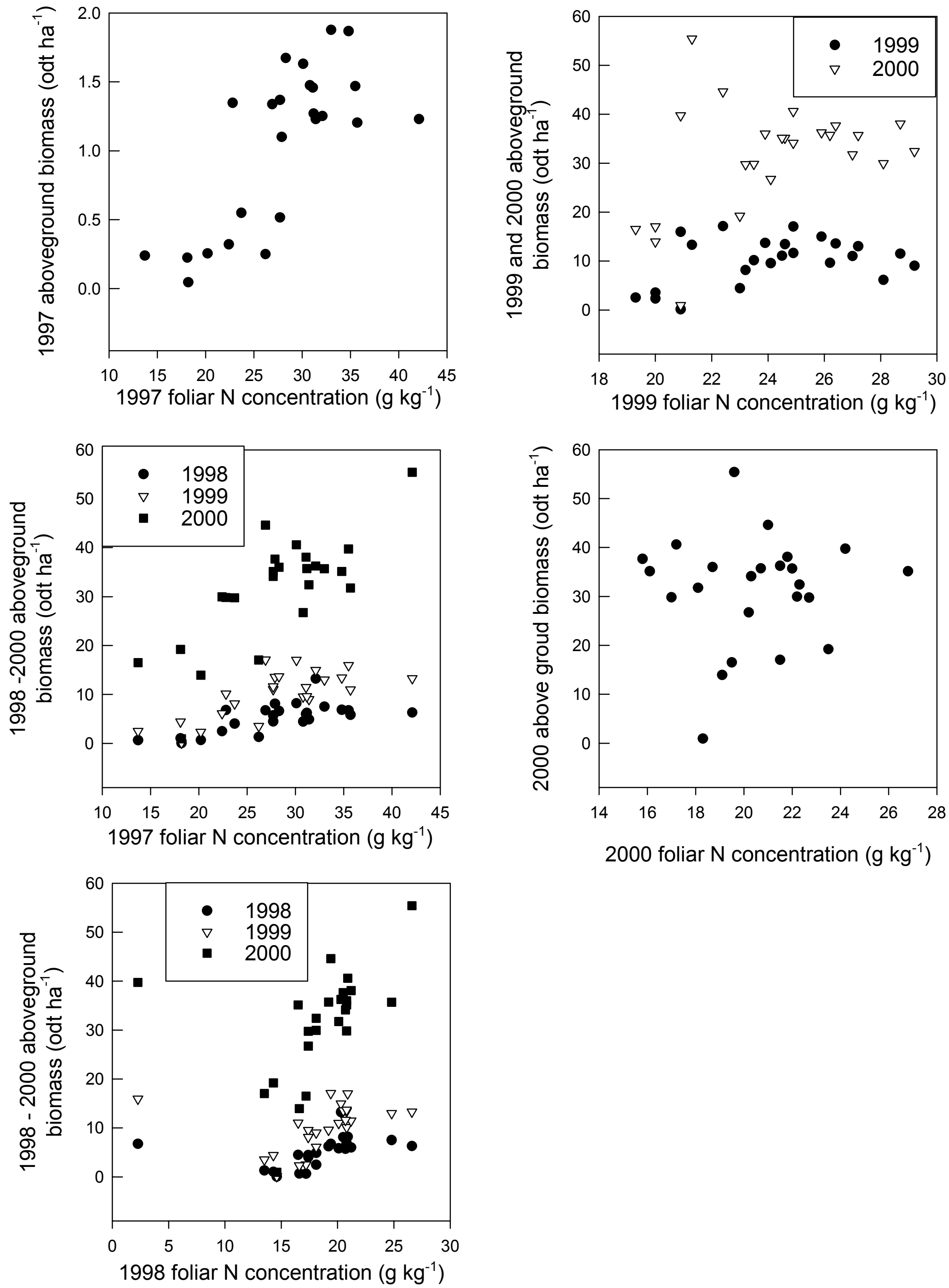

Figure 2.6. Foliar N concentration versus aboveground biomass from 1997 –2000 for hybrid poplar clone NM6 established using six different alternative site preparation methods in central NY.

Willow foliar nitrogen concentrations in 1997 had a strong correlation with aboveground biomass in 1997, 1998, 1999, and 2000 (Table 2.11, Figure 2.7). The relationship between 1998 foliar N concentrations and aboveground biomass in 1998 – 2000 was weak ($r < 0.50$). The relationship was stronger again for foliar N concentrations in 1999 and 2000 and biomass production in 1999 and 2000 with r-values ranging from 0.56 – 0.68.

Foliar Phosphorus Concentration

Foliar P concentrations for poplar were greatest in the establishment year (1997), ranging from 1.8 to 2.0 g kg^{-1} (Figure 2.8). Concentrations decreased to below 2 g kg^{-1} for all treatments in 1998 and continued to decrease slightly over the next two years. In contrast, willow foliar P concentrations were low in the establishment year (1997), ranging from 0.6 – 1.2 g kg^{-1}. Following coppice the level increased to 2 – 2.5 g kg^{-1} in 1998. P concentrations decreased across all willow treatments in 1999. In 2000, the pattern varied among treatments. It decreased for the fall tillage treatment, remained stable for the cover crop and spring tillage treatments, and increased for the no–till, strip tillage and no weed control treatments.

The interaction between species and treatment was only significant for foliar P concentrations in the establishment year (Table 2.12). Foliar P concentrations were significantly greater in the weed control treatments in 1997, 1998 and 1999 (Table 2.13). foliar P concentrations versus the no-till treatments throughout the experiment. In 1997, the poplar fall tillage treatment had higher foliar P concentrations than the cover crop treatment. This comparison was not significant in the willow or at any time in the rest of the study. In 1998 and 2000, willow foliar P concentrations were greater than poplar across all treatments.

Foliar Potassium Concentration

In the establishment year (1997), poplar foliar K concentrations ranged from 10 to 15 g kg^{-1} (Figure 2.9). In the first year of coppice growth (1998), K concentrations decreased in all but the strip tillage and no weed control treatments. Foliar K concentrations declined in all treatments in 1999 to 9 to 11 g kg^{-1}. In 2000, all concentrations increased in all treatments to 12 to 14 g kg^{-1}.

Willow K foliar concentrations ranged from 5 to 10 g kg^{-1} in the establishment year (1997). In the first year of coppice growth (1998), concentrations decreased in the fall treatment, did not change in the cover crop and spring tillage treatments, and increased in the strip tillage, no-till and no weed control treatments. In 1999, the pattern varied among treatments. Concentrations increased in the fall, cover crop, and strip tillage treatments, remained the same as in 1998 in the cover crop and spring tillage treatments and decreased in the no weed control treatment. In 2000, concentrations increased in all treatments to 10 to 16 g kg^{-1}.

The interaction term for foliar K concentration was only significant in 2000 (Table 2.14). From 1997 through 1999, poplar foliar K concentrations were greater in poplar than in willow (Table 2.15). Treatment main effects were significant in 1997 and 1999 when the concentrations were greater on weed control and tillage plots compared to

The comparison was not significant in 2000. Tillage treatments had significantly higher significant differences in poplar foliar K concentrations among the treatments.

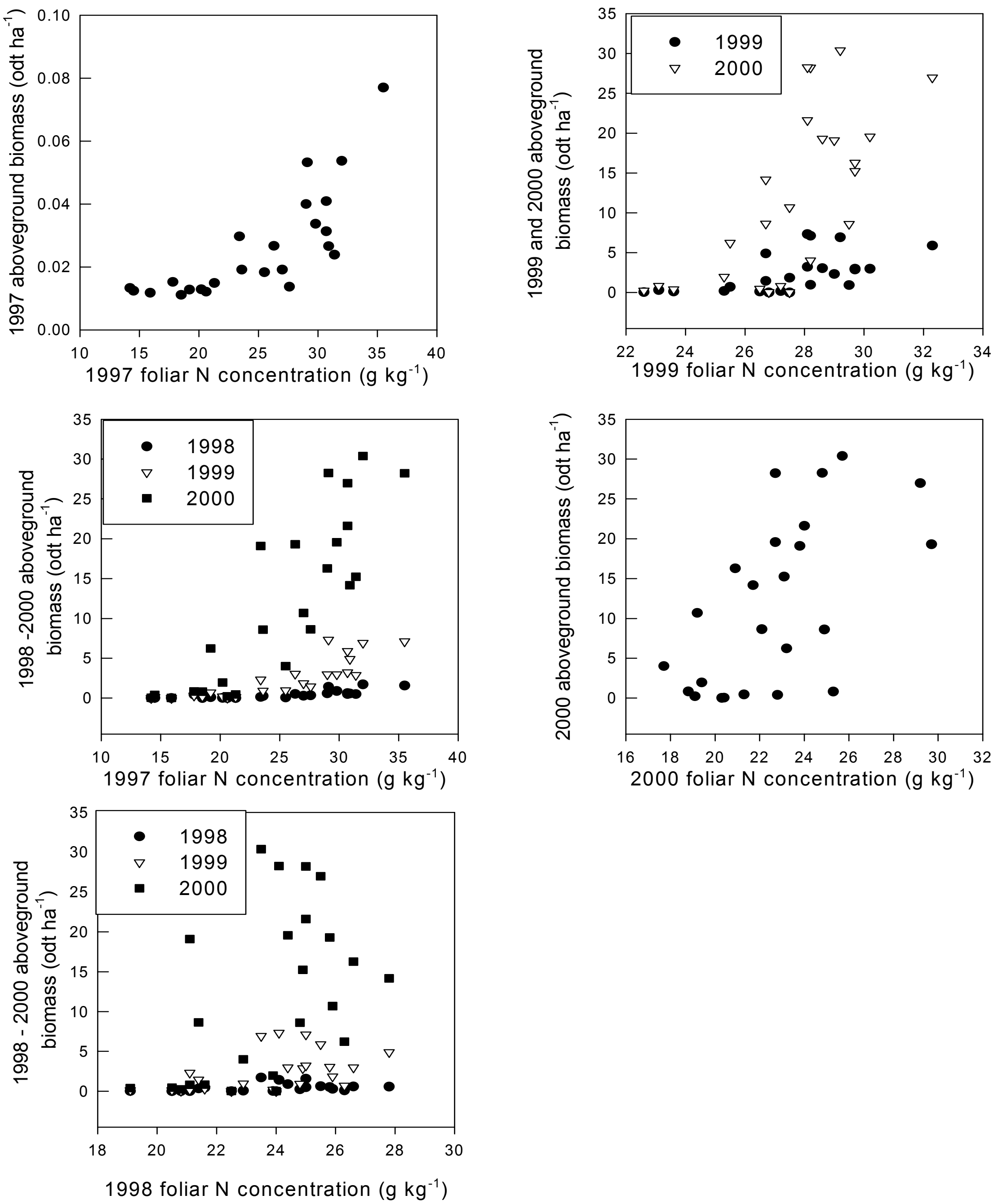

Figure 2.7. Foliar N concentration versus aboveground biomass from 1997 – 2000 for willow clone SV1 established using six different alternative site preparation methods in Central NY.

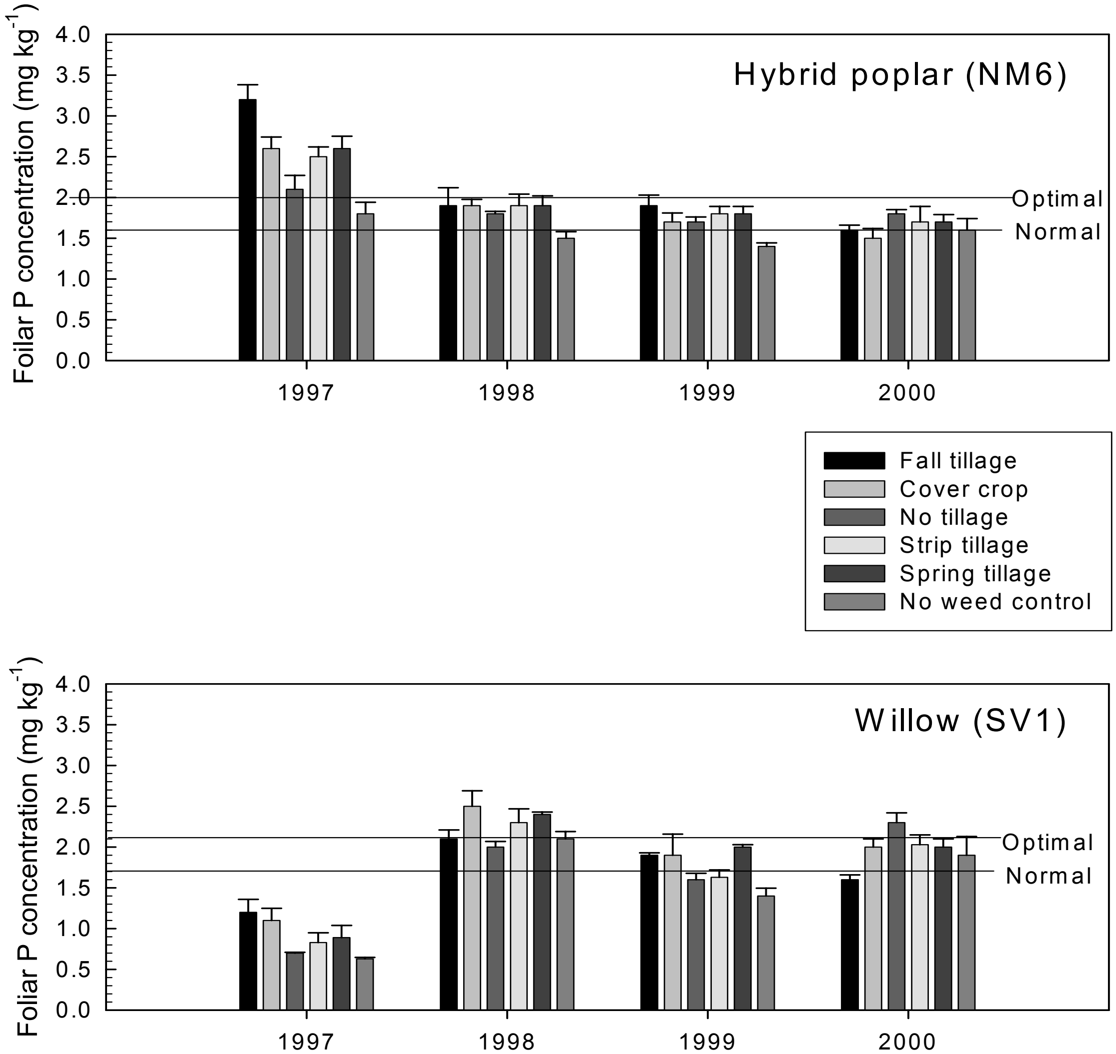

Figure 2.8. Foliar P concentrations (mean + SE) from 1997 – 2000 for hybrid poplar (NM6) and willow (SV1) established using six different site preparation treatments.
Values for normal and optimat levels are from Kopinga and van den Burg (1995).

Table 2.12. Mean square and p-values from ANOVAs for foliar P concentrations over four years for poplar (NM6) and willow (SV1) biomass crops for six different site preparation treatments in Lafayette, NY.

		1997		1998		1999		2000	
Source	df	Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value
Block	3	0.0016	0.0838	0.0008	0.2891	0.0009	0.1377	0.0002	0.8156
Treatment	5	0.0080	<0.0001	0.0021	0.0128	0.0028	0.0004	0.0019	0.0305
Species	1	0.2982	<0.0001	0.0202	<0.0001	0.0001	0.6130	0.0133	<0.0001
Treatment x species	5	0.0011	0.1701	0.0006	0.4406	0.0006	0.2674	0.0007	0.4386
Error	33	0.0007		0.0006		0.0004		0.0007	

Table 2.13. Linear contrasts and p-values for foliar P concentrations over four years for one willow (SV1) and one poplar (NM6) clone grown using six different site preparation treatments.

	1997		1998		1999		2000	
Linear contrast	Estimate ($g\ kg^{-1}$)	p-value	Estimate ($g\ kg^{-1}$)	p-value	Estimate ($g\ kg^{-1}$)	p-value	Estimate ($g\ kg^{-1}$)	p-value
	Simple Effects Poplar (NM6)				**Main Effects**			
Weed control – no weed control	0.75	<0.0001	0.29	0.0044	0.04	<0.0001	0.12	0.2247
Tillage – no-till	0.56	0.0007	0.24	0.0205	0.18	0.0490	-0.29	0.0067
(Fall + cover crop) – spring	0.22	0.1991	-0.08	0.4906	-0.05	0.6427	-0.19	0.0930
Fall – cover crop	0.39	0.0502	-0.14	0.2808	0.07	0.5201	-0.14	0.2856
Spring – strip tillage	0.12	0.5447	0.03	0.7964	0.15	0.1731	0.02	0.8991
Willow - poplar			0.41	<0.0001	0.03	0.6263	0.33	<0.0001
	Willow (SV1)							
Weed control – no weed control	0.03	0.0479						
Tillage – no-till	0.33	0.0342						
(Fall + cover crop) – Spring	0.25	0.1385						
Fall – cover crop	0.04	0.8221						
Spring – strip tillage	0.06	0.7516						

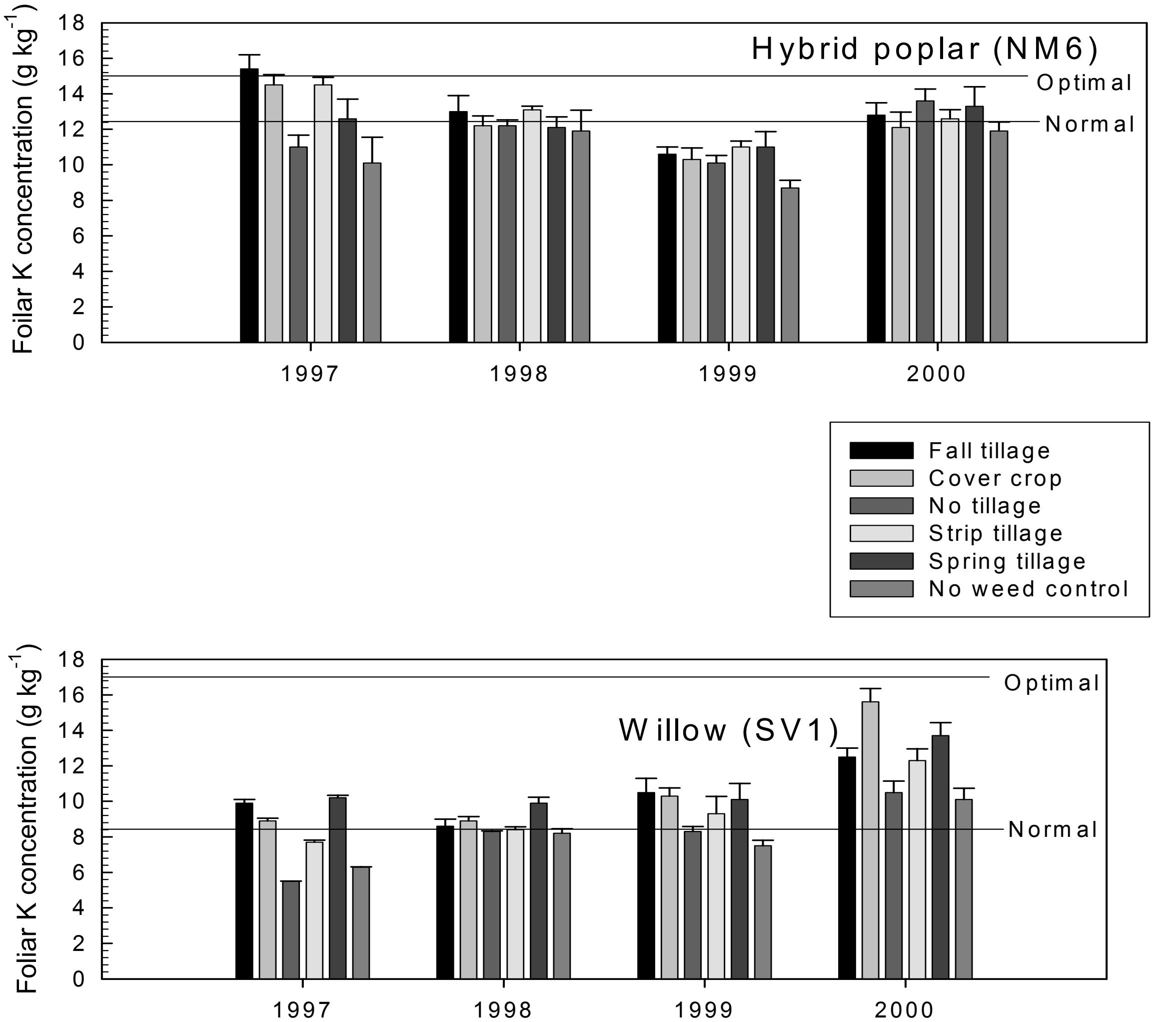

Figure 2.9. Foliar K concentrations (mean + SE) from 1997 – 2000 for hybrid poplar (NM6) and willow (SV1) established using six different site preparation treatments.
Values for normal and optimal levels are from Kopinga and van den Burg (1995).

Table 2.14. Mean square and p-values from ANOVAs for foliar K concentrations over four years for poplar (NM6) and willow (SV1) biomass crops for six different site preparation treatments in Lafayette, NY.

		1997		1998		1999		2000	
Source	DF	Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value
Block	3	0.0947	0.0966	0.0305	0.0516	0.0779	0.0005	0.0350	0.1552
Treatment	5	0.2852	0.0002	0.0102	0.4584	0.0798	<0.0001	0.0869	0.0027
Species	1	2.8595	<0.0001	1.6500	<0.0001	0.1055	0.0027	0.0095	0.4823
Treatment x species	5	0.0484	0.3440	0.0161	0.2121	0.0143	0.2382	0.1011	0.0010
Error	33	0.0414		0.0107		0.0100		0.0188	

Table 2.15. Linear contrasts and p-values for foliar K concentrations over four years for one willow (SV1) and one poplar (NM6) clone grown using six different site preparation treatments.

	1997		1998		1999		2000	
Linear contrast	Estimate ($g\ kg^{-1}$)	p-value	Estimate ($g\ kg^{-1}$)	p-value	Estimate ($g\ kg^{-1}$)	p-value	Estimate ($g\ kg^{-1}$)	p-value
			Main Effects				**Simple Effects Poplar (NM6)**	
Weed control – no weed control	2.81	0.0017	0.64	0.1475	2.10	0.0001	0.96	0.2245
Tillage – no-till	3.50	0.0002	0.53	0.2356	1.22	0.0185	-0.91	0.2590
(Fall + cover crop) – spring	0.83	0.3766	-0.27	0.5782	-0.14	0.8019	-0.81	0.3564
Fall – cover crop	0.93	0.3921	0.23	0.6785	0.22	0.7252	0.63	0.5328
Spring – strip tillage	0.25	0.8141	0.15	0.7859	0.46	0.4683	0.67	0.5110
Willow - poplar	-4.88	<0.0001	-3.71	<0.0001	-0.94	0.0136		
							Willow (SV1)	
Weed control – no weed control							2.92	0.0006
Tillage – no-till							3.02	0.0005
(Fall + cover crop) – spring							0.32	0.7116
Fall – cover crop							-3.17	0.0032
Spring – strip tillage							1.39	0.1752

However, willow foliar K concentrations were greater in the weed control versus no weed control, and tillage versus no-till. The willow cover crop treatment had higher foliar K concentrations compared to the fall tillage treatment.

Foliar Calcium Concentration

The interaction between species and treatments was significant in 1997 and 1998 for foliar calcium concentrations (Table 2.16). In the establishment year (1997), poplar and willow no weed control treatments had higher concentrations of foliar Ca versus the weed control treatments (Figure 2.10, Table 2.17). The comparison was not significant for no weed control and no-till treatments respectively. In 2000, there were no either

Table 2.16. Mean square and p-values from ANOVAs for foliar Ca concentrations over four years for poplar (NM6) and willow (SV1) biomass crops for six different site preparation treatments in Lafayette, NY.

		1997		1998		1999		2000	
Source	df	Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value
Block	3	0.1189	0.0598	0.0137	0.7394	0.0619	0.2977	0.1375	0.2185
Treatment	5	0.0785	0.1400	0.0519	0.1882	0.2590	0.0010	0.0945	0.3946
Species	1	0.1206	0.1058	1.587	<0.0001	1.0555	<0.0001	0.6018	0.0135
Treatment x species	5	0.1758	0.0058	0.0883	0.0367	0.0557	0.3537	0.0352	0.8463
Error	33	0.0436		0.0325		0.0484		0.0883	

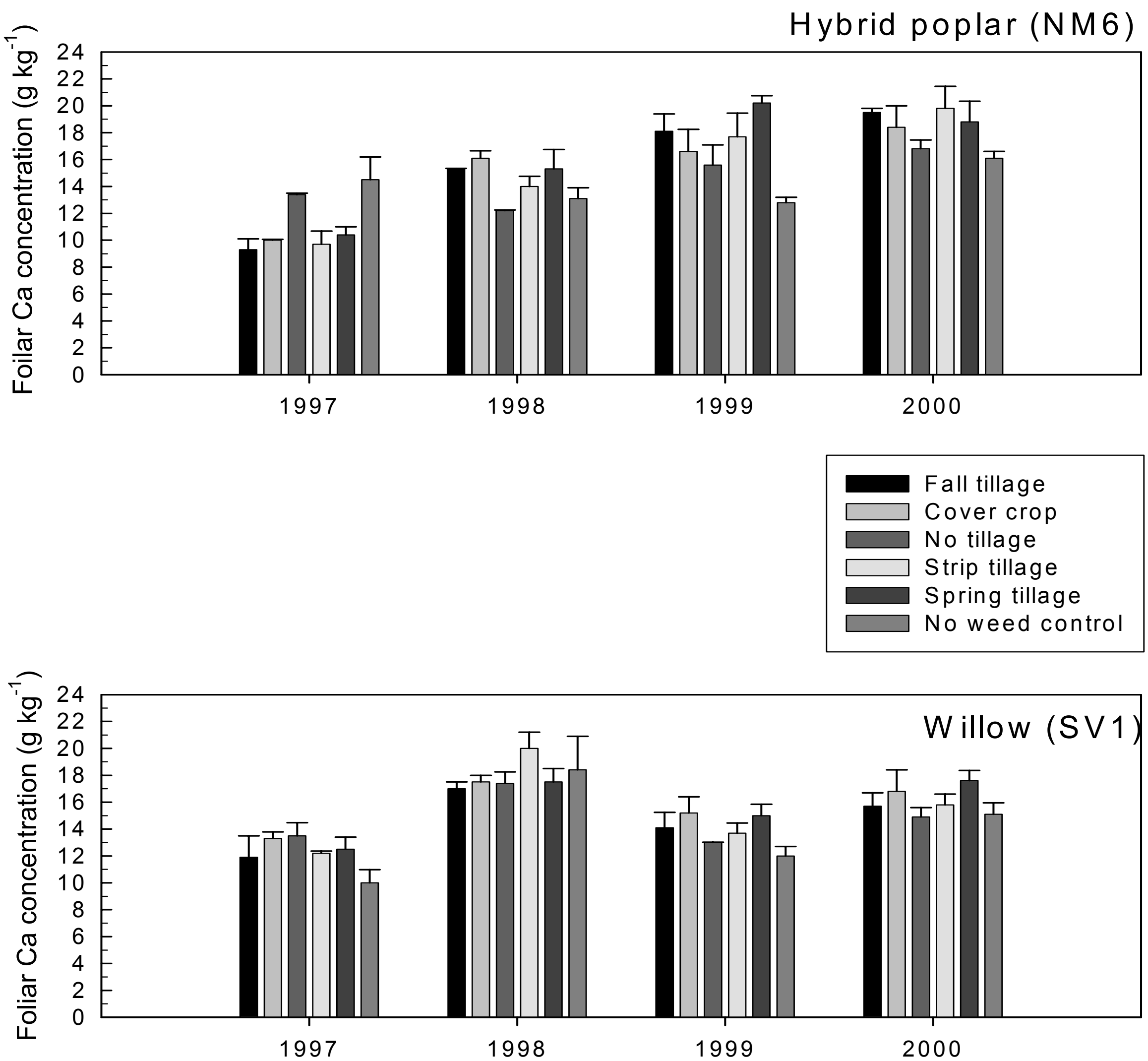

Figure 2.10. Foliar Ca concentrations (mean + SE) from 1997 – 2000 for hybrid popolar (NM6) and willow (SV1) established using six different site preparation treatments.

Table 2.17. Linear contrasts and p-values for foliar Ca concentrations over four years for one willow (SV1) and one poplar (NM6) clone grown using six different site preparation treatments.

	1997		1998		1999		2000	
Linear contrast	Estimate ($g\ kg^{-1}$)	p-value	Estimate ($g\ kg^{-1}$)	p-value	Estimate ($g\ kg^{-1}$)	p-value	Estimate ($g\ kg^{-1}$)	p-value
	Simple Effects Poplar (NM6)				**Main Effects**			
Weed control – no weed control	-4.02	0.0023	1.48	0.1333	3.57	0.0002	1.79	0.1369
Tillage – no-till	-3.48	0.0084	2.99	0.0044	2.01	0.0285	1.93	0.1179
(Fall + cover crop) – spring	-0.75	0.5871	0.48	0.6597	-1.63	0.0997	-0.64	0.6325
Fall – cover crop	-0.58	0.7138	-0.76	0.5471	0.26	0.8187	0.04	0.9817
Spring – strip tillage	0.76	0.6312	1.37	0.2795	1.93	0.0913	0.41	0.7903
Willow - poplar					-2.97	<0.0001	-2.24	0.0151
	Willow (SV1)							
Weed control – no weed control	2.74	0.0313	-0.49	0.6126				
Tillage – no-till	-0.96	0.4493	0.63	0.5230				
(Fall + cover crop) – spring	0.10	0.9405	-0.21	0.8447				
Fall – cover crop	-1.40	0.3821	-0.61	0.6290				
Spring – strip tillage	0.29	0.8533	-2.50	0.0517				

poplar or willow in the first year of coppice growth (1998). Poplar foliar Ca concentrations were significantly greater in the tillage treatments versus no-till in 1997 and 1998. In the second (1998) and third (1999) year of coppice growth, poplar foliar Ca concentrations were significantly higher than in willow.

Foliar Magnesium Concentration

The interaction between species and treatment was only significant in the establishment year (1997) for foliar Mg concentration (Table 2.18). In 1997, poplar foliar Mg concentrations were significantly greater in the no weed control and no-till plots versus the weed control and tillage plots (Figure 2.11, Table 2.19). Willow foliar Mg concentrations in 1997 were higher in the weed control, no-till and cover crop treatments versus the no weed control, tillage and fall tillage treatments. In 1998, 1999 and 2000, willow foliar Mg concentrations were significantly greater than in poplar. The only other difference between treatments in during the three years of coppice growth (1998 – 2000) was a significantly higher level in the no-till versus tillage treatments in 1999.

Table 2.18. Mean square and p-values from ANOVAs for foliar Mg concentrations over four years for poplar (NM6) and willow (SV1) biomass crops for six different site preparation treatments in Lafayette, NY.

		1997		1998		1999		2000	
Source	df	Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value
Block	3	0.0071	0.0195	0.0007	0.6591	0.0049	0.0144	0.0040	0.1907
Treatment	5	0.0093	0.0018	0.0004	0.8812	0.0035	0.0270	0.0026	0.3883
Species	1	0.1776	<0.0001	0.3320	<0.0001	0.0200	0.0003	0.0284	0.0015
Treatment x species	5	0.0119	0.0003	0.0014	0.4055	0.0005	0.8158	0.0018	0.5924
Error	33	0.0019		0.0013		0.0012		0.0024	

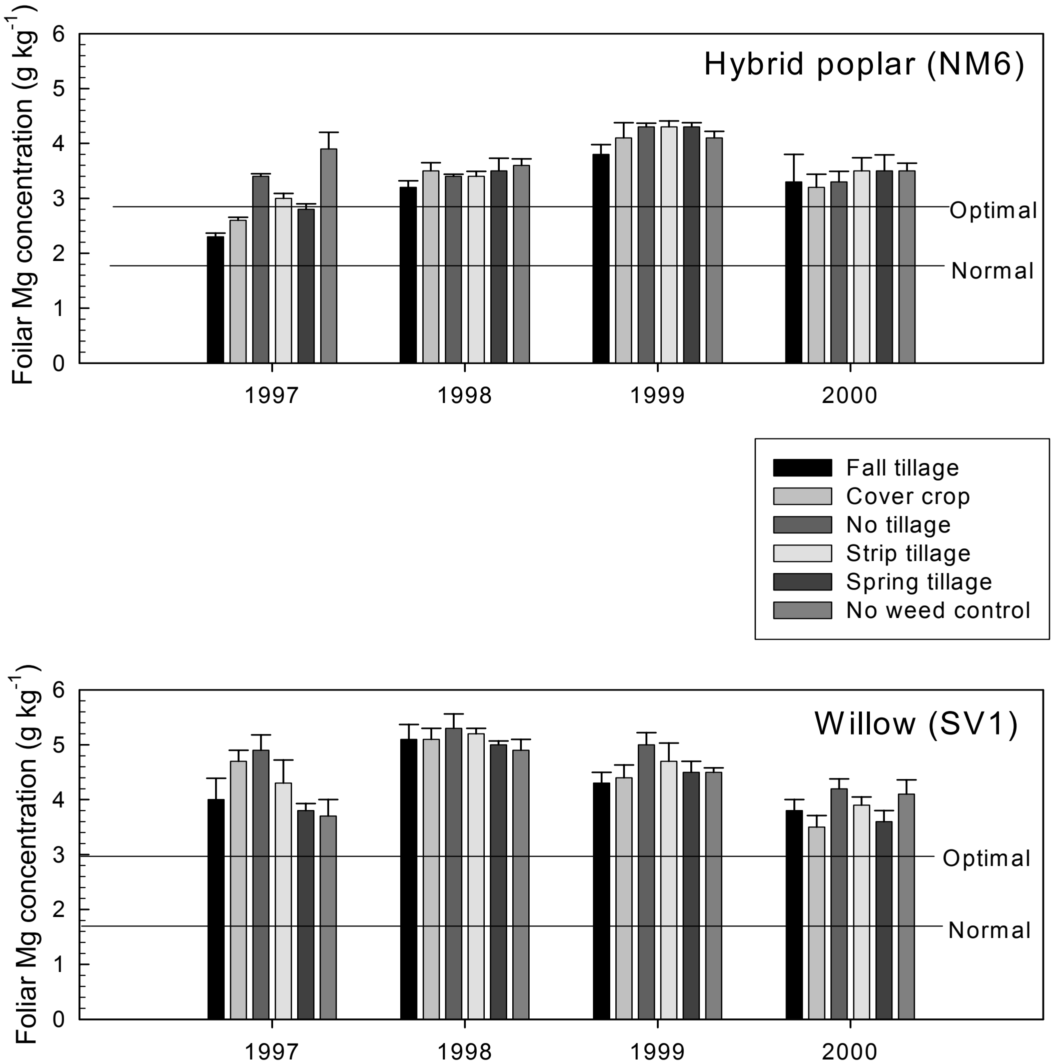

Figure 2.11. Foliar Mg concentrations (mean +SE) from 1997 – 2000 for hybrid poplar (NM6) and willow (SV1) established using six different site preparation treatments.
Values for normal and optimal levels are from Kopinga and van den Burg (1995).

Table 2.19. Linear contrasts and p-values for foliar Mg concentrations over four years for one willow (SV1) and one poplar (NM6) clone grown using six different site preparation treatments.

	1997		1998		1999		2000	
Linear contrast	Estimate ($g\ kg^{-1}$)	p-value	Estimate ($g\ kg^{-1}$)	p-value	Estimate ($g\ kg^{-1}$)	p-value	Estimate ($g\ kg^{-1}$)	p-value
	Simple Effects Poplar (NM6)				**Main Effects**			
Weed control – no weed control	-1.04	0.0004	0.03	0.8122	0.14	0.3578	-0.24	0.2259
Tillage – no-till	-0.65	0.0203	-0.10	0.4828	-0.34	0.0309	-0.22	0.2689
(Fall + cover crop) –spring	-0.35	0.2484	-0.10	0.5399	-0.26	0.1260	-0.06	0.8018
Fall – cover crop	-0.23	0.4967	-0.12	0.5200	-0.17	0.3787	0.22	0.3878
Spring – strip tillage	-0.17	0.6188	-0.03	0.8581	-0.07	0.7038	-0.22	0.3962
Willow - poplar			1.66	<0.0001	0.41	0.0008	0.49	0.0018
	Willow (SV1)							
Weed control – no weed control	0.65	0.0190						
Tillage – no-till	-0.73	0.0100						
(Fall + cover crop) – spring	0.48	0.1165						
Fall – cover crop	-0.70	0.0484						
Spring –strip tillage	-0.48	0.1983						

Soil Characteristics

Soil characteristics for the surface layer (0 –15 cm) in 1997 are listed in Tables 2.20 and 2.21. There were few significant differences in the soil characteristics measured at the 0 – 15 cm depth in 1997. The interaction between treatments and species was only significant for nitrogen and calcium concentrations (Table 2.22). Soil nitrogen concentrations ranged from 2.0 – 2.5 g kg^{-1} in the poplar treatments and 1.9 – 2.7 g kg^{-1} in the willow treatments. Soil N concentrations were greater in the no-till treatments versus the tilled treatments for willow, but this comparison was not significant in the poplar treatments (Tables 2.23). Calcium concentrations were greater in the fall and cover crop treatments versus the spring tillage treatments for willow, but not for poplar (Table 2.24). Cation exchange capacity was significantly greater in the willow treatments versus the poplar treatments. Phosphorus concentrations were greater in the no-till treatments versus the tillage treatments. There were no differences in bulk density, soil carbon, K or Mg concentrations among the treatments.

Table 2.20. Soil characteristics for the 0 - 15 cm depth in 1997 for willow (SV1) established with six different site preparation treatments in Lafayette, NY.

	Bulk Density ($Mg\ m^{-3}$)		pH		Soil Carbon ($Mg\ ha^{-1}$)		Nitrogen ($g\ kg^{-1}$)		P ($mg\ kg^{-1}$)	
Treatment	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	1.27	0.035	7.58	0.119	64.99	2.41	2.29	0.15	33.23	8.20
Cover crop	1.21	0.088	7.68	0.012	57.53	3.96	1.91	0.41	31.12	15.69
No till	1.27	0.076	7.59	0.196	70.79	3.57	2.67	0.56	53.88	23.10
Strip till	1.35	0.039	7.49	0.148	74.79	3.94	2.33	0.28	37.43	15.48
Spring tillage	1.26	0.054	7.71	0.283	66.78	1.98	2.36	0.41	43.83	27.17
No weed control	1.23	0.017	7.64	0.069	65.03	2.37	2.30	0.29	36.59	14.84

	K ($mg\ kg^{-1}$)		Ca ($mg\ kg^{-1}$)		Mg ($mg\ kg^{-1}$)		CEC ($cmol\ kg^{-1}$)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	83.15	22.05	4275.1	458.3	599.4	136.4	17.86	0.53
Cover crop	67.00	24.72	3709.8	628.3	450.4	179.3	17.40	1.61
No till	88.55	25.19	2657.8	1035.2	586.3	83.9	20.47	1.01
Strip till	87.66	15.92	3014.9	528.5	534.8	105.7	19.71	1.78
Spring tillage	68.53	16.30	2373.3	2007.4	455.1	318.0	19.79	2.87
No weed control	94.21	24.37	4100.3	323.1	571.1	84.8	18.36	2.03

Table 2.21. Soil characteristics for the 0 - 15cm depth in 1997 for poplar (NM6) established with six different site preparation treatments in Lafayette, NY.

	Bulk Density ($Mg\ m^{-3}$)		pH		Soil Carbon ($Mg\ ha^{-1}$)		N ($g\ kg^{-1}$)		P ($mg\ kg^{-1}$)	
Treatment	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	1.18	0.049	7.62	0.143	61.64	4.83	2.15	0.12	37.87	16.49
Cover crop	1.24	0.092	7.60	0.987	66.09	3.39	2.46	0.28	36.57	12.73
No till	1.27	0.091	7.42	0.143	67.64	8.73	2.29	0.32	33.08	14.63
Strip till	1.35	0.017	7.49	0.176	68.24	2.48	2.19	0.18	31.27	15.81
Spring tillage	1.29	0.053	7.56	0.052	62.88	0.88	2.02	0.11	32.78	8.54
No weed control	1.25	0.043	7.57	0.135	67.54	4.87	2.39	0.45	53.90	22.92

	K ($mg\ kg^{-1}$)		Ca ($mg\ kg^{-1}$)		Mg ($mg\ kg^{-1}$)		CEC ($cmol\ kg^{-1}$)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	67.71	6.72	2979.3	1137.4	462.1	35.3	16.93	3.47
Cover crop	70.91	13.96	3467.6	1101.1	518.4	154.2	16.03	5.67
No till	86.30	30.13	2713.3	97.6	427.0	42.8	16.61	2.78
Strip till	84.14	4.61	3088.9	758.3	571.1	61.2	15.57	3.19
Spring tillage	75.50	10.28	3831.6	540.1	521.1	107.5	15.01	3.14
No weed control	71.38	10.86	3411.5	813.5	604.6	156.6	18.47	4.74

Table 2.22. Mean square and p-values from ANOVAs for soil properties at 0 – 15 cm depth in 1997 for six different site preparation treatments in Lafayette, NY with one willow (SV1) and one poplar (NM6) clone.

		Bulk Density		pH		Soil Carbon		N		P	
Source	df	Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value
Block	3	0.051	0.0093	0.024	0.3576	104.96	0.1966	0.0033	0.0174	257.43	0.4678
Treatment	5	0.018	0.1900	0.033	0.2032	107.04	0.1661	0.0011	0.3193	188.364	0.6747
Species	1	0.001	0.9206	0.060	0.1051	11.52	0.6730	0.0004	0.4782	37.36	0.7250
Treatment x species	5	0.004	0.8905	0.014	0.6567	61.29	0.4540	0.0023	0.0366	370.05	0.3100
Error	33	0.0113		0.0217		2098.29		0.0009		296.8349	

		K		Ca		Mg		CEC	
Source	df	Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value
Block	3	1335.0	0.2940	240059.1	0.8488	22524.1	0.3555	14.1970	0.2324
Treatment	5	2359.7	0.2613	1403174.0	0.1986	12980.0	0.6673	2.8620	0.9074
Species	1	366.4	0.3101	134752.5	0.7012	2864.3	0.7084	68.7124	0.0111
Treatment x species	5	1314.5	0.5835	1715639.6	0.1197	21674.4	0.3912	7.8026	0.5405
Error	33	11381.5		899460.1		20132.8		9.4441	

Table 2.23. Linear contrast estimates and p-values for soil characteristics at 0 - 15 cm depth in 1997 for one willow (SV1) and one poplar clone (NM6) grown using six different site preparation treatments.

Linear contrast	Bulk Density Estimate ($Mg\ m^{-3}$)	Bulk Density p-value	pH Estimate	pH p-value	Soil Carbon Estimate ($Mg\ ha^{-1}$)	Soil Carbon p-value	N Estimate ($g\ kg^{-1}$)	N p-value	P Estimate ($mg\ kg^{-1}$)	P p-value
	Main Effects						**Simple Effects Poplar (NM6)**		**Main Effects**	
Weed control – no weed control	0.034	0.4667	-0.02	0.6128	-0.14	0.9628	-0.22	0.3350	-8.13	0.2287
Tillage – no-till	0.003	0.9461	0.09	0.1392	-3.85	0.2422	-0.14	0.6078	-7.97	.02471
(Fall + cover crop) – spring	-0.46	0.3858	0.02	0.8012	-2.27	0.5262	0.31	0.1629	-3.61	0.6299
Fall – cover crop	0.004	0.9459	-0.03	0.6630	1.51	0.7149	-0.30	0.1812	1.71	0.8430
Spring – strip	-0.078	0.2057	0.14	0.0598	-6.69	0.1109	-0.25	0.4792	3.94	0.6475
Willow - poplar	0.003	0.9301	0.07	0.1059	0.98	0.6808			1.76	0.7234
							Willow (SV1)			
Weed control – no weed control							0.01	0.9525		
Tillage – no-till							-0.42	0.0212		
(Fall + cover crop) – spring							-0.30	0.2077		
Fall – cover crop							0.40	0.1044		
Spring – strip							0.02	0.8830		

Table 2.24. Linear contrasts and p-values for soil characteristics at 0 - 15 cm depth in 1997 for one willow (SV1) and one poplar (NM6) clone grown using six different site preparation treatments.

Linear contrast	K		Ca		Mg		CEC	
	Estimate (mg kg^{-1})	p-value	Estimate (mg kg^{-1})	p-value	Estimate (mg kg^{-1})	p-value	Estimate (cmol$_c$ kg^{-1})	p-value
	Main Effects		**Simple Effects Poplar (NM6)**		**Main Effects**			
Weed control – no weed control	-4.85	0.5091	-195.36	0.7002	-75.32	0.1811	-0.88	0.4748
Tillage – no-till	-11.85	0.1195	628.61	0.2290	7.41	0.8961	-1.25	0.3478
(Fall + cover crop) – spring	0.18	0.9830	-608.19	0.2870	19.44	0.7547	-0.35	0.7970
Fall – cover crop	6.48	0.4952	-488.38	0.4572	46.38	0.5195	0.68	0.6650
Spring – strip tillage	-13.88	0.1484	742.69	0.2606	-64.78	0.3696	0.23	0.8821
Willow - poplar	5.52	0.3152			15.45	0.7096	2.49	0.0099
			Willow (SV1)					
Weed control – no weed control			-894.70	0.0839				
Tillage – no-till			684.75	0.1909				
(Fall + cover crop) – spring			1622.19	0.0066				
Fall – cover crop			565.38	0.3900				
Spring – strip tillage			-644.63	0.3278				

There were few differences in soil characteristics in 1997 at the 15 – 30 cm depth. Soil characteristics are listed in Tables 2.25 and 2.26. The only significant interaction term was for soil carbon (Table 2.27). Soil carbon content at this depth ranged from 41 to 61 t ha^{-1}, which was slightly less than the surface layer. The tilled poplar treatments had a significantly greater soil carbon content versus the no-till treatment (Table 2.28). However, this comparison was not significant under willow. Under the willow, soil carbon was significantly greater in the no weed control treatments versus the weed control treatments. The willow fall tillage treatment had higher soil carbon levels versus the cover crop treatment, but this difference was not significant under poplar. Main effect treatments at 15 – 30 cm depth in 1997 were significant for bulk density. Bulk density in the tilled treatments was significantly greater than the untilled treatments and the cover crop treatment bulk density was greater than the fall tillage treatment. Cation exchange capacity was greater in the spring tillage treatment compared to the treatments tilled in the fall (Table 2.29). There were no differences among the treatments in pH, N, P, K, Ca and Mg.

There were only a few significant differences among the poplar and willow treatments in soil characteristics at the 0 – 15 cm in 2000. Soil characteristics are listed in Tables 2.30 and 2.31. The interaction between site preparation treatment and species was significant for pH, N, P, Mg and cation exchange capacity (Table 2.32). Soil pH in 2000 ranged from 7.49 - 7.82. Under poplar, pH was 0.19 units higher in the tilled treatments versus the no-till and 0.22 units higher in the fall tillage treatment versus the cover crop treatment (Table 2.33). Under the willow, pH was 0.15 units higher in the fall tillage treatments (fall tillage and cover crop treatments) versus the spring tillage treatment. Nitrogen concentrations were 0.35 g kg^{-1} higher under the willow weed control treatment versus the no weed control treatment. Under poplar the pattern was reversed, but was not statistically significant. Under poplar, magnesium concentrations were 65.7 mg kg^{-1} higher in the no-till treatment versus the tilled treatment and 85.4 mg kg^{-1} higher in the cover crop treatments versus the fall tillage treatments (Table 2.34). These differences were not significant under willow. The

only significant difference in cation exchange capacity was under the poplar where the no weed control treatment was 2.2 $cmol_c$ kg^{-1} higher than the weed control treatment. The only significant differences for main effects were for soil carbon. The no-till treatments had 7.5 Mg ha^{-1} more soil carbon than the tilled treatments. Linear contrasts indicated that there were no significant differences among treatments for bulk density, P, K and Ca.

Soil characteristics were similar among the treatments at 15 – 30 cm depth in 2000. Soil characteristics are listed in Tables 2.35 and 2.36. The only significant interaction term was for phosphorus concentration (Table 2.37). However, there were no differences among the site preparation treatments within each species (Table 2.38). The only significant differences among the main effects were for bulk density. Bulk density was greater under weed control treatments versus the no weed control treatments and less under poplar compared to willow (Table 2.38). Soil carbon levels ranged from 60 to 72 Mg ha^{-1}, but there were no differences among the treatments. There were no differences among the treatments for pH, N, P, K, Ca, Mg and CEC (Table 2.39).

Table 2.25. Soil characteristics for 15 - 30 cm depth in 1997 for willow (SV1) established with six different site preparation treatments in Lafayette, NY.

	Bulk Density ($Mg\ m^{-3}$)		pH		Soil Carbon ($Mg\ ha^{-1}$)		N ($g\ kg^{-1}$)		P ($mg\ kg^{-1}$)	
Treatment	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	1.42	0.077	7.70	0.073	53.08	4.72	1.57	0.2	30.40	10.03
Cover crop	1.65	0.042	7.96	0.286	41.03	3.20	1.37	0.6	10.91	13.36
No till	1.40	0.054	7.76	0.327	52.25	3.29	1.63	0.3	22.32	13.26
Strip till	1.59	0.050	7.88	0.240	50.15	6.08	1.37	0.4	24.03	9.19
Spring tillage	1.53	0.064	7.83	0.246	46.81	4.72	1.32	0.3	63.36	77.21
No weed control	1.49	0.058	7.78	0.275	58.98	4.15	1.62	0.4	30.44	15.72

	K ($mg\ kg^{-1}$)		Ca ($mg\ kg^{-1}$)		Mg ($mg\ kg^{-1}$)		CEC ($cmol\ kg^{-1}$)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	45.19	13.17	3484.0	704.9	501.0	114.6	12.87	5.23
Cover crop	59.60	28.38	2089.5	1520.4	490.6	158.5	14.31	4.37
No till	39.68	3.29	2657.9	1021.6	462.3	108.7	15.62	4.00
Strip till	43.89	6.43	2802.3	766.2	461.3	145.9	11.32	2.58
Spring tillage	34.99	7.09	2923.4	1132.5	438.4	107.6	15.46	4.66
No weed control	46.60	9.78	2432.5	1760.1	491.6	180.9	13.06	3.34

Table 2.26. Soil characteristics for 15 - 30 cm depth in 1997 for poplar (NM6) established with six different site preparation treatments in Lafayette, NY.

	Bulk Density ($Mg\ m^{-3}$)		pH		Soil Carbon ($Mg\ ha^{-1}$)		N ($g\ kg^{-1}$)		P ($mg\ kg^{-1}$)	
Treatment	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	1.51	0.071	7.82	0.179	59.34	3.46	1.77	0.26	23.93	16.48
Cover crop	1.63	0.620	7.64	0.013	60.71	3.11	1.49	0.20	32.30	18.24
No till	1.34	0.042	7.82	0.333	45.93	2.92	146	0.09	37.30	43.09
Strip till	1.56	0.017	7.69	0.063	54.46	1.37	1.43	0.11	32.97	16.63
Spring tillage	1.43	0.091	7.77	0.172	51.67	3.61	1.50	0.19	30.55	14.53
No weed control	1.50	0.049	7.69	0.162	52.76	1.45	1.50	0.15	32.29	10.00

	K ($mg\ kg^{-1}$)		Ca ($mg\ kg^{-1}$)		Mg ($mg\ kg^{-1}$)		CEC ($cmol\ kg^{-1}$)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	48.50	5.64	2174.9	1592.8	583.0	149.9	12.05	2.98
Cover crop	44.96	7.80	3064.5	540.6	449.0	70.1	13.66	6.35
No till	40.89	4.95	1861.5	520.1	431.8	117.3	13.79	3.85
Strip till	49.15	8.89	3153.1	369.5	475.5	16.8	14.35	2.84
Spring tillage	47.20	6.83	3806.9	1028.2	446.6	142.8	16.17	3.40
No weed control	43.09	3.08	2926.1	1170.1	445.3	116.1	16.29	0.87

Table 2.27. Mean square and p-values from ANOVAs for soil properties at 15 – 30 cm depth in 1997 for six different site preparation treatments in Lafayette, NY with one willow (SV1) and one poplar (NM6) clone.

		Bulk Density		pH		Soil Carbon		N		P	
Source	df	Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value
Block	3	0.0129	0.4462	0.0077	0.9322	58.58	0.3811	0.00049	0.6686	174.7555	0.8958
Treatment	5	0.0710	0.0016	0.0051	0.9922	79.52	0.2384	0.00091	0.4504	584.3458	0.6503
Species	1	0.0051	0.5531	0.0813	0.2248	170.00	0.0894	0.00026	0.6053	20.7299	0.8786
Treatment x species	5	0.0085	0.7040	0.0513	0.4523	184.99	0.0151	0.0047	0.7751	749.6262	0.5200
Error	33	0.0142		0.0531		55.49		0.00094		874.6911	

		K		Ca		Mg		CEC	
Source	df	Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value
Block	3	131.03	0.3591	2023107.0	0.1690	22836.0	0.2344	6.65	0.7413
Treatment	5	153.11	0.2891	1129549.8	0.4346	10271.6	0.6477	13.27	0.5359
Species	1	4.91	0.8396	118977.1	0.7479	65.6	0.9482	3.36	0.6490
Treatment x species	5	165.32	0.2498	1754586.0	0.2018	4709.9	0.9046	9.45	0.7048
Error	33	118.07		1132671.4		15291.8		15.92	

Table 2.28. Linear contrast estimates and p-values for soil characteristics at 15 - 30 cm depth in 1997 for one willow (SV1) and one poplar (NM6) clone grown using six different site preparation treatments.

Linear contrast	Bulk Density		pH		Soil Carbon		N		P	
	Estimate ($Mg\ m^{-3}$)	p-value	Estimate	p-value	Estimate ($Mg\ ha^{-1}$)	p-value	Estimate ($g\ kg^{-1}$)	p-value	Estimate ($mg\ kg^{-1}$)	p-value
	Main Effects				**Simple Effects Poplar (NM6)**		**Main Effects**			
Weed control – no weed control	0.012	0.7994	0.05	0.5734	1.66	0.6872	-0.07	0.5586	-8.13	0.2287
Tillage – no-till	0.171	0.0008	-0.01	0.9310	10.61	0.0155	-0.07	0.5710	-7.97	0.2471
(Fall + cover crop) – spring	0.071	0.1741	-0.02	0.8013	8.35	0.0759	0.14	0.3030	-3.61	0.6299
Fall – cover crop	-0.179	0.0048	-0.04	0.7291	-1.37	0.7960	0.24	0.1204	1.70	0.8430
Spring – strip	-0.092	0.1306	0.02	0.8800	-2.78	0.6012	0.02	0.9174	3.95	0.6475
Willow - poplar	-0.210	0.5502	0.08	0.2074			-0.04	0.5977	1.76	0.7234
					Willow (SV1)					
Weed control – no weed control					-10.31	0.0163				
Tillage – no-till					-4.48	0.2900				
(Fall + cover crop) – spring					0.23	0.9587				
Fall – cover crop					12.05	0.0284				
Spring – strip					3.33	0.5317				

Table 2.29. Linear contrasts and p-values for soil characteristics at 15 - 30 cm depth in 1997 for one willow (SV1) and one hybrid poplar (NM6) clone grown using six different site preparation treatments.

	K		Ca		Mg		CEC	
Linear contrast	Estimate (mg kg^{-1})	p-value	Estimate (mg kg^{-1})	p-value	Estimate (mg kg^{-1})	p-value	Estimate (cmol$_c$ kg^{-1})	p-value
			Simple Effects					
	Main Effects		**Poplar (NM6)**		**Main Effects**			
Weed control – no weed control	0.56	0.8953	-113.95	0.8509	5.50	0.9111	273.51	0.6287
Tillage – no-till	6.40	0.1465	1188.34	0.0609	33.66	0.5040	188.04	0.7444
(Fall + cover crop) – spring	8.47	0.0816	-1187.19	0.0861	63.40	0.2535	-1250.66	0.0537
Fall – cover crop	-5.44	0.3258	-889.63	0.2597	72.19	0.2601	-1.52	0.9983
Spring – strip tillage	-5.43	0.3267	653.75	0.4056	-25.86	0.6843	1251.05	0.0926
Willow - poplar	-0.64	0.8402			2.33	0.9492	456.42	0.2822
			Willow (SV1)					
Weed control – no weed control			358.91	0.5546				
Tillage – no-till			166.92	0.7873				
(Fall + cover crop) – spring			-136.63	0.8402				
Fall – cover crop			1394.50	0.0810				
Spring – strip tillage			121.06	0.8770				

Table 2.30. Soil characteristics for 0 – 15 cm depth in 2000 for willow (SV1) established with six different site preparation treatments in Lafayette, NY.

	Bulk Density ($Mg\ m^{-3}$)		pH		Soil Carbon ($Mg\ ha^{-1}$)		N ($g\ kg^{-1}$)		P ($mg\ kg^{-1}$)	
Treatment	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	1.31	0.031	7.67	0.112	62.66	1.98	2.20	0.12	31.84	12.08
Cover crop	1.36	0.025	7.69	0.083	68.22	1.12	1.98	0.33	36.77	19.30
No till	1.36	0.084	7.61	0.186	77.45	5.00	2.52	0.26	53.35	21.07
Strip till	1.39	0.029	7.49	0.104	74.30	2.82	2.37	0.36	41.94	20.85
Spring tillage	1.36	0.064	7.52	0.124	70.14	2.50	2.33	0.29	54.42	14.95
No weed control	1.37	0.027	7.61	0.132	67.14	3.26	1.93	0.21	36.58	18.52

	K ($mg\ kg^{-1}$)		Ca ($mg\ kg^{-1}$)		Mg ($mg\ kg^{-1}$)		CEC ($cmol\ kg^{-1}$)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	72.15	9.35	2623.8	63.0	382.5	46.8	18.39	0.98
Cover crop	71.84	7.32	2369.2	542.1	317.7	44.6	16.90	2.97
No till	83.26	31.20	2597.4	404.3	387.5	45.7	16.43	3.13
Strip till	69.65	9.63	2505.1	238.9	372.7	86.9	18.40	2.08
Spring tillage	71.10	25.99	2767.1	283.5	393.6	92.3	19.29	1.67
No weed control	70.91	23.35	2245.7	271.4	318.2	39.2	16.98	2.17

Table 2.31. Soil characteristics for 0 – 15 cm depth in 2000 for poplar (NM6) established with six different site preparation treatments in Lafayette, NY.

	Bulk Density ($Mg\ m^{-3}$)		pH		Soil Carbon ($Mg\ ha^{-1}$)		N ($g\ kg^{-1}$)		P ($mg\ kg^{-1}$)	
Treatment	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	1.36	0.016	7.82	0.173	65.10	3.69	2.03	0.19	41.73	19.26
Cover crop	1.33	0.054	7.60	0.110	68.22	1.41	2.40	0.28	40.12	11.74
No till	1.36	0.084	7.51	0.071	73.66	3.04	2.38	0.34	27.72	14.29
Strip till	1.39	0.028	7.61	0.079	69.89	2.44	2.18	0.26	37.02	25.99
Spring tillage	1.36	0.064	7.74	0.202	65.50	3.74	2.04	0.20	35.53	23.03
No weed control	1.37	0.027	7.63	0.062	72.07	3.45	2.51	0.36	54.00	13.36

	K ($mg\ kg^{-1}$)		Ca ($mg\ kg^{-1}$)		Mg ($mg\ kg^{-1}$)		CEC ($cmol\ kg^{-1}$)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	64.01	4.64	2719.9	557.7	275.4	54.25	16.75	1.17
Cover crop	71.43	22.76	2583.1	184.3	360.9	67.26	15.89	3.38
No till	71.45	12.90	2598.4	256.4	398.3	17.06	18.21	1.89
Strip till	78.25	15.64	2391.6	280.3	346.7	15.57	17.76	1.68
Spring tillage	46.59	27.41	2539.9	422.5	347.1	41.09	17.46	1.49
No weed control	71.60	13.78	2753.6	155.6	390.1	61.57	19.88	2.24

Table 2.32. Mean square and p-values from ANOVAs for soil properties at 0 – 15 cm depth in 2000 for six different site preparation treatments in Lafayette, NY with one willow (SV1) and one poplar (NM6) clone.

		Bulk Density		pH		Soil Carbon		N		P	
Source	df	Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value
Block	3	0.0119	0.2204	0.0029	0.9198	74.02	0.1083	0.0038	0.0006	170.2935	0.6975
Treatment	5	0.0032	0.8280	0.0385	0.0794	127.04	0.0085	0.0011	0.0825	97.6081	0.9230
Species	1	0.0004	0.8170	0.0308	0.1953	10.00	0.5906	0.0002	0.5825	117.3960	0.5685
Treatment x species	5	0.0130	0.8865	0.0351	0.1054	32.24	0.4611	0.0028	0.0011	556.5073	0.1950
Error	33	0.2546		0.0176		33.87		0.0005		353.8051	

		K		Ca		Mg		CEC	
		Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value
Block	3	193.01	0.6752	396406.36	0.3325	11914.15	0.0050	6.0564	0.2932
Treatment	5	323.05	0.5175	366394.78	0.6605	4130.16	0.1431	4.8519	0.4132
Species	1	421.59	0.2969	76284.83	0.4152	954.1032	0.5252	0.0933	0.8886
Treatment x species	5	268.16	0.6169	678719.30	0.3255	8386.45	0.0101	7.4469	0.1904
Error	33	375.26		112038.23		2313.3044		4.6852	

Table 2.33. Linear contrast estimates and p-values for soil characteristics at 0 - 15 cm depth for 2000 one willow (SV1) and one poplar (NM6) clone grown using six different site preparation treatments.

Linear contrast	Bulk Density		pH		Soil Carbon		N		P	
	Estimate ($Mg\ m^{-3}$)	p-value	Estimate	p-value	Estimate ($Mg\ ha^{-1}$)	p-value	Estimate ($g\ kg^{-1}$)	p-value	Estimate ($mg\ kg^{-1}$)	p-value
	Main Effects		**Simple Effects Poplar (NM6)**		**Main Effects**		**Simple Effects Poplar (NM6)**			
Weed control – no weed control	0.0007	0.8456	0.02	0.7662	-0.09	0.9708	-0.30	0.0549	-17.58	0.0897
Tillage – no-till	-0.021	0.5552	0.19	0.0136	-7.55	0.0035	-0.22	0.1681	10.88	0.2975
(Fall + cover crop) – spring	-0.021	0.5912	-0.03	0.7159	-1.77	0.5074	0.17	0.3004	5.40	0.6348
Fall – cover crop	00.010	0.8334	0.22	0.0189	-4.34	0.1638	-0.36	0.0737	1.60	0.9029
Spring – strip	-0.028	0.5405	0.13	0.1595	-4.28	0.1696	-0.14	0.4673	-1.49	0.9094
Willow - poplar	-0.006	0.8147			0.91	0.6074				
			Willow (SV1)				**Willow (SV1)**			
Weed control – no weed control			-0.02	0.7906			0.35	0.0284	7.08	0.4868
Tillage – no-till			-0.02	0.7781			0.31	0.0565	-12.11	0.2469
(Fall + cover crop) – spring			0.15	0.0575			-0.24	0.1725	-20.12	0.0826
Fall – cover crop			-0.02	0.8051			0.22	0.2657	-4.92	0.7074
Spring – strip			0.03	0.7525			0.04	0.8355	12.48	0.3439

Table 2.34. Linear contrast estimates and p-values for soil characteristics at 0 - 15 cm depth for 2000 one willow (SV1) and one poplar (NM6) clone grown using six different site preparation treatments.

Linear contrast	K		Ca		Mg		CEC	
	Estimate (mg kg^{-1})	p-value	Estimate (mg kg^{-1})	p-value	Estimate (mg kg^{-1})	p-value	Estimate ($cmol_c$ kg^{-1})	p-value
	Main Effects				**Simple Effects Poplar (NM6)**			
Weed control – no weed control	-1.28	0.8622	69.86	0.5960	-44.44	0.1546	-2.23	0.0318
Tillage – no-till	-9.23	0.2265	-35.41	0.7920	-65.74	0.0421	-0.94	0.3536
(Fall + cover crop) – spring	11.01	0.1884	-79.53	0.5893	-29.00	0.4017	-0.85	0.4017
Fall –cover crop	-3.56	0.7098	195.69	0.2534	-85.39	0.0372	0.56	0.5814
Spring – strip tillage	-15.10	0.1202	205.18	0.2315	0.44	0.9912	-0.19	0.8476
Willow - poplar	5.93	0.2864	-79.73	0.4181				
					Willow (SV1)			
Weed control – no weed control					52.62	0.0937	0.90	0.4574
Tillage – no-till					-20.92	0.5068	1.81	0.1483
(Fall + cover crop) – spring					-43.49	0.2113	-1.65	0.2277
Fall – cover crop					64.83	0.1091	1.49	0.3421
Spring – strip tillage					20.87	0.6000	0.89	0.5693

Table 2.35. Soil characteristics for 15 - 30 cm depth in 2000 for willow (SV1) established with six different site preparation treatments in Lafayette, NY.

	Bulk Density ($Mg\ m^{-3}$)		pH		Soil Carbon ($Mg\ ha^{-1}$)		N ($g\ kg^{-1}$)		P ($mg\ kg^{-1}$)	
Treatment	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	1.39	0.019	7.72	0.05	60.34	1.17	1.98	0.1	31.07	12.42
Cover crop	1.36	0.057	7.75	0.11	61.97	1.03	1.87	0.1	32.64	17.25
No till	1.39	0.048	7.61	0.09	69.56	3.62	2.11	0.2	51.20	23.66
Strip till	1.42	0.024	7.60	0.11	64.07	6.73	2.09	0.5	38.97	25.66
Spring tillage	1.47	0.059	7.63	0.07	71.29	1.74	2.18	0.5	43.41	13.30
No weed control	1.38	0.024	7.79	0.18	72.18	13.60	2.01	0.3	31.24	12.96

	K ($mg\ kg^{-1}$)		Ca ($mg\ kg^{-1}$)		Mg ($mg\ kg^{-1}$)		CEC ($cmol\ kg^{-1}$)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	56.72	16.05	2646.1	350.3	346.5	76.45	16.41	2.77
Cover crop	52.22	5.44	2757.9	201.1	337.1	59.38	16.75	0.96
No till	46.05	6.45	2648.5	426.3	379.9	38.96	19.24	2.38
Strip till	52.37	12.63	2826.7	119.8	330.0	112.53	17.44	2.53
Spring tillage	53.04	6.22	2570.3	379.3	358.0	62.95	14.64	5.58
No weed control	51.45	14.87	2783.0	538.3	295.9	51.45	17.66	0.93

Table 2.36. Soil characteristics for 15 - 30 cm depth in 2000 for poplar (NM6) established with six different site preparation treatments in Lafayette, NY.

	Bulk Density ($Mg\ m^{-3}$)		pH		Soil Carbon ($Mg\ ha^{-1}$)		N ($g\ kg^{-1}$)		P ($mg\ kg^{-1}$)	
Treatment	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	1.49	0.044	7.76	0.135	70.46	4.83	1.91	0.35	40.19	16.33
Cover crop	1.53	0.070	7.67	0.073	70.03	4.59	2.03	0.22	39.67	15.50
No till	1.45	0.031	7.67	0.131	65.05	3.41	2.05	0.48	27.69	11.80
Strip till	1.51	0.024	7.74	0.126	61.30	6.85	1.75	0.59	19.49	8.22
Spring tillage	1.51	0.056	7.67	0.083	70.88	3.45	2.12	0.18	32.49	15.54
No weed control	1.38	0.030	7.68	0.099	64.36	4.22	2.19	0.39	45.71	20.68

	K ($mg\ kg^{-1}$)		Ca ($mg\ kg^{-1}$)		Mg ($mg\ kg^{-1}$)		CEC ($cmol\ kg^{-1}$)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fall tillage	45.19	8.84	2799.3	457.5	256.5	48.84	13.88	4.29
Cover crop	53.08	10.78	2483.3	301.9	320.6	91.03	16.82	4.84
No till	51.00	5.79	2327.5	186.2	320.0	48.75	17.08	4.06
Strip till	42.43	9.38	2469.2	386.4	290.7	69.75	14.63	2.86
Spring tillage	51.50	16.06	2392.1	208.0	334.4	63.31	17.34	0.23
No weed control	47.86	5.04	2734.9	254.9	347.5	47.92	18.35	2.91

Table 2.37. Mean square and p-values from ANOVAs for soil properties at 15 – 30 cm depth in 2000 for six different site preparation treatments in Lafayette, NY with one willow (SV1) and one poplar (NM6) clone.

		Bulk Density		pH		Soil Carbon		N		P	
Source	df	Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value
Block	3	0.0152	0.1155	0.0032	0.8648	190.66	0.2151	0.00325	0.0152	69.2413	0.8757
Treatment	5	0.0116	0.1795	0.0148	0.3545	64.50	0.7510	0.00076	0.4653	108.2114	0.8736
Species	1	0.0693	0.0037	0.0025	0.6641	2037	0.8898	0.00014	0.6824	180.6183	0.4453
Treatment x species	5	0.0067	0.4654	0.0174	0.2685	102.23	0.5298	0.00075	0.4780	521.1364	0.1570
Error	33	0.0071		0.0129		121.43		0.00081		302.6375	

		K		Ca		Mg		CEC	
		Mean square	p-value	Mean square	p-value	Mean square	p-value	Mean square	p-value
Block	3	87.99	0.5198	49597.4	0.7480	20964.1	0.0010	37.66	0.0086
Treatment	5	34.83	0.9068	107690.6	0.5011	2959.9	0.4479	11.36	0.2550
Species	1	144.21	0.2698	351075.4	0.0985	10523.2	0.0717	10.81	0.2591
Treatment x species	5	80.12	0.6274	75295.4	0.6855	4585.2	0.2138	5.31	0.6652
Error	33	114.48		121464.6		3038.3		8.20	

Table 2.38. Linear contrast estimates and p-values for soil characteristics at 15 - 30 cm depth for 2000 one willow (SV1) and one poplar (NM6) clone grown using six different site preparation treatments.

Linear contrast	Bulk Density		pH		Soil Carbon		N		P	
	Estimate ($Mg\ m^{-3}$)	p-value	Estimate	p-value	Estimate ($Mg\ ha^{-1}$)	p-value	Estimate ($g\ kg^{-1}$)	p-value	Estimate ($mg\ kg^{-1}$)	p-value
	Main Effects								**Simple Effects Poplar (NM6)**	
Weed control – no weed control	0.070	0.0466	-0.05	0.2291	-1.77	0.6864	-0.09	0.4655	-13.80	0.1430
Tillage – no-till	0.041	0.2940	0.05	0.2257	-1.01	0.8226	-0.09	0.4856	5.27	0.5790
(Fall + cover crop) – spring	-0.051	0.1883	0.08	0.1211	-5.38	0.2775	-0.20	0.1493	7.44	0.4749
Fall – cover crop	-0.003	0.9477	0.03	0.6361	-0.60	0.9158	-0.05	0.9752	0.51	0.9657
Spring – strip	0.028	0.5268	-0.02	0.6767	8.40	0.1450	0.22	0.1523	13.00	0.2820
Willow - poplar	-0.076	0.0051	-0.01	0.6535	-0.44	0.8922	0.03	0.7143		
									Willow (SV1)	
Weed control – no weed control									-13.80	0.1430
Tillage – no-till									5.27	0.5790
(Fall + cover crop) – spring									7.44	0.4749
Fall – cover crop									0.51	0.9657
Spring – strip									13.00	0.2820

Table 2.39. Linear contrast estimates and p-values for soil characteristics at 15 - 30 cm depth for 2000 one willow (SV1) and one poplar (NM6) clone grown using six different site preparation treatments.

	K		Ca		Mg		CEC	
Linear contrast	Estimate ($mg\ kg^{-1}$)	p-value	Estimate ($mg\ kg^{-1}$)	p-value	Estimate ($mg\ kg^{-1}$)	p-value	Estimate ($cmol_c\ kg^{-1}$)	p-value
	Main Effects							
Weed control – no weed control	0.71	0.8640	-166.85	0.2130	5.71	0.8280	-1.42	0.2699
Tillage – no-till	2.29	0.5871	130.06	0.3394	-28.22	0.2960	-1.52	0.1366
(Fall + cover crop) – Spring	-0.47	0.9186	190.41	0.2039	-31.00	0.2947	-1.06	0.4578
Fall – cover crop	-1.69	0.7515	102.11	0.5516	-27.33	0.4221	-1.77	0.2866
Spring – strip tillage	4.87	0.3641	-166.78	0.3329	35.80	0.2946	0.92	0.5751
Willow - poplar	3.47	0.2646	171.04	0.0898	29.61	0.1363	0.95	0.3205

Changes in Soil Characteristics Over Three Years

There were only a few significant changes in soil characteristics measured at 0 – 15 cm between 1997 and 2000 (Table 2.40). The only significant change for pH was an increase of 0.19 units in the fall tillage treatments under poplar. Soil N concentrations decreased by 0.1 g kg^{-1} and 0.4 g kg^{-1} respectively in the fall tillage and no weed control treatments under willow, but not under poplar. There were no significant changes in soil P or K concentrations in any of the treatments (Table 2.40 and 2.41). Calcium concentrations decreased in one poplar and three willow treatments. It decreased by 1292 mg kg^{-1} in the spring tillage treatments under poplar. Decreases in soil Ca concentrations occurred in the willow fall tillage (1652 mg kg^{-1}), cover crop (1341 mg kg^{-1}), and no weed control treatments (1855 mg kg^{-1}). Magnesium concentrations decreased under four treatments in poplar and willow. The differences were significant under poplar in the fall tillage (187 mg kg^{-1}), strip tillage (224 mg kg^{-1}), spring tillage (174 mg kg^{-1}) and no weed control treatments (215 mg kg^{-1}). Under willow, Mg decreased in the fall tillage (217 mg kg^{-1}), no-till (199 mg kg^{-1}), strip tillage (162 mg kg^{-1}) and no weed control treatments (253 mg kg^{-1}). There were no significant changes in cation exchange capacity over the four-year period.

Between 1997 and 2000 at the 15 – 30 cm depth, several treatments had significant increases in soil carbon content and N concentrations and significant decreases in Mg concentrations (Tables 2.42 and 2.43). Soil carbon levels increased under poplar for the no-till (19 t ha^{-1}), spring tillage (19 t ha^{-}1) and no weed control (12 t ha^{-1}) treatments and under willow for the cover crop (21 t ha^{-1}) and spring tillage (24 t ha^{-1}) treatments. Most of the willow and poplar treatments had significant increases in soil nitrogen concentrations. Under poplar, soil N concentrations increased under the cover crop (0.5 g kg^{-1}), spring tillage (0.6 g kg^{-1}), and no weed control treatments (0.7 g kg^{-1}). Soil N concentrations increased under willow in the fall tillage (0.4 g kg^{-1}), no-till (0.5 g kg^{-1}), strip tillage (0.7 g kg^{-1}), spring tillage (0.9 g kg^{-1}), and no weed control treatments (0.4 g kg^{-1}). Decreases in Mg concentrations occurred in three poplar treatments, the fall tillage (326 mg kg^{-1}), cover crop (128.4 mg kg^{-1}) and strip tillage (183.8 mg kg^{-1}). Decreases under willow were of a similar magnitude, ranging from 80 – 196 mg kg^{-1}, but were not significant for any of the treatments. Changes in bulk density, pH and soil P, K and Ca concentrations were limited to one or two treatments each. The only significant change in bulk density was a decrease of 0.28 g cm^{-3} in the strip tillage treatments under willow. Soil pH decreased by 0.28 units in willow strip tillage treatment. Significant increases in soil P concentrations occurred in the poplar fall tillage treatment (16.26 mg kg^{-1}). There were larger increases in soil P concentrations under the willow cover crop (22 mg kg^{-1}) and no-till (29 mg kg^{-1}) treatments, but they were not significant. K, Ca concentrations and cation exchange capacity did not change significantly under any poplar or willow treatments.

Table 2.40. Changes in soil characteristics at 0 – 15 cm depth from the end of the establishment year (1997) through the end of the first rotation (2000) for six different site preparation treatments for one willow (SV1) and one poplar (NM6) clone.

	Bulk Density (Mg m^{-3})			Soil pH			Soil Carbon (Mg ha^{-1})			N (g kg^{-1})			P (mg kg^{-1})		
Treatment	Mean	SE	p-value†	Mean	SE	p-value	Mean	SE	p-value	Mean	SE	p-value	Mean	SE	p-value
							Hybrid Poplar (NM6)								
Fall tillage	0.192	0.158	0.0927	0.19	0.08	0.0927	3.46	3.24	0.3642	-0.11	0.15	0.2430	3.86	10.04	0.4980
Cover crop	0.00	0.052	1.0000	0.00	0.02	1.0000	2.13	3.66	0.6010	-0.06	0.16	0.4617	3.55	7.175	0.3947
No-till	0.087	0.185	0.4144	0.09	0.09	0.4144	6.02	5.12	0.5976	0.08	0.07	0.0907	-5.35	5.0124	0.1223
Strip tillage	0.116	0.138	0.1914	0.12	0.07	0.1714	1.66	2.96	0.6154	-0.01	0.20	0.9696	5.75	12.97	0.4408
Spring tillage	0.177	0.190	0.1590	0.18	0.08	0.1590	2.62	4.01	0.5610	0.02	0.14	0.8267	2.75	16.20	0.7568
No weed control	0.062	0.102	0.3095	0.06	0.05	0.3095	4.52	1.93	0.1010	0.11	0.22	0.3773	0.108	9.732	0.9836
							Willow (SV1)								
Fall tillage	0.085	0.215	0.4880	0.09	0.10	0.4880	-2.32	3.62	0.5669	-0.10	0.07	0.0564	-1.40	19.94	0.8975
Cover crop	0.012	0.095	0.8101	0.01	0.05	0.8101	10.69	4.22	0.0850	0.06	0.52	0.8266	5.65	15.79	0.5258
No-till	0.022	0.178	0.8168	0.02	0.09	0.8168	6.65	4.74	0.2546	-0.14	0.36	0.4906	-0.530	19.56	0.9601
Strip tillage	0.00	0.125	1.0000	0.00	0.07	1.0000	-0.50	2.84	0.8708	0.04	0.18	0.6990	4.511	12.23	0.5141
Spring tillage	- 0.190	0.191	0.1417	-0.19	0.10	0.1417	3.37	2.82	0.3199	-0.04	0.16	0.6698	10.561	31.14	0.5450
No weed control	- 0.022	0.101	0.6865	-0.02	0.05	0.6865	2.11	1.82	0.3309	-0.37	0.10	0.0044	0.015	13.79	0.9984

† p-values are from a paired t-test of soil characteristics in 2000 – 1997.

Table 2.41. Changes in soil characteristics at 0 – 15 cm depth from the end of the establishment year (1997) through the end of the first rotation (2000) for six different site preparation treatments for one willow (SV1) and one poplar (NM6) clone.

	K (mg kg^{-1})			Ca (mg kg^{-1})			Mg (mg kg^{-1})			CEC (cmol$_c$ kg^{-1})		
Treatment	Mean	SE	p-value†	Mean	SE	p-value	Mean	SE	p-value	Mean	SE	p-value
						Hybrid Poplar (NM6)						
Fall tillage	-3.695	2.66	0.0696	-259.2	1651.8	0.7741	-186.7	77.09	0.0168	-0.178	2.87	0.9090
Cover crop	0.527	20.88	0.9629	-884.5	1114.7	0.2107	-157.5	183.2	0.1840	-0.138	7.46	0.9727
No-till	-14.85	34.90	0.4574	-114.9	162.91	0.2533	-28.70	59.20	0.4038	1.507	1.39	0.1186
Strip tillage	-5.886	17.05	0.5395	-697.3	938.2	0.2339	-224.3	65.93	0.0065	2.192	2.37	0.1615
Spring tillage	-28.91	30.16	0.1511	-1291.7	503.7	0.0144	-174.0	119.5	0.0620	2.447	2.85	0.1847
No weed control	0.221	14.24	0.9771	-657.8	661.6	0.1409	-214.5	98.68	0.0255	1.410	3.24	0.4492
						Willow (SV1)						
Fall tillage	-11.00	20.03	0.3522	-1651.4	477.5	0.0062	-216.9	132.7	0.0469	0.531	1.20	0.4427
Cover crop	4.847	19.93	0.6600	-1340.6	692.3	0.0305	-132.7	150.8	0.1767	-0.490	2.92	0.7550
No-till	-5.282	21.65	0.6591	-60.37	1053.1	0.9160	-198.7	106.6	0.0336	-4.345	4.72	0.2520
Strip tillage	-18.01	15.29	0.0997	-509.8	759.3	0.2719	-162.1	99.21	0.0469	-1.305	2.20	0.3218
Spring tillage	2.565	19.73	0.8817	396.9	2282.2	0.7510	-61.55	374.9	0.7643	-0.504	1.29	0.4930
No weed control	-23.30	46.58	0.3908	-1854.5	124.3	<0.0001	-253.0	56.22	0.0029	-1.377	0.99	0.6990

† p-values are from a paired t-test of soil characteristics in 2000 – 1997.

Table 2.42. Changes in soil characteristics at 15 – 30 cm depth from the end of the establishment year (1997) through the end of the first rotation (2000) for six different site preparation treatments for one willow (SV1) and one poplar (NM6) clone.

	Bulk Density (Mg m^{-3})			Soil pH			Soil Carbon (Mg ha^{-1})			N (g kg^{-1})			P (mg kg^{-1})		
Treatment	Mean	SE	p-value†	Mean	SE	p-value	Mean	SE	p-value	Mean	SE	p-value	Mean	SE	p-value
							Poplar (NM6)								
Fall tillage	-0.550	0.022	0.6485	-0.06	0.06	0.6485	11.12	5.25	0.1250	0.14	0.17	0.4527	16.26	3.09	0.0134
Cover crop	0.037	0.064	0.3256	0.04	0.02	0.3256	9.32	4.25	0.1156	0.54	0.05	0.0013	7.37	14.10	0.6352
No-till	-0.152	0.267	0.3366	-0.15	0.07	0.3366	19.11	3.05	0.0517	0.58	0.20	0.0623	-9.61	21.27	0.6825
Strip tillage	0.057	0.123	0.4203	0.06	0.03	0.4203	6.84	3.54	0.4052	0.32	0.27	0.3185	-13.48	11.55	0.3276
Spring tillage	-0.105	0.164	0.2919	-0.11	0.04	0.2919	19.20	2.37	0.0270	0.61	0.10	0.0095	1.95	1.84	0.3701
No weed control	-0.020	0.154	0.8127	-0.02	0.04	0.8127	11.60	1.41	0.0260	0.69	0.19	0.0368	13.42	6.18	0.1182
							Willow (SV1)								
Fall tillage	0.015	0.097	0.7776	0.02	0.03	0.7776	7.26	2.91	0.3011	0.41	0.14	0.0573	0.68	3.39	0.8548
Cover crop	-0.207	0.197	0.1267	-0.21	0.05	0.1267	20.94	2.09	0.0153	0.50	0.28	0.1732	21.73	8.72	0.0883
No-till	-0.155	0.251	0.3059	-0.16	0.06	0.3059	17.31	3.36	0.0822	0.48	0.11	0.0213	28.89	16.12	0.1711
Strip tillage	-0.282	0.165	0.0419	-0.28	0.04	0.0419	13.92	3.39	0.1323	0.72	0.22	0.0505	14.94	12.98	0.3331
Spring tillage	-0.200	0.253	0.2132	-0.20	0.06	0.2132	24.48	3.21	0.0317	0.86	0.16	0.0130	-19.95	44.94	0.6871
No weed control	0.012	0.234	0.9217	0.01	0.06	0.9217	13.20	4.87	0.2667	0.38	0.03	0.0006	0.80	7.48	0.9217

† p-values are from a paired t-test of soil characteristics in 2000 – 1997.

Table 2.43. Changes in soil characteristics at 15 – 30 cm depth from the end of the establishment year (1997) through the end of the first rotation (2000) for six different site preparation treatments for one willow (SV1) and one poplar (NM6) clone.

	K (mg kg^{-1})			Ca (mg kg^{-1})			Mg (mg kg^{-1})			CEC ($cmol_c$ kg^{-1})		
Treatment	Mean	SE	p-value†	Mean	SE	p-value	Mean	SE	p-value	Mean	SE	p-value
						Poplar (NM6)						
Fall tillage	-3.31	6.54	0.6476	624.4	813.2	0.4985	-326.5	56.9	0.0105	1.83	3.47	0.6341
Cover crop	8.11	7.92	0.3811	-581.3	418.6	0.2592	-128.4	20.8	0.0087	3.15	2.12	0.2336
No-till	10.11	4.28	0.0991	466.0	256.6	0.1669	-111.7	75.0	0.2330	3.28	3.93	0.4643
Strip tillage	-6.71	6.91	0.4028	683.9	225.9	0.0564	-184.8	39.2	0.0180	0.27	2.68	0.9236
Spring tillage	4.30	5.33	0.4785	-1414.8	462.0	0.0549	-112.2	53.7	0.1278	1.16	1.66	0.5326
No weed control	4.76	1.75	0.0723	-191.2	566.25	0.7578	-97.79	65.1	0.2297	2.06	1.75	0.3231
						Willow (SV1)						
Fall tillage	11.54	13.24	0.4478	-837.9	465	0.1694	-154.5	56.4	0.0713	3.27	3.31	0.3956
Cover crop	-7.38	16.03	0.6766	688.4	682.6	0.3997	-153.6	53.8	0.0649	2.43	2.47	0.3967
No-till	6.37	2.84	0.1106	-9.3	517.7	0.9867	-82.3	41.6	0.1419	3.66	1.05	0.0944
Strip tillage	8.47	7.00	0.3125	24.4	406.3	0.9559	-131.2	51.9	0.0858	6.11	2.51	0.0926
Spring tillage	18.06	5.97	0.0566	-353.1	659.2	0.6294	-80.4	60.1	0.2733	0.50	1.86	0.8353
No weed control	4.85	12.21	0.7178	350.5	744.5	0.6816	-195.8	53.5	0.0930	4.60	1.58	0.0617

† p-values are from a paired t-test of soil characteristics in 2000 – 1997.

Discussion

Survival

Hybrid Poplar (NM6)

Survival after the establishment year was greater than 91% for all but the no weed control treatment, which had 84% survival. Survival of 80% has been suggested as a cutoff between successful and failed establishment for high density SRWC (Bergkvist et al. 1996). On this site, if the poplar survived the first year it generally survived through the first rotation indicating that interstool competition did not become a factor in the first rotation (Verwijst 1996). NM6 planted at a similar (Tharakan et al. 2001) or lower density (Hansen et al. 1984b, Hansen et al. 1986, White et al. 1991) had high survival rates and a minimal amount of mortality over the first three to four years. In contrast, poplar planted at a higher density of 40,000 plants ha^{-1} (DeBell et al. 1996) or 111,000 plants ha^{-1} (Kopp et al. 2001b) experienced strong interstool competition, resulting in significant decreases in survival over time.

The only site preparation treatment in this study that had a significant effect on survival during the first rotation was the no weed control treatment. Not controlling weeds at all during establishment has a negative effect on survival (Hansen 1984b, Clay and Dixon 1996, Wagner 2000). The effect of different site preparation techniques on the survival of poplar varies among studies. White et al. (1991) reported no difference in survival between tilled and no-till treatments planted with hybrid poplar planted at 10,000 trees ha^{-1}. There was no difference in survival among five site preparation treatments in an irrigated trial with hybrid poplar planted at 1,200 trees ha^{-1} (Hansen et al. 1984b). In contrast, Hansen et al. (1986) reported that mortality of two hybrid poplar clones was 5% on tilled treatments compared to 15% on no-till treatments.

Willow (SV1)

Willow survival was greater than 84% in all treatments in the first year, but it declined in some treatments in subsequent years. High initial survival appears to be a characteristic of clone SV1 across a wide range of sites. In 10 out of 11 clone-site trials in the northeastern United States, clone SV1 establishment year survival was greater than 90% (Tharakan et al. 2001). Following cutback in this study, survival declined in the no-till, strip tillage, and no weed control treatment so that by the end of the second year of coppice growth (1999) survival was below 80% on all three treatments. Mortality was not due to interstool competition because all the stools were growing poorly and were not fully occupying the site. The small size of the stools made them susceptible to competition with the surrounding weeds, especially in 1999, which was a dry year. The spring tillage, fall tillage, and cover crop treatments all maintained survival of greater than 84% over the first rotation, indicating that these treatments more effectively controlled weeds so the stools could achieve a size that allowed them to survive (Verwijst 1996).

Aboveground Biomass Production

Hybrid Poplar (NM6)

Establishment year biomass production for NM6 ranged from 0.2 odt ha^{-1} to 1.5 odt ha^{-1}. The four best treatments (spring tillage, cover crop, fall tillage and strip tillage) all had production greater than 1.2 odt ha^{-1}, which is in the middle of the range

of values reported from trials where NM6 was grown at a comparable density and with management practices similar to the fall or spring tillage treatments (Table 2.44).

Production may have been limited in 1997 by the low precipitation, which was only 59% of the 30 year normal from April through the end of July (NOAA 2002).

In the first year of coppice growth after cutback estimated biomass production ranged from 0.7 to 7.7 odt ha^{-1}. The four best treatments had values greater than 6.5 odt ha^{-1}. This study was not fertilized until the second year after cutback, which may have limited biomass production. In 1998, foliar N concentrations were just at or below sufficient levels of 2.2% recommended for *P. euramericana* (Kopinga and van den Burg 1995) or 2% for *P. deltoides* (Carter and White 1971, Blackmon and White 1972, Blackmon 1977, Kopinga and van den Burg 1995). Estimated aboveground biomass of NM6 in unfertilized plots at three other sites in New York ranged from 1.2 to 8.0 odt ha^{-1} (Ballard et al. 2000), similar to the values in this study. Plots fertilized with 100 kg N ha^{-1} had yields that were 23 to 152% greater than unfertilized treatments depending on the site (Ballard et al. 2000). After the second year of coppice growth, aboveground biomass in this study was estimated at 2.1 to 12.6 odt ha^{-1}, with the four best treatments above 12.0 odt ha^{-1}. These estimated values were below the lowest levels reported on three other sites in New York (Table 2.44). Production in the second year after cutback (1999) in this trial was probably limited by the severe drought in 1999, when precipitation from April through August was only 44% of the 30-year average (NOAA 2002).

Growth in the third year after cutback in this trial was exceptional, with some treatments increasing their aboveground biomass by more than 300%. Final biomass production was greater than 36 odt ha^{-1} for the four best treatments (fall tillage, cover crop, strip tillage and spring tillage), which is greater than yields recorded at three other sites in New York and one in Vermont (Table 2.44). The no-till treatment yield (28.5 odt ha^{-1}) was at the low end of the range of values from the other studies. The high yields in strip tillage treatment suggest that there is the potential to develop this approach to site preparation for the system used in this study. Previous studies of strip tillage have reported significantly lower production compared to fall tillage (Von Althen 1981). The initial plant density in the current experiment was greater than in Von Althen's (1981) study, which allowed the plants to capture the site more rapidly and out compete weeds.

The first three-year rotation yields were not significantly different among the four best treatments, all of which reached the projected first rotation yield of 12 odt ha^{-1} yr^{-1} for this system (Abrahamson et al. 1998). Treatment effects that were apparent among the four best treatments in the establishment year were not evident after cutback. In the first and second year of coppice growth after cutback, estimated aboveground biomass in the no-till treatment was 39% and 55% less, respectively, than the best treatment. By the end of the first rotation the yield on the no-till treatment was 28.5 odt ha^{-1}, or about 24% less than the best treatment. This reduction was similar to what Hansen (1986) reported on an excessively drained sand, but much less than what occurred on a poorly drained loam. In

Table 2.44. Aboveground biomass production of poplar (NM6) and willow (SV1) biomass crops in other trials grown at similar densities in the Northeastern United States. All trials were established using a combination of mechanical and chemical weed control similar to the fall or spring tillage treatments in this trial, were fertilized with 100 Kg N ha^{-1} in the first year after cutback, and were not irrigated.

Location	Establishment year	First year after cutback	Second year after cutback	Harvest	Source
		Poplar (NM6) (odt ha^{-1})			
Canastota, NY				34.2	Volk, T.A. (unpublished data 2002)
King Ferry, NY		4.0	13.0	23.4	Ballard et al. 2000
Sommerset, NY		7.0	17.9	27.8	Ballard et al. (2000)
Tully, NY		10.4	21.1	32.8	Ballard et al. (2000)
Tully, NY	1.5	6.2		33.8	Tharakan (1999)
Wolcott, NY				38.1	Volk, T.A. (unpublished data 2002)
Peter's Tract, DE	3.1				Volk et al. (2000a)
Roaring Branch, PA	0.1				Volk et al. (2000b)
Burlington, VT				31.4	Volk, T.A. (unpublished data 2002)
		Willow (SV1) (odt ha^{-1})			
Canastota, NY				29.3	Volk, T.A. (unpublished data 2002)
King Ferry, NY		2.4	8.9	16.2	Ballard et al. (2000)
Sommerset, NY		4.4	17.5	27.1	Ballard et al. (2000)
Tully, NY		10.0	21.3	28.2	Ballard et al. (2000)
Tully, NY	0.8	7.2		22.3	Tharakan (1999)
Tully, NY		10.9	19.6	31.5	Adegbidi et al. (2001)
Tully, NY – First Rotation				26.8	Volk et al. (2001)
Tully, NY – Second Rotation				32.1	Volk et al. (2001)
Wolcott, NY				25.4	Volk, T.A. (unpublished data 2002)
Peter's Tract, DE	0.1				Volk et al. (2000a)
Roaring Branch, PA	0.02				Volk et al. (2000b)
Burlington, VT				25.4	Volk, T.A. (unpublished data 2002)
Lafayette, NY					
Tully, NY – First Rotation				26.8	Volk et al. (2001)
Tully, NY – Second Rotation				32.1	Volk et al. (2001)

contrast, McKittrick (1990) found that the standing volume of clone DN55 was similar on no-till and cultivated treatments.

Weed competition is the greatest threat to the successful establishment of SRWC. Clay and Dixon (1996) found that poplar and willow biomass crops that had lower production during establishment and immediately following cutback due to weed competition had an ability to make up some of this difference over time. This was not the case in this experiment. Not controlling weeds in this trial decreased first rotation poplar yields by 22.0 odt ha^{-1} compared to cultivated treatments, supporting the assertion that weeds must be controlled if SRWC are to be productive (Hansen 1984a, Danfors et al. 1998, Labrecque et al. 1994, Volk et al. 1999).

Willow – SV1

Establishment year production of willow clone SV1 in this trial ranged from 0.01 to 0.04 odt ha^{-1}. These values are at the low end of values from other studies where SV1 was grown at similar densities and with management practices comparable to the fall or spring tillage treatments (Table 2.44). Production may have been limited in 1997 by the limited precipitation, which was only 59% of the 30 year normal from April through the end of July (NOAA 2002). This limited production was a factor in the low first rotation yield. Low production in the first year of the rotation of SRWC has been shown to have a negative effect on production over the entire first rotation (Harrington and DeBell 1984, Willebrand et al.1993, Hytönen 1995a). One year of low production in annually harvested systems has been shown to have a long lasting negative effect on production (Willebrand and Verwijst 1993, Willebrand et al. 1993, Kopp et al. 2001b). Establishment year biomass production of SV1 is typically an order of magnitude less than hybrid poplar clones (Table 2.44), which may be due to differences in the rate and peak of leaf area development (Tharakan 1999).

First year coppice production (1998) after cutback of SV1 in this study was 0.02 to 1.1 odt ha^{-1}. This trial was not fertilized until the beginning of the second year of coppice growth (1999), which may have limited production in 1998. Foliar N concentrations were at or below levels that are considered normal for shrub willow (Kopinga and van den Burg 1995) and well below levels required for optimal growth (Ericsson et al. 1992, Rytter and Ericsson 1993, Kopinga and van den Burg 1995, Labrecque et al. 1998, Jug et al. 1999, Labrecque and Teodorescu 2001, von Fircks et al. 2001). Estimated aboveground biomass in unfertilized plots at three other sites in New York ranged from 0.5 to 5.8 odt ha^{-1} (Ballard et al. 2000). Fertilized treatments of SV1 in Ballard et al. (2000) had 12 – 351% more aboveground biomass than unfertilized treatments.

Relative growth rates in the first year of growth (1998) after cutback in this trial were 100 to 2,750%, but establishment year production was low in this study so aboveground biomass was limited. Relative growth rates in the second (9 – 778%) and third years (250 – 672%) after cutback continued to be high in all but the no-till treatment, in spite of the severe drought conditions in 1999. Estimated annual growth increments in the third year of coppice growth were 19.4, 17.1 and 11.0 odt ha^{-1}, respectively, for the spring tillage, cover crop and fall tillage treatments. Estimated mean annual increments as high as 36.5 odt ha^{-1} have been recorded for irrigated plots of SV1 (Kopp et al. 1997). Once SV1 occupied the site, its production potential was expressed.

However, in the best treatments in this study it took two to three years for the willow to occupy the site, which reduced first rotation yields. This pattern emphasizes the importance of site preparation and establishment so that the SRWC can rapidly occupy the site.

Aboveground biomass production ranged from 0.4 to 23.0 odt ha^{-1} at the end of the first rotation. Production of the best treatments – spring tillage (23.0 odt ha^{-1}) and cover crop (21.7 odt ha^{-1}) - was at the low end of first rotation values for unirrigated trials in the region (Table 2.44). The success of these two alternative methods of site preparation on this site suggests that further work needs to be conducted to develop these approaches for a wider range of sites with different soils and site histories.

The low production in the establishment year and first two years of coppice growth restricted the first rotation aboveground production in this trial. Weed competition was probably the largest single factor limiting production, as has been noted in other studies (Labrecque et al. 1994, Danfors et al. 1998, Volk et al. 1999, Ballard et al. 2000), and it was compounded by the drought in 1999. Not controlling weeds in this study significantly decreased first rotation willow yields by 12.0 odt ha^{-1} compared to the treatments with weed control. Reduced tillage site preparation techniques were not effective for establishing SV1 on this site. The no-till treatment reduced first rotation production on this site by 97%, similar to reductions reported for no-till poplar (Hansen 1986) and willow (Clay and Dixon 1996). Strip tillage reduced willow production by 60%, similar to the results for hybrid poplar reported by Von Althen (1981).

Foliar Nitrogen Concentration

Nitrogen is the element that is most limiting to the growth of SRWC in temperate regions (Hansen and Pope 1988, Rytter and Ericsson 1993, Hansen and Norby 1998, Labreqcue et al. 1998). Because of the difficulty in reliably assessing available nitrogen in the soil, foliar nitrogen concentrations have been used to assess the plant's nutrient status and determine fertilizer requirements of crops, orchards, plantations and SRWC.

The significantly lower foliar N concentrations for poplar and willow in the no weed control, no-till and strip tillage treatments has been found in other studies of SRWC (Aird 1962, Hansen et al. 1988, Labrecque et al. 1993), plantations (Kennedy 1984, Cogliastro et al. 1990, Zutter et al. 1999), and orchards (Merwin and Stiles 1994). The SRWC in this study did not capture the site as quickly in these treatments and weed competition was more severe. Higher N concentrations in plots with better weed control may be due to reduced competition for N and water and/or increases in microbial activity and mineralization (Cogliastro et al. 1990). Soil nitrate and ammonium levels were negatively correlated with the amount of weeds in newly planted loblolly pine (Nusser and Wentworth 1987). Soil nitrate levels in weed free plots were double that in weedy plots in a radiata pine stand during the first growing season, but net N mineralization was similar (Smethurst and Nambiar 1989). They attributed the difference to greater N uptake by the weeds. Higher soil temperatures (Cogliastro et al. 1990, Zutter et al. 1999) and soil moisture (Zutter et al. 1999) and have been found in plots with better weed control in hardwood and pine plantations. Moisture and warmer conditions favor mineralization and uptake of N and uncontrolled weed populations compete with the planted woody crop for available nitrogen and soil moisture.

Hybrid Poplar

In the establishment year, foliar N concentrations of the fall, cover crop and spring tillage treatments exceeded 30 g kg^{-1}, which is considered the minimum that should be maintained for optimal growth of hybrid poplar (Heilman 1993, Heilman and Fu-Guang 1993, Hansen 1994, Hansen et al. 1988). In the three years following coppicing, none of the treatments foliar N concentrations were at or above 30 g kg^{-1}, ranging from 16 to 26 g kg^{-1}. Kopinga and van den Burg (1995) consider 22 g kg^{-1} to be a cut off between low and too low levels for *P. euramericana*. A 20 g kg^{-1} foliar N concentration has been suggested as a minimum required for good growth of *P. deltoides* (Carter and White 1971, Blackmon and White 1972, Blackmon 1977, Kopinga and van den Burg 1995). In the first year after coppice, only the spring tillage treatment had foliar nitrogen concentrations above 22 g kg^{-1}. The fall tillage and cover crop treatments were between 20 and 22 g kg^{-1}, but not significantly lower than the spring treatment. Concentrations in all the treatments were highest in 1999 following fertilization, but only the cover crop and strip tillage treatments were in the normal range of 26 – 30 g kg^{-1} (Heilman 1993, Heilman and Fu-Guang 1993, Hansen 1994, Kopinga and van den Burg 1995). The drought in 1999 may have limited N uptake from the N fertilizer that was added (Hansen 1994) and/or the 100 kg N ha^{-1} may have been insufficient to meet the requirements of the crop. Foliar N concentrations dropped below 22 g kg^{-1} in the most rapidly growing treatments - fall tillage, cover crop, strip tillage and spring tillage - in 2000.

The higher concentrations of foliar N in the establishment year found in this study have been reported in other studies with hybrid poplar (Heilman 1985, Hansen et al. 1988, Hansen 1994), other hardwoods (Kennedy 1984) and loblolly pine (Zutter et al. 1999). These higher levels may be a physiological age related characteristic (Heilman et al. 1985, Hansen 1994) or it may be due to higher soil N availability due to the warmer soil conditions in these relatively open stands (McLaughlin et al 1985), the nitrogen released from the mineralization of organic matter incorporated into the soil during site preparation (Kennedy 1984), and/or the relatively small total nitrogen requirement of one year old trees compared to older trees (Hansen 1994, Zutter et al. 1999).

A strong positive relationship between foliar N concentrations and growth has been reported in other poplar studies up until the time of canopy closure (Aird 1962, Carter and White 1971, Hansen and Tolsted 1985, Hansen et al. 1988), although the relationship was not evident for black cottonwood and several hybrids grown in the Pacific Northwest (Heilman 1994). In this study, there was a significant relationship between 1997 foliar N concentrations and aboveground biomass in 1997 ($r = 0.74$). The relationship between 1997 foliar N concentrations and aboveground biomass production in 1998, 1999 and 2000 remained strong. This suggested that factors effecting the establishment of the poplar had a lasting effect on the first rotation production.

In the first year after coppice (1998), the relationship between foliar nitrogen concentrations and aboveground biomass in 1998, 1999 and 2000 remained strong. The relationship between 1999 foliar nitrogen concentrations and aboveground biomass was significant but weak starting with in 1999. As hybrid poplars close canopy, which occurred in the latter half of 1998 in most of the treatments in this study except the no weed control plot, the tree foliage biomass stabilizes and the amount of N cycling between the trees and the soil increases (Hansen et al. 1988). The application of N fertilizer in 1999 increased foliar N concentrations and narrowed their range. As a result, there were no significant differences in foliar N concentrations or aboveground biomass among the five treatments that had closed canopy. This change in nutrient dynamics and the application of N fertilizer in 1999 resulted in a breakdown in the positive correlation between of the foliar N concentrations and aboveground biomass.

Willow (SV1)

Optimal foliar N concentrations for willow are in the range of 30 to 40 g kg^{-1}, depending on the species (Ericsson et al. 1992, Rytter and Ericsson 1993, Kopinga and van den Burg 1995, Labrecque et al. 1998, Jug et al. 1999, Labrecque and Teodorescu 2001, von Fircks et al. 2001). In the establishment year, the cover crop and fall tillage treatments were at or above the 30 g kg^{-1} level, suggesting that in the establishment year nitrogen was not limiting for these treatments. The no-till and no weed control treatments had foliar N concentrations between 17 and 19 g kg^{-1}, which Kopinga and van den Burg (1995) consider below normal. In the strip tillage treatment foliar N concentrations were at the border line between low and normal range. Weed competition was heavier in these treatments, which increased the competition for nutrients and/or water. The small amount of willow growth during 1997 limited the volume of soil that they could exploit, which may have increased the competition for water and/or nutrients.

The foliar N concentrations of the SV1 treatments did not reach optimal levels in any of the three years after coppice. In 1998, foliar nitrogen concentrations dropped in the fall tillage, cover crop, and spring tillage treatments, but remained between

23 – 28 g kg^{-}, levels which are considered to be normal (Kopinga and van den Burg 1995). Foliar nitrogen concentrations in the no-till and strip tillage treatments increased, but levels remained low. Fertilization with 100 kg N ha^{-1} in 1999 increased foliar N concentrations in all treatments, but did not raise them to levels that are considered optimal for shrub willows. The dry conditions in 1999 may have limited N uptake and/or the amount of N applied may not have been sufficient to raise foliar N concentrations to optimal levels under these site conditions. Other studies in the region have suggested that the application of 100 kg N ha^{-1} once in a rotation is sufficient for optimal production (Labrecque et al. 1998, Adegbidi 1999, Ballard et al. 2000). Concentrations decreased in all treatments in 2000 so that only the cover crop and spring tillage treatments had normal levels. These two treatments had the highest biomass production at the end of the rotation. All other treatments had low concentrations of foliar N (Kopinga and van den Burg 1995).

Similar to poplar and other hardwood and softwood plantations, aboveground biomass production of willow is typically strongly correlated with foliar N concentrations (Ericsson et al. 1992, Labrecque et al. 1998, Labrecque et al. 2001). Jug et al. (1999) did not find a strong correlation, but N fertilizer was applied annually and foliar N concentrations were at or close to optimal levels over two rotations. Foliar N concentrations covered a wide range of values in this experiment and were positively correlated with aboveground biomass production. As with hybrid poplar, the correlation was very strong between 1997 foliar N concentrations and aboveground biomass in 1997 – 2000. Following coppicing the relationship was still significant, but was much weaker. Other factors such as survival and the size of the plants at the end of 1997, which affected their ability to compete with weeds and the size of the root system, were probably more important factors determining aboveground biomass than nitrogen availability and uptake. In 1999, N fertilizer was applied and the canopies began to close in the latter half of 1999 in the treatments with better growth. By the end of 1999 there were no significant differences in foliar N concentrations or aboveground biomass among the three most productive treatments (spring tillage, cover crop, and fall tillage) that had closed canopy. Both of these factors contributed to the weak correlation between foliar N concentrations and aboveground biomass.

Foliar Concentrations of P, K, and Mg

Hybrid Poplar (NM6)

Ranges of foliar concentrations of P, K, and Mg for hybrid poplar required for normal growth are 1.6 – 2.0 mg kg^{-1}, 12.5 – 15 mg kg^{-1}, and 1.8 – 2.8 mg kg^{-1} respectively (Kopinga and Burg 1995). Using these guidelines, foliar nutrient concentrations should be above the upper limit of the normal range for the best growth (identified as the optimal line on Figures 2.8 – 2.11). Foliar P concentrations in the no weed control treatment were below normal in 1998 and 1999. In 2000, concentrations in the cover crop treatment were just below normal. Foliar K concentrations in the no-till and no weed control treatments were below the normal level in the establishment year. The following year (1998), the fall tillage and strip tillage treatments had foliar K concentrations in the normal range. In 1999, the concentrations decreased to below normal for all treatments due to the drought conditions during the growing season. At the end of the rotation all the treatments were above the normal level except for the cover crop and no weed control treatments. Magnesium was found in very high concentrations in the soil on this site, and it is reflected in the foliar Mg concentrations. In 1997, only the fall tillage and cover crop treatments were below the optimal level. For the remainder of the experiment all treatments had foliar Mg concentrations that were above the optimal level. In most instances the treatments that had below normal levels of P, K and/or Mg were in the treatments with the greatest level of weed competition. The drought conditions added to this competition in 1999 and further restricted the poplar's ability to take up nutrients. The normal to optimal P, K, and Mg foliar concentrations in the treatments with good growth indicate that these nutrients were available in adequate supply on this site and that the plants could make use of them.

Willow (SV1)

Normal concentrations of P, K, and Mg in shrub willow foliage required for normal growth are 1.7 – 2.1 mg kg^{-1}, 8.5 – 19 mg kg^{-1}, and 1.7 – 2.0 mg kg^{-1} respectively (Kopinga and Burg 1995). For optimal growth, foliar concentrations should be greater than the upper limit of the normal range (indicates as the optimal line in Figures 8 - 11). Using these guidelines, the only instances where foliar P concentrations were not in the normal range in this study were the no-till, strip tillage and no weed control plots in 1999. Foliar K concentrations in 1999 were below normal levels in the no-till, strip tillage and no weed control treatments. In the final year of the study, foliar K concentrations for all treatments were all in the normal range. Foliar magnesium concentrations were in the optimal range for all treatments in all years. As was the case with poplar, the willow treatments with below normal levels of foliar nutrients were the ones with heavy weed competition. The drought conditions in 1999 further restricted nutrient uptake in these and other treatments.

Soil Characteristics

There were very few differences in soil characteristics among the site preparation treatments at the beginning of the study in 1997 at both the 0 – 15 and 15 – 30 cm depths. The differences among treatments that were significant for soil carbon were not consistent between the willow and poplar clones. Cation exchange capacity was significantly different between the poplar and willow. The willow and poplar had only been planted a few days to few weeks prior to the collection of the soil samples, so there is no reason why they should have had an impact on soil characteristics. The short and variable amount of time between the implementation of tillage and collection of soil samples (seven months and one month prior to sampling respectively for treatments that had fall or spring tillage operations) may have effected the degree of change in soil characteristics. In addition, soil characteristics have a high degree of spatial variability, making small changes across large plots, such as the ones in this experiment, difficult to detect.

By the end of the first rotation, there were still only a few detectable differences among the treatments at the 0 –15 cm depth and almost none at the 15 – 30 cm depth. SRWC are perennial so there is no disturbance of the soil after the initial tillage and planting operations. Since differences among treatments were not evident shortly after the treatments were applied it is not surprising that differences among treatments were not apparent four years later.

The intensive nature of SRWC management, the high density of the plantings and the frequent and repeated harvests have raised concerns about the impact of nutrient removal in the biomass on soil fertility and other characteristics (Stone 1979, Heilman and Norby 1998, Adegbidi et al. 2001). However, in this study only a few soil characteristics had detectable changes over the first rotation. The high spatial variability of soil characteristics, the past land use history on the site, the dynamic cycling of many of the nutrients measured, the limited amount of time for these crops to influence these cycles, and the limited depth of soil sampling in this study are all factors that complicate detection of the impact of SRWC on soil characteristics. With these caveats in mind, there were notable detectable changes in soil carbon and Mg at the 15 – 30 cm depth.

Soil carbon levels at the start of this experiment were quite high, compared to other sites with SRWC that have been studied in central New York (Ulzen-Appiah 2002). Over the first rotation, soil carbon levels were maintained in the 0 –15 cm layer in all the treatments. Increases in soil carbon levels at the 15 – 30 cm depth occurred in three of the six treatments under poplar (no-till, spring tillage, no weed control) and two under willow (cover crop, spring tillage). Under poplar, the increases ranged from 11 – 19 t ha^{-1}. The increases under willow were slightly larger, ranging from 21 – 24 t ha^{-1}. Soil C levels under hybrid poplar (Hansen 1993, Grigal and Burguson 1998) and sweetgum (Tolbert et al. 2002) SRWC have been shown to decrease in the first few years after planting. These losses are assumed to be associated increased oxidation of organic matter following tillage and prior to canopy closure when soil temperature is increased (Hansen 1993, Reicosky et al. 1995, Tolbert et al. 2002). Soil erosion is another factor that has been cited as important in losses of soil carbon prior to canopy closure in SRWC (Kort et al. 1998, Tolbert et al. 2002). When cover crops were planted between rows of SRWC of sweetgum, erosion was reduced and there was no decrease in soil carbon in the first few years after establishment (Tolbert et al. 2002). By the time SRWC of poplar and sweetgum were five to twelve years old, soil C levels had increased significantly in the upper 30 cm (Hansen 1993, Grigal and Burguson 1998, Tolbert et al. 2002). The SRWC system in this experiment had a much higher planting density that probably resulted in greater inputs of organic matter early in the first rotation compared to more widely spaced SRWC. Annual foliage litter inputs of 3 to 6 t ha^{-1} have been reported for densely planted willow and hybrid poplar (Adegbidi 1994, Ericsson 1994). The other major input of organic matter to the soil in these systems is fine roots. Fine root turnover in four-year-old willow can contribute up to 6.8 odt ha^{-1} yr^{-1} to the top 50 cm of the soil (Rytter 1999). The rapid site capture by poplar in this study, the substantial weed cover in some treatments, and the lack of additional tillage to control weeds reduced soil carbon losses through oxidation and erosion. Higher density SRWC may not be prone to the initial decreases in soil C that have been reported for more widely spaced poplar or sweetgum, especially if some vegetation cover is left on the soil.

Ulzen-Appiah (2002) studied soil carbon levels in willow crops across several sites in central NY ranging from two to 12-years-old. The willow was planted and managed similar to the fall tillage treatment in the current experiment. His model suggested that soil carbon levels peak between the ages of five and seven and decline slightly by age 12. However, the model presented only explained 12% of the variation in soil carbon content over time and it was only applied to the top 20 cm of the soil. Jug et al. (1999) reported that 7 – 10 years after agricultural sites were planted with SRWC, soil carbon levels in the top 30 cm were the same or greater. Studies of poplar and sweetgum suggest that soil C levels had increased significantly over a five to twelve year period (Hansen 1993, Grigal and Burguson 1998, Tolbert et al. 2002). The increases had primarily occurred in the surface soil layers in these studies, but in some cases occurred at greater depths. Hansen (1993) noted that increases in soil carbon in poplar plantations occurred at depths greater than 30 cm. In the current study, there were no changes in soil carbon levels in the surface 15 cm of soil over the first rotation, but significant increases did occur at the15 - 30 cm depth.

The methods of sampling and analyzing soil samples collected to assess carbon levels varies among studies and creates problems in comparing their results. Both Hansen (1993) and Grigal and Burguson (1998) included the litter layer in their surface layer soil samples. Hansen (1993) included the carbon content of all the fine roots that were removed while sieving the soil in his total soil carbon content calculations. In this experiment, litter was removed from the site prior to sampling and roots removed from the soil during sieving were excluded from the total soil carbon content. The inclusion of these components would have increased soil carbon levels in the 2000 sample, particularly in the 0 -15 cm layer.

This study indicates that soil carbon levels are maintained in the surface soil and increased in the lower soil level over the first rotation. This pattern is different from some of the other studies on SRWC, but there a number of factors that affect comparisons among studies. Changes in soil organic carbon levels depend on previous land use, management practices for SRWC and site specific characteristics such as texture and climate (Hansen 1993, Jug et al. 1999, Tolbert et al. 2002). Differences in the collection, processing and analysis of soil samples further complicate comparisons among studies.

Soil carbon is a good indicator of soil productivity and sustainability, however it is not always a good indicator of short-term changes. Ulzen-Appiah (2002) found that soil microbial biomass is a more sensitive indicator of soil organic matter changes over short periods than total soil carbon.

Several of the poplar treatments with the best production had significant decreases in Mg concentrations over the first rotation at both 0-15 and 15 – 30 cm. Decreases were significant for several willow treatments at the 0 – 15 cm depth. Magnesium concentrations in NM6 wood are in the range of 0.46 – 0.68 g kg^{-1} (Adegbidi et al. 2001). With aboveground biomass of 2.1 – 12.5 odt ha^{-1} at the end of 1999 in these poplar treatments, 0.9 – 9.2 kg Mg ha^{-1} would have been tied up in the aboveground biomass. Concentrations of Mg in SV1 biomass 0.40 - 0.85 g kg^{-1} (Adegbidi et al. 2001) and aboveground biomass at the end of 1999 were 0.12 – 3.8 odt ha^{-1}, so about 0.1 – 3.0 kg Mg ha^{-1} would be bound up in the aboveground biomass. Using shoot:root ratios for similar age willow crops (Table 34, Chapter 2), belowground biomass may increase these figures by 20 – 115%. Measured changes in soil Mg concentrations from 1997 – 2000 converted to content changes are an order of magnitude greater than what is tied up in the woody biomass. Labrecque et al. (1998) reported similar decreases in Mg content on a clay soil over one rotation of willow biomass crops, even when 20 – 60 kg Mg ha^{-1} was added in sludge. On a clay loam site that originally had a much lower Mg content, there was no change in Mg content over the first rotation (Labrecque et al. 1998). The amount of Mg tied up in the biomass production is only a small factor in the changes in Mg concentrations in this trial. This is further supported by the fact that there were significant decreases in Mg concentrations over the four-year period in the no weed control for poplar and willow at the 0 –15 cm depth, where woody biomass production was limited. Changes in soil Mg concentrations were probably effected more by leaching and erosion losses rather than accumulation in biomass. Soil Mg concentrations on tilled plots were lower than no-till plots in the 0 - 15 cm layer in 2000, supporting the idea that loses of Mg occurred through leaching and erosion.

Conclusions

First rotation aboveground biomass production in this experiment indicated that the spring tillage and cover crop treatments are viable alternatives to the currently recommended fall tillage approach for both willow and hybrid poplar. In addition, the strip tillage treatment had good biomass production with poplar. These alternatives to the standard fall tillage treatment will be helpful in reducing erosion potential on many sites by providing cover for the soil over a longer period while the woody crop is becoming established. Alternative site preparation treatments often produce different results depending on the field history, soil texture, soil drainage conditions, and climate. The site in this study was fallow for two years prior to the initiation of this experiment and had a well developed stand of perennial and annual weeds. As a result, this was a challenging site to successfully control weeds and successfully establish SRWC using alternative methods of site preparation. This study indicates that further work should be conducted to develop these approaches for a wider range of sites. In the mean time, caution should be taken when transferring these results to other sites that have different soil and site history characteristics.

The four best poplar treatments produced over 36 odt ha^{-1} in the first rotation, which are among the best results to date in this region. This site seems to be well suited for hybrid poplar production using a variety of site preparation techniques. First-rotation yields of willow at this site were low relative to other trials in the region. The poor establishment year growth of the willow on this site clearly affected its production over the first three-year rotation. The reasons for this poor establishment year growth are not precisely clear, but are probably related to weed competition, the low level of precipitation in 1999, and possibly soil conditions. The long term impact of poor establishment of willow emphasizes that effective establishment of SRWC is essential to their long term biological and economic success.

Weed control is most frequently the primary factor limiting the establishment and production of SRWC. While the importance of effective weed control during establishment of SRWC has been emphasized for decades, it is still often neglected. The drastic differences in production throughout the first rotation between the no weed control treatment and the rest of the treatments again emphasizes the need to effectively control weed competition during the establishment phase.

Concern has been expressed over the years that the intensive production methods associated with SRWC, especially the repeated harvesting, will have detrimental impact on soil fertility and productivity. The conversion of this site from a fallow condition to SRWC had very few detectable impacts on the soil conditions regardless of the type of site preparation. Soil carbon levels were maintained in the surface soil layer and actually increased in the lower layer over the first four years. There were changes in Mg concentrations over the first rotation that were related more to site conversion than to SRWC production and will probably not have long term impacts on the productivity of the site because of the high level of Mg in the soil. However, the impacts of SRWC on soil quality over a longer period still need to be more accurately assessed.

CHAPTER 3: INTEGRATION OF COVER CROPS DURING THE ESTABLISHMENT OF SRWC

Introduction

Current site preparation recommendations for SRWC involve the use of herbicides and tillage in the fall prior to planting to control weeds and prepare the soil (Abrahamson et al. 2002, Armstrong 1999, Danfors et al. 1998). While this approach is effective for establishing SRWC, little vegetation cover is left on the site for one to two years. This increases the potential for soil erosion and non-point source pollution from sites with certain topographic and soil characteristics (Kort et al. 1998, Malik et al. 2000, Mann and Tolbert 2000). Ranney and Mann (1994) reported that soil erosion rates of up to 40 t ha^{-1} yr^{-1} could occur during establishment of SRWC.

The potential for soil erosion during establishment of SRWC is a concern for a variety of reasons. There is increasing attention surrounding non-point source pollution from agriculture lands and the detrimental effect it is having on surface water supplies (Welsh 1991). Non-point source pollution is one of the environmental concerns related to SRWC (Heilman and Norby 1998). Soil erosion could have a detrimental effect on long-term sustainability of SRWC (Lal 1998, Mann and Tolbert 2000, Vance 2000). Finally, soil erosion could have a negative impact on the public perception and acceptance of SRWC (Tolbert and Mann 1998, Tolbert et al. 2002). Alternative methods of site preparation need to be developed that reduce soil erosion potential without compromising the successful establishment and rapid early growth of SRWC.

The integration of cover crops into annual and perennial agricultural production systems has been developed to reduce runoff and soil erosion, and to improve soil infiltration rates, soil moisture availability, nutrient availability, and weed control (Merwin and Pritts 1993, Teasdale 1996, Teasdale 1998). However, only a limited amount of research has been done on integrating cover crops during the establishment of SRWC. Living cover crops have not been recommended during the establishment of SRWC or other tree crops because they compete for water, nutrients and light resulting in reduced growth and survival (Hansen et al. 1984a, Shribbs and Skroch 1986, Cogliastro et al. 1990, Ferm et al. 1994, Merwin and Stiles 1994, Malik et al. 2001). A viable alternative would be to establish a cover crop in the fall after site preparation is completed and then kill it just prior to planting in the spring. This would provide ground cover during the late fall, winter and early spring prior to planting, If the cover crop is killed just prior to planting and not turned into the soil then a protective mulch would be left on the soil surface during the first growing season. This mulch has the potential to reduce soil erosion and weed growth while helping to maintain soil moisture and organic matter levels. This approach has been successful in vineyards (Pool et al. 1990) and orchards (Shribbs and Skroch 1986), and has shown potential in short-rotation sweetgum (*Liquidambar styraciflua* L.) plantations (Malik et al. 2001).

Winter rye cover crop residues reduced weed populations (Liebl et al. 1992, Teasdale et al. 1991). The greatest weed control effect occurs during the first 30 – 45 days after the cover crop is killed and before the mulch begins to decompose. By 50 to 60 days after the cover crop is killed the residue's effect on weed biomass decreased (Weston 1990, Moore et al. 1994, Masiunas et al. 1995). Weed suppression from residue has been attributed to physical impedance of weed growth, changes in the characteristics of light reaching the soil, modifications of soil temperature (Teasdale and Mohler 1993), and the release of allelopathic compounds (Barnes et al. 1987, Burgos and Talbert 2000). Cover crop residue usually does not effectively control weed populations unless pre-emergence herbicides are also applied as part of the weed management strategy for annual crops (Teasdale et al. 1991, Teasdale 1996), although there have been exceptions (Liebl et al. 1992). The combination of cover crop resides and pre-emergence herbicides has been shown to improve weed control compared to either one alone (Wicks et al. 1994, Teasdale 1998).

A previous experiment on alternative methods of site preparation for high density poplar and willow SRWC indicated that the inclusion of winter rye cover crops was as effective as the standard fall tillage site preparation technique without cover crops (Chapter 3). In that study, the cover crop was disked under in the spring, which limited residue cover on the soil surface in the first year after planting. Other approaches to managing a winter rye cover crop that leave residue on the soil surface have been developed for annual cropping systems (Teasdale and Mohler 1993, Wilkins and Bellinder 1996, Teasdale 1998). The main objective of this study was to determine the effect of different ways of managing winter rye cover crops on the survival and aboveground biomass production of poplar and willow SRWC. A second objective was to determine if a winter rye cover crop could be used to control weed populations during establishment without the use of pre-emergence herbicides.

Materials and Methods

This study was located at the State University of New York College of Environmental Science and Forestry (SUNY-ESF) Genetics Field Station in Tully, NY ($42^0$47’30”N, $76^0$07’30”W, elevation 391m). The soil is a well-drained to somewhat excessively well-drained Palmyra gravelly silt loam (*Glossoboric Hapludalf*) with a gentle slope of 0 to 3% (Hutton and Rice 1977). The site was mowed once in summer of 1999 and sprayed with glyphosate (2.25 kg ai ha^{-1}) several weeks later. Two weeks after spraying with glyphosate, the site was moldboard plowed to a depth of 20 – 25 cm and then cross-disked. Cover crop treatments were planted with Aroostook winter rye *(Secale cereale L.*) the last week in September with a Brillion seeder at 124 kg ha^{-1}.

The study design is a split plot with the whole plots in a randomized block design with four replications. Four whole plot cover crop treatments were: (1) control with no cover crop planted (control), (2) rye cover crop mowed with a sickle bar mower in the spring (Mow), (3) rye cover crop sprayed with glyphosate (2.25 kg ai ha^{-}1) in the spring and mowed with a sickle bar mower (S&M); (4) rye sprayed with glyphosate (2.25 kg ai ha^{-1}) in the spring (Spray). Four subplot treatments were randomly applied to the whole plots at the time of planting the SRWC ; (i) willow clone (SV1) sprayed with pre-emergence herbicides following planting, (ii) SV1 with no pre-emergence herbicides, (iii) poplar clone (NM6) sprayed with pre-emergence herbicides (iv) NM6 with no pre-emergence herbicides. The subplot treatments with no pre-emergence herbicides (ii and iv) were not applied to the whole plot control treatment. Abbreviations used for whole plot and subplot treatments are listed in Table 3.1. Whole plots were 12 double rows wide (27.4 m) and 21.3 m long. Subplots were three double rows wide (6.9 m) and 21 m long. Measurement plots were 6.7m long in the center double row.

Glyphosate (2.25 kg ai ha^{-1}) was applied to the appropriate treatments on May 17, 2000. The Mow and S&M treatments were mowed on June 6, 2000. Unrooted, dormant cuttings 20 cm long were planted June 9, 2000 with a Step planter in the double-row design at a density of 14,376 plants ha^{-1}. The pre-emergence herbicide treatments were

Table 3.1 Abbreviations for whole and subplot treatments for a poplar (NM6) and a willow (SV1) clone that were planted following the application of different winter rye cover crop management techniques.

Whole Plot	Subplot	Abbreviation
Control – no rye cover crop planted	Pre-emergence herbicides applied	Control (P)
Rye cover crop mowed in the spring	Pre-emergence herbicides applied	Mow (P)
	No pre-emergence herbicides applied	Mow (NP)
Rye cover crop sprayed with glyphosate in the spring	Pre-emergence herbicides applied	Spray (P)
	No pre-emergence herbicides applied	Spray (NP)
Rye cover crop sprayed and mowed in the spring	Pre-emergence herbicides applied	S&M (P)
	No pre-emergence herbicides applied	S&M (NP)

sprayed with a mixture of oxyflourfen (1.12 kg ai ha^{-1}) and simazine (2.25 kg ai ha^{-1}) two days after planting.

Soil water content (θ), rye residue cover and weed cover were measured in each measurement plot every week from early June to early November in 2000 and every two weeks from late May until late September 2001. Soil moisture in the top 15 cm was measured at three locations in each measurement plot using a TRIME-FM TDR connected to a P3 probe. Cover crop residue and weed cover were measured using the line intercept method. Two lines originating at the northeast and northwest corners of the measurement plots were run diagonally to the southwest and southeast corners, respectively. The presence or absence of weed cover or rye residue was assessed at 15 cm intervals. All the plots were rototilled June 29 – 30, 2001 to reduce weed competition.

Survival was assessed at the end of each growing season. In December 2000 all the poplar or willow plants were coppiced at 2 – 4 cm above the soil surface. In the measurement plots, all the aboveground biomass was collected and dried at 65^{o}C to a constant weight and weighed. After leaf fall in 2001, the diameter of all stems was measured 30 cm above the soil and the maximum height of each stool was measured. Aboveground biomass was estimated for each plot using allometric equations developed for one-year-old after coppice SV1 and NM6 grown at the same site (Table 2.5).

Statistical Analysis

ANOVA was used to assess treatment effects on survival and aboveground biomass at the end of the 2000 and 2001 growing seasons. Treatment effects on rye residue were assessed at the beginning (June 14) and end (November 3) of the 2000 growing season and the beginning (May 27) and middle (June 29) of the 2001 growing season. Treatment effects on weed cover were assessed at the beginning (June 14) and end (November 3) of the 2000 growing season and the beginning (May 27), middle (June 29) and end (September 14) of the 2001growing season. The 2001 growing season was separated into two sections because the site was rototilled on June 29, 2001. Treatment effects on soil water content were assessed at the beginning and end of the 2000 and 2001 growing season. The following split plot model was used for all variables.

$$y_{ijk} = \mu + b_i + t_j + b*t_{ij} + c_k + t*c_{jk} + \varepsilon_{ijk}$$

Where:

y_{ijk} = i^{th} observation of the j^{th} treatment of the k^{th} clone

μ = overall mean of the observations

b_i = added effect of the i^{th} block

t_j = added effect of the t^{th} cover crop treatment

$b*t_{ij}$ = interaction effect between the b^{th} block and the t^{th} cover crop treatment

c_k = added effect of the c^{th} planting treatment

$t*c_{jk}$ = interaction effect between the t^{th} cover crop treatment and the c^{th} planting treatment

ε_{ijk} = random effect associated with the y_{ijk}, ε_{ijk} NID(0, σ^2)

Significance of the cover crop by planting treatment interaction was assessed at α= 0.20 (Stehman and Meredith 1995). If the interaction was significant for one of the points in time assessed for a variable then simple effects were tested at all time periods. The following simple effects contrasts were tested for poplar and willow separately:

1. Control (P) – (S&M (P) + Mow(P) + Spray (P))/3
2. S&M (P) – Mow(P)
3. S&M (P) – Spray (P)
4. (S&M (P) + Mow(P) + Spray (P))/3 –(S&M (NP) + Mow(NP) + Spray (NP))/3
5. Mow (P) – Mow (NP)
6. Spray (P) – Spray (NP)
7. S&M (P) – S&M (NP)

All split plot analyses were conducted using Proc Mixed (SAS 1999). The Satterthwaite approximation was used to determine denominator degrees of freedom for linear contrasts (Kuehl 1994).

Analysis of changes in rye residue cover, weed cover and soil water content over time was done by assessing treatment effects for estimated coefficients for quadratic polynomial response curves (Meredith and Stehman 1991). The same split plot model and set of contrasts explained above were used.

Results

Survival

Survival varied among the cover crop and planting treatments at the end of the first and second growing season (Table 3.2). The interaction was not significant after the first growing season but it was after the second growing season.

Survival of poplar clone NM6 was greater than 87% in all but one treatment (Figure 3.1) at the end of the first growing season (2000). The exception was the Mow (NP) treatment where survival was 74%. There were no significant differences among the poplar treatments (Table 3.3), but survival in the Mow (P) treatment was 17.5% higher than on the Mow (NP) treatment. Poplar survival decreased less than 6% between 2000 and 2001 in all but the Mow (NP) treatment. Survival was greater than 83% at the end of the first growing season after coppice (2001) in six of the seven poplar treatments. Survival on the Mow (NP) treatment dropped by 30% to 44% at the end of 2001. At the end of 2001, poplar survival was significantly greater for Mow (P) compared to the Mow (NP) treatment. For the Spray and S&M treatments there was no difference in survival between the (P) and (NP) treatments.

Table 3.2. P-values from ANOVAs for survival and aboveground biomass in 2000 and 2001 for a poplar (NM6) and a willow (SV1) clone that were planted following the application of different winter rye cover crop management techniques.

	Numerator df	Denominator df	Survival 2000	Survival 2001	Biomass 2000	Biomass 2001
Cover crop treatment	3	9	0.0394	0.0061	0.0025	0.0018
Planting treatments	3	30	0.0002	0.0011	<0.0001	<0.0001
Cover crop * planting treatments	7	30	0.3262	0.0516	0.0011	0.1273

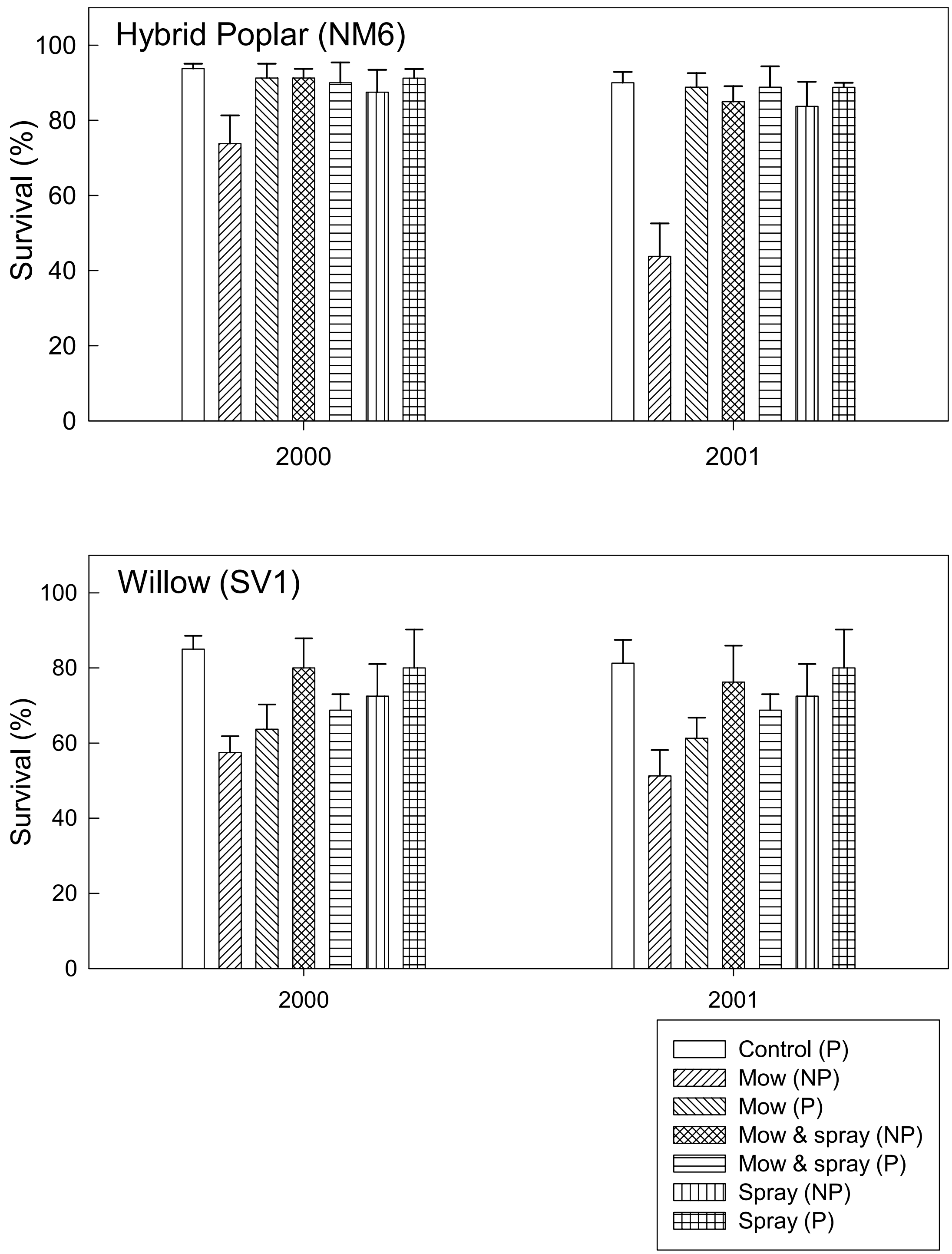

Figure 3.1. Survival (mean + SE) for poplar (NM6) and willow (SV1) in 2000 and 2001 established usinge different management techniques for a winter rye cover crop.
(P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after plantin, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Table 3.3. Estimates and p-values for contrasts on survival in 2000 and 20001 for a poplar (NM6) and a willow (SV1) clone that were planted following the application of different winter rye cover crop management techniques.

Linear Contrast	2000 Survival Estimate (%)	p-value	2001 Survival Estimate (%)	p-value
	Main Effects Poplar and willow		Simple Effects Poplar (NM6)	
Control (P) – cover crop(P)	2.92	0.6673	1.25	0.8683
Spray & mow (P) – mow (P)	0.00	1.0000	0.00	1.0000
Spray & mow(P) – spay(P)	1.25	0.8803	0.00	1.0000
Cover crop (P) – cover crop (NP)	6.67	0.2048	17.92	0.0041
Mow (P) – mow (NP)	17.50	0.0585	45.00	<0.0001
Spray (P) – spray (NP)	-1.25	0.8894	3.75	0.7110
Spray & mow (P) – spray & mow(NP)	3.75	0.6770	5.00	0.6217
	Willow (SV1)			
Control (P) – cover crop(P)	13.17	0.0420	11.25	0.1357
Spray & mow (P) – mow(P)	16.25	0.0560	18.75	0.0450
Spray & mow(P) – spay(P)	11.25	0.1804	11.25	0.2208
Cover crop (P) – cover crop (NP)	0.83	0.8725	3.33	0.5690
Mow (P) – mow (NP)	6.25	0.4886	10.00	0.3265
Spray (P) – spray (NP)	-11.25	0.2164	-7.50	0.4602
Spray & mow (P) – spray & mow(NP)	7.50	0.4067	7.50	0.4602

† (P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Survival of willow clone SV1 ranged from 58 – 85% at the end of the first growing season (2000) with only the control, M&S (NP) and Spray (P) treatments having survival $\geq$ 80%. Cover crops significantly reduced willow survival compared to the Control (P) (Table 3.3). There was no significant difference in survival between cover crop (P) and (NP) treatments. Survival changed less than 6% in any one treatment between 2000 and 2001. At the end of the first growing season after coppice (2001), the difference in survival between the Control (P) and the cover crop treatments was no longer significant. Survival on the S&M (P) treatment was greater than the Mow (P). The use of pre-emergence herbicides did not have any impact on survival within any given cover crop treatment.

Aboveground Biomass

The interaction between cover crop and planting treatments was significant for aboveground biomass at the end of the first and second growing season (Table 3.2).

Aboveground biomass of poplar at the end of the first growing season (2000) varied by from 0.02 to 0.5 odt ha^{-1} across the treatments (Figure 3.2). Poplar aboveground biomass was significantly greater in the cover crop treatments compared to the Control (P) when pre-emergence herbicides were applied after planting (Table 3.4). On the

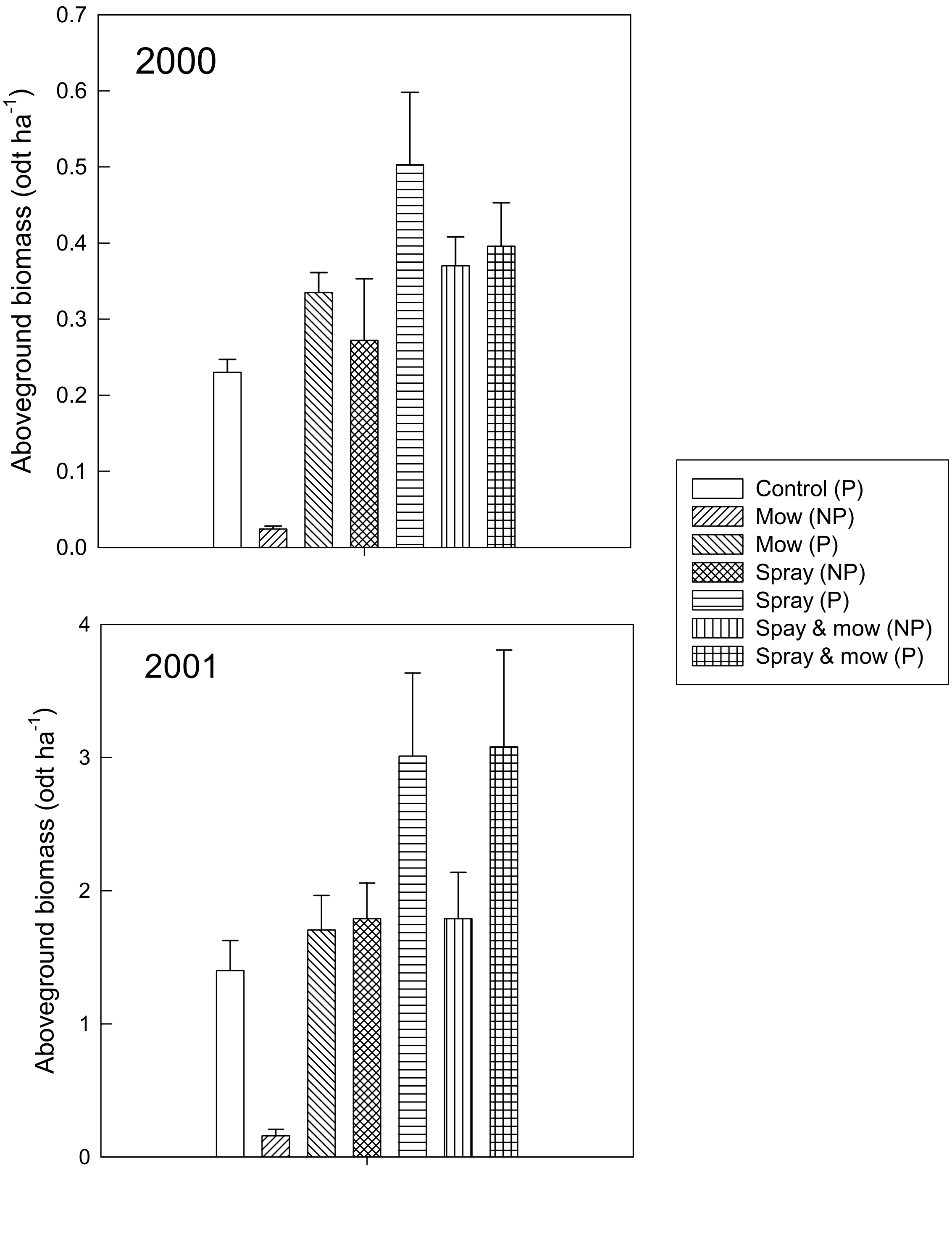

Figure 3.2. Aboveground biomass (mean +SE) for poplar (NM6) in 2000 and 2001 established using different management techniques for a winter rye cover crop.
(P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Table 3.4. Estimates and p-values for contrasts on aboveground biomass in 2000 and 20001 for a poplar (NM6) and a willow (SV1) clone that were planted following the application of different winter rye cover crop management techniques.

Linear Contrast	2000 Biomass Estimate (odt ha^{-1})	2000 Biomass p-value	2001 Biomass Estimate (odt ha^{-1})	2001 Biomass p-value
	Poplar (NM6)			
Control (P) – cover crop (P)†	-0.185	0.0003	-1.204	0.0008
Spray & mow (P) – mow(P)	0.060	0.3017	1.375	0.0015
Spray & mow(P) – spay(P)	-0.107	0.0707	0.068	0.8654
Cover crop (P) – cover crop (NP)	0.1898	<0.0001	1.351	<0.0001
Mow (P) – mow (NP)	0.3121	<0.0001	1.545	0.0001
Spray (P) – spray (NP)	0.2312	0.0006	1.220	0.0017
Spray & mow (P) – spray & mow(NP)	0.026	0.6721	1.288	0.0010
	Willow (SV1)			
Control (P) – cover crop(P)	0.001	0.9890	-0.538	0.1058
Spray & mow (P) – mow(P)	0.031	0.5987	0.465	0.2481
Spray & mow(P) – spay(P)	0.007	0.9092	-0.325	0.3790
Cover crop (P) – cover crop (NP)	0.040	0.2661	0.995	<0.0001
Mow (P) – mow (NP)	0.053	0.3944	0.950	0.0115
Spray (P) – spray (NP)	0.029	0.6341	1.248	0.0014
Spray & mow (P) – spray & mow(NP)	0.038	0.5419	0.788	0.0333

† (P) indicates that the treatment was sprayed with preemergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with preemergence herbicides.

mowed or sprayed cover crop treatments, aboveground biomass was significantly less when pre-emergence herbicides were not applied (NP) compared to those same treatments where pre-emergence herbicides were applied (P). At the end of the second growing season (2001), poplar aboveground biomass ranged from 0.16 to 0 3.1 odt ha^{-1}. The Spray (P) and S&M (P) treatments had the greatest aboveground biomass and were not significantly different. Cover crop treatments produced 1.2 odt ha^{-1} more biomass than the Control (P) when pre-emergence herbicides were applied. The S&M cover crop treatment significantly increased aboveground biomass production compared to the Mow treatment. Applying pre-emergence herbicides increased the aboveground biomass production across each of the cover crop treatments.

Willow aboveground biomass at the end of the first growing season (2000) varied from 0.004 to 0.09 odt ha^{-1} and was lower than poplar production (Figure 3.3). There were no significant differences in aboveground biomass among the treatments (Table 3.4). Willow aboveground biomass ranged from 0.07 to 1.84 odt ha^{-1} at the end of the second growing season (2001). There was no difference in aboveground biomass between the Control (P) and cover crop treatments when pre-emergence herbicides were applied.

The application of pre-emergence herbicides increased the aboveground biomass for all of the cover crop treatments compared to treatments where no pre-emergence herbicide was applied.

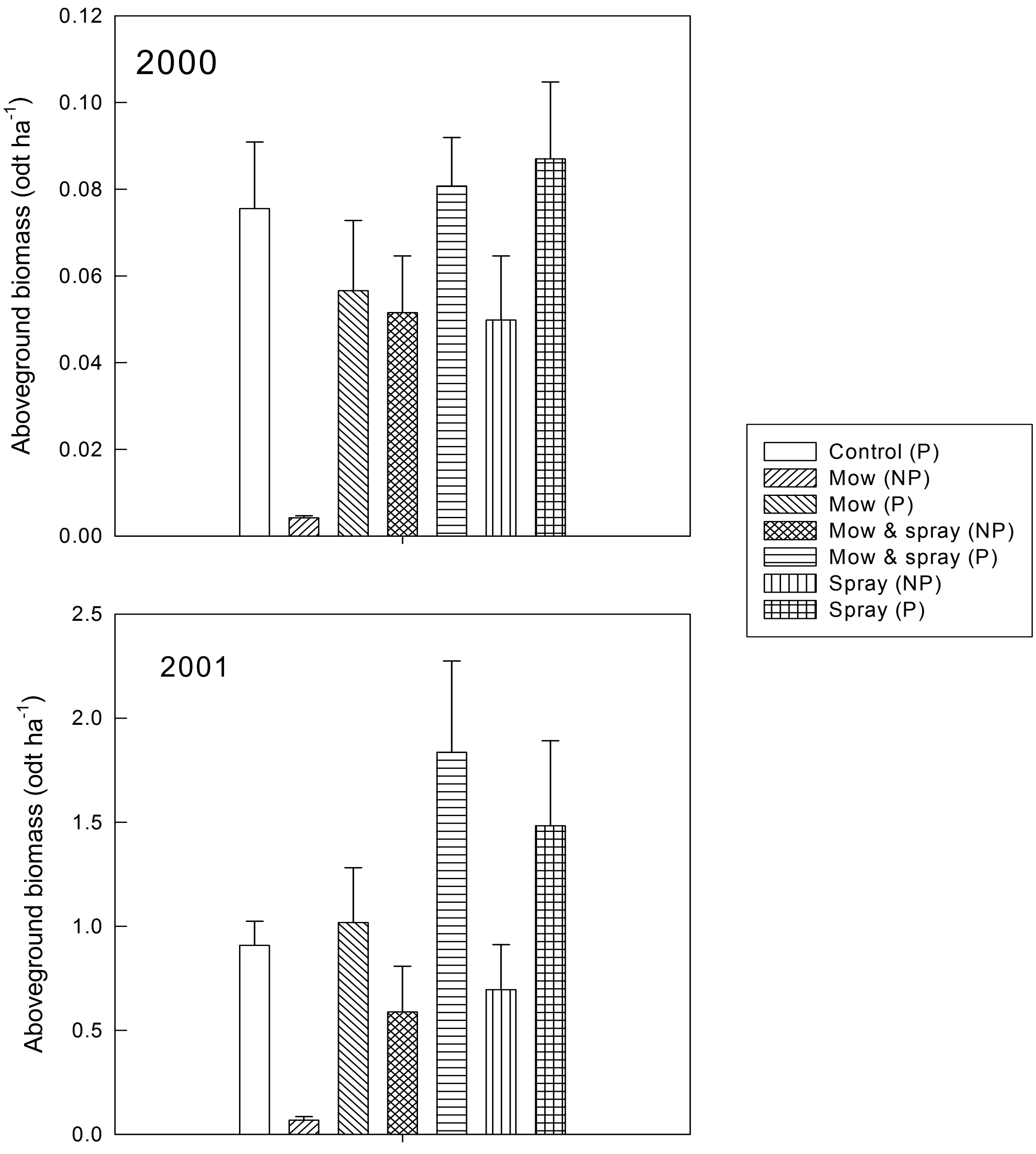

Figure 3.3. Above ground biomass (mean +SE) for willow (SV1)) in 2000 and 2001 established using different management techniques for a winter rye cover crop.
(P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Rye Residue

Just after planting the willow and poplar biomass crops, rye residue cover varied from 21 to 88% among the cover crop treatments (Figure 3.4 and 3.5, Table 3.5). The S&M (P) treatment had significantly less residue cover compared to either the Mow (P) or Spray (P) treatments under both poplar and willow (Table 3.6). During the first

growing season (2000) there were significant differences in the average value for residue cover across all time periods (z) and the linear (b) and quadratic (q) terms (Tables 3.7 and 3.8). The differences were similar for willow and poplar. The S&M (P) treatment had significantly less residue cover than either the Spray (P) or Mow (P) treatments. The Spray (P) and Mow (P) treatments had higher residue cover and lower rates of change in residue cover than the Spray (NP) and Mow (NP) treatments respectively.

By the end of the first growing season (2000) rye residue cover ranged from 0 to 70%. The differences that were significant were similar among the treatments under poplar and willow. Cover crop treatments had significantly more residue than in the Control (P) (Table 3.6). The S&M (P) treatment had significantly less residue cover than either the Spray (P) or Mow (P) treatments. The amount of rye residue was significantly less in the Mow (P) or Spray (P) treatments where compared to the Mow (NP) or Spray (NP) respectively.

At the beginning of the second growing season (2001) the amount of rye residue cover had decreased to below 6% under both willow and poplar except in the Mow (P) and Spray (P) treatments, which had between 30 and 71% cover. The patterns between treatments were similar for poplar and willow. The amount of rye residue cover was significantly greater on the cover crop treatments compared to the Control (P) (Table 3.9). The S&M (P) treatment had significantly less residue than either the Mow (P) or Spray (P) treatments. Over the course of the next eight weeks there were differences in the average residue cover across time and the rates of change of cover (Table 3.10 and 3.11). These treatment differences were due to higher level of residue cover in the Mow (P) and Spray (P) treatments at the beginning of the year.

Just before the site was rototilled in the middle of the 2001 growing season (June 29) the amount of rye residue ranged from 0 to 21%. Differences among treatments were similar under poplar and willow. The cover crop treatments had significantly more rye residue cover than the Control (P) (Table 3.9). The Mow (P) treatment had about 20% more residue cover than the S&M (P). The difference between the Spray (P) and S&M (P) treatments was no longer significant. The Mow (P) treatment had significantly more residue cover than the Mow (NP). Following rototilling, rye residue dropped to zero percent on all treatments.

Weed Cover

The interactions among the cover crop and planting treatments were significant for weed cover at the beginning and end of the 2000 growing season (Table 3.12). Weed cover varied from 0 to 17% shortly after planting (Figures 3.6, 3.7). The differences between treatments were similar under both poplar and willow. The Mow (P) treatment had significantly less weed cover compared to the Mow (NP) treatment (Table 3.13). The use of pre-emergence herbicides did not have a significant effect on weed cover for the Spray or S&M treatments at the beginning of the 2000 growing season. During the coarse

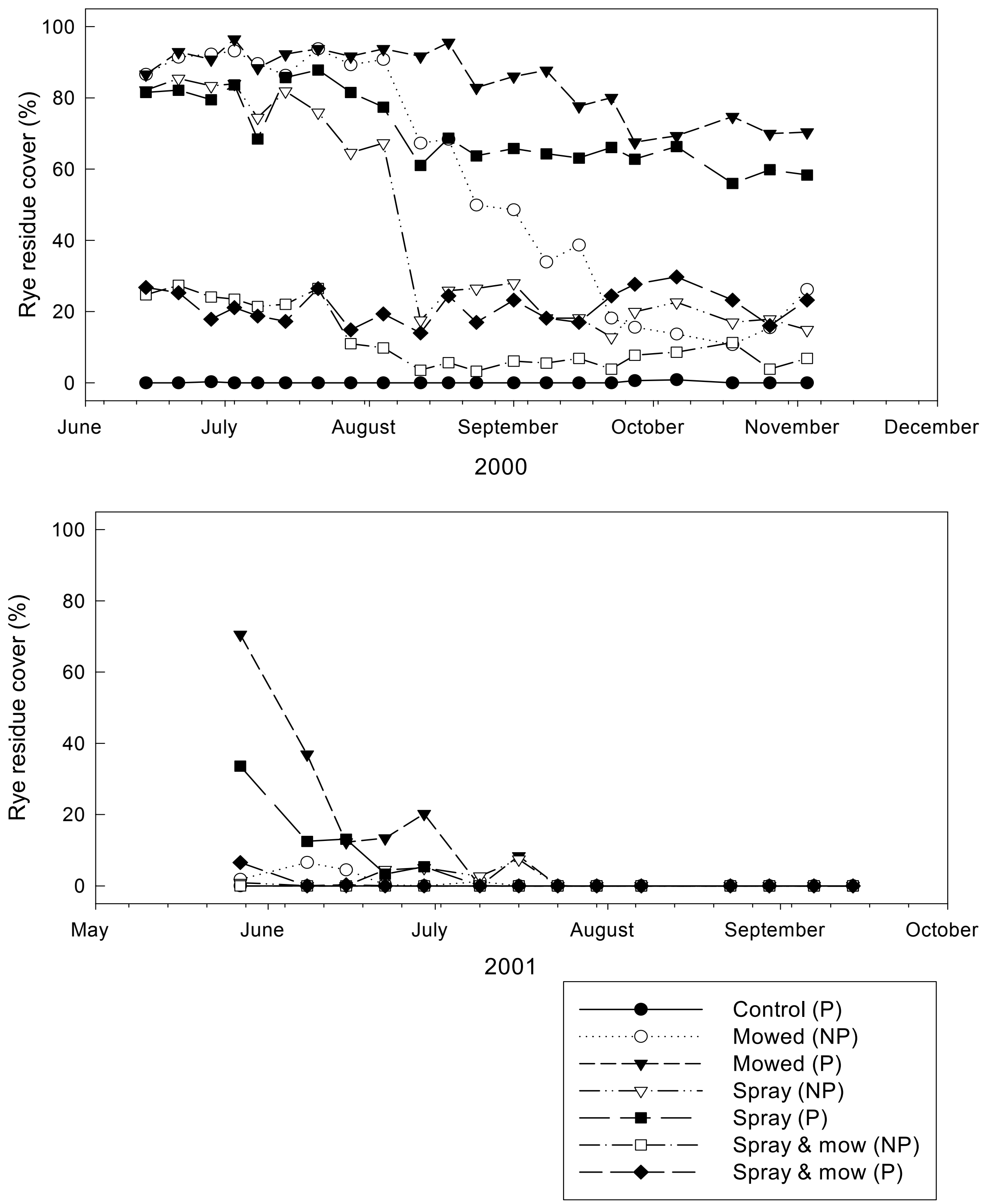

Figure 3.4. Rye residue cover for poplar (NM6) in 2000 and 2001 established using different management techniques for a winter rye cover crop.
(P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

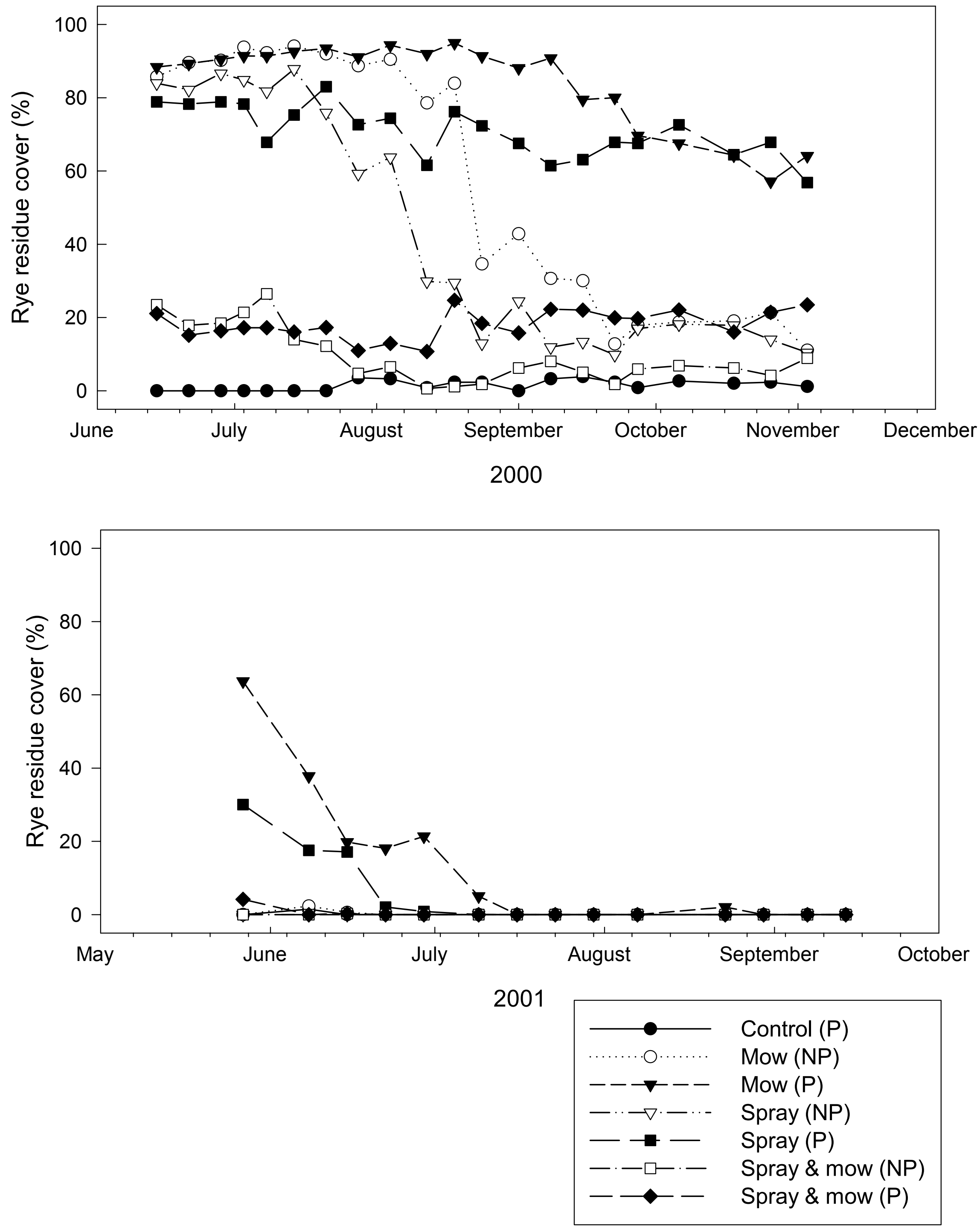

Figure 3.5. Rye residue cover for willow (SV1) in 2000 and 2001 established using different management techniques for a winter rye cover crop.
(P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Table 3.5 . P-values from ANOVAs for rye residue cover at the beginning and end of the growing seasons in 2000 and beginning and middle of the 2001 growing season.
Poplar (NM6) and willow (SV1) clones were planted following the application of different winter rye cover crop management techniques.

	Numerator df	Denominator df	June 14, 2000	Nov. 3, 2000	May 27, 2001	June 29, 2001
Cover crop treatment	3	9	<0.0001	<0.0001	<0.0001	0.0082
Planting treatments	3	30	0.9122	<0.0001	<0.0001	0.0021
Cover crop * planting treatments	7	30	0.9347	0.0040	<0.0001	0.0008

Table 3.6. Estimates and p-values for contrasts on rye residue cover at the beginning and end of the growing seasons in 2000 for a poplar (NM6) and a willow (SV1) clone that were planted following the application of different winter rye cover crop management techniques.

Linear Contrast	June 14, 2000 Estimate (%)	p-value	November 3, 2000 Estimate (%)	p-value
	Poplar (NM6)			
Control (P) – cover crop (P)†	-63.98	<0.0001	-53.96	<0.0001
Spray & mow (P) – mow(P)	-59.82	<0.0001	-57.14	<0.0001
Spray & mow(P) – spay(P)	-53.76	<0.0001	-35.12	0.0004
Cover crop (P) – cover crop (NP)	0.49	0.8614	37.99	<0.0001
Mow (P) – mow (NP)	0.00	1.0000	53.16	<0.0001
Spray (P) – spray (NP)	-0.59	0.9037	43.45	<0.0001
Spray & mow (P) – spray & mow(NP)	2.08	0.6724	16.36	0.0736
	Willow (SV1)			
Control (P) – cover crop(P)	-62.80	<0.0001	-50.29	<0.0001
Spray & mow (P) – mow(P)	-67.26	<0.0001	-50.59	<0.0001
Spray & mow(P) – spay(P)	-57.74	<0.0001	-33.33	0.0007
Cover crop (P) – cover crop (NP)	-1.58	0.5773	41.33	<0.0001
Mow (P) – mow (NP)	2.67	0.5871	63.00	<0.0001
Spray (P) – spray (NP)	-5.05	0.3079	46.42	<0.0001
Spray & mow (P) – spray & mow(NP)	-2.38	0.6291	13.58	0.1091

† (P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Table 3.7. P-values from ANOVAs for estimated coefficients of a quadratic polynomial response curve for rye residue cover during the 2000 growing season.
Poplar (NM6) and willow (SV1) clones were planted following the application of different winter rye cover crop management techniques.

	Numerator df	Denominator df	Whole Unit (z)	Linear (b)	Quadratic (q)
Cover crop treatment	3	9	<0.0001	<0.0001	0.0033
Planting treatments	3	30	<0.0001	<0.0001	0.0722
Cover crop * planting treatments	7	30	0.2504	<0.0001	0.0355

Table 3.8. Estimates and p-values for contrasts of estimated coefficients of a quadratic polynomial response curve for rye residue cover during the 2000 growing season.
Poplar (NM6) and willow (SV1) clones were planted following the application of different winter rye cover crop management techniques.

	Poplar (NM6)					
	Whole Unit (z)		Linear (b)		Quadratic (q)	
Linear Contrast	Estimate	p-value	Estimate	p-value	Estimate	p-value
Control (P) – cover crop (P)†	-59.58	<0.0001	0.79	0.0272	0.017	0.7441
Spray & mow (P) – mow(P)	-63.65	<0.0001	1.20	0.0066	0.174	0.0112
Spray & mow(P) – spay(P)	-50.34	<0.0001	1.46	0.0012	0.093	0.1599
Cover crop (P) – cover crop (NP)	20.27	<0.0001	2.86	<0.0001	-0.047	0.1708
Mow (P) – mow (NP)	26.71	0.0002	3.01	<0.0001	0.069	0.2461
Spray (P) – spray (NP)	25.77	0.0004	3.29	<0.0001	-0.166	0.0073
Spray & mow (P) – spray & mow(NP)	8.34	0.2059	1.29	0.0051	-0.043	0.4623
	Willow (SV1)					
Control (P) – cover crop(P)	-57.70	<0.0001	0.66	0.0606	0.038	0.4736
Spray & mow (P) – mow(P)	-65.86	<0.0001	1.61	0.0004	0.204	0.0034
Spray & mow(P) – spay(P)	-51.96	<0.0001	1.19	0.0072	0.052	0.4224
Cover crop (P) – cover crop (NP)	20.87	<0.0001	3.18	<0.0001	-0.069	0.0451
Mow (P) – mow (NP)	25.88	0.0003	3.01	<0.0001	0.056	0.3390
Spray (P) – spray (NP)	26.78	0.0002	3.20	<0.0001	-0.168	0.0066
Spray & mow (P) – spray & mow(NP)	9.97	0.1329	1.33	0.0041	-0.097	0.1040

† (P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Table 3.9. Estimates and p-values for contrasts on rye residue cover at the beginning and middle of the growing seasons in 2001 for a poplar (NM6) and a willow (SV1) clone that were planted following the application of different winter rye cover crop management techniques.

Linear Contrast	May 27, 2001 Estimate (%)	p-value	June 29, 2001 Estimate (%)	p-value
	Poplar (NM6)			
Control (P) – cover crop (P)†	-36.90	<0.0001	-8.53	0.0283
Spray & mow (P) – mow(P)	-63.99	<0.0001	-20.26	<0.0001
Spray & mow(P) – spay(P)	-27.08	0.0009	-5.36	0.2483
Cover crop (P) – cover crop (NP)	36.01	<0.0001	6.85	0.0071
Mow (P) – mow (NP)	68.75	<0.0001	20.25	<0.0001
Spray (P) – spray (NP)	32.73	0.0003	0.29	0.9430
Spray & mow (P) – spray & mow(NP)	6.54	0.4216	0.00	1.0000
	Willow (SV1)			
Control (P) – cover crop(P)	-32.64	<0.0001	-7.44	0.0539
Spray & mow (P) – mow(P)	-59.52	<0.0001	-21.43	<0.0001
Spray & mow(P) – spay(P)	-25.89	0.0015	-0.89	0.8459
Cover crop (P) – cover crop (NP)	32.63	<0.0001	7.44	0.0038
Mow (P) – mow (NP)	63.69	<0.0001	21.42	<0.0001
Spray (P) – spray (NP)	30.05	0.0007	0.89	0.8302
Spray & mow (P) – spray & mow(NP)	3.17	0.6079	0.00	1.0000

† (P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Table 3.10 . P-values from ANOVAs for estimated coefficients of a quadratic polynomial response curve for rye residue cover during the first half of the 2001 growing season.
Poplar (NM6) and willow (SV1) clones were planted following the application of different winter rye cover crop management techniques.

	Numerator df	Denominator df	Whole Unit (z)	Linear (b)	Quadratic (q)
Cover crop treatment	3	9	<0.0001	0.0002	0.0003
Planting treatments	3	30	<0.0001	<0.0001	<0.0001
Cover crop * planting treatments	7	30	<0.0001	0.0031	<0.0001

Table 3.11. Estimates and p-values for contrasts of estimated coefficients of a quadratic polynomial response curve for rye residue cover during the first half of the 2001 growing season. Poplar (NM6) and willow (SV1) clones were planted following the application of different winter rye cover crop management techniques.

	Poplar (NM6)					
	Whole Unit (z)		Linear (b)		Quadratic (q)	
Linear Contrast	Estimate	p-value	Estimate	p-value	Estimate	p-value
Control (P) – cover crop (P)†	-15.20	<0.0001	6.76	0.0002	-3.69	0.0001
Spray & mow (P) – mow(P)	-29.30	<0.0001	11.09	<0.0001	-6.73	<0.0001
Spray & mow(P) – spay(P)	-12.20	0.0034	5.26	0.0109	-1.67	0.1183
Cover crop (P) – cover crop (NP)	13.63	<0.0001	-6.86	<0.0001	3.81	<0.0001
Mow (P) – mow (NP)	28.05	<0.0001	-11.42	<0.0001	8.49	<0.0001
Spray (P) – spray (NP)	11.49	0.0076	-7.85	0.0003	2.03	0.0549
Spray & mow (P) – spray & mow(NP)	1.37	0.7365	-1.31	0.5037	0.89	0.3894
	Willow (SV1)					
Control (P) – cover crop(P)	-15.23	<0.0001	6.06	0.0006	-2.25	0.0121
Spray & mow (P) – mow(P)	-31.28	<0.0001	9.58	<0.0001	-3.78	<0.0001
Spray & mow(P) – spay(P)	-12.69	0.0025	6.54	0.0020	-0.02	0.9845
Cover crop (P) – cover crop (NP)	15.31	<0.0001	-6.13	<0.0001	2.25	0.0006
Mow (P) – mow (NP)	31.57	<0.0001	-10.18	<0.0001	5.58	<0.0001
Spray (P) – spray (NP)	13.54	0.0020	-7.38	0.0006	0.57	0.5792
Spray & mow (P) – spray & mow(NP)	0.83	0.8376	-0.83	0.6698	0.59	0.5648

† (P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Table 3.12. P-values from ANOVAs for weed cover at the beginning and end of the 2000 growing and the beginning, middle and end of 2001 growing season for a poplar (NM6) and a willow (SV1) clone that were planted following the application of different winter rye cover crop management techniques.

	Numerator df	Denominator df	June 15, 2000	Nov. 1, 2000	May 26, 2001	June 29, 2001	Sept. 15, 2001
Cover crop treatment	3	9	0.0046	<0.0001	0.0039	0.5529	0.0213
Planting treatments	3	30	0.0020	<0.0001	0.0826	0.1609	<0.0001
Cover crop * planting treatments	7	30	0.0017	0.0010	0.0212	0.5647	0.4464

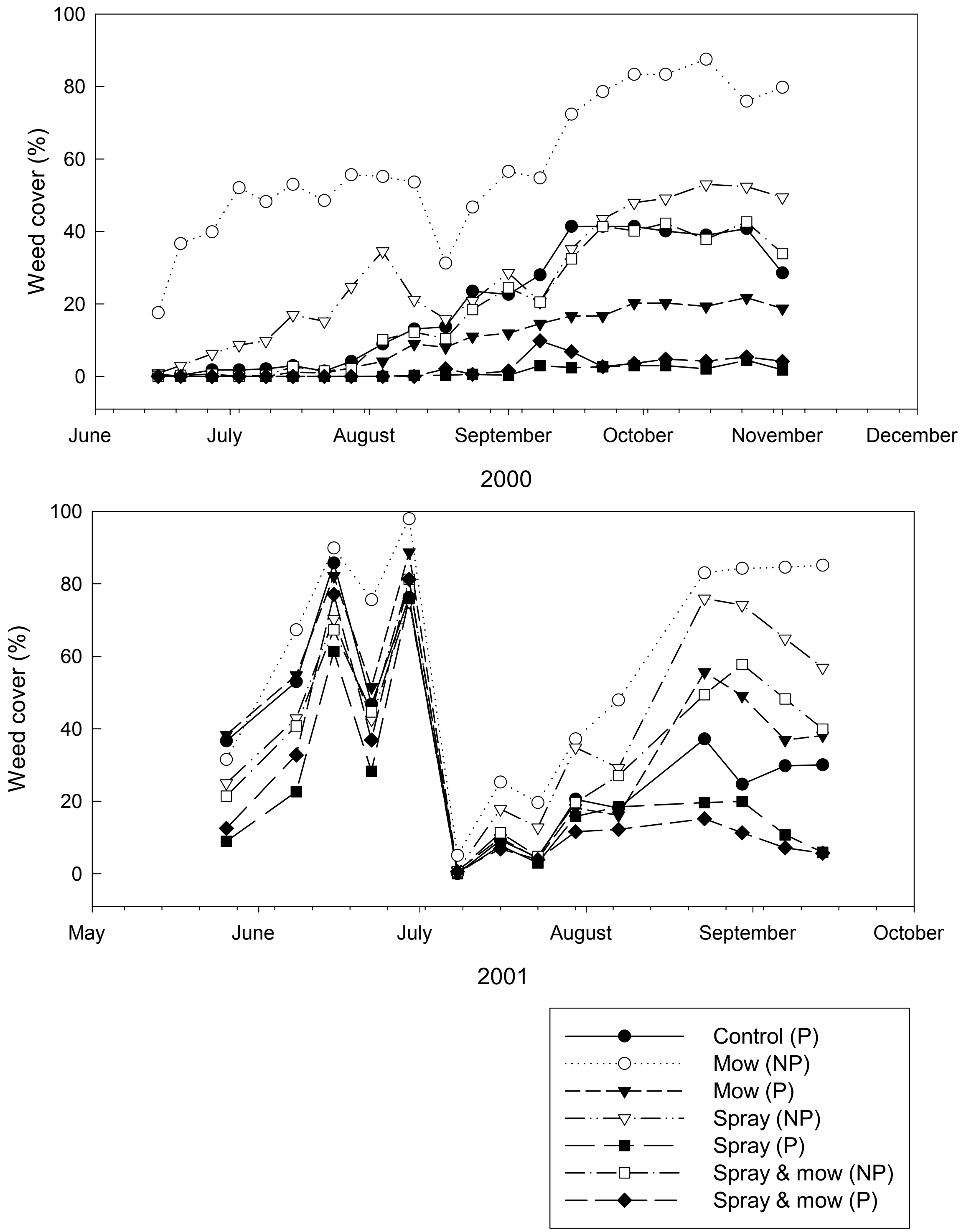

Figure 3.6. Weed cover for poplar (NM6) in 2000 and 2001 established using different management techniques for a winter rye cover crop.
(P) indicates that the treatment was sprayed with pre-emercence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

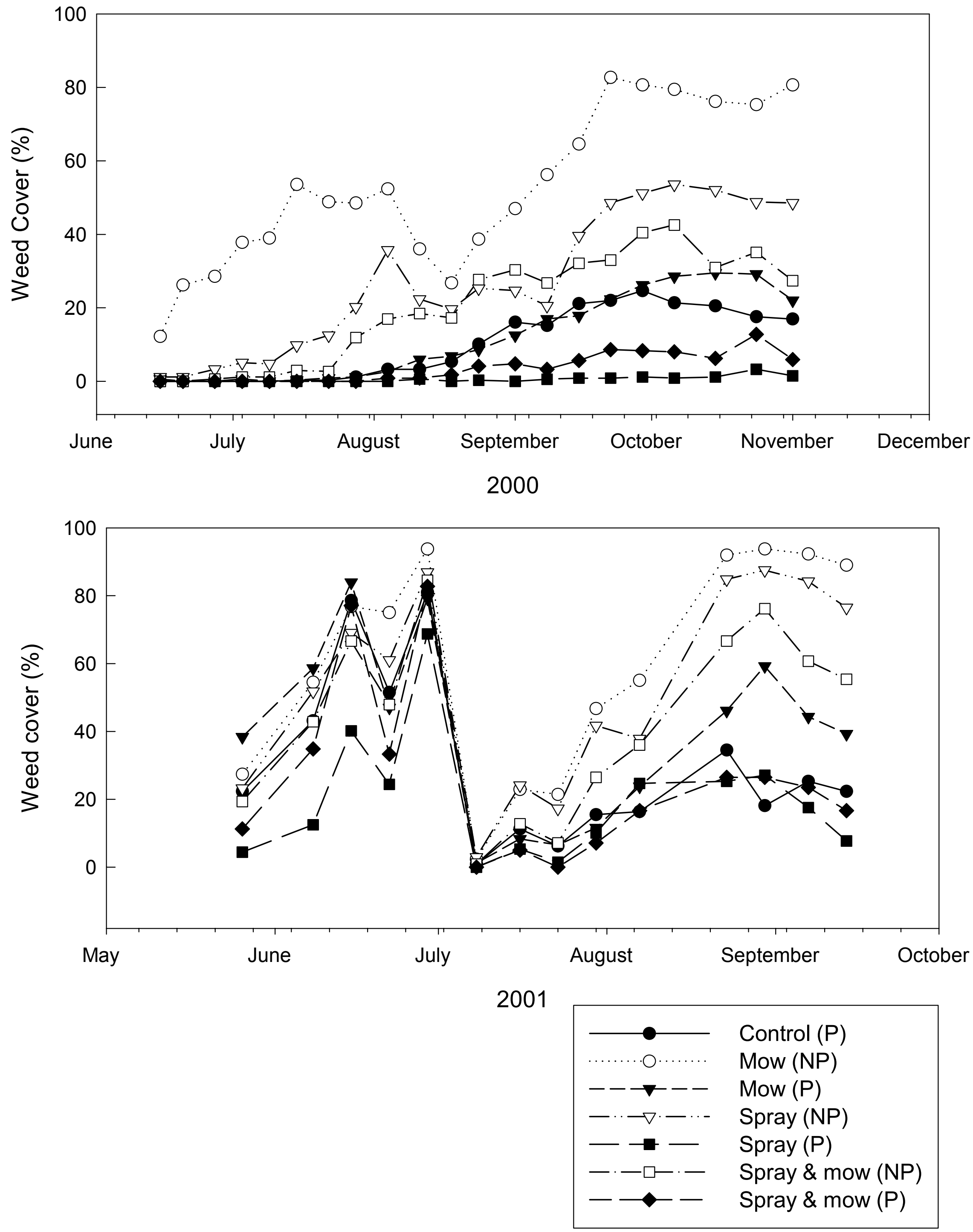

Figure 3.7. Weed cover for willow (SV1) in 2000 and 2001 established using different management techniques for a winter rye cover crop.
(P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Table 3.13. Estimates and p-values for contrasts on weed cover at the beginning and end of the growing seasons in 2000 for a poplar (NM6) and a willow (SV1) clone that were planted following the application of different winter rye cover crop management techniques.

	June 14, 2000		November 3, 2000	
Linear Contrast	Estimate (%)	p-value	Estimate (%)	p-value
	Poplar (NM6)			
Control (P) – cover crop (P)†	-0.07	0.9767	20.33	0.0007
Spray & mow (P) – mow(P)	0.59	0.8469	-13.58	0.0368
Spray & mow(P) – spay(P)	0.00	1.0000	2.38	0.7250
Cover crop (P) – cover crop (NP)	-5.95	0.0015	-46.13	<0.0001
Mow (P) – mow (NP)	-16.96	<0.0001	-61.01	<0.0001
Spray (P) – spray (NP)	-0.89	0.7652	-47.62	<0.0001
Spray & mow (P) – spray & mow(NP)	0.00	1.0000	-29.76	<0.0001
	Willow (SV1)			
Control (P) – cover crop(P)	-0.19	0.9372	7.14	0.2012
Spray & mow (P) – mow(P)	-0.59	0.8469	-16.07	0.0222
Spray & mow(P) – spay(P)	0.00	1.0000	3.46	0.5105
Cover crop (P) – cover crop (NP)	-3.26	0.0180	-42.36	<0.0001
Mow (P) – mow (NP)	-11.61	0.0004	-58.63	<0.0001
Spray (P) – spray (NP)	-1.19	0.6906	-47.02	<0.0001
Spray & mow (P) – spray & mow(NP)	0.00	1.0000	-21.42	0.0022

† (P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

of the first growing season, weed cover developed at a slower rate and was lower on average in the cover crop treatments under poplar but not under willow (Table 3.14 and Table 3.15). The use of pre-emergence herbicides reduced the rate of weed cover development in all cover crop treatments under both poplar and willow.

At the beginning of the second growing season (2001) weed cover ranged from 4 to 38%. Weed cover was significantly less in the cover crop treatments compared to the Control (P) under poplar but not under willow (Table 3.16). The S&M (P) treatment continued to have significantly less weed cover compared to the Mow (P) treatment under both willow and poplar. Weed cover was still significantly less under the Spray (P) compared to Spray (NP). The application of pre-emergence herbicides after planting no longer had a significant effect on weed cover for the Mow or S&M treatments.

By the end of the first growing season weed cover ranged from 2 to 81%. Weed cover was significantly less on the cover crop treatments compared to the Control (P) under poplar, but not under willow (Table 3.13). Other differences among the treatments were similar under poplar and willow. The S&M (P) treatment has significantly less weed cover compared to Mow (P). There was no difference in weed cover between the S&M (P) and Mow (P) treatments. The application of pre-emergence herbicides following planting significantly reduced the amount of weed cover for all of the cover crop treatments.

Weed cover increased rapidly on all the treatments during the next eight weeks of the second growing season. The rate of increase was greater in the Control (P) compared to the cover crop treatments under poplar but the rates were not significantly different under willow (Table 3.17 and 3.18). The use of pre-emergence herbicides with cover

Table 3.14 . P-values from ANOVAs for estimated coefficients of a quadratic polynomial response curve for weed cover during the 2000 growing season. Poplar (NM6) and willow (SV1) clones were planted following the application of different winter rye cover crop management techniques.

	Numerator df	Denominator df	Whole Unit (z)	Linear (b)	Quadratic (q)
Cover crop treatment	3	9	<0.0001	0.0132	0.0007
Planting treatments	3	30	<0.0001	<0.0001	0.1440
Cover crop * planting treatments	7	30	<0.0001	0.1004	0.3173

Table 3.15. Estimates and p-values for contrasts of estimated coefficients of a quadratic polynomial response curve weed cover during the 2000 growing season. Poplar (NM6) and willow (SV1) clones were planted following the application of different winter rye cover crop management techniques.

	Poplar (NM6)					
	Whole Unit (z)		Linear (b)		Quadratic (q)	
Linear Contrast	Estimate	p-value	Estimate	p-value	Estimate	p-value
Control (P) – cover crop (P)†	13.84	0.0002	1.94	0.0002	0.021	0.4818
Spray & mow (P) – mow(P)	-6.78	0.1131	-0.97	0.0984	-0.021	0.5573
Spray & mow(P) – spay(P)	0.89	0.8322	0.14	0.8028	0.002	0.9456
Cover crop (P) – cover crop (NP)	-28.87	<0.0001	-2.02	<0.0001	-0.054	0.0240
Mow (P) – mow (NP)	-47.92	<0.0001	-1.42	0.0057	-0.045	0.2647
Spray (P) – spray (NP)	-23.12	<0.0001	-2.42	<0.0001	-0.045	0.2589
Spray & mow (P) – spray & mow(NP)	-13.55	0.0017	-2.23	<0.0001	-0.072	0.0781
	Willow (SV1)					
Control (P) – cover crop(P)	3.58	0.1874	0.71	0.1385	0.001	0.9926
Spray & mow (P) – mow(P)	-7.24	0.0913	-1.21	0.0419	-0.069	0.0593
Spray & mow(P) – spay(P)	2.52	0.5490	0.41	0.4712	0.011	0.7576
Cover crop (P) – cover crop (NP)	-26.67	<0.0001	-2.03	<0.0001	0.008	0.7026
Mow (P) – mow (NP)	-40.12	<0.0001	-1.39	0.0064	0.003	0.9415
Spray (P) – spray (NP)	-23.58	<0.0001	-2.86	<0.0001	-0.036	0.3728
Spray & mow (P) – spray & mow(NP)	-15.29	0.0010	-1.83	0.0006	0.059	0.1441

† (P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Table 3.16. Estimates and p-values for contrasts on weed cover at the beginning, middle and end of the 2001 growing season for a poplar (NM6) and a willow (SV1) clone that were planted following the application of different winter rye cover crop management techniques.

	Poplar (NM6)					
	May 27, 2001		June 29, 2001		Sept. 14, 2001	
Linear Contrast	Estimate (%)	p-value	Estimate (%)	p-value	Estimate (%)	p-value
Control (P) – cover crop (P)†	16.67	0.0090	-5.75	0.5759	13.49	0.2272
Spray & mow (P) – mow(P)	-25.89	0.0013	-7.44	0.5550	-32.44	0.0223
Spray & mow(P) – spay(P)	3.57	0.6305	5.35	0.6700	-0.29	0.9824
Cover crop (P) – cover crop (NP)	-6.05	0.1220	-2.78	0.5593	-43.04	<0.0001
Mow (P) – mow (NP)	6.84	0.3067	-9.22	0.2664	-47.02	0.0002
Spray (P) – spray (NP)	-16.07	0.0209	0.89	0.9135	-50.89	<0.0001
Spray & mow (P) – spray & mow(NP)	-8.93	0.1852	0.00	1.0000	-33.22	0.0041
	Willow (SV1)					
Control (P) – cover crop(P)	3.26	0.4826	3.06	0.6918	1.09	0.9211
Spray & mow (P) – mow(P)	-27.08	0.0008	3.57	0.7760	-22.69	0.1023
Spray & mow(P) – spay(P)	6.84	0.3589	13.98	0.2763	8.91	0.5093
Cover crop (P) – cover crop (NP)	-5.25	0.1769	-11.51	0.0204	-52.38	<0.0001
Mow (P) – mow (NP)	11.01	0.1049	-13.58	0.0834	-49.70	<0.0001
Spray (P) – spray (NP)	-18.75	0.0080	-18.15	0.0334	-68.75	<0.0001
Spray & mow (P) – spray & mow(NP)	-8.04	0.2318	-1.79	0.8280	-38.69	0.0014

† (P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Table 3.17. P-values from ANOVAs for estimated coefficients of a quadratic polynomial response curve for weed cover during the first half of the 2001 growing season.
Poplar (NM6) and willow (SV1) clones were planted following the application of different winter rye cover crop management techniques.

	Numerator df	Denominator df	Whole Unit (z)	Linear (b)	Quadratic (q)
Cover crop treatment	3	9	0.0271	0.5669	0.0169
Planting treatments	3	30	0.0016	0.2599	0.4240
Cover crop * planting treatments	7	30	0.1091	0.0051	0.1767

Table 3.18. Estimates and p-values for contrasts of estimated coefficients of a quadratic polynomial response curve weed cover during the first half of the 2001 growing season.

	Poplar (NM6)					
	Whole Unit (z)		Linear (b)		Quadratic (q)	
Linear Contrast	Estimate	p-value	Estimate	p-value	Estimate	p-value
Control (P) – cover crop (P)†	9.44	0.1679	-5.32	0.0343	-1.91	0.1499
Spray & mow (P) – mow(P)	-15.00	0.0781	3.43	0.1386	-1.42	0.3757
Spray & mow(P) – spay(P)	8.69	0.2953	0.21	0.9430	-2.31	0.1529
Cover crop (P) – cover crop (NP)	-8.02	0.0247	0.47	0.7066	1.13	0.2442
Mow (P) – mow (NP)	-9.34	0.1218	-3.37	0.0534	3.38	0.0497
Spray (P) – spray (NP)	-11.72	0.0549	3.98	0.0766	1.57	0.3489
Spray & mow (P) – spray & mow(NP)	-2.97	0.6157	1.81	0.4096	-1.55	0.3554
	Willow (SV1)					
Control (P) – cover crop(P)	8.84	0.1951	0.83	0.7265	-2.19	0.0985
Spray & mow (P) – mow(P)	-13.57	0.1086	7.14	0.0218	0.29	0.8524
Spray & mow(P) – spay(P)	17.79	0.0394	0.09	0.9756	-3.53	0.0070
Cover crop (P) – cover crop (NP)	-12.26	0.0011	-2.45	0.0604	1.06	0.2774
Mow (P) – mow (NP)	-3.04	0.4956	-8.33	0.0006	0.17	0.9188
Spray (P) – spray (NP)	-28.33	<0.0001	0.38	0.8597	3.27	0.0148
Spray & mow (P) – spray & mow(NP)	-3.40	0.4586	0.59	0.7857	-1.27	0.4464

† (P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Poplar (NM6) and willow (SV1) clones were planted following the application of different winter rye cover crop management techniques.

crops at the beginning of 2000 still significantly reduced the amount of weed cover during the first half of the 2001 growing season compared to cover crop treatments without pre-emergence herbicides (NP). The rates of increase in weed cover were not different between the (P) and (NP) cover crop treatments.

By the middle of the second growing season and just before the site was rototilled, weed cover across all plots ranged from 68 to 97%. There were no differences in weed cover among the treatments under poplar (Table 3.16). Under willow, weed cover was still significantly less under the cover crop treatments compared to the control. Weed cover was lower in Spray (P) compared to Spray (NP) in willow plots (Table 3.16). Rototilling reduced weed cover below 5% on all the treatments. Weed cover developed rapidly following rototilling. The linear rate of increase was greater for cover crop treatments that included pre-emergence herbicides compared to those that did not under both willow and poplar (Table 3.19 and 3.20). The S&M (P) had a lower rate of weed cover development compared to the now (P) treatment, but it was not different than the Spray (P) treatment.

By the end of the second growing season weed cover ranged from 6 to 88%. The difference in weed cover was not significant between the cover crop treatments where pre-emergence herbicides had been applied and the Control (P) (Table 3.16). Weed cover was significantly less in the S&M (P) compared to the Mow (P) under poplar, but not under willow.

Table 3.19 . P-values from ANOVAs for estimated coefficients of a quadratic polynomial response curve for weed cover in the second half of the 2001 growing season.
Poplar (NM6) and willow (SV1) clones were planted following the application of different winter rye cover crop management techniques.

	Numerator df	Denominator df	Whole Unit (z)	Linear (b)	Quadratic (q)
Cover crop treatment	3	9	0.0206	0.0227	0.4247
Planting treatments	3	30	<0.0001	<0.0001	0.3545
Cover crop * planting treatments	7	30	0.5787	0.3758	0.6085

Table 3.20. Estimates and p-values for contrasts of estimated coefficients of a quadratic polynomial response curve weed cover during the second half of the 2001 growing season.
Poplar (NM6) and willow (SV1) clones were planted following the application of different winter rye cover crop management techniques.

	Poplar (NM6)					
	Whole Unit (z)		Linear (b)		Quadratic (q)	
Linear Contrast	Estimate	p-value	Estimate	p-value	Estimate	p-value
Control (P) – cover crop (P)†	3.36	0.4292	1.38	0.3203	0.217	0.4147
Spray & mow (P) – mow(P)	-17.16	0.0159	-5.29	0.0037	0.039	0.9049
Spray & mow(P) – spay(P)	-2.97	0.6585	-0.52	0.7607	0.336	0.3024
Cover crop (P) – cover crop (NP)	-25.68	<0.0001	-6.32	<0.0001	0.065	0.6970
Mow (P) – mow (NP)	-27.01	<0.0001	-5.25	0.0009	-0.048	0.8686
Spray (P) – spray (NP)	-29.56	<0.0001	-7.63	<0.0001	0.115	0.6902
Spray & mow (P) – spray & mow(NP)	-20.47	0.0007	-6.07	0.0002	0.127	0.6593
	Willow (SV1)					
Control (P) – cover crop(P)	-1.11	0.8393	-1.21	0.3863	0.173	0.5127
Spray & mow (P) – mow(P)	-13.16	0.0586	-3.43	0.0500	0.034	0.9159
Spray & mow(P) – spay(P)	0.29	0.9647	1.00	0.5532	0.538	0.1031
Cover crop (P) – cover crop (NP)	-30.84	<0.0001	-6.74	<0.0001	0.280	0.0989
Mow (P) – mow (NP)	-30.56	<0.0001	-5.73	0.0004	0.577	0.0518
Spray (P) – spray (NP)	-37.50	<0.0001	-8.73	<0.0001	-0.202	0.4850
Spray & mow (P) – spray & mow(NP)	-23.47	<0.0001	-5.75	0.0003	0.466	0.1130

† (P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Under both poplar and willow weed cover was significantly less under the cover crop treatments were pre-emergence herbicides were applied following planting compared to the same treatments were pre-emergence herbicides were not applied.

Soil Water Content

There were significant differences in soil water content among treatments at the beginning and end of the 2000 growing season (Table 3.21). At the beginning of the 2000 growing season soil moisture was significantly higher under the cover crop treatments compared to the Control (P) under both willow and poplar plantings (Table

3.22, Figures 3.8 and 3.9). During the coarse of the growing season, soil water content was significantly lower in the Control (P) compared to the cover crop treatment (p = 0.0094). There were no other significant differences in average (z) soil water content or linear and quadratic rates of change among the treatments (Table 3.23).

At the end of the first growing season (2000) there were no significant differences in soil water content among treatments under willow. In the poplar treatments, soil water content in the cover crop treatments was significantly greater than the control. Soil moisture was higher in the S&M (P) compared to the Mow (P) treatment.

At the beginning of the second growing season (2001) there were no differences in soil water content under poplar (Table 3.24). Under willow, the soil water content was greater under the Control (P) compared to the cover crop treatments. There were no significant differences in average (z) soil water content or linear and quadratic rates of change among the treatments during the second growing season (Table 3.25, Figures 3.8 and 3.9). At the end of the second growing season, soil water content was not different under any of the poplar treatments. The only significant difference under the willow treatments was that it was lower in the S&M (P) than either the Mow (P) or Spray (P) (Table 3.24) .

Discussion

Incorporating cover crops into the establishment phase of SRWC can reduce erosion potential and non-point source pollution without compromising successful establishment. In order for this integration to be effective it is essential to minimize competition between the cover crop and the SRWC (Hansen et al. 1984a, Cogliastro et al. 1990, Ferm et al. 1994, Malik et al. 2001). One way to accomplish this is to plant a winter cover crop and kill it in the spring just prior to planting. This method has been developed for annual agriculture and orchard systems (Merwin and Stiles 1994, Teasdale, 1998) but have not been tried for SRWC. This method was tested and found to be effective for SRWC in this study. Poplar aboveground biomass increased and survival was not affected by the cover crop treatments compared to the Control (P) over the first two growing seasons. The cover crop treatments reduced willow survival in the first growing season. Despite this reduction, willow aboveground biomass in the cover crop treatments was similar to the Control (P) during the first two growing seasons. The positive or neutral effect of cover crops on aboveground biomass only occurred when pre-emergence herbicides were applied immediately following planting.

The use of pre-emergence herbicides to control weeds is part of the recommended procedures for the successful establishment of SRWC (Danfors et al. 1998, Kopp et al. 1991, Netzer 1995, Wagner 2000, Abrahamson et al. 2002). Increased economic and social pressure to reduce the use of herbicides in annual cropping systems has prompted the study of cover crop residue as an alternative to the use of pre-emergence herbicides (Merwin and Pritts 1993, Teasdale 1998). Residues reduce weed populations during the first 30 – 45 days after the cover crop is killed, but by 50 to 60 days the effect of the residue on weed biomass was reduced (Weston 1990, Moore et al. 1994, Masiunas et al. 1995). As a result, residues alone typically do not provide an acceptable level of weed control over the entire growing season (Wicks et al. 1994, Masiunas et al. 1995, Teasdale et al. 1991). In this study, weed cover in the cover crop treatments that did not include pre-emergence herbicides developed at a faster rate during the first growing season and was 20 – 61% greater by the end of the season. Although survival of poplar or willow

Table 3.21. P-values from ANOVAs for soil moisture at the beginning and end of the 2000 and 2001 growing for a poplar (NM6) and a willow (SV1) clone that were planted following the application of different winter rye cover crop management techniques.

	Numerator df	Denominator df	June 16, 2000	Oct. 31, 2000	May 16, 2001	Sept. 28, 2001
Cover crop treatment	3	9	0.0063	0.0315	0.8024	0.1893
Planting treatments	3	30	0.8478	0.9790	0.9362	0.3065
Cover crop * planting treatments	7	30	0.6932	0.1149	0.1664	0.8759

Table 3.22. Estimates and p-values for contrasts for soil moisture at the beginning and middle of the growing season in 2000 for a poplar (NM6) and a willow (SV1) clone that were planted following the application of different winter rye cover crop management techniques.

	June 16, 2000		Oct. 31, 2000	
Linear Contrast	Estimate (m^3 m^{-3})	p-value	Estimate (m^3 m^{-3})	p-value
	Poplar (NM6)			
Control (P) – cover crop (P)†	-6.04	0.0012	-3.77	0.0041
Spray & mow (P) – mow(P)	-2.25	0.2895	-3.25	0.0293
Spray & mow(P) – spay(P)	0.85	0.6869	-0.90	0.6278
Cover crop (P) – cover crop (NP)	-0.12	0.9173	0.86	0.3766
Mow (P) – mow (NP)	-0.02	0.9897	1.21	0.4727
Spray (P) – spray (NP)	-2.15	0.2741	0.61	0.7187
Spray & mow (P) – spray & mow(NP)	1.82	0.3518	0.78	0.6461
	Willow (SV1)			
Control (P) – cover crop(P)	-3.49	0.0127	1.14	0.4517
Spray & mow (P) – mow(P)	-1.73	0.4152	-0.45	0.8071
Spray & mow(P) – spay(P)	0.03	0.9905	-0.62	0.7381
Cover crop (P) – cover crop (NP)	-0.94	0.4047	-0.37	0.7021
Mow (P) – mow (NP)	-2.90	0.1435	-1.45	0.3924
Spray (P) – spray (NP)	-0.83	0.6720	0.67	0.6967
Spray & mow (P) – spray & mow(NP)	0.90	0.6443	0.99	0.5579

† (P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

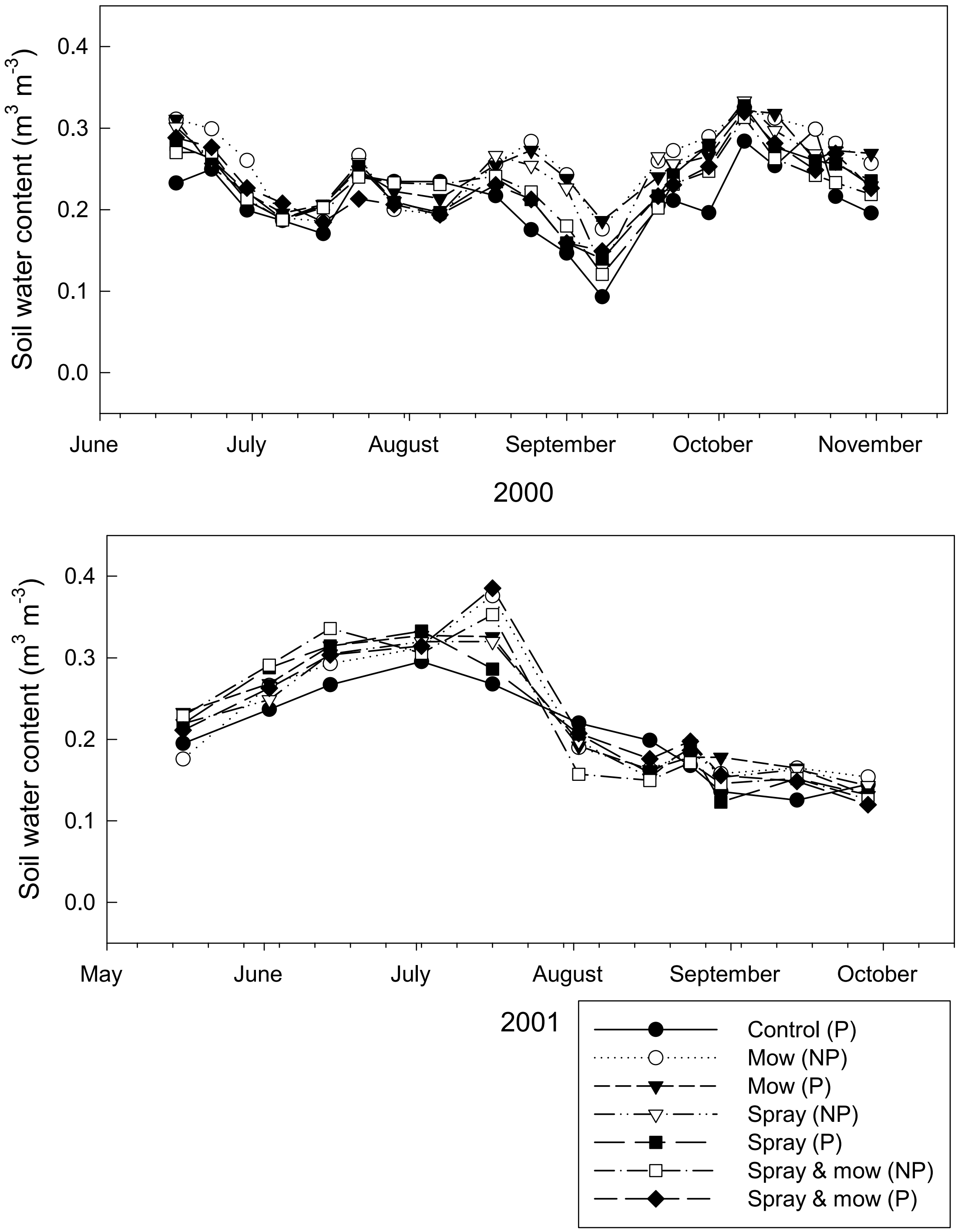

Figure 3.8. Soil water content under poplar (NM6) in 2000 and 2001 established using different management techniques for a winter rye cover crop.
(P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

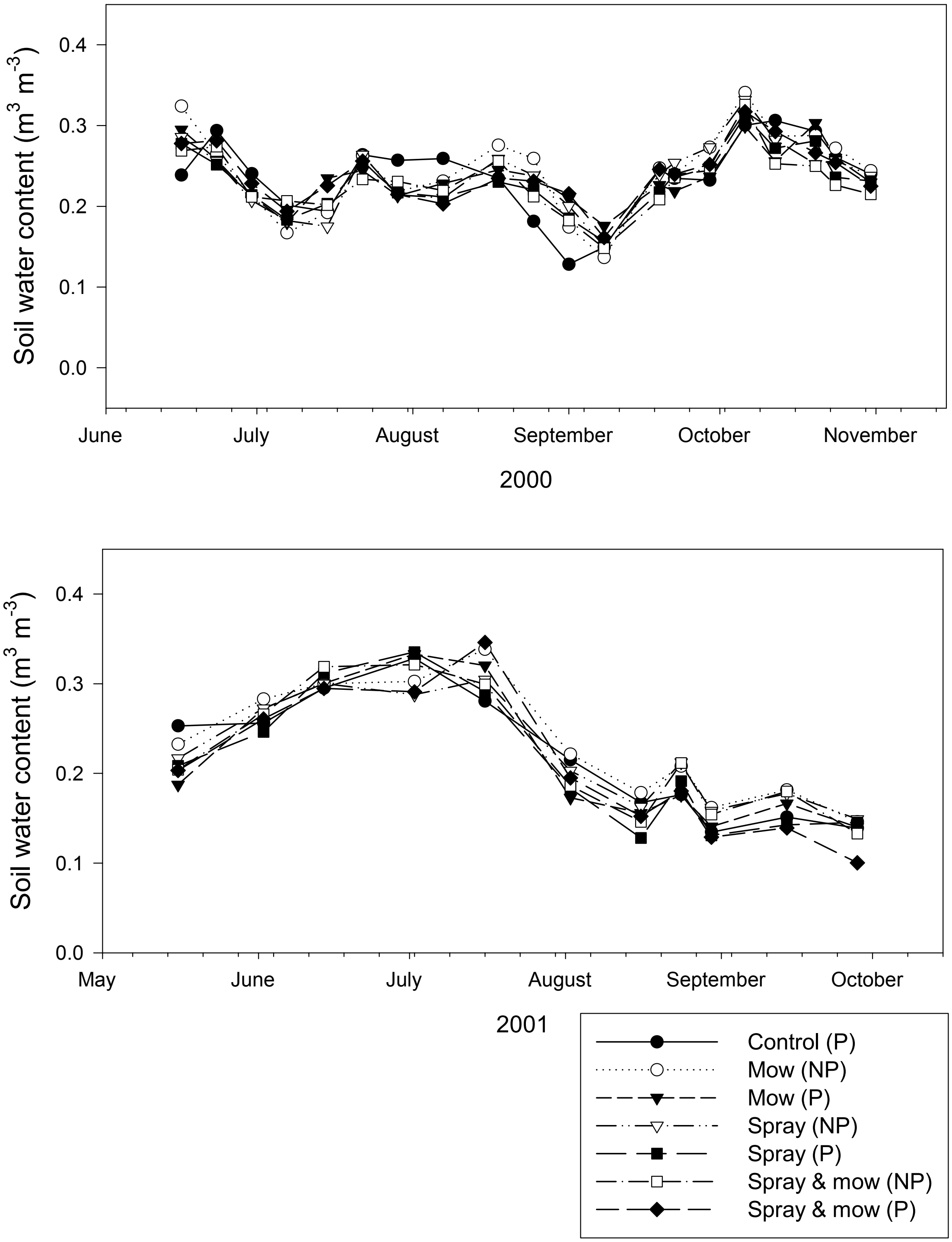

Figure 3.9. Soil water content under willow (SV1) in 2000 and 2001 established using different management techniques for a winter rye cover crop.
(P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Table 3.23. P-values from ANOVAs for estimated coefficients of a quadratic polynomial response curve for soil water content during the 2000 growing season.
Poplar (NM6) and willow (SV1) clones were planted following the application of different winter rye cover crop management techniques.

	Numerator df	Denominator df	Whole Unit (z)	Linear (b)	Quadratic (q)
Cover crop treatment	3	9	0.0724	0.3741	0.9196
Planting treatments	3	30	0.4950	0.9625	0.6883
Cover crop * planting treatments	7	30	0.2169	0.9203	0.4942

Table 3.24 Estimates and p-values for contrasts for soil moisture at the beginning and middle of the growing season in 2001 for a poplar (NM6) and a willow (SV1) clone that were planted following the application of different winter rye cover crop management techniques.

	May 16, 2001		Sept. 28, 2001	
Linear Contrast	Estimate (m^3 m^{-3})	p-value	Estimate (m^3 m^{-3})	p-value
	Poplar (NM6)			
Control (P) – cover crop (P)†	-2.61	0.2760	1.62	0.3626
Spray & mow (P) – mow(P)	-2.15	0.4608	-1.12	0.5648
Spray & mow(P) – spay(P)	0.81	0.8717	-1.21	0.5351
Cover crop (P) – cover crop (NP)	1.31	0.4338	-1.35	0.1921
Mow (P) – mow (NP)	5.70	0.0557	-2.27	0.2054
Spray (P) – spray (NP)	0.00	1.0000	-1.13	0.5222
Spray & mow (P) – spray & mow(NP)	-1.75	0.5445	-0.65	0.7139
	Willow (SV1)			
Control (P) – cover crop(P)	5.32	0.0305	1.05	0.5108
Spray & mow (P) – mow(P)	1.58	0.5878	-3.95	0.0494
Spray & mow(P) – spay(P)	-0.53	0.8549	-3.48	0.0269
Cover crop (P) – cover crop (NP)	-1.81	0.2841	-1.42	0.1718
Mow (P) – mow (NP)	-3.52	0.1255	-0.63	0.7245
Spray (P) – spray (NP)	-0.83	0.7757	-0.37	0.8324
Spray & mow (P) – spray & mow(NP)	-0.08	0.9793	-3.26	0.0735

† (P) indicates that the treatment was sprayed with pre-emergence herbicides immediately after planting, (NP) indicates that the treatment was not sprayed with pre-emergence herbicides.

Table 3.25 . P-values from ANOVAs for estimated coefficients of a quadratic polynomial response curve for soil water content during the 2001 growing season.
Poplar (NM6) and willow (SV1) clones were planted following the application of different winter rye cover crop management techniques.

	Numerator df	Denominator df	Whole Unit (z)	Linear (b)	Quadratic (q)
Cover crop treatment	3	9	0.7321	0.1484	0.1649
Planting treatments	3	30	0.0107	0.2955	0.2264
Cover crop * planting treatments	7	30	0.5830	0.2001	0.6276

was not affected, aboveground biomass production was lower in all of the cover crop treatments when no pre-emergence herbicide was used. An acceptable level of weed control during the establishment of SRWC will not be obtained using cover crop residue alone without the use of pre-emergence herbicides or supplemental tillage. However, the use of cover crops and their proper management could reduce the amount of herbicide required to obtain an acceptable level of weed control (Wick et al. 1994, Teasdale 1998).

Combining the use of cover crops and pre-emergence herbicides could be used to enhance weed control and early production of SRWC. Rye residue cover of less than 40% has little effect on weed density, while residue cover levels of over 95% can reduce weed density by up to 75% in annual cropping systems (Teasdale et al. 1991, Teasdale and Mohler 1993). Initial residue cover values in this study were greater than 80% in the Mow and M&S treatments at the beginning of the first growing season. Under poplar, the combination of cover crop residue and pre-emergence herbicide reduced the rate of weed cover development compared to the control. But a similar effect was not found under willow. The cover crop treatments that included the use of contact and pre-emergence herbicides had the lowest levels of weed cover and rates of development. The incorporation of cover crops during the establishment of SRWC could enhance weed control in an integrated weed management system.

The method used to manage the cover crop prior to planting affected the aboveground biomass production of the willow and poplar biomass crops. The use of a contact herbicide or mowing to kill the cover crop in the spring had no effect on aboveground biomass of either poplar or willow at the end of the first growing season (2000) when a pre-emergence herbicide was used following planting. However, the effect of these treatments was evident at the end of the second growing season (2001). Poplar aboveground biomass was greatest on the Spray (P) and S&M (P) treatments. Willow aboveground biomass was not significantly different among the cover crop treatments.

Under both willow and poplar, the Mow (P) treatment resulted in higher weed cover compared to the S&M (P) and Spray (P) treatments by the end of the first year. The use of contact herbicides to kill cover crops in the spring has been found to enhance weed suppression of certain perennial or annual weeds that tolerate mowing or are below the level of the mower (Wilkins and Bellinder 1996). Planting year treatment effects on weed cover were still evident in the second growing season (2001). Weed cover was still higher in the Mow (P) compared to the S&M (P) treatment. Following rototilling in the middle of the second growing season, the rate of weed cover development and average weed cover in the S&M (P) and Spray (P) treatments was significantly less than the Mow (P) treatment. These differences in weed cover affected aboveground biomass production.

The amount of residue cover is an important factor determining the susceptibility of a field to soil erosion. The amount of residue cover is a function of the amount of biomass produced by the cover crop and its persistence on the soil surface as residue (Teasdale 1998). In this study the Mow (P), Mow (NP), Spray (P), and Spray (NP) treatments provided 65 to 80% cover until early August in the first growing season. Residue cover decreased rapidly in the Mow (NP) and Spray (NP) treatments late in the growing season, but still provided between 10 – 20% cover until early November. This pattern is typical for rye residue (Masiunas et al. 1995), but the rate of residue decay is affected by environmental factors, principally temperature and moisture, that vary from site to site and year to year.

Large amounts of residue on the soil surface can adversely affect planting and subsequent germination and growth of soybeans (Libel et al. 1992) and corn (Raimbault et al. 1991). The large amount of residue on the soil surface may have adversely affected planting and the contact between the soil and the planted, dormant cutting. This was most evident on the Mow treatment because the coulters on the planter tended to push the cover crop residue into the soil rather than cut it. While not quantified, this was probably a factor in the lower survival for willow and lower aboveground biomass production for willow and poplar in the Mow treatment. The S&M treatments had less than 25% residue cover at the beginning of the first growing season. Spraying the cover crop with a post-emergence herbicide killed the rye and by the time the rye was mowed almost three weeks later, it was dry and cut into smaller pieces and less uniformly distributed compared to the rye that was mowed when it was green or only sprayed. While the S&M approach at managing the cover crop resulted in good SRWC aboveground biomass production, it does not provide the same amount of residue cover.

Soil water content is usually reduced the longer a winter cover crop like rye is left to grow during the spring because of the additional transpiration. The effect is most pronounced in years when spring rainfall is low (Libel et al. 1992, Vaughan and Evanylo 1998). In this study, the three week period between when the rye was sprayed with a contact herbicide or killed by mowing had no effect on soil moisture between these treatments because of the wet spring conditions. Precipitation was above the 30 year average in April, May and June of 2000 (Figure 2.1).

Cover crop residue can increase soil water content by increasing infiltration rates and reducing evaporation. The effect on soil water content is most apparent in this region during years with below average rainfall (Vaughan and Evanylo 1998). The cover crop treatments, particularly the Spray and S&M, helped to retain soil moisture during the spring, resulting in a higher soil water content compared to the Control (P) at the beginning of the 2000 growing season. Over the entire growing season soil water content was lower in the Control (P) compared to the cover crop treatments under poplar, which may have been a factor in the greater aboveground biomass in the poplar cover crop treatments. There was no difference in soil water content over the first growing season under willow. The different cover crop management practices did not have a consistent discernable affect on soil water content during this study

<u>Conclusions</u>

The potential for soil erosion during the establishment of SRWC needs to be addressed because of the potential negative impacts on the long term productivity of the system, non-point source pollution, and public perceptions. Techniques to incorporate cover crops into annual agricultural systems have been developed for several decades, but have not been tried for SRWC. This study shows that cover crops can effectively be incorporated during the establishment of SRWC.

The method used to manage cover crops during the establishment of SRWC requires balancing three critical factors, aboveground biomass production, weed control, and residue cover. Reduced production during the establishment of SRWC can have a negative effect on production over the entire first rotation (Harrington and DeBell 1984, Willebrand et al.1993, Hytönen 1995a). The need for effective weed control during the first two growing seasons is essential for the successful establishment and long term production of SRWC. The amount of residue cover is an important factor in determining the susceptibility of a field to soil erosion. In this study, the most effective cover crop management system that balanced these three critical factors was the Spray (P) treatment where the rye cover crop was killed with a post-emergence herbicide in the spring and sprayed with pre-emergence herbicides after planting. Recent developments in mechanically controlling cover crops, such as rolling, roll-chopping, undercutting or partial rototilling have been more effective than mowing in some situations (Creamer and Dabney 2002) and should be studied as options for using cover crops during the establishment of SRWC. Further research is required to determine the most effective combinations of cover crop species to use, methods and timing of cover crop control, amounts of residue to leave on the soil, and applications rates for various pre-emergence herbicides for SRWC that are grown across a range of site conditions.

CHAPTER 4: CONCLUSIONS

The effective implementation of sound management practices during the establishment phase of SRWC is critical to both their economic and biological success. These experiments examined the effect of alternatives to the currently recommended fall site preparation practices on the early growth and development of SRWC. Results from both experiments indicate that alternative practices can be implemented that should improve the sustainability of the system while maintaining or improving biomass production.

The alternative site preparation and rye cover crop experiments indicated that concerns about soil erosion during the establishment phase could effectively be addressed without compromising, and in some cases increasing, aboveground biomass production. In the alternative site preparation experiment, first rotation aboveground biomass production in the spring tillage and cover crop treatments was similar to or greater than the currently recommended fall tillage approach for both willow and hybrid poplar. Poplar biomass production in the strip tillage treatment was also similar to the fall tillage treatment. Poplar production was greater than 12.0 odt ha^{-1} yr^{-1} for all four of these treatments. Willow biomass production on the spring tillage, cover crop and fall tillage treatments were not significantly different and ranged from 4.7 to 8.0 odt ha^{-1} yr^{-1}. These alternatives (spring tillage, cover crop and strip tillage) to the standard fall tillage recommendation for site preparation will help reduce soil erosion during the establishment phase.

The approach to managing cover crops during the establishment of SRWC requires balancing three critical factors, aboveground biomass production, weed control, and residue cover. In the alternative site preparation experiment, biomass production was good in the cover crop treatment, but the rye cover crop was disked under during the spring. This reduced the length of time that the rye provided cover for the soil. In the rye cover crop experiment, the most effective management system that balanced these three critical factors was the Spray (P) treatment, where the rye cover crop was killed with a post-emergence herbicide in the spring, the SRWC was planted and the site was immediately sprayed with pre-emergence herbicides. Biomass production was similar to or greater than the Control (P), which had no cover crop planted on it but did have pre-emergence herbicides applied. Recent developments in mechanically controlling cover crops, such as rolling, roll-chopping, undercutting or partial rototilling have been more effective than mowing in some annual cropping systems and should be studied as options for using cover crops during the establishment phase of SRWC. Further research is required to determine the most effective combinations of cover crop species to use, methods and timing of cover crop control, amounts of residue to leave on the soil, and applications rates for various pre-emergence herbicides for SRWC that are grown across a range of site conditions.

Weed control is the primary factor limiting the successful establishment and production of SRWC. While the importance of effective weed control during establishment of SRWC has repeatedly been emphasized, it is still often neglected. There were drastic differences in first rotation biomass production in the alternative site preparation experiment between the no weed control treatment and the rest of the treatments. In the rye cover crop experiment, the amount of weed cover had an effect on aboveground biomass production, particularly in those treatments where pre-emergence herbicides were not used. These results once again emphasize the need to effectively control weed competition during the establishment phase. An acceptable level of weed control was not obtained in the rye cover crop experiment by using cover crop residue alone without pre-emergence herbicides. Combining the proper management of cover crops and pre-emergence herbicides enhanced weed control and needs to be developed further as part of an integrated weed control strategy for SRWC.

Concern has been expressed that the intensive production methods associated with SRWC will have detrimental impacts on soil fertility and productivity. There were only a few detectable changes in soil characteristics three years after the conversion of the site from a fallow condition to SRWC in the alternative site preparation experiment, regardless of the type of site preparation. Soil carbon levels in the surface 15 cm, which were high at the beginning of the experiment (62.7 – 77.5 Mg C ha^{-1}), were maintained. In the 15 – 30 cm layer, soil carbon levels were maintained or increased in some treatments by 12 to 24 Mg ha^{-1}. There were decreases in Mg concentrations over the first three years of the experiment, particularly at the 0 - 15 cm depth. These changes were related more to site conversion than SRWC production since the amount of Mg accumulated in aboveground and root biomass accounted for less than 5% of the estimated change in Mg content. The changes in Mg concentrations were similar across treatments whether the SRWC grew well or poorly, providing further indication that the changes were not primarily due to the growth of the SRWC. These changes are only for one site over a three year period. The impacts of SRWC on soil quality over a longer period across a range of sites still needs to be assessed.

These three studies indicate that changes can be made to the current recommendations for site preparation and establishment of SRWC. A wide range of factors including field history, soil characteristics, and climate affected the results of this experiment. Further research needs to be conducted to develop these approaches for a wider range of conditions. In the mean time, caution must be taken when transferring these results to other sites that have different soil, climate and site history characteristics.

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