Short-Rotation Woody Crops Program
at
State University of New York
College of Environmental Science & Forestry

Biomass Power for Rural Development
Technical Report:

APPLICATION OF POULTRY MANURE ON WILLOW BIOMASS CROPS (NYSERDA / EGG FARM DIVISION, WEGMANS FOOD MARKETS, INC.)

Final Report

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EXECUTIVE SUMMARY

The State University of New York College of Environmental Science and Forestry (SUNY-ESF), Wegmans Egg Farm, Inc., the New York State Energy Research and Development Authority (NYSERDA), and the U.S. Department of Energy Biomass Power for Rural Development program initiated a cooperative study in 1996 entitled "Application of Poultry Manure on Willow Biomass Crops". Wegmans Egg Farm was interested in growing willow biomass crops to provide both a crop where their poultry manure can be applied and wood chips for use as a carbon source for their poultry manure composting operation. Because rapidly growing willow plants can utilize a high nutrient load, such a system would be environmentally beneficial by minimizing nutrient run-off and N leaching from land applied poultry manure. In addition, willow chips would provide a reliable, inexpensive, local source of carbon for their poultry manure composting operation. The project had three phases: (1) small-scale field trial, (2) operational scale demonstration trial and (3) composting trial utilizing willow biomass.

A small-scale field trial with composted poultry manure from Wegmans Egg Farm was initiated in 1996 and harvested during the winter of 1998-99. Results showed that a single top-dressing of composted poultry manure at a rate of 69 tonnes (t) ha^{-1} applied to coppiced willow biomass crops increased their annual growth rate by almost 40%, compared to the control (11.6 to 8.4 oven dry tonnes (odt) ha^{-1} yr^{-1}) over a three-year rotation. These organically amended plots had similar annual aboveground biomass production as plots fertilized with slow-release nitrogen fertilizer at the rate of 300 kg N ha^{-1} (11.2 odt ha^{-1} yr^{-1}). Annual growth rates remained consistent throughout the three-year rotation in organically amended plots, but decreased in slow-release nitrogen fertilized plots. The investigation of soil nitrogen availability in the small-scale field trial showed that by the end of the willow crop's three-year rotation, net available nitrogen was negligible in slow-release N plots, while composted poultry manure plots were still releasing nitrogen into the system. This observation helps explain why stem annual growth rates decreased in slow-release N fertilized plots over the three-year rotation.

Operational scale demonstration plantings were established in 1997, 1998, and 1999 on portions of the Wegmans Egg Farm near Wolcott, NY. Wet composted or raw chicken manure (11.2-20.2 t ha^{-1}) was applied to all fields the fall prior to planting. The 1997 planting was plowed under because survival was less than 50% due to severe weed competition. Mean survival was better

for the 1998 demonstration planting (77%), the 1998 clone-site trial (78%), and the 1999 demonstration planting (80%).

In April 2001, a compost trial was conducted comparing two commonly utilized Wegmans' chip sources, one providing hardwood chips, the other conifer chips, and chips from three-year-old willow grown at Tully, NY. The willow chips were considered too large after the first chipping, thus further processing with a collision mill was necessary to reduce their size. However, particle size distribution comparisons done later revealed that the second process was probably unnecessary. Comparable parameters existed between the different compost treatments after a 24-day processing period. Percent moisture did not differ among the three treatments. Organic matter concentration in both the hardwood and willow compost treatments was similar, though both were higher than the conifer treatment. There were no differences among the treatments in N concentration. The results indicate that willow crops grown on Wegmans land can be utilized in the composting operation without compromising compost quality, and Wegmans has used several tractor-trailer loads of chips from willow crops harvested from their land in their composting operation during 2002.

With the completion of this research project, Wegmans can apply this information to their commercial composting operation. The first phase of the project demonstrated the expected increase production of willow biomass and a significant reduction in nutrient leachate from the willow plantings. The second phase of the project provided information needed for implementing larger scale plantings within this system, particularly the need for weed control. The nutrient rich manure provides an ideal growing medium for weed populations as well as willow trees. The final phase of the project demonstrated the viability of using locally grown willow chips as a carbon source for the composting operation. Willow chips from trees grown in the second phase have been successfully used in the composting operation. This project demonstrates the effectiveness of growing willow crops onsite to achieve the goals Wegmans Egg Farm set forth in both growing crops on nutrient rich sites (with incorporated chicken manure) and providing a "home-grown" carbon source (willow chips) for their commercial composting operation.

ACKNOWLEDGMENTS

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INTRODUCTION

Chicken layer manure (layer manure) is a major agricultural residue in New York state with an annual production of 160,000 tonnes (Lander et al. 1998; USDA 2002). Because of its strong odor, nutrient instability and concerns about non-point source pollution, disposal of layer manure poses various challenges to large producers of chicken eggs. Statewide, about 40% of layer manure is composted. Due to changes in confined animal feeding operations (CAFO) regulations, it is expected that 80% of layer manure will be composted within five years (Wright pers. comm.). Wegmans Egg Farm, Inc., a subsidiary of Wegmans Food Markets, Inc., located in Central New York, is one of the largest single producers of layer manure in New York at 13,600 tonnes annually.

Currently, Wegmans composts about 70% of their layer manure. Of the remainder, 15% is semi-composted and land applied while 15% is land applied as raw manure. To maintain the carbon source for their commercial composting operation, Wegmans Egg Farm purchases wood chips from sources as far away as Connecticut. The wood chips are mixed with raw manure to increase the carbon:nitrogen ratio (C:N), as carbon availability plays an important role in N immobilization (Barrington et al. 2001), a primary concern for composting operations. The costs of purchasing and transporting wood chips and running the composting operation are presently greater than revenues generated from the sale of composted manure.

The State University of New York College of Environmental Science and Forestry (SUNY-ESF) initiated its "Short-Rotation Woody Crops Program" in 1983. The objective of this Program was to investigate cultural systems for the establishment, tending, and harvesting of short-rotation hybrid poplar clones. In 1985, the Program was expanded to ascertain the potential of *Salix* spp. (willow) as a high-yielding woody biomass feedstock. Since then, the Program's emphasis has shifted to willow clones that have the potential to be the basis for a high-yielding short-rotation woody biomass feedstock for bioenergy and bioproducts in the northeastern and mid-western United States.

Efforts are now underway to develop a commercial willow biomass cropping system in New York State by members of the Salix Consortium with major funding from the Department of Energy (DOE), New York State Energy Research and Development Authority (NYSERDA), and the United States Department of Agriculture (USDA). Willow biomass demonstration farms of approximately 280 ha have been established in central and western NY. Willow clone-site trials and demonstration plots have been established in New York, Vermont, Pennsylvania, Delaware, Wisconsin, Michigan, North Carolina, New Jersey, Pennsylvania and Quebec, Canada.

The willow biomass cropping system is based on a 3-4 year coppice harvest cycle of 15,000 plants per hectare. For crop establishment, site preparation is done in the autumn and spring prior to planting of 20-25 cm long dormant cuttings. After the first growing season, the young stems are cut back (coppiced) during the winter. The following spring (year 2) the trees regenerate (coppice growth) from the stumps. At this time, inorganic fertilizers or organic soil amendments are surface applied over the willow or incorporated between the rows of willow. After three or four years of undisturbed growth, the crop is ready for winter season harvest. The wood chips from harvested willow biomass crops grown on Wegmans farm could then be used for poultry manure composting operations. The following spring (after harvest), organic soil amendments, such as composted poultry manure, are applied as the willow rapidly produces new sprouts. Seven harvests are expected from each initial planting before replanting. A rotation can be established with consecutively planted fields, whereby a portion of the total willow biomass crop is harvested each year, thus providing acreage for yearly poultry manure application as an organic soil amendment/fertilizer.

Wegmans Egg Farm is interested in incorporating willow biomass crops into their nutrient management system in two ways. First, willow is grown as a crop on land where poultry manure is applied. Greenhouse and field studies indicate that there is negligible N leaching from established willow plantings, even with annual applications of nitrogen fertilizer. However, some 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. Second, the harvested willow crop is used as a carbon source for their composting operation. It is anticipated that such a two-step system would be environmentally beneficial by minimizing nutrient run-off and leaching from the poultry manure while providing a reliable, inexpensive, local source of carbon for the composting operation. A cooperative study was initiated in 1997 to demonstrate the feasibility of incorporating willow crops into the poultry manure nutrient management system at Wegmans. The project was divided into three phases: (1) a small-scale field trial, (2) a larger, operational scale demonstration trial and (3) a layer manure composting trial utilizing willow biomass chips as the carbon source.

Chapter 1: Effect of Surface Application of Composted Poultry Manure, Lime-Stabilized Sewage Sludge, and Sulfur-Coated Urea on the Growth of Willow Biomass Crops under Field Conditions[1]

Introduction

Hansen and Baker (1979) showed that short-rotation intensive cultural systems have high nutrient requirements. In order to maintain and increase production levels, addition of inorganic and/or organic nutrient sources to soil is required. As part of the biomass project at SUNY-ESF, Kopp et al. (1993) reported that fertilization with N, P and K at the rate of 336, 112 and 224 kg ha^{-1} yr^{-1}, respectively, increased the rate at which willow clones reached their annual maximum production. They observed a maximum stem biomass production of 16 oven dry tonnes (odt) ha^{-1} yr^{-1} with the best clone. Kopp et al. (1997) reported as much as 22.4 odt ha^{-1} yr^{-1} for willow clone SV1 irrigated and fertilized with 224, 112 and 224 kg ha^{-1} yr^{-1} of N, P and K, respectively. Sahm (1995) applied 10 to 20 Mg ha^{-1} of wood ash to willow crops, but did not observe any significant effects on biomass production.

An investigation of the use of organic residuals as source of nutrients for willow biomass crops was initiated as part of the SUNY-ESF biomass project. A greenhouse study was conducted in 1996 (Adegbidi 1999). Initial results from this study formed the basis for field scale trials that were initiated in 1997 at the SUNY-ESF Genetics Field Station at Tully, NY. The study objectives were:

- To determine willow biomass crop growth response to selected organic amendments and various rates of slow release N fertilizer,
- To determine nitrogen availability of applied organic residuals.

The following hypotheses were tested:

1- The application of organic residuals and slow-release N fertilizer has no effect on willow biomass production.

2- Organic residuals produce as much willow biomass as mineral N fertilizer.

3- The utilization of plastic mulch for weed control and to conserve soil moisture has no effect on willow biomass production.

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[1] Hector Adegbidi received a Ph. D. from SUNY-ESF in July 1999. While at SUNY-ESF, Dr. Adegbidi conducted several experiments dealing with soil nitrogen dynamics. The following study by Dr. Adegbidi was initiated to evaluate the effect of surface applications of composted poultry manure from Wegmans Egg Farm, lime-stabilized sewage sludge, and sulfur-coated urea on the growth of willow biomass crops under field conditions.

4- There is no difference between organic residuals and mineral N fertilizers with regard to available mineral N during the first year after application.

5- There is no difference between organic residuals and mineral N fertilizers with regard to available mineral N during later years of rotation.

Materials and Methods

Biomass response

The soil at the site is a Glossoboric Hapludalf of the Palmyra series described by Hutton and Rice (1977). The parent material is a gravelly, sandy outwash derived from limestone, sandstone and shale. Topographically, the site is located on a glacial outwash terrace with a gentle slope varying between 0 and 3%. The soil is porous with good to excessive drainage. Soil texture is gravelly loam with gravel percentage varying from 25% in the Ap horizon to 60% in the IIC horizon. Rooting depth in the Palmyra soils ranges from 60 to 100 cm. Available water capacity is moderate to high and reaction ranges from medium acid to neutral in the surface layer.

In May of 1996, organic amendments, slow-release N fertilizer and plastic mulch were applied to plots of willow clone SV1 (*Salix dasyclados*). The willow plants were planted during the spring of 1995, in the double-row design at the density of 15,200 plants ha^{-1}, and coppiced during the winter of 1995/96. The eight treatments applied included:

- Control (no application of soil amendment),
- Plastic mulch cover of the soil,
- Composted poultry manure (PMC) top-dressed at 2.50 cm thick, equivalent to 69.25 Mg ha^{-1} and 1340 kg ha^{-1} of TKN (Total Kjeldahl Nitrogen),
- Lime-stabilized sludge (LMB) top-dressed at 2.50 cm thick, equivalent to 129.5 Mg ha^{-1} and 1400 kg ha^{-1} of TKN,
- Lime-stabilized sludge (LMB) top-dressed at 2.50 cm thick and covered with plastic mulch,
- Sulfur-coated urea fertilizer (slow-release N) top-dressed at 300 kg N ha^{-1},
- Sulfur-coated urea fertilizer (slow-release N) top-dressed at 200 kg N ha^{-1},
- Sulfur-coated urea fertilizer (slow-release N) top-dressed at 100 kg N ha^{-1}.

The composted poultry manure was obtained from the Wegmans egg farm located in Wolcott, NY. The lime-stabilized sludge was obtained from the Viro-Garnics Company in Syracuse. Table 1.1 shows the characteristics of the organic amendments.

The experimental design was a randomized complete block design of eight treatments replicated three times (Figure 1.1). Each elementary plot was 8.9 m long by 7.3 m wide (65 m^2) and contained four double rows of plants, with 12 plants in each row. In each plot, the measurement plot was defined by the eight central trees in each of the two central rows (21.81 m^2) (Figure 1.2).

At the end of the first and second growing seasons after treatment application, the diameters of all stems were measured at 30 cm above the soil, and the woody biomass was estimated for each plot, based on a regression equation developed by Ballard et al. (1999). At the end of the third year, biomass harvest and sampling were conducted according to the appropriate Standard Operating Procedure (SOP) (Appendix 2). The measurement plots were harvested after complete leaf fall, and the harvested stem biomass was weighed. A subset of plot biomass was sampled for percent moisture, which was used to convert fresh weight to dry weight. Measurement plot dry weight was expanded to a hectare basis.

At the end of the third growing season, a soil auger was used to collect soil samples by depth (0-10, 10-20, 20-40 cm) from each plot. Soil samples were collected from three randomly chosen locations within each plot and composited by depth.

Table 1.1. Characteristics of organic materials used as soil amendments in the field study at the SUNY-ESF Genetics Field Station, Tully, NY.

	C	TKN[a]	NO_3-N	NH_4-N	P	K	Ca	Mg	Cu	Zn	Ni	Pb	Mo	Cr	Cd	pH	Dens.
				----------g/kg----------								----------mg/kg----------					g/cm^3
Composted Poultry Manure	379	14.4	0.0	0.6	24.2	21.1	87.6	6.6	ND	280	24.1	1.6	1.7	3.9	0.3	9.3	0.28
Lime-Stabilized Sludge	113	9.2	0.0	0.0	6.1	3.3	207.5	6.5	133	89	40.3	32.8	4.1	38.7	7.2	11.9	0.52

ND: non-detectable

a: TKN: Total Kjeldahl Nitrogem

NO3-N and NH4-N: 2M KCL Extraction

Other elements: 6N HCl digested extration

Dens.: density

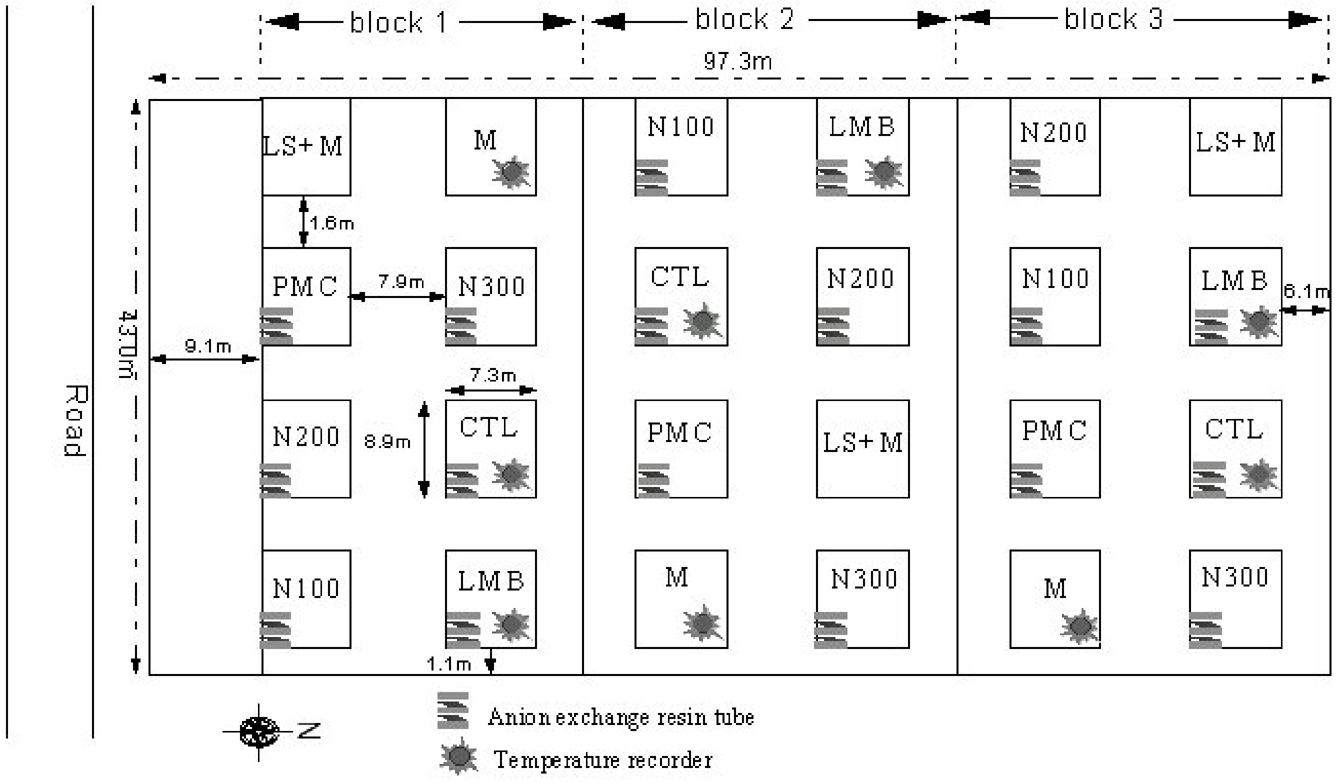

Figure 1.1. Layout of field study on the utilization of organic amendments and slow-release nitrogen fertilizer as nutrient sources for willow clone SV1 at Tully, NY.

CTL = control; PMC = Composted Poultry Manure; M = Plastic Mulch; LMB = Lime-stabilized Sludge; LS+M = Lime-stabilized

Sludge + Plastic Mulch; N100 = 100 kg N/ha of slow-release N; N200 = 200 kg N/ha of slow-release N; N300 = 300 kg N/ha of slow release N.

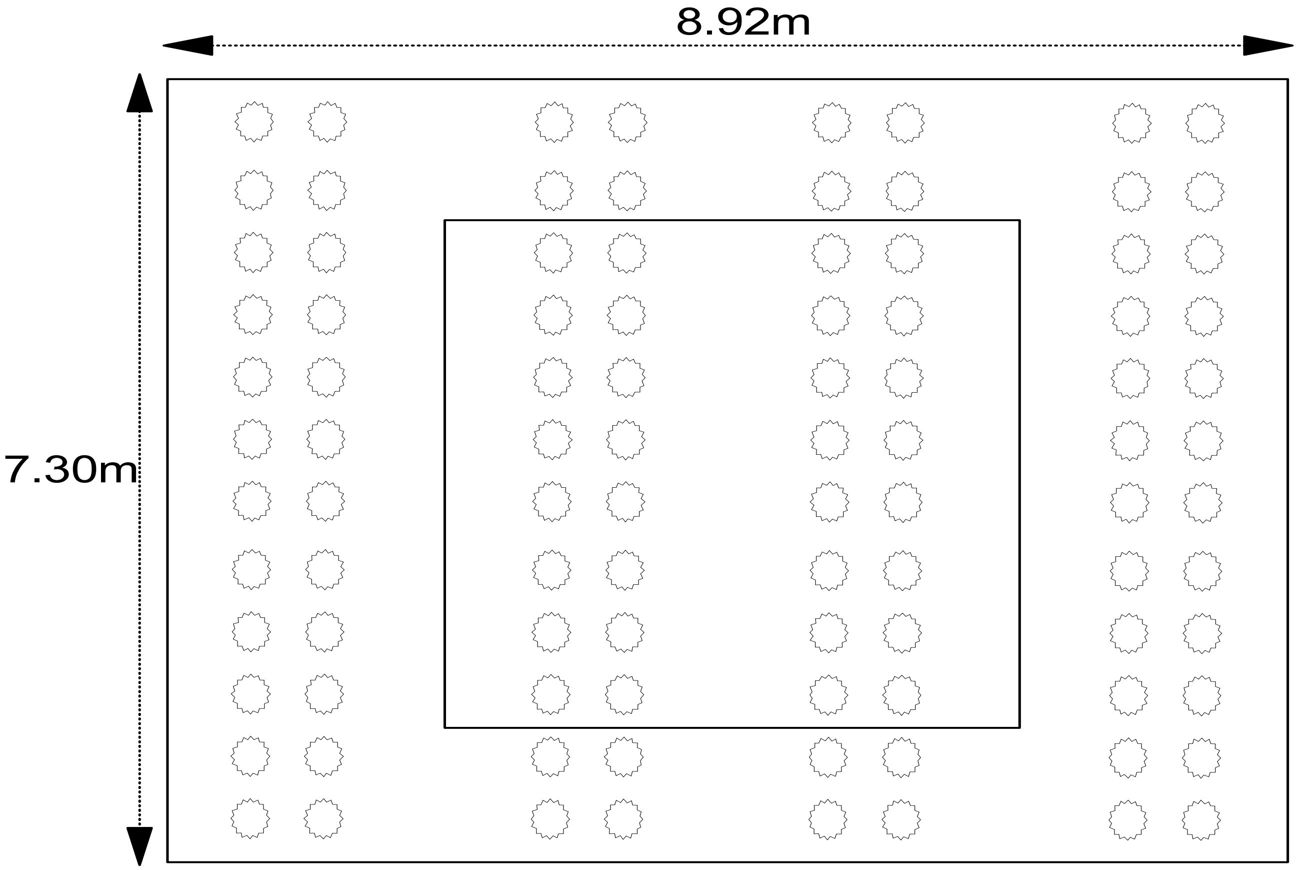

Figure 1.2. Detailed plot map illustrating plants arranged in 4 double-rows and 12 plants/row. [Central rectangle (4.9 m x 4.45 m) delineates measurement plot.]

Nitrogen dynamics in the field

To estimate nitrate quantities at the bottom of the rooting zone, anion-exchange resin columns (Adegbidi 1999) were installed at approximately 30 cm deep in the soil profile in the plots (Figure 1.3). The resin columns were installed in the central aisle between the two central rows of each plot. In contrast to resin columns used in the pot study, which were installed below the root mass and should have collected leaching soil solution nitrogen, the resin columns in the field study were longer (25 cm), so their tops were installed 5 cm below the top-dressed material. Therefore, resin columns should collect available nitrogen (since root uptake is excluded). The anion-exchange resin was J. T. Baker manufactured IONAC A-554, Cl^- form, Type II beads (16-50 mesh). The resin columns were installed at the beginning (third week of May) and collected at the end of each growing season (second to fourth week of November). After retrieval, resin columns were analyzed and their nitrate concentrations were determined.

Air temperature and precipitation amounts were recorded throughout the experiment.

Laboratory procedures

Laboratory procedures including sample drying, sample preparation for analyses, pH, total elements and trace metals determinations were conducted according to the methods reported by Bickelhaupt and White (1982). Nitrate and ammonium determinations were done according the procedures reported by Bremner (1965).

Statistical analyses

The SAS program was used to perform all the statistical analyses. Analysis of variance was used to evaluate treatment effects on biomass production and resin-captured NO_3-N. The general linear model with fixed effects was used for the analysis of variance. The data was analyzed as a randomized complete block design and the model was written as:

$y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij}$, where

$y_{ij} = j^{th}$ observation of the i^{th} amendment treatment

μ = overall mean of all observations

τ_i = added effect of the i^{th} treatment measured as deviation from μ

β_j = effect of the j^{th} block

ε_{ij} = random effect associated with y_{ij} , ε_{ij} NID$(0, \sigma^2)$

Linear and polynomial regression models were used to determine and test relationships between biomass production (as the dependent variable) and applied rate of slow-release N fertilizer (independent variable). Linear contrasts between treatments and groups of treatments were tested with the Student T-test. Significance of hypotheses was assessed at $\propto = 0.05$ for simple effects and $\propto = 0.20$ for interactions.

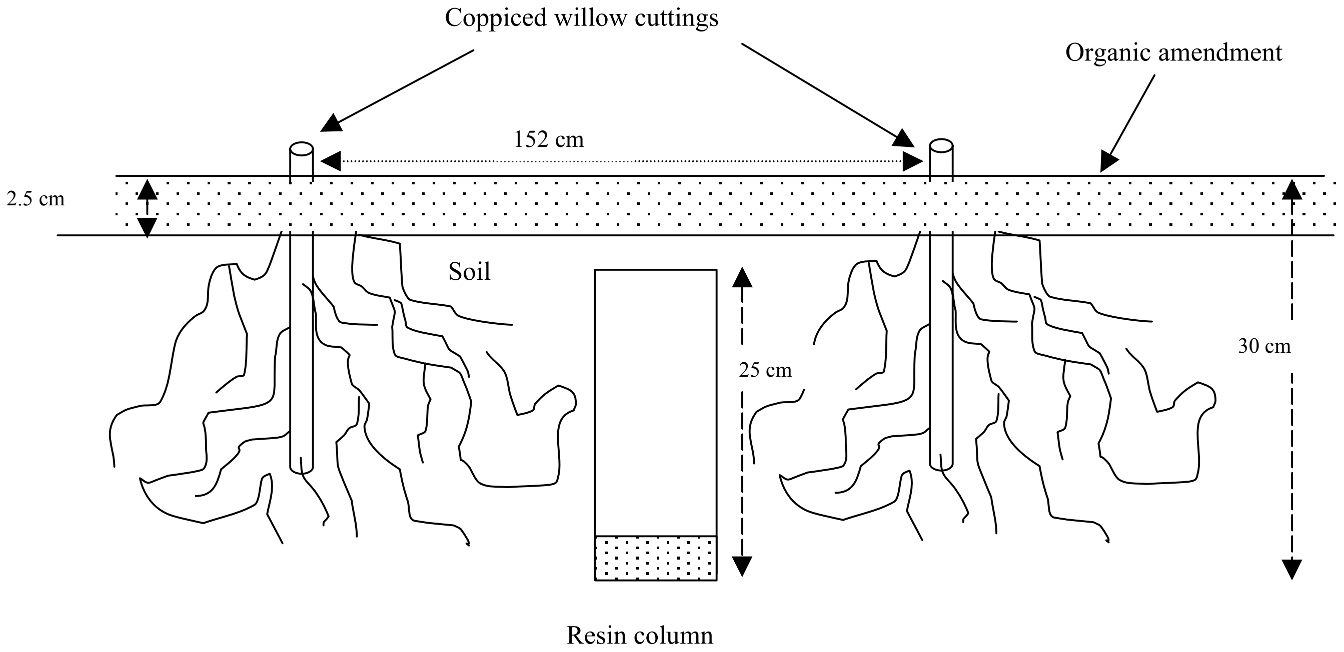

Figure 1.3. Cross-section of soil in field plots showing resin column and top-dressed organic amendment.

Results

Biomass production

Year-one and year-two estimates

Estimated stem biomass ranged from 5.7 to 13.2 and 13.5 to 23.4 odt ha^{-1} for one- and two-year-old stem biomass, respectively (Figure 1.4). For year-one, 300 kg N ha^{-1} followed by the lime-stabilized sludge produced the highest biomass. For year-two, 300 kg N ha^{-1} and the composted poultry manure produced the highest biomass. A priori contrasts (Table 1.2) showed, for both year-one and year-two, that organic amendments and inorganic N fertilizer increased stem biomass relative to non-additive treatment plots (control and plastic mulch) ($p < 0.01$). No significant difference was observed between the organic amendments and the slow-release N fertilizer for either year. The composted poultry manure and the lime-stabilized sludge treatments performed equally well. The plastic mulch treatment, whether alone or associated with the lime-stabilized sludge, did not have any significant effect on biomass production (Table 1.2).

Year-three harvested biomass

Biomass harvested and measured at the end of the rotation ranged from 24.1 to 34.8 odt ha^{-1} (Figure 1.4). The composted poultry manure and the lime-stabilized sludge + mulch treatments produced the greatest biomass. Biomass production was significantly greater in organic amendments plots than in the control plots ($p < 0.01$), whereas, the comparison between slow-release N plots and control plots was only marginally significant ($p = 0.07$) (Table 1.2). The difference between all organic amendments and all the slow-release N treatments was not statistically significant ($p = 0.11$). There was no significant difference between the composted poultry manure and the lime-stabilized sludge treatments ($p = 0.73$). There was no significant effect of the plastic mulch, whether it was used alone ($p = 0.77$) or associated with the limed-stabilized sludge ($p = 0.60$).

Biomass increase relative to control

The net effect of the various treatments on the biomass production was calculated and expressed as the percent biomass increase relative to the control.

*Net effect treatment X = (biomass X – biomass Control)*100/biomass Control*

The application of the different treatments increased biomass production relative to the control by 8 to 134%, 7 to 75% and 9 to 39% in year-one, year-two and year-three, respectively (Figure 1.5). The 300 kg N ha^{-1} rate of slow-release fertilizer produced the greatest increase in biomass relative to control at the end of year-one and year-two while the lime-stabilized sludge covered with plastic mulch produced the greatest increase relative to control at the end of year-three. A priori contrasts (Table 1.3) for all 3 years showed that there were no significant differences between organic amendments and slow-release N fertilizer treatments ($p = 0.81$, $p = 0.20$ and $p = 0.12$ for year-one, year-two and year-three, respectively). Similarly, there were no differences between composted poultry manure and lime-stabilized sludge treatments ($p = 0.83$, $p = 0.58$ and $p = 0.83$ for years one, two and three, respectively). The plastic mulch treatment did not have any significant effect on the relative biomass increase.

Annual growth rate

Annual growth rate in year-one, equivalent to year-one biomass production, varied from 5.7 to 13.2 odt ha^{-1} yr^{-1} (Figure 1.6). A priori contrasts for year-one annual growth rate are the same as those for year-one biomass production (Table 1.2). The organic amendments and the 300 kg N $ha^{-1}$of slow-release N produced the highest growth rates ($p < 0.01$). There was no significant difference of annual growth rate between organic amendments and slow-release fertilizer in year-one ($p = 0.78$).

Annual growth of year-two (biomass year-two – biomass year-one) ranged from 7.9 to 11.8 odt ha^{-1} yr^{-1} (Figure 1.6). Composted poultry manure and lime-stabilized sludge treatments had the greatest growth

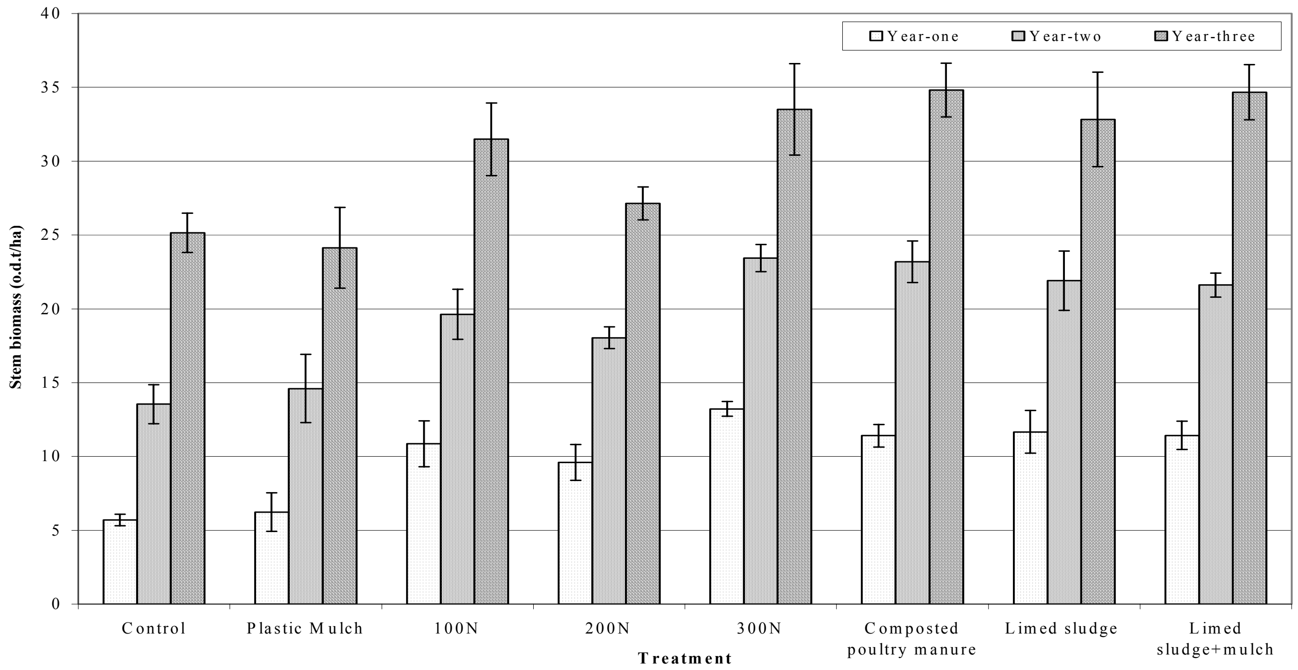

Table 1.2. Linear contrasts and p-values associated with the null hypothesis of no difference for oven dry-stem biomass produced by willow clone SV1 after one, two, and three years of growth in the field study at the SUNY-ESF Genetics Field Station, Tully, NY.

Contrast	Year-one		Year-two		Year-three	
	Estimate (t/ha)	p-value	Estimate (t/ha)	p-value	Estimate (t/ha)	p-value
Additive - Non-additive[a]	5.40	<0.01	7.23	<0.01	7.77	<0.01
Slow-release N - Control	5.53	<0.01	6.83	<0.01	5.57	<0.01
Organic amendment[b] - Control	5.80	<0.01	8.70	<0.01	8.96	<0.01
Organic amendment - Slow-release N	0.27	0.78	1.87	0.16	3.40	0.11
Composted poultry manure - Sludge[c]	-0.14	0.92	1.42	0.46	1.07	0.73
Control: mulch - no mulch	0.54	0.75	1.06	0.63	-1.01	0.77
Lime-stabilized sludge: mulch - no mulch	-0.24	0.88	-0.30	0.89	1.84	0.60

a: Non-additive = Control + plastic mulch

b: Organic amendment = lime-stabilized sludge + lime-stabilized sludge covered with plastic mulch + composted poultry manure

c: Sludge = lime-stabilized sludge + lime-stabilized sludge covered with plastic mulch

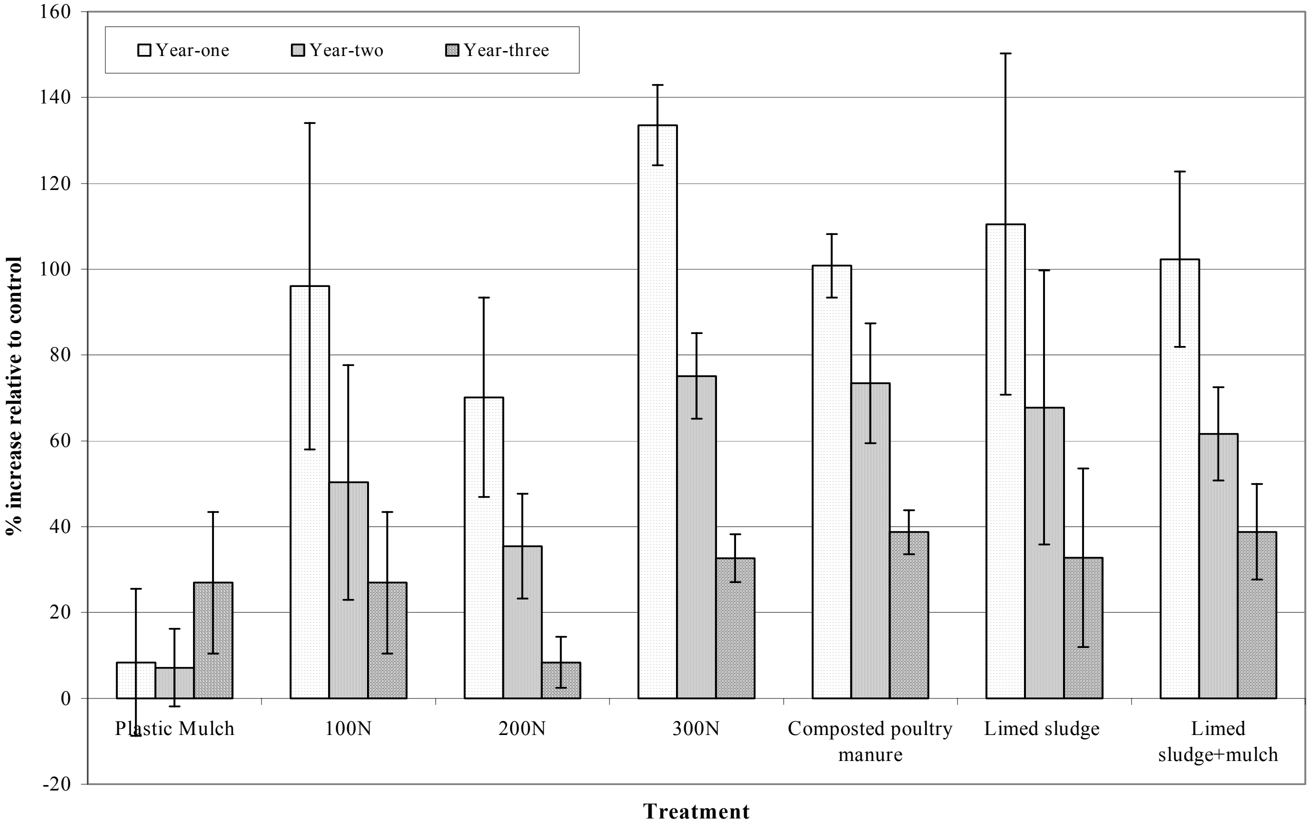

Figure 1.5. Net effects of treatments on stem biomass of willow clone SV1 expressed as percent biomass increase relative to control in the field study. *(Each bar represents one standard error).*

Table 1.3. Linear contrasts and p-values associated with the null hypothesis of no difference for biomass increase relative to control during year-one, year-two, and year-three of rotation in the field study at the SUNY-ESF Genetics Field Station, Tully, NY.

Contrast	Year-one		Year-two		Year-three	
	Estimate (%)	p-value	Estimate (%)	p-value	Estimate (%)	p-value
Organic amendment[a] - Slow-release N	4.6	0.81	18.9	0.20	14.1	0.12
Composted poultry manure - Sludgeb	-5.8	0.83	8.7	0.58	2.8	0.83
Lime-stabilized sludge: mulch-no mulch	-8.3	0.80	-6.0	0.74	5.7	0.70

a: Organic amendment = lime-stabilized sludge + lime-stabilized sludge covered with plastic mulch + composted poultry manure

b: Sludge = lime-stabilized sludge + lime-stabilized sludge covered with plastic mulch

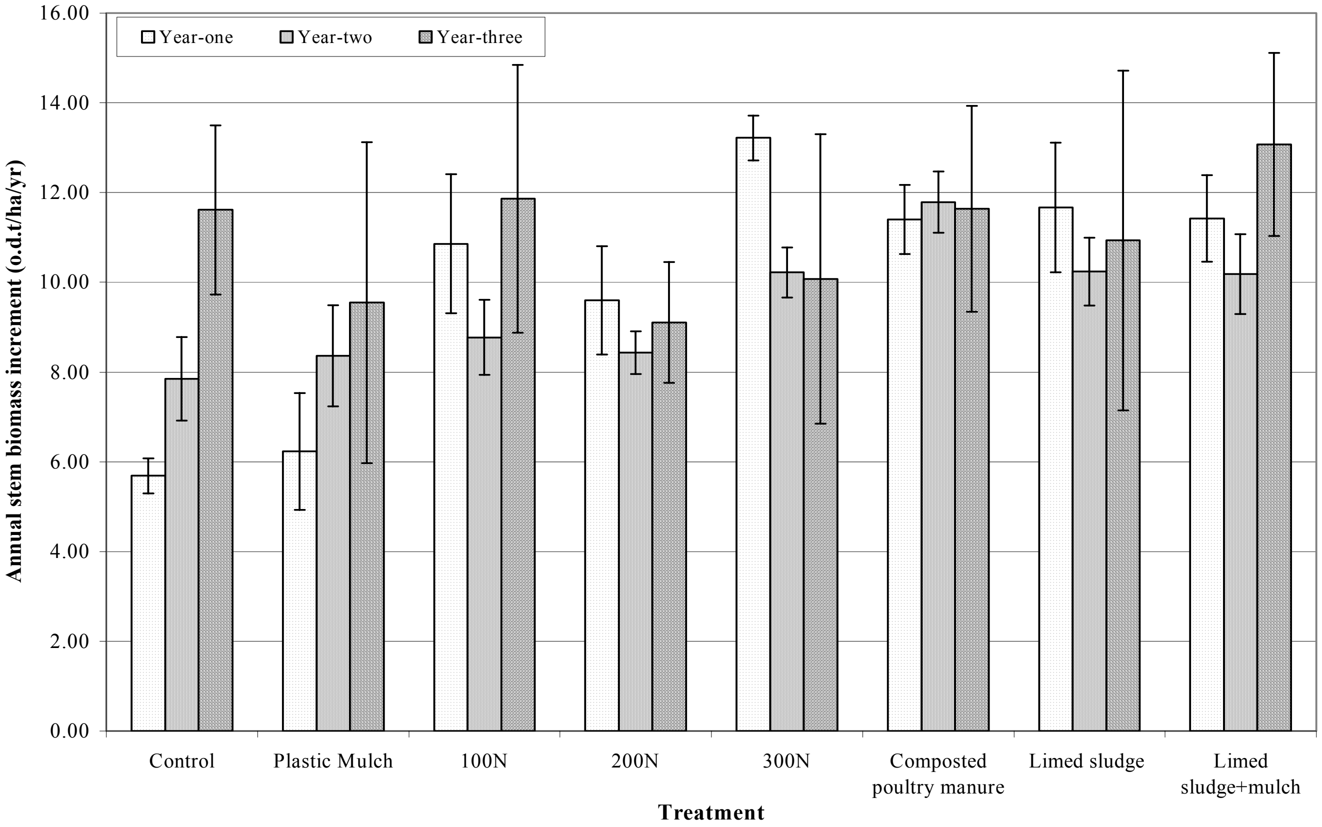

Figure 1.6. Annual growth rate of willow clone SV1 stem biomass during year-one, year-two, and year-three of rotation cycle in the field study. *(Each bar represents one standard error.)*

Table 1.4. Linear contrasts and p-values associated with the null hypothesis of no difference for year-two and year-three annual growth rate of willow clone SV1 in the field study at the SUNY-ESF Genetics Field Station, Tully, NY.

Contrast	Year-two		Year-three	
	Estimate (t/ha)	p-value	Estimate (t/ha)	p-value
Additive - Non-additive[a]	1.83	<0.01	0.54	0.60
Slow-release N - Control	1.29	0.16	-1.26	0.39
Organic amendment[b] - Control	2.89	<0.01	0.27	0.85
Organic amendment - Slow-release N	1.60	0.02	1.53	0.15
Composted poultry manure - Sludge[c]	1.58	0.11	-0.37	0.81
Control: mulch - no mulch	0.52	0.63	-2.06	0.25
Lime-stabilized sludge: mulch - no mulch	-0.06	0.96	2.14	0.24

a: Non-additive = Control + plastic mulch

b: Organic amendment = lime-stabilized sludge + lime-stabilized sludge covered with plastic mulch + composted poultry manure

c: Sludge = lime-stabilized sludge + lime-stabilized sludge covered with plastic mulch rate during year-two. A priori contrasts (Table 1.4) showed that growth rate during year-two was greater in treated plots, all pooled together, compared to control plots ($p < 0.01$). Similarly, year-two growth rate was greater in organically amended plots compared to slow-release N fertilized plots ($p = 0.02$). Comparison between slow-release N fertilized plots and control plots was not significant ($p = 0.16$). Comparing within the organic amendments, there was no significant difference between composted poultry manure and lime-stabilized sludge plots ($p = 0.11$). The plastic mulch, whether used alone or associated with the lime-stabilized sludge, did not have any significant effect on year-two annual growth rate ($p = 0.63$ and $p = 0.96$ respectively).

Year-three annual growth rate (biomass year-three – biomass year-two) ranged from 9.1 to 13.1 odt ha^{-1} yr^{-1}. Though the lime-stabilized sludge + mulch treatment had the greatest apparent growth rate in year-three, none of the tested contrasts were statistically significant (Table 1.4). No differences were observed between (1) treated and control plots; (2) organic amendments and slow-release N fertilized plots; and (3) poultry manure and lime-stabilized sludge plots.

The annual growth rate showed different patterns with time from one treatment to another. It increased with time for the control and plastic mulch treatments, decreased in year-two and increased in year-three for the 100 and 200 kg N ha^{-1}, and the two lime-stabilized sludge treatments. Annual growth rate decreased with time for the 300 kg N ha^{-1} treatment, and remained constant for the composted poultry manure treatment (Figure 1.6).

Biomass response curve to slow-release N rates

Modeling biomass response as a function of slow-release N fertilizer rates did not indicate a strong relationship between biomass and N addition (Table 1.5). For year-one and year-two, all three models (linear, quadratic and cubic model) were statistically significant and explained between 59 and 81% variability in biomass. For year-three, none of the three models was significant at $\propto = 0.05$ and only 26 to 54% of the variability of biomass is accounted for by the models. Cubic response does not correspond to any theoretical rate-yield response curves, indicating that biomass response in this experiment was determined by some other factors not accounted for in the models. Within the used range of slow-release N fertilizer rates, the quadratic response was essential linear and showed no curvature. This left the linear model as the only one acceptable in this study.

For year-three, the linear model (Figure 1.7) showed that only 26% of the variability in biomass production was explained by the fertilizer rate ($r^2 = 0.26$). The p-value for the test of the monomial coefficient was not significant ($p = 0.09$). Only the intercept was significant ($p < 0.01$).

Resin-captured nitrate-N

Resin-captured NO_3-N ranged from 28 to 378, 35 to 363 and 28 to 167 kg N ha^{-1} respectively for year-one, year-two and year-three after treatment application (Figure 1.8). The variability of the data was high. Coefficients of variation ranged from to 39 to 107%, 16 to 125% and 56 to 81% respectively for year-one, year-two and year-three data.

Tests of various contrasts (Table 1.6) showed that during year-one, more NO_3-N was available in the treated plots than in the control plots ($p = 0.03$). There was no significant difference between organically amended plots and slow-release N fertilized plots ($p = 0.68$). Organically amended plots had greater NO_3-N than control plots ($p = 0.06$). Comparing organic amendments among themselves, lime-stabilized sludge treated plots had more NO_3-N than composted poultry manure treated plots ($p = 0.01$).

During year-two and year-three, organically amended plots appeared to have greater amounts of NO_3-N than control and slow-release N treated plots (except for the 200 kg N ha^{-1} treatment). However, the contrasts did not show statistically significant differences except for the contrast “organic amendments – slow-release N” for year-three ($p = 0.06$) (Table 1.6). In year-two, there were no significant treatment effects.

Regarding resin-captured NO_3-N, the following general trends were evident with time:

- NO_3-N in slow-release N and lime-stabilized sludge treated plots decreased from year-one to year-three,
- NO_3-N in composted poultry manure treated plots increased from year-one to years two and three,
- NO_3-N in control plots increased from year-one to year-three.

The net effects of the applied treatments were estimated by deducting NO_3-N of control plots from corresponding NO_3-N of the various treatments (Figure 1.9). Net effects ranged from 19 to 350, 35 to 328 and –96 to 43 kg N ha^{-1} for year-one, year-two and year-three after treatment application, respectively. Contrasts showed no differences between organically amended and slow-release N plots during year-one and year-two ($p = 0.71$ and $p = 0.78$ respectively) (Table 1.7). However, in year-three organically amended plots had significantly higher NO_3-N than slow-release N plots ($p = 0.05$). Net NO_3-N in all slow-release N treatment plots was negative during the third year after treatment application (Figure 1.9). The comparison between lime-stabilized sludge and composted poultry manure showed that lime-stabilized sludge had more NO_3-N than composted poultry manure in year-one (p = 0.02). In year-two and year-three, estimates showed trends of greater (though not statistically significant) net NO_3-N in composted poultry manure treated plots than in lime-stabilized sludge treated plots (p = 0.68 and p = 0.50 respectively).

	Year-one			Year-two			Year-three		
	Estimate	p-value	r^2	Estimate	p-value	r^2	Estimate	p-value	r^2
Linear:		<0.01	0.59		<0.01	0.63		0.09	0.26
a	6.6	<0.01		14.4	<0.01		26.2	<0.01	
b	0.02	<0.01		0.006	<0.01		0.02	0.09	
Quadratic:		0.01	0.61		0.01	0.63		0.25	0.26
a	6.3	<0.01		14.3	<0.01		26.2	<0.01	
b	0.03	0.13		0.03	0.21		0.02	0.62	
c	-0.4 E-4	0.56		-0.2 E-4	0.83		0.6 E-6	0.99	

a: Models

- Linear: y = a + b*N
- Quadrati y = a + b*N + c*N2 where

y = Biomass production in o.d.t./ha
N = fertilizer rate in kg N/ha
a, b, and c = parameter estimates

Table 1.5. Polynomial models[a] of biomass response to rates of slow-release fertilizer in the field study.

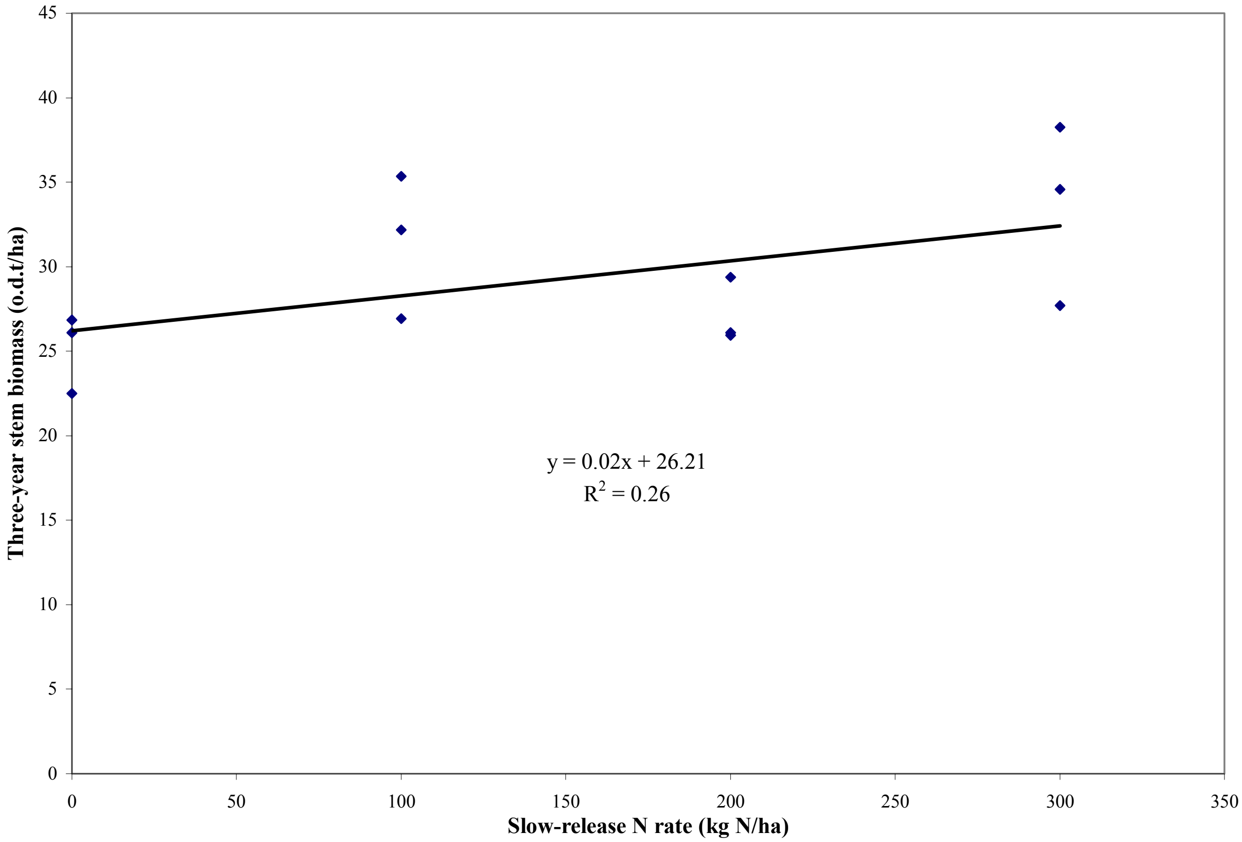

Figure 1.7. Three-year stem biomass as a function of slow-release N fertilizer application rate in the field study.

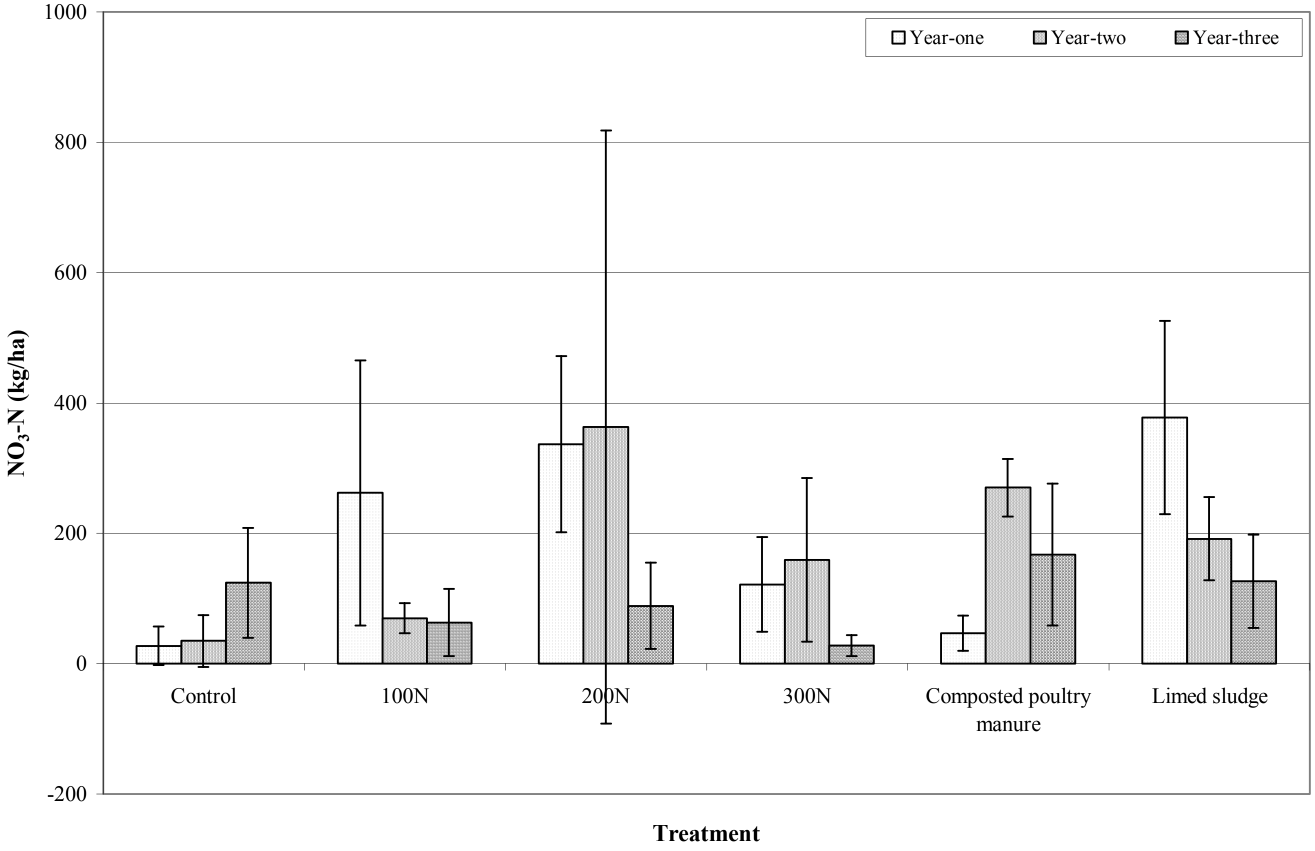

Figure 1.8. Mean annual NO_3-N captured by resin columns during year-one, year-two, and year-three in the field study. (*Each bar represents one standard error.)*

Table 1.6. Linear contrasts and p-values associated with the null hypothesis of no difference for resin-capture NO_3-N during year-one, year-two, and year-three of rotation in the field study at the SUNY-ESF

Contrast	Year-one		Year-two		Year-three	
	Estimate (kg N/ha)	p-value	Estimate (kg N/ha)	p-value	Estimate (kg N/ha)	p-value
Additive[a] - Control	201.10	0.03	175.90	0.19	-29.20	0.57
Slow-release N - Control	212.30	0.03	162.50	0.25	-64.00	0.25
Organic amendment[b] - Control	184.40	0.06	196.00	0.19	23.00	6.90
Organic amendment -Slow-release N	-27.90	0.68	33.50	0.76	87.00	0.06
Composted poultry manure -Lime-stabilized sludge	-331.30	0.01	78.2	0.64	51.1	0.53

a: Additive = lime-stabilized sludge + lime-stabilized sludge covered with plastic mulch + composted manure + slow-release N

b: Organic amendment = lime-stabilized sludge + lime-stabilized sludge covered with plastic mulch + composted poultry manure

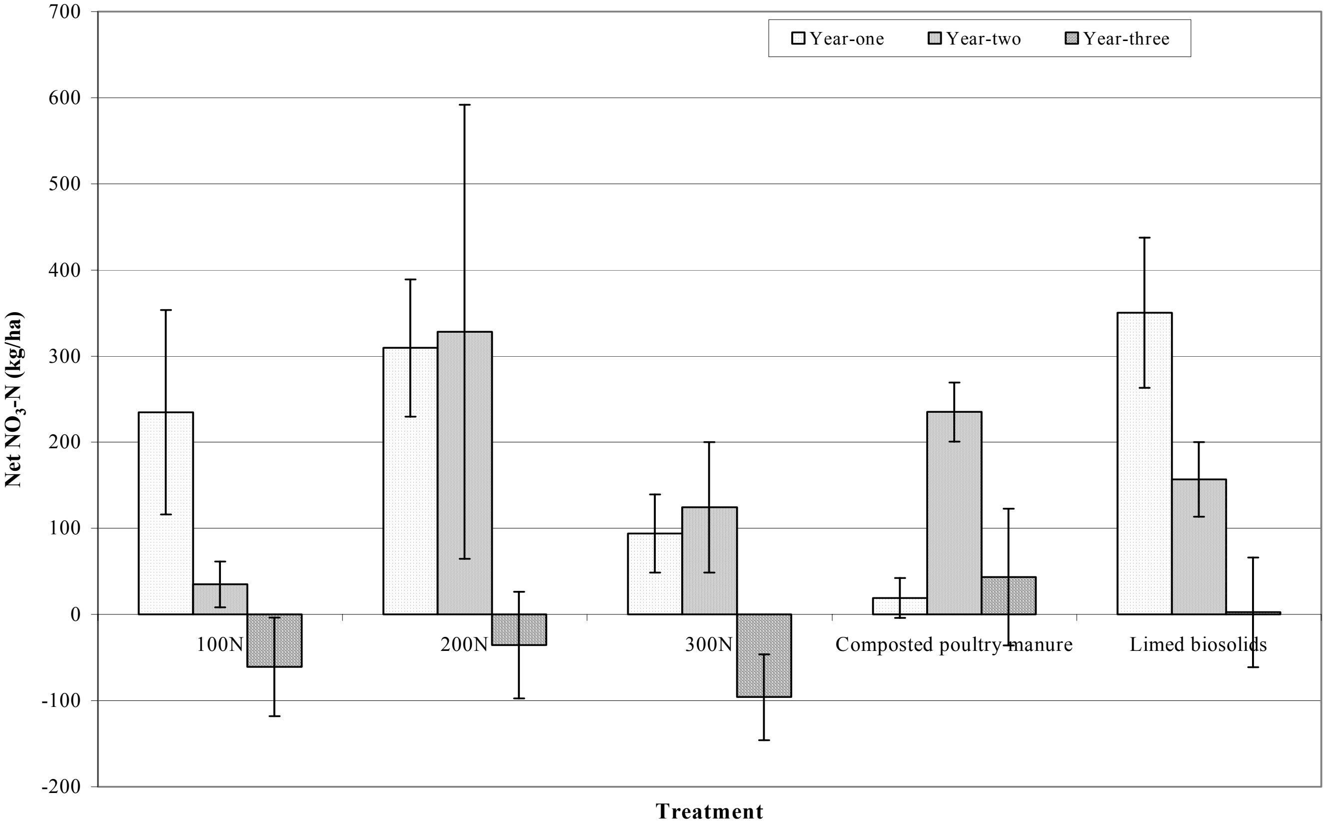

Figure 1.9. Net effects of treatments on mean annual NO$_3$.N captured by resin columns during year-one, year-two, and year-three in the field study. *(Each bar represents one standard error.)*

Table 1.7. Linear contrasts and p-values associated with the null hypothesis of no difference for treatments net effects on resin-captured NO$_3$.N during year-one, year-two, and year-three of rotation in the field study at the SUNY-ESF Genetics Field Station, Tully, NY.

Contrast	Year-one		Year-two		Year-three	
	Estimate (kg N/ha)	p-value	Estimate (kg N/ha)	p-value	Estimate (kg N/ha)	p-value
Organic amendment[a] -Slow-release N	-27.9	0.71	33.5	0.78	87.0	0.05
Composted poultry manure -Lime-stabilized sludge	-331.3	0.02	78.2	0.68	51.1	0.50

a: Organic amendment = lime-stabilized sludge + lime-stabilized sludge covered with plastic mulch + composted poultry manure

Soils data

Soil chemical data prior to the installation of the experiment were unavailable. However, comparison of soil chemical characteristics among treatments three years after treatment application reveals important differences. These differences were most strongly expressed at the surface and decreased with depth (Table 1.8). In the 0-10 cm layer, organic amendments significantly increased soil organic matter, pH, and concentrations of N, P and Ca relative to the control and slow-release N treatments. Lime-stabilized sewage sludge increased soil pH by almost two units while composted poultry manure increased pH by one unit. Soil beneath composted poultry manure exhibited levels of extractable K, P and Mg that were approximately three times greater than those of other treatments. Those effects dissipated with depth. Lime-stabilized sludge treatments exhibited higher pH and exchangeable Ca relative to the other treatments and the control. As was the case with composted poultry manure, these effects dissipated with depth.

Table 1.8. Mean soil characteristics (organic matter, pH, total N, and available P, K, Ca and Mg) at 0-10, 10-20 and 20-40 cm depths, three years after application of amendments. (Within a column, means followed by a same letter are not statistically different by Duncan's Multiple Range Test at $\alpha = 0.05$).

Treatment	OM g/kg	pH	N g/kg	P mg/kg	K mg/kg	Ca mg/kg	Mg mg/kg
0-10 cm							
Control	54.3 b	5.33 c	1.85 c	17.2 c	71.6 b	745 c	59 b
Mulch	54.5 b	5.07 c	1.89 c	10.5 c	61.2 b	525 c	40 bc
N – 100 kg/ha	59.3 b	5.23 c	1.90 c	11.5 c	59.4 b	820 c	56 bc
N – 200 kg/ha	57.3 b	5.07 c	2.06 bc	8.6 c	79.8 b	616 c	48 bc
N – 300 kg/ha	58.7 b	5.13 c	2.10 bc	11.3 c	45.5 b	770 c	41 bc
Composted poultry manure	67.8 a	6.30 b	2.54 a	217.2 a	239.8 a	1564 b	141 a
Lime-stabilized sludge	67.3 a	7.13 a	2.44 a	55.2 b	53.6 b	3884 a	32 c
Lime-stabilized sludge + mulch	67.2 a	7.27 a	2.29 ab	59.0 b	58.8 b	3713 a	37 bc
10-20 cm							
Control	51.3 b	5.30 bc	1.85 b	13.6 bc	40.5 b	691 b	49 ab
Mulch	53.7 ab	5.23 bc	1.84 ab	13.0 bc	43.3 b	501 b	34 ab
N – 100 kg/ha	53.2 ab	5.30 bc	1.68 ab	8.6 bc	42.1 b	714 b	47 ab
N – 200 kg/ha	52.9 ab	5.07 c	1.68 b	8.1 c	40.0 b	593 b	45 ab
N – 300 kg/ha	53.5 ab	5.37 bc	1.93 ab	12.2 bc	33.7 b	966 b	42 ab
Composted poultry manure	55.9 ab	5.77 ab	1.89 ab	39.6 a	120.9 a	884 b	54 a
Lime-stabilized sludge	55.1 ab	5.70 ab	2.09 a	16.9 bc	32.7 b	1873 a	21 b
Lime-stabilized sludge + mulch	60.2 a	6.17 a	2.09 a	21.0 b	44.1 b	2272 a	29 ab
20-40 cm							
Control	46.4 a	5.40 a	1.38 a	18.7 abc	40.7 b	689 c	44 a
Mulch	40.8 a	5.17 a	1.51 a	12. c	39.0 b	391 c	24 a
N – 100 kg/ha	47.1 a	5.33 a	1.70 a	7.70 c	34.9 b	686 c	44 a
N – 200 kg/ha	45.9 a	5.17 a	1.28 a	10.3 c	32.8 b	534 c	36 a
N – 300 kg/ha	48.2 a	5.50 a	1.53 a	11.4 c	28.7 b	725 c	31 a
Composted poultry manure	46.7 a	5.67 a	1.56 a	26.0 a	68.9 a	803 bc	45 a
Lime-stabilized sludge	54.0 a	5.70 a	1.73 a	25.3 ab	31.2 b	1719 a	22 a
Lime-stabilized sludge + mulch	48.2 a	5.80 a	1.71 a	15.0 abc	35.0 b	1465 ab	27 a

Discussion

Biomass production

Over the three-year rotation cycle, mean annual growth rate of stem biomass in control plots was 8.3 o.d.t/ha. This annual yield of stem in a non-fertilized control compared well with mean annual increment of 8 to 14 o.d.t/ha reported by Willebrand et al. (1993) in an experiment of various willow clones fertilized with 100 kg N ha^{-1} yr^{-1}. Kowalik and Randerson (1994) reported annual yield ranging from 5.2 to 9.6 odt ha^{-1} in non-fertilized plots of various willow clones. The quality of the experimental site, considered a naturally good agricultural soil, is probably the reason for the relatively high yield of the non-fertilized plots in the current experiment.

For the slow-release N fertilizer treatments, mean annual stem growth rates were 10.5, 9.0 and 11.2 odt ha^{-1} for 100, 200 and 300 kg N ha^{-1} respectively. These yields represented average increases of 25, 7 and 33% relative to the control. For organic amendments, mean annual stem yield was 10.9, 11.6 and 11.6 odt ha^{-1} for the treatments of lime-stabilized sludge, lime-stabilized sludge + plastic mulch and composted poultry manure respectively, representing average increases of 30, 38 and 38% relative to the control. The significant contrasts "Slow-release N – Control" and "Organic amendments – Control" (Table 1.2) showed that the utilization of organic amendments and slow-release N fertilizer significantly increased biomass production, compared to the control, thereby rejecting the first hypothesis of this study.

Various authors observed significant increase of yield in SRIC systems following application of organic residuals and fertilizers. Nielsen (1994) observed that willow crop biomass yield increased from 5.8 to 7.4 and 8.9 odt ha^{-1} respectively with 300 and 600 kg N ha^{-1} applied as sewage sludge. Colletti et al. (1993) reported 30% increase in biomass production when sewage sludge was used as fertilizer in biofuels systems in Iowa. Kowalik and Randerson (1994) reported that annual yield increased 50% (from 9.6 to 14.4 odt ha^{-1}) when *Salix amygdalina* plots were irrigated with wastewater. Hodson et al. (1994) observed that tree biomass doubled and quadrupled with application of 100 and 300 kg N ha^{-1} as sewage sludge associated with lime. Willow crop yields significantly increased as a result of fertilization with N, K and P fertilizers (Hytonen et al. 1987; Ferm et al., 1989; Kopp et al., 1993).

In the current study, annual production with the slow-release N fertilizer and the organic amendments were similar and slightly less than the range of expected annual yield (11.25 to 18 o.d.t/ha) for SRIC systems of willow as defined by Abrahamson et al. (1998). Cannel and Smith (1980) and McEroy and Dawson (1985) reported that in coppice systems first harvest yield is generally low and is followed by increasing yields in subsequent harvests. This reason might explain why, in this experiment, yields were lower than one would have expected. However, this experiment showed that the application of organic amendments and slow-release N fertilizer significantly increased biomass production of willow crops as shown by the significant contrasts “Organic amendments – Control” and “Slow-release N – Control” (Table 1.2).

Though the contrasts “Organic amendments - slow-release N” (Table 1.2) were non-significant, indicating that the two types of nutrient source performed equally, the organic amendments produced slightly more biomass than slow-release N as shown by the positive estimates. Moreover, those estimates increased from year-one to year-three while their p-value decreased, suggesting that the longer the rotation, the higher and more significant becomes the difference between the organic amendments and the slow-release N fertilizer. It is common knowledge that while the effect of mineral N fertilizers only last a few years, organic amendments continue to mineralize and provide nutrient to plants over a longer period. The contrasts of annual growth rate (Table 1.4) confirmed the longer lasting effect of organic amendments on biomass production compared to slow-release N: in year-two, the contrasts “ Organic amendments – Control” and “Organic amendments – Slow-release N” were significant whereas the contrast “Slow-release N – Control” was not significant. Overall, organic amendments produce as much biomass as the highest rates of slow-release N fertilizer, thereby confirming the second hypothesis of this study.

With regard to the use of plastic mulch, consistent with the third stated hypothesis, no significant effect was found on biomass production (Tables 1.2 and 1.4). It was observed during the study that no weeds grew, even in the plots without plastic mulch. An effective initial chemical weed control and a rapid canopy closure by the plants would explain why the use of the plastic mulch did not make any difference in terms of biomass production.

Biomass response curve

The attempt to model the biomass response to rates of slow-release fertilizer was unsuccessful (Table 1.5 and Figure 1.7). The following reasons could be evoked to explain why the modeling was non-conclusive:

- biomass production of the control plots was naturally quite high, diminishing the response to fertilizer application,
- the data displayed high variability within application treatment,
- biomass production at 200 kg N/ha was inexplicably lower than biomass at 100 kg N ha^{-1}.

This observation also indicates that besides N, biomass was determined by some other site variables not accounted for in this study.

Resin-captured NO_3-N: available NO_3-N

The installation of the resin columns in the field excluded root uptake and facilitated resin collection of available NO_3-N carried downward in the soil column by drainage water. For year-one, one would have expected available NO_3-N to be higher in mineral fertilizer (slow-release N) than in organic amendment plots. Although the negative estimate of the contrast "Organic amendments – Slow-release N" (Table 1.6) seemed to support that idea, the difference was not significant ($p = 0.68$). The fourth hypothesis of this study stating that during the first year after application slow-release N treated plots and organically amended plots have similar amounts of available mineral N was accepted. High variability contributed to the non-significant difference. Kolberg et al. (1997) observed high variability in resin bag estimates of net nitrogen mineralization and calculated that tens to hundreds of resin samples would be required to achieve good precision levels. The high variability of the data could also explain the nonsensical observations of 250 kg N ha^{-1} and more resin-captured NO_3-N for the treatments of 100 and 200 kg N ha^{-1} of slow-release N. One other source of variability in the data is the placement of the resin in the field. It was suspected in this experiment that the installation of the resin columns in auger-dug holes influenced the flow of water and nutrients through the columns. In addition, disturbance may have contributed to large losses of N, the soil substrate itself having a high pH. Subler et al. (1995) reported about the disadvantages of the resin bag technique associated with the method of placement. They mentioned that soil disturbance while installing resin bags would alter the flow of water and nutrients to the bags. The significant difference between the lime-stabilized sludge and the composted poultry manure treatments were probably due to the combination of confounding factors evoked above.

During year-two, there was no difference of available nitrogen between organic amendment plots and slow-release N plots as shown by the non-significant contrast "Organic amendments – Slow-release N" (Table 1.6). However, during year-three, available nitrogen was higher in organic amendment plots than in slow-release N plots ($p = 0.06$). Contrary to the fifth stated hypothesis of this study, available N was higher in organic amendments plots than in mineral N fertilized plots during later years of the rotation cycle. The greater amounts of available N in organic amendment plots could be explained by the fact that mineralization of organic N would still be proceeding while almost the entire amount of N provided by the slow-release N would have been released during the first season. This greater amount of available N in the organic amendment plots would explain why annual growth rate of year-two and year-three was greater in organically amended plots than in slow-release N plots (Table 1.4). Organic amendments create a more desirable situation for water quality and biomass production.

Net available NO_3-N contributed by treatments

In control plots, there were 27, 35 and 124 kg N/ha as available NO_3-N for year-one, year-two and year-three respectively. Net available NO_3-N contributed by treatments was calculated by deducting corresponding control values (Figure 1.9). For the composted poultry manure treatment, net available NO_3-N was 19, 235 and 43 kg N ha^{-1} for year-one, year-two and year-three respectively. These values, relative to the initial loading of 1336 kg ha^{-1} of TKN, represented net nitrogen mineralization rates of 1.4, 17.6 and 3.2%, respectively. Net N mineralization rate observed for year-one was comparable to (1) 0.4 to 5.8% reported by Tyson and Cabrera (1993) for composted poultry manure incubated at 25^0C for 56 days and (2) 3% found by N'Dayegamiye et al. (1997) for various composted farm manures. Average daily temperature recorded in the field were approximately 15, 13 and 17^0C for years one, two and three, respectively. These temperatures could explain the relatively lower mineralization rates compared to most literature figures. Many authors found much higher net mineralization rates for composted poultry manure: Hadas and Portnoy (1994) reported 11 to 29% after 32 weeks of incubation at 30°C, and Castellanos and Pratt (1981) found 28% after 10 weeks of incubation at 23°C. Net N mineralization rate for year-two was much greater as one would expect from composts, while year-three rate was less again. After three years, cumulative net mineralization of composted poultry manure was estimated at approximately 22%.

In the lime-stabilized sludge treatment, net available NO_3-N was 350, 157 and 2 kg N ha^{-1} for year-one, year-two and year-three respectively. These numbers, reported to the initial loading of 1400 kg ha^{-1} of TKN, represented nitrogen net mineralization rates of respectively 25.0, 11.2 and 0.1% respectively. Published values of mineralization rate for lime-stabilized sludge are not currently available since it is not a common product. However, many authors have studied the mineralization rate of other sewage sludge waste products. Epstein et al. (1978), after 15 weeks of incubation at 35°C, observed net N mineralization rates of 7-9%, 4-5%, 40-42% and 36-46% respectively for composted digested sludge, composted raw sludge, digested sludge and raw sludge. Barbarick et al. (1996) reported net N mineralization rates of 25-57% and 62-78% after one year for 6.7 and 28.6 t ha^{-1}, respectively, of sewage sludge applied to dryland wheat. The relatively high rate of net N mineralization observed in this study (25%) for year-one could probably be explained by soil disturbance or preferential flow caused by the installation of the resin columns. The cumulative net N mineralization rate for lime-stabilized sludge over the three years of this study was estimated at approximately 36%. Barbarick et al. (1996) found 13-43% and 41-67% as net nitrogen mineralization over 5 years for sewage sludge applied at 6.7 and 28.6 t ha^{-1}, respectively, to dry land wheat. From all these studies, it appears that net N mineralization rate of organic residuals depends specifically on the type of residual and its intrinsic characteristics, and the prevailing conditions of the experimental setting.

Overall, mineralization of organic amendments in this study shows that organic residuals progressively release their nitrogen into the soil system, still providing nutrient to plants well after the effect of mineral fertilizers applied at the beginning of the rotation cycle has faded.

Soils

Soil chemical data showed that organic amendments had a positive effect on organic matter, exchangeable cations and extractable P. Soil organic matter increases were probably due to a combination of increased root production and residual applied organic amendments. Increased soil organic matter improves soil physical characteristics such as soil water retention and movement, soil structure and porosity. Such improvement of the soil organic matter status in organically amended plots contributes to the sustainability of willow bioenergy plantations as discussed by Abrahamson et al. (1998). Increased soil pH is an important advantage associated with the use of lime-stabilized sludge and composted poultry manure on low pH soils. This is particularly beneficial in contrast to the soil acidification observed on the same site in willow stands repeatedly fertilized with inorganic fertilizers (Adegbidi 1994).

Conclusions

The current field study showed that the top-dressing of composted poultry manure and lime-stabilized sewage sludge increased the annual growth rate of willow stem biomass by approximately 40% (8.3 to 11.7 odt ha^{-1}). Organically amended plots had similar stem biomass production as plots fertilized with slow-release nitrogen fertilizer at the rate of 300 kg N ha^{-1}. Analysis of the annual growth rates showed that rates remained consistent through the rotation cycle in organically amended plots while it decreased in slow-release fertilized plots. The results also suggested that other factors than nitrogen addition rate determined biomass production.

The investigation of nitrogen availability showed that by the end of the rotation cycle net available nitrogen was zero in slow-release N plots while organically amended plots were still releasing nitrogen into the system. This last observation explains why stem biomass annual growth rate decreased in slow-release N fertilized plots.

Overall, the field study showed that organic residuals can advantageously be used as soil amendments in willow biomass plantations. Such utilization increases biomass production, provides a safe disposal of organic wastes and reduces the production cost of willow biomass crops.

Chapter 2: Field Demonstration: Operational Application of Poultry Manure to Biomass Crops

Introduction

In 1997, the first in a series of demonstration plantings of willow biomass crops, with incorporated raw poultry manure, was established on land owned by Wegmans Egg Farm near Wolcott, NY. The objectives of this planting and subsequent plantings were: (1) to investigate the operational feasibility of land application of raw and composted poultry manure on willow biomass crops as a means of managing manure, and (2) to provide a local source of carbon (wood chips) for Wegmans layer manure composting operation. Willow crops would provide a 'closed-loop' system for management of poultry manure from Wegmans Egg Farm. Land application of poultry manure on rapidly growing willow biomass crops could be an ideal use for this material, because of the perennial nature of the crop, the extensive root system, coppicing ability, and sustainable rapid growth of the willow crops. The advantages of such a system are:

> 1) the manure acts as a beneficial soil organic amendment/fertilizer, replacing the need for the application of commercial fertilizers on willow biomass crops,
>
> 2) decomposition and mineralization of the manure slowly releases nutrients during the 3-4 year willow plant growth cycle and minimizes manure odor, and
>
> 3) rapidly growing willow plants utilize the nutrients thereby preventing them from entering ground and surface waters.

As part of this study, approximately seven ha of willow and poplar biomass crops were planted over three years, 1997 (3 ha), 1998 (2.4 ha), and 1999 (2 ha).

1997 Demonstration Planting and Clone-site Trial

The 1997 willow biomass crop consisted of a 2.5 ha demonstration planting and a 0.5 ha clone-site trial. The demonstration planting and the clone-site trial were immediately adjacent to each other on the same field, which was in corn in 1996. Wet chicken manure compost was applied in the fall 1996 at a rate of 16 t ha^{-1} and incorporated by disking. The nutrient analysis of the wet chicken manure compost is listed in Table 2.1. Glyphosate (2.24 kg ai ha^{-1}) was applied in spring 1997 to kill emerging weeds. The site was disked twice immediately before planting. The demonstration area was planted with 25 cm cuttings on May 27-29 with a Fröebbesta planter, using the Swedish double-row spacing. Four willow (S25, S301, S365, and SV1) and two hybrid poplar clones (NM5 and NM6) were established in the field in an un-replicated design. Twenty-five cm cuttings of eleven willow clones and two hybrid poplar clones were hand-planted on May 22-23 in the clone-site trial, using a randomized complete block design, with three replications. The clone-site trial plots consisted of three double rows, with 60 trees per double row. Preemergence herbicide (simizine) was applied to the site at a rate of 2.24 kg ai ha^{-1} after planting. The many large rocks were removed by hand after planting (June 30- July 2).

The 1997 clone-site trial and demonstration areas developed a severe weed problem during the first growing season. A delay in applying the pre-emergent herbicide was most likely the major cause of these weed problems. A large number of weeds had germinated by the time of application. Preemergence herbicides do not control seedlings that are already established. Repeated attempts to mechanically control the weeds were complicated by rocky soil conditions and increased fertility due to the incorporated raw poultry manure. Weed control was not successful and the willow crop suffered severe mortality due to competitive pressure from thick weed populations.

Survival data and height measurements were collected from the clone-site trial in October 1997. Survival ranged from 29% (PUR34) to 70% (S19), with an overall average of 49% (Table 2.2). Mean height was 76 cm for all clones, ranging from 49 (PUR34) to 108 cm (NM5) (Table 2.3). A combination of severe weed competition and damage from mechanical weed control efforts contributed to the low survival. Sites with good site preparation and weed control generally have survival rates of 80% or better for most clones. Due to the poor survival, a decision was made to abandon this planting and replant in 1998 in an adjacent field.

1998 Demonstration Planting and Clone-site Trial

The 1998 site consisted of a 1.9 ha demonstration area and a 0.5 ha clone-site trial. The demonstration planting and the clone-site trial were adjacent to each other on the same field, which was in wheat during 1997. The 1998 site was less stony and had fewer weeds than the 1997 site, which allowed for better site preparation. Wet chicken manure compost was applied at a rate of 20.2 tons ha^{-1}, followed by chisel-plowing, in September 1997. The site was disked twice immediately prior to planting. Both the demonstration area and clone-site trial were planted with 25 cm cuttings on May 12-14. The demonstration area included one poplar (NM6) and three willow (S25, SV1, and SX64) clones planted with a Frobbesta planter, using Swedish double-row spacing. The clone-site trial included one poplar and eleven willow clones in a randomized complete block design, with four replications. The plots consisted of three double rows, approximately 16 m long, with 150 plants per plot. The preemergence herbicide oxyfluorfen was applied at a rate of 1.12 kg ai ha^{-1} on May 13. On June 14, fusilade was applied at 0.35 kg ha^{-1} to control grass that was developing in the clone-site trial and demonstration area. Mechanical weed control was conducted during August 1998, using a multi-head rototiller. Survival data was collected during the fall of 1998 and 1999 in the clone-site trial. Survival was measured in the demonstration area in the fall of 1998, using a standard operating procedure (SOP) (see Appendix 4) for determining survival in commercial plantings. The trees were coppiced in the winter of 1998-99. Mechanical weed control was conducted during the spring 1999 using a multi-head rototiller.

Survival in the clone-site trial at the end of the first growing season averaged 78% for all clones, ranging from 40% (SX67) to 99% (NM6). There was little change in the clone-site survival between 1998 and 1999 (Table 2.3). Average survival remained at 78% at the end of the first rotation (2001). Mean biomass production at the clone-site trial was 21.5 odt ha^{-1} for the first rotation, ranging from 10 odt ha^{-1} (FC188) to 38 odt ha^{-1} (NM6). Biomass production in the clone-site trial compared favorably to other clone-site trials conducted by SUNY-ESF. First year survival in the demonstration area averaged 77%, ranging from 67% (S25) to 95% (NM6) (Table 2.4). Improved survival over the 1997 planting was probably due to better site preparation and weed control.

1999 Demonstration Planting

The 1999 site consisted of a 2 ha demonstration planting, which was in corn in 1998. High rise layer manure was applied at a rate of 11.2 tons ha^{-1}, followed by disking, in December 1998. Nutrient analysis for the high rise manure is summarized in Table 2.1. Spring site preparations included plowing and disking. Two willow and one poplar clone were planted on June 10 with a Step-planter, which planted 20 cm cuttings from willow and poplar whips. The Step-planter increases efficiency and should improve survival rates compared to the Fröebbesta planter. Cuttings can be buried by the Fröebbesta planter resulting in plants that fail to emerge through the soil. This is not a problem with the Step-planter. Preliminary analysis indicates that the Step-planter plants at approximately 1 ha hr^{-1} vs. 0.25 ha hr^{-1} for the Fröebbesta planter. Simazine was applied about two weeks after planting, at a rate of 2.24 kg ai ha^{-1}. Weeds were controlled mechanically using a multi-head rototiller. Survival data was collected during September using a standard operating procedure (SOP) (see Appendix 4). The site was coppiced in January 2000.

Survival in the 1999 demonstration area was 77, 78, and 84% for clones SV1, NM6, and SX61, respectively (Table 2.4). A delay in the application of the preemergence herbicide necessitated mechanical cultivation to achieve weed control. Some plants were severely damaged during cultivation operations. Survival was also reduced due to a severe drought that affected the region during June and July of 1999.

Table 2.1. Nutrient analysis of wet compost (1997) and high rise poultry manure (1999) applied to fields prior to planting willow biomass crops. Data supplied by Wegmans Egg Farm.

	Wet Compost	High Rise Manure
Moisture (%)	55.58	21.32
Results are on a dry matter basis		
Mineral matter (%)	42.52	37.94
Organic matter (%)	57.48	62.06
TKN Nitrogen (%)	2.13	3.59
Ammonia – N (%)	NA	0.32
Phosphorus (%)	2.75	2.45
Potassium (%)	1.18	2.75
Calcium (%)	16.0	10.93
Magnesium (%)	0.78	0.76
Sulfur (%)	0.46	0.75
Sodium (%)	NA	0.37
Boron (ppm)	34	40
Manganese (ppm)	541	282
Copper (ppm)	39	36
Zinc (ppm)	442	446
Iron (ppm)	NA	668
Note: NA indicates that data was not available		

Table 2.2. Height and survival (mean ± standard error) of willows and poplars in the 1997 Wolcott, NY clone-site trial. Measurements were taken during October 1997 and are based on a 100% survey.

Clone	Height (cm)	Survival (%)
NM5	108 (8)	59.5 (6.5)
SX67	102 (4)	48.7 (17.5)
NM6	91 (2)	54.8 (2.8)
SX61	82 (9)	59.8 (5.0)
S301	79 (9)	34.3 (7.7)
S19	72 (5)	69.6 (0.8)
SX64	71 (9)	52.0 (15.2)
S25	70 (16)	39.8 (15.0)
SA2	68 (6)	54.3 (20.4)
SV1	68 (3)	48.0 (6.7)
PUR12	67 (4)	38.9 (9.5)
S365	65 (6)	49.1 (20.7)
PUR34	49 (3)	28.7 (0.8)
Mean	109 (8)	49.0 (2.8)

Table 2.3. Survival (mean ± standard error) for the clone-site trial planted at Wolcott, NY in 1998. Data was collected in both the establishment year (1998) and the first year after coppice (1999). Survival is based on a 100% survey.

	Survival(%)	
Clone	1998	1999
B193	81.7 (3.7)	81.3 (3.3)
S365	67.5 (16.0)	67.1 (13.7)
SV1	75.4 (10.3)	75.4 (9.1)
S25	89.6 (5.1)	89.6 (4.3)
FC189	88.4 (5.6)	88.3 (4.8)
NM6	99.2 (0.6)	98.8 (0.4)
FC188	69.6 (9.5)	68.8 (7.5)
SX61	71.7 (10.9)	71.7 (9.6)
PUR34	84.2 (7.9)	84.2 (6.8)
S301	90.8 (2.3)	90.4 (1.8)
SX67	40.0 (10.4)	40.0 (9.1)
B195	81.3 (2.5)	80.4 (2.7)
Mean	78.1 (3.9)	78.0 (3.4)

Table 2.4. Survival on two demonstration fields planted at Wolcott, New York in 1998 and 1999. The 1998 site was planted with a Frobbesta planter. The 1999 site was planted with a Step planter. Data was collected at the end of the first growing season.

	Survival (%)	
Clone	1998 Planting	1999 Planting
NM6	95	78
S25	67	-
SV1	70	77
SX61	-	84
SX64	74	-
Mean	77	80

Chapter 3: Evaluation of Willow Biomass for Composting Operations

Introduction

Chicken layer manure (layer manure) is a major agricultural residue in New York State with an annual production of 160,000 tonnes (Lander et al. 1998; USDA 2002). Because of its strong odor, nutrient instability and concerns about non-point source pollution, disposal of layer manure poses various challenges to large producers of chicken eggs. Statewide, about 40% of layer manure is composted. Due to changes in confined animal feeding operations (CAFO) regulations, it is expected that 80% of layer manure will be composted within five years (Wright pers. comm.). Wegmans Egg Farm, a subsidiary of Wegmans Food Markets, Inc., located in central New York, is one of the largest producers of layer manure in New York at 13,600 tonnes annually.

Currently, Wegmans composts about 70% of their layer manure. Of the remainder, 15% is semi-composted and land applied while 15% is land applied as raw manure. To maintain the carbon source for the composting operation, Wegmans Egg Farm purchases wood chips from sources as far away as Connecticut. The chips are mixed with raw manure to increase the carbon:nitrogen ratio (C:N), as carbon availability plays an important role in N immobilization (Barrington et al. 2001), a primary concern for composting operations. The costs of purchasing and transporting wood chips and running the composting operation are presently greater than revenues generated from the sale of the compost. One solution would be to grow willow biomass crops on the farm as a carbon source. However, there was concern by the operators that willow chips might not be as effective as other carbon sources in the composting operation. This chapter presents results of composting of layer manure using willow chips compared with two other commonly used wood chips within the standard Wegmans composting process.

Methods

Compost facility

The composting facility at Wegmans Egg Farm consists of six bays, each 62 m in length, 6 m wide and 1 m in height. Raw layer manure is mixed 1:1 by volume with wood chips in one end of each bay using a bucket loader. A small amount of mature compost is included as an inoculant. Each day's mixture is referred to as a slug. A Farmer Automatic "Compostamatic" machine regularly mixes the material, resulting in an average daily slug movement of about 2.2 m along the length of the bay. After approximately 24 to 28 days, the compost is removed from the opposite end of the bay, and stored for sale or on-farm use. At the time of this experiment, conifer and hardwood chips were being used in the composting operation and were stored separately in large piles under cover.

Wood chips

Three-year-old willow was harvested at the State University of New York College of Environmental College and Forestry (SUNY-ESF) Experiment Station in Tully, NY, in December 1999. It was stored outside as whole stems in open piles. In March 2000, the willow stems were chipped using a Gravely 1200 Series Pro chipper and blown into a trailer. Nine systematic samples were taken (Briggs et al. 1986) for particle size distribution and nutrient concentration assessment. Due to the larger observed size of the willow chips relative to the conifer and hardwood chips being used, the willow chips were further processed in a collision mill at Mesa Engineering Systems in Skaneatles, NY. The processed chips were transported to Wegmans Egg Farm where they were stored outside, uncovered, for about two weeks before the start of the composting experiment.

Prior to the start of the composting experiment, six two-liter samples of each wood chip type were collected from random locations and depths within the piles. Three samples were used to assess the particle size distribution while the other three samples were dried at 65°C to a constant weight to determine bulk density and nutrient concentrations. Percent moisture was determined by the following equation:

$$\text{Percent moisture} = (\text{wet weight} - \text{dry weight}) / \text{wet weight}$$

Following grinding, total N was determined using the macro-Kjedahl method. To determine P, K, Ca, and Mg, the samples were ashed at 470ºC and dissolved in 0.6 N HCl. Phosphorus was determined by the ammonium molybdate vanadate method. Potassium, Ca, and Mg were determined by atomic absorption spectrophotometry (Bickelhaupt and White 1982).

Manure

Six one-liter samples of raw layer manure were taken from three random locations and depths in the storage pile at Wegmans Egg Farm. Three samples were used to determine percent moisture and bulk density. The other three samples, for nutrient concentrations, were put on ice for transport back to SUNY-ESF, where they were stored frozen at –10°C. The samples were packed on dry ice and sent to Brookside Laboratories, Inc. in New Knoxville, OH, who routinely analyze samples for Wegmans. At Brookside, manure samples were analyzed for pH and percent moisture. TKN was determined colorimetrically using EPA method 351.2 (EPA 2002). Carbon and C:N was determined utilizing a Carlo Erba Nitrogen/Carbon analyzer. Phosphorus, K, Ca, Mg, B, Fe, Mn, S, Cu and Zn concentrations were determined by inductively coupled plasma mass spectrometry (ICP) after nitric/perchloric digestion (Standard Methods 3030H; Clesceri et al. 1989).

Compost

The composting experiment included three treatments; (1) composting using hardwood chips (HW), (2) using conifer chips (CON) and (3) using willow chips (W), with three replications each. To avoid contamination of W with the hardwood or conifer chips, no new material was added to the W bay for one day prior to the start of the experiment. The "Compostamatic" machine turned the slugs 17% more frequently than usual because one bay normally used was closed for repair, thus the composted material reached the end of the treatment bays at 21 days rather than the usual 24-28 days. Three one-liter subsamples were taken from each bay on sequential days (i.e. from different slugs), starting on the second, eighth, 14th and 21st days after the composting mixture began. These samples were used to assess percent moisture, pH, C, C:N, and nutrient concentrations (see *Manure*). Three one-liter samples per treatment per replication were used to assess bulk density at days eight and 21. Three three-liter samples per treatment per replication were used to determine the particle size distribution of the final compost. Differences in physical and chemical characteristics from the three treatments were assessed using ANOVA (Keuhle 1994). Treatment differences were tested using the following linear contrasts:

$$\tfrac{1}{2} * (HW+W) - CON$$

and

$$HW - W$$

Comparison of the response curves between the treatments over time was assessed with repeated measures analysis (Meredith and Stehman 1991). All statistical analyses were conducted using SAS v8.0 (SAS 1999).

Results

Wood Chips and Manure

Prior to processing in the collision mill, 86% of the willow chips were smaller than 6.35 mm, but only 42% were smaller than 2 mm (Figure 3.1). Following processing in the collision mill, all of the willow chips were smaller than 6.35 mm and 74% were smaller than 2 mm. In contrast, all hardwood chips and conifer chips were smaller than 6.35 mm with 98% and 99%, respectively, smaller than 2 mm. There was no difference in bulk density between hardwood and conifer chips (Table 3.1). Willow chips had less than half the bulk density of either of the other chips. Conifer chips averaged 35.6 ± 4.1% moisture. Hardwood and willow chips averaged 18.3 ± 0.8% and 19.0 ± 4.2% moisture, respectively.

Percent N varied significantly among all chip types. Willow chips averaged 0.42% N, conifer chips averaged 0.26% N and hardwood chips averaged 0.10% N (Table 3.1). Willow chips were highest in P at 0.06%, significantly greater than conifer chips (0.02) or hardwood chips (0.01). Willow chips were also highest in K. The characteristics of the raw layer manure are presented in Table 3.2.

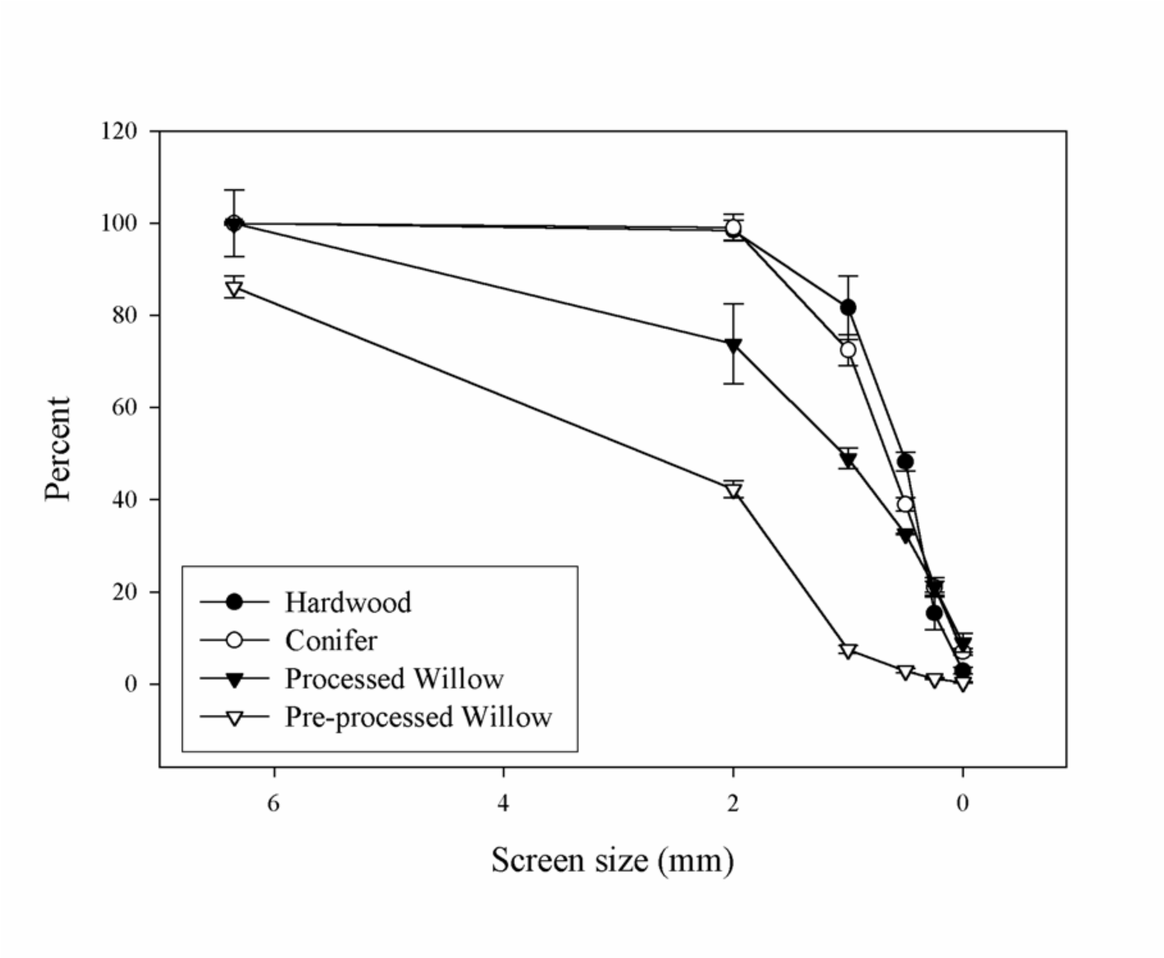

Figure 3.1. Particle size distribution of wood chips used in the composting trial. "Processed" refers to the collision mill reduction of willow chip size. The "0" refers to particle sizes less than 0.25 mm.

Table 3.1. Mean nutrient concentration (%) and bulk density (g cm^{-3}) of wood chips used in the layer manure composting experiment. SE is standard error.

	N		P		K		Ca		Mg		Bulk Density	
Wood chips	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Hardwood	0.101	0.005	0.008	0.0008	0.038	0.0004	0.164	0.027	0.028	0.006	0.16	0.01
Conifer	0.255	0.018	0.023	0.0021	0.120	0.0084	4.812	0.281	0.831	0.050	0.16	0.01
Willow	0.425	0.023	0.058	0.0003	0.172	0.0068	0.582	0.014	0.048	0.005	0.07	0.01

Table 3.2. Characteristics of manure composted at Wegmans Egg Farm in April 2001. SE is standard error.

	Sampled manure	
	Mean	SE
Moisture (%)	71.14	0.79
Organic Matter (%)	66.60	1.22
TKN (%)	5.65	0.14
P (%)	2.19	0.04
K (%)	2.40	0.07
Ca (%)	10.04	0.44
Mg (%)	0.72	0.03
Na (%)	0.37	0.02
S (%)	0.71	0.04
C (%)	34.14	0.82
pH	7.87	0.03
C:N	6.05	0.28

Compost

Repeated measures analysis revealed that there was a significant ($\alpha = 0.05$) linear decline in organic matter concentration across all treatments (Figure 3.2), but there were no differences in the rates of change among the treatments. There was a significant cubic response in percent moisture for both HW and W. The response in carbon concentration was a significantly linear decline for all treatments. There was also a significant quadratic response in W and a significant cubic component in HW. The response curves for N had significant linear and quadratic declines, with no differences among the rates. There was a significant linear increase in P among all treatments (HW $p = 0.09$), with no differences in the rates of change. All treatments demonstrated a significant linear increase in K, though W had a higher rate of change. A significant linear increase in pH was observed for all treatments, with no significant differences in rates, although there was a cubic response in W.

After 21 days, particle size distributions of the compost were similar for all three treatments (Figure 3.3), though there were some differences. W (13.6%) had the greatest amount of particles larger than 2 mm CON (2.4%) or HW (4.5%). In the 0.5 – 1.0 mm category there was a significant ($p \leq 0.0001$) difference between all treatments (CON, 32.2%, HW, 26.2%, W, 20.9%). In the pan (0) category, all treatments significantly differed ($p=0.0011$; W, 3.3%, HW, 2.4%, CON, 1.7%).

There were no differences among the compost treatments in TKN, percent moisture, or concentrations of Ca, B, Fe, and Zn. HW and W were higher in carbon concentration and lower in Cu concentration than CON. There were differences ($p \leq 0.05$) between compost treatments in organic matter content, P, K, Mg, Na, S and Mn (Table 3.3). HW and W were higher in organic matter than

CON. W was highest in P and K. W had higher Mg than HW, but CON was higher in Mg than either other treatment. There was no difference in S concentration between CON and the other treatments, but W was higher than HW. CON was higher in Mn than the other composts. The pH of W was greater than HW, but neither was different from CON. The bulk density of CON was higher than HW and W at eight days ($p = 0.0582$; Table 3.4). There was no difference in bulk density between the composts at 21 days ($p = 0.8317$). Across all treatments, the bulk density of the 21-day compost treatments was significantly greater than the bulk density of the compost treatments at eight days ($p = 0.0001$).

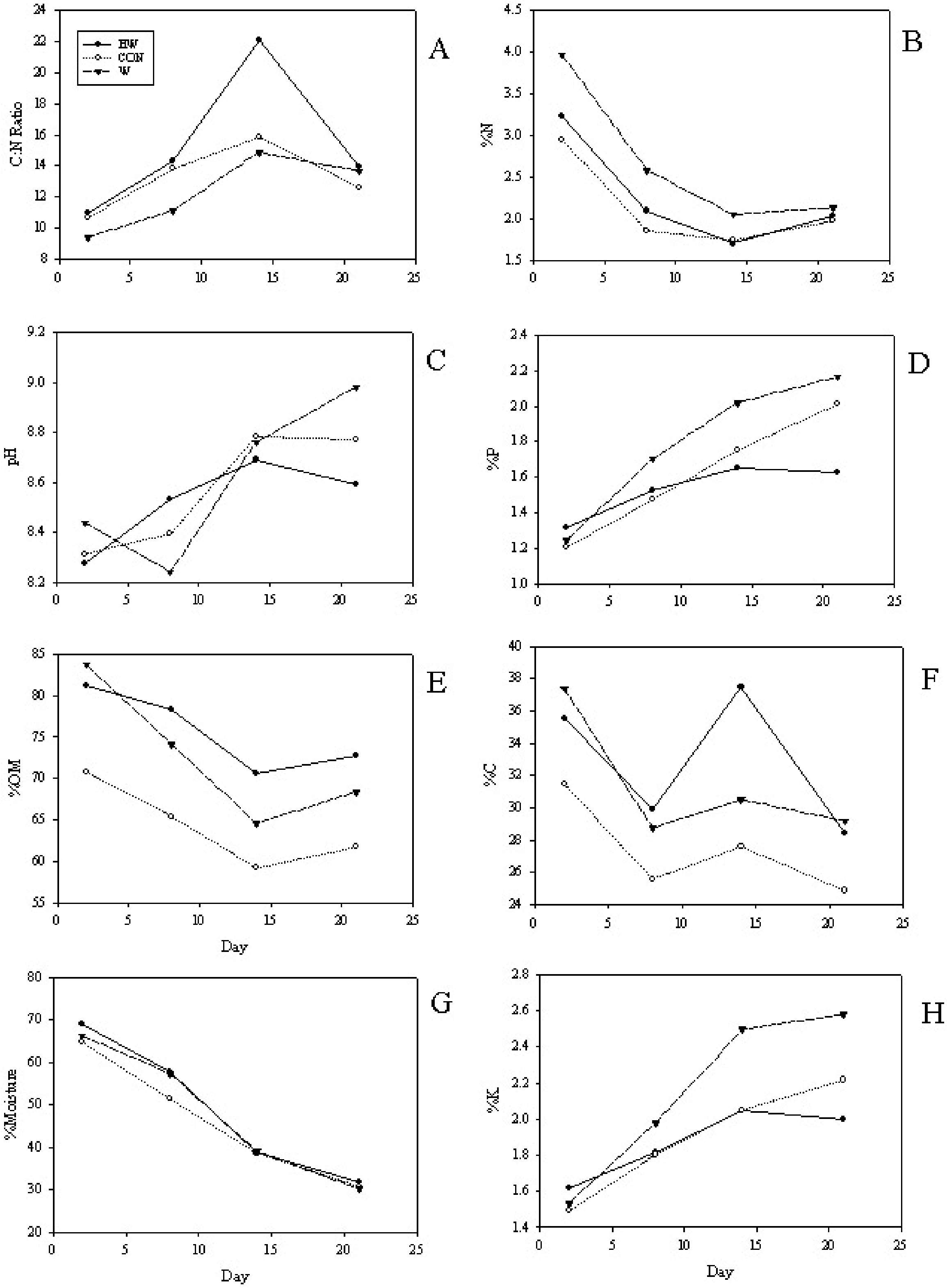

Figure 3.2. Repeated measures response curves of selected parameters of layer compost over the 24 day experiment. A)C:N ratio; B)%N; C) pH; D)%P; E)%OM; F)%C; G) %moisture; H)%K. The X-axes are number of days in the experiment.

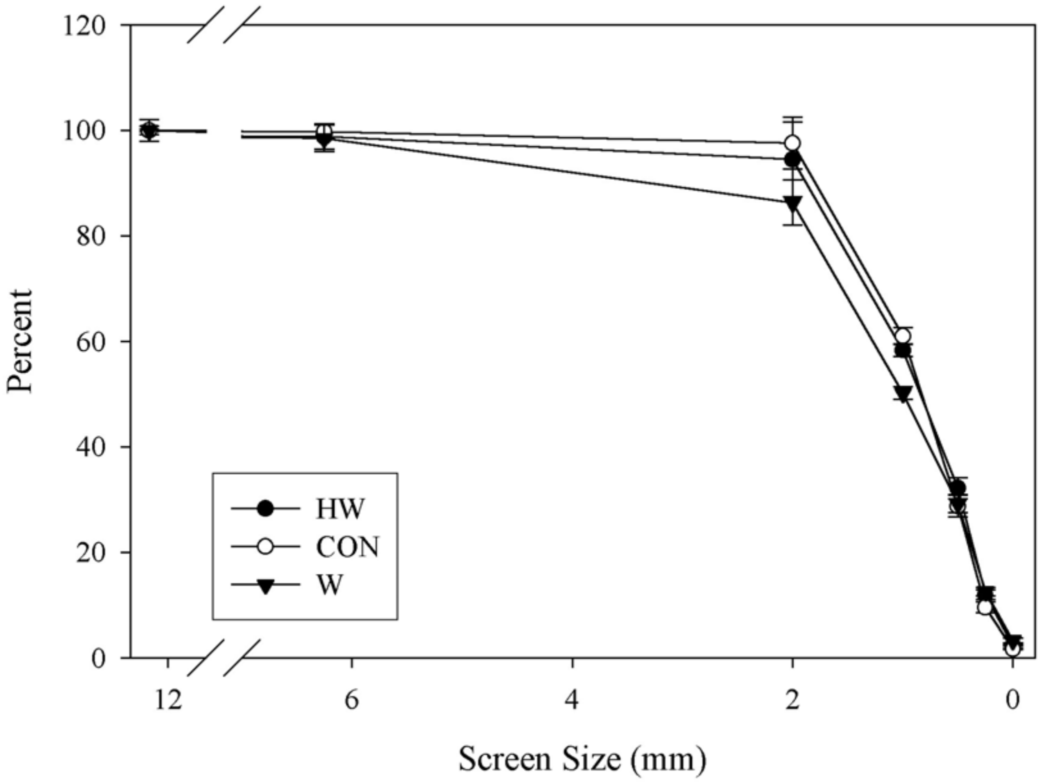

Figure 3.3. Particle size distribution of the three compost treatments after 21 days.

Table 3.3. Characteristics of layer compost produced using three different types of wood chips as a carbon source with contrasts comparing the treatments. SE is standard error.

	Hardwood		Conifer		Willow		Contrast p-values*	
	Mean	SE	Mean	SE	Mean	SE	1/2(HW+W)-CON	HW-W
Moisture (%)	31.83	3.74	30.87	3.82	30.21	1.90	0.9714	0.7374
Organic Matter (%)	72.68	1.75	61.74	1.90	68.38	1.89	**0.0082**	0.1516
TKN (%)	2.03	0.06	1.97	0.11	2.13	0.07	0.3151	0.4344
P (%)	1.63	0.08	2.01	0.16	2.16	0.08	0.4369	**0.0149**
K (%)	2.00	0.03	2.22	0.08	2.58	0.05	0.3526	**0.0004**
Ca (%)	8.13	0.75	11.72	1.37	10.52	0.55	0.0869	0.1283
Mg (%)	0.68	0.02	0.94	0.05	0.82	0.03	**0.0044**	**0.0358**
Na (%)	0.31	0.01	0.36	0.01	0.39	0.01	0.6296	**0.0019**
S (%)	0.49	0.00	0.57	0.2	0.58	0.01	0.1335	**0.0037**
C (%)	28.38	1.64	24.86	0.87	29.17	1.16	**0.0447**	0.6754
pH	8.59	0.09	8.77	0.14	8.98	0.02	0.9034	**0.0292**
C:N ratio	13.95	0.64	12.65	0.28	13.69	0.64	0.1306	0.7511
B (ppm)	39.17	0.72	43.87	6.54	49.75	5.45	0.9255	0.1800
Fe (ppm)	2632.54	441.21	3340.31	974.33	1675.12	129.47	0.1704	0.3182
Mn (ppm)	529.12	60.31	926.51	115.56	480.29	61.56	**0.0061**	0.6927
Cu (ppm)	34.19	0.14	52.28	6.96	41.50	4.26	**0.0466**	0.3151
Zn (ppm)	333.09	6.96	365.04	28.68	380.73	47.67	0.8442	0.3382

*p-values are from ANOVA linear contrasts and in bold if significant at α=0.05.

Table 3.4. Mean bulk density of layer manure compost produced using three different types of wood chips as a carbon source at eight and 21 days. SE is standard error.

	Bulk Density (g cm^{-3})				
	Eight days		21 days		t-test[*]
Chip type	Mean	SE	Mean	SE	p-value
Hardwood	0.230	0.007	0.288	0.029	0.0001
Conifer	0.253	0.017	0.294	0.016	0.0001
Willow	0.207	0.008	0.306	0.012	0.0001

[*] Student's t-test comparing means at eight days to means at 21 days.

Discussion

Chips

The particle size of willow chips coming out of the chipper were visually assessed by Wegmans personnel to be too large for the composting process. Before being processed in the collision mill, 13% of the chips were 6.35 mm or greater, with only 4% greater than 25.4 mm in size. After processing in the collision mill, all willow chips were 6.35 mm or less. The largest conifer or hardwood chips were about 6.35 mm, thus if the desired maximum particle size is 6.35 mm, the second chipping only affected 13% of the willow chips. However, processing the willow chips in the collision mill increased the percentage of willow chips in the lower size classes by an average of 25% per size class. A second processing step for willow chips is inconvenient and expensive, and may be unwarranted given these results. There are indications that unmilled willow chips will work just as well (Wadsworth pers. comm.).

Chip nutrients probably had little effect on the nutrient status of the final layer compost, due to the low nutrient concentration in the chips relative to manure. Willow had the highest concentrations of N and P, likely due to the young age of the wood (three-year-old) and the higher bark to wood ratio of willow chips relative to the other wood chips used in this experiment. Bark from three-year-old willow has double the concentrations of P and K relative to the wood (Tharakan et al. 2002) that results in higher concentrations in the willow chips. The Ca and Mg concentrations in the conifer chips were an order of magnitude higher than is usual for coniferous wood. Another sample of the chips was analyzed, and similar results were obtained. The low standard error suggests that some contaminant high in Ca and Mg was present in the conifer chip pile.

The bulk density of the willow chips was less than half that of the other chips at the start of the composting trial. The hardwood and conifer chips were stored in large piles wherein the weight of the chip mass has a compacting effect (Schaub-Szabo and Leonard 1999), while the willow chips, present in much smaller quantities, were not subject to that condition. However, since the composing mixture was done by volume rather than weight, less willow (by weight) was used in the composting process. It should be noted that the specific gravity of willow (0.30 – 0.50; Deka et al. 1999, Kenney et al. 1990) is lower than that for most hardwoods (e.g. sugar maple 0.71, red oak 0.95) and many conifers (e.g. white pine 0.42, lodgepole pine 0.72) (Reade 2002), so even under equal compaction willow will have a lower bulk density than most other wood chips.

Manure

The characteristics of the layer manure in this study were similar to a 1997 assessment made by Wegmans. Percent moisture was a little lower, as was N and P. Both pH and C:N were a bit higher than the previous assessment. The values of pH, N and C:N in this study were similar to pullet manure (Elwell et al. 1998).

Compost

The results of this study compare well with results from numerous other studies. The composting process reduced the raw layer manure's percent moisture, N, P, C and S concentrations, while increasing pH and C:N. The N concentrations were higher than that found for raw layer manure mixed with organic municipal waste composted in a drum aerobic reactor (Young et al. 2000), though lower than that found by Guerra-Rodriguez et al. (2001) for reactor composted poultry manure. Phosphorus in this study was higher than the 0.82% found by Young et al. (2000). Most carbon losses (~70%) are in the form of CO_2 emissions, while the remainder is incorporated into the cellular structure of the microbes (Barrington et al. 2001). Loss of S is likely due to volatilization, though the sequestration of both ammonium and S as $(NH_4)_2SO_4$ may be a factor (Ekinci et al. 2000). Overall, the pH range in this study was higher than the range of 7.0-7.8 found by Young et al. (2000), but was similar to the 8.2-8.9 found by Guerra-Rodriguez et al. (2001). The C:N ratios in this study were higher than Gagnon and Simard (1999) found for poultry manure in a windrow compost (10:1), although both total C (37.4%) and total N (3.7%) were much higher than found in that study. However the C:N ratio found by Guerra-Rodriguez et al. (2001) was 13.27, similar to that found in this study, though both C (41.03%) and N were much greater in that study. The variability in nutrient concentrations suggests that composting methods strongly affect the nutrient makeup of the final compost, although variability in initial manure nutrients may also have an affect.

Within this study, N was not different between HW and W, though both were significantly higher than CON. Higher concentrations of P and K were found in W compared to HW, though neither was different than CON. W and CON had higher S concentrations than HW. CON was lower in carbon concentration than the other treatments, but higher in both Mn and Cu concentrations. Bulk density varied between treatments early in the process, probably due to differences among the wood chips and the heterogeneous nature of early compost (Gagnon and Simard 1999). The similarity in bulk density of the final products indicates that all chip types work equally well in the composting process.

Each compost treatment behaved similarly over time, with significant linear response curves in all parameters measured. There were some differences in the rates of change, but all of the 21-day composts were similar to each other and previous assessments of Wegmans compost. The similarity among the treatments in C:N and N suggest equal degrees of maturity among all compost treatments (Wu et al. 2000). The continuing rise in P in W suggests that it may be less mature than HW (Wu et al. 2000), but neither W or HW was different from CON. Another commonly used indicator of maturity is pH. Compost pH generally increases greatly from the initial state, but declines somewhat and then stabilizes at maturity (Wu et al. 2000; Raviv et al. 1999). While none of the compost treatments were fully mature after 21 days, the response curve for willow compost indicates pH was still rising at the final sampling. Of course, the pH of the willow compost fell between samples one and two, contrary to expectation, thus any inferences must be considered with sampling variability in mind. The significant quadratic response in N is probably due to the nitrification of ammonium (Bernal et al. 1998) that occurs as compost approaches maturity. The significant cubic response of carbon, due to an elevation measured at day 14, corresponds with a period of elevated CO_2 levels (immature compost) (Hue and Liu 1995). However, Bernal et al. (1998) found a similar response in poultry compost over time when accounting for carbon speciation. To some degree, these responses may be due to variability with the compost mixture as sampled. Early in the composting process, the mixture is quite heterogeneous, becoming more homogenous over time (Gagnon and Simard 1999).

Conclusions

Comparison between different carbon sources demonstrates that willow chips produce a compost of similar quality to that produced by the other normally used wood chips. This result, in addition to the other environmental benefits associated with the on-farm production of willow biomass crops, suggests that willow has the potential to be developed as an important part of an on-farm nutrient management system.

Summary

With the completion of this research project, Wegmans can apply this information to their commercial composting operation. The first phase of the project demonstrated the expected increase production of willow biomass and a significant reduction in nutrient leachate from the willow plantings. The second phase of the project provided information needed for implementing larger scale plantings within this system, particularly the need for weed control. The nutrient rich manure provides an ideal growing medium for weed populations as well as willow trees. The final phase of the project demonstrated the viability of using locally grown willow chips as a carbon source for the composting operation. Willow chips from trees grown in the second phase have been successfully used in the composting operation. This project demonstrates the effectiveness of growing willow crops onsite to achieve the goals Wegmans Egg Farm set forth in both growing crops on nutrient rich sites (with incorporated chicken manure) and providing a "home-grown" carbon source (willow chips) for their commercial composting operation.

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APPENDIX 1: STANDARD OPERATING PROCEDURES FOR SAMPLING STEM MOISTURE CONTENT AND NUTRIENTS IN HARVESTED PLOTS

1) Using a systematic random sampling procedure, select four (4) stools in each plot. Flag selected stools to distinguish them from the rest of the plot.

2) Harvest the selected stools and bundle them so they may be weighed with the harvested plot, and then set the bundle aside to be chipped. Label the bundle (on the flagging and on at least one stem with a permanent marker).

3) Chipping of stems should be done soon after harvest. If bags of chips cannot be weighed immediately, it would be better to transport bundled whips, or delay chipping to minimize the time between chipping and taking green weight measurements of the chips. Chip **all** stems (including dead ones) from the four (4) selected stools onto a tarp.

4) Thoroughly mix all chips.

5) From the thoroughly mixed ships, take one (1) large grocery bag, approximately 2-3 kg for nutrient concentration and percent moisture determination.

6) As soon as possible after chipping: weigh the bag of chips, to two decimal places using a digital scale (e.g., Mettler balance). Record the weight on the bag **and** the tally sheet.

7) Dry the sample in the drying room (SUB 1, Illick Hall) at 65^{o}C to a constant weight (about one (1) week).

8) Weigh the sample after it has reached a constant temperature, and record on data sheet.

9) Grind the dry sample to pass through a two millimeter (2 mm) sieve.

10) After grinding, split the sample (as many times as needed) to fit into small brown sample bottles; be sure to label bottles.

11) Follow lab procedures for nutrient analyses.

APPENDIX 2. STANDARD OPERATING PROCEDURES FOR SAMPLING WILLOW FOLIAGE FOR NUTRIENT CONCENTRATION MEASUREMENTS

Purpose: to diagnose nutrition status of plantations as a basis for: (1) prescribing fertilizer amendments, and (2) relating nutrient status to wood production.

Sampling dates: sampling should occur late in the growing season, preferably between August 15 and September 15. Late season foliage should be green (photosynthetically active). If foliage has started to senesce, as indicated by a change in color (green to yellow), it should not be collected.

Sample location--programmatic: All research, demonstration, and commercial plantings will be sampled for foliage nutrient analysis at various times in plantation development. Demonstration and commercial plantings will be sampled the summer before dormant season harvest, e.g., at the end of the first growing season (before cut back), at the end of the fourth growing season (3-yr-old plants on 4-yr-old root systems), etc. All research plantings will, at minimum, be sampled using this schedule with additional samples taken as dictated by the study.

Sample location--within area (NOTE--an area may be a single rep in the case of a clone site trial, or a large planting block in the case of a commercial planting): A number of trees should be sampled across the area from as many trees as possible. For example, 10 leaves from each of ten "trees" of a single clone would be adequate for large-leaved clones. NOTE that the sample size of 10 trees is a minimum. Sampling of more trees, perhaps up to 30 per area, would be better.

Sample location--with a tree crown: Ten to 20 leaves from the top one third of a crown (sun-exposed portion of crown).

Sample quantity: Depends on the clone. A total of 200 leaves (10 leaves from 10 trees) of small-leaved clones (e.g., Salix purpurea) or 100 leaves from large-leaved clones (e.g., Salix dasyclados). The purpose here is to produce enough dry tissue to perform various nutrient analyses, including a reserve amount of material for reanalysis if necessary, perhaps as part of the Quality Assurance Program.

Sample quality: mature, "normal" leaves are to be collected. Mature connotes fully formed, normal sized leaves. Normal is a clone-specific; year-to-year condition defined by the general quality of foliage for all of the trees in the area. It may be that foliage is normally discolored by nutrient stress or disease, or partially missing due to insects. The description of "normal" condition should be included with sample information (see below), particularly if it deviates from green, whole, healthy tissue.

Sample information: each sample should be uniquely identified by date of sampling, sample I.D. number, area location, clone, rep, and any miscellaneous notes about condition. This information should be recorded with the field sample collection (brown bag) and study notebook.

Field and laboratory techniques: follow Bickelhaupt and White (1982). In particular, care should be given to either cooling (ice packs, refrigerator) or drying (preferable) samples the same day as collected.

APPENDIX 3. STANDARD OPERATING PROCEDURES FOR SURVIVAL ASSESSMENT OF DEMONSTRATION PLANTINGS

Purpose: to determine tree survival (percentage) in large demonstration or commercial plantations as a basis for: (1) assessing success of plantation establishment, and (2) monitoring changes in survival over the life of a plantation.

Sampling dates: Survival sampling can be conducted at any time during the year, providing trees have not been recently harvested and can be identified as alive or dead. Demonstration and commercial plantings will be sampled for survival at various times in plantation development. Survival sampling will be conducted before dormant season harvest, e.g., at the end of the first growing season (before cut back), and at the end of the fourth growing season (3-yr-old plants on 4-yr-old root systems), etc.

Sample location: Survival will be assessed by recording the number of live stools in a minimum of 30 row-sections for a given planting (site). A row-section (R-S) is defined as a single row with a length of 10 trees (alive or dead; theoretically, 20-ft. or 6-meters long; see Figure 1). NOTE: the sample size of 30 row-sections is a *minimum*. Sampling of more row-sections may be required in larger plantings (see Figure 1 area SV1-3).
Row-sections will be located within an area using a two-stage cluster sample (see the example below).

Sampling information: Survival data will be recorded on a survival sampling data sheet (attached), and will be filled out completely at the time of sampling.

The following procedure outlines, by way of an EXAMPLE, the selection of row-sections for survival assessment: (use the survival sampling data sheet to facilitate these procedures; example and blank forms are attached).

I. PRIOR TO RECORDING SURVIVAL DATA:

a) Enter data sheet information: date, observer, site, clone, and other comments on conditions of the planting.

b) Determine the number of areas by clone. Using the site map, determine the number of areas or block for the clone being measured. An area that is greater than five double-rows wide should be treated as two areas (for ease of locating row-sections); simply divide the area in half (e.g., an area with 7 double-rows can be divided into 4 and 3 double-row areas).

c) Determine row length (L) *for each area.* NOTE: The row lengths may vary within and between areas at a given site. The row length for each area should either be determined by pacing, from a map, or using a tape measure (please note on the data sheet which method was used). Record the row length (L) of each area on the data sheet. For this example, assume the row lengths of area SV1-1 and SV1-2 is 900 ft., and area SV1-3 is 1600 ft.

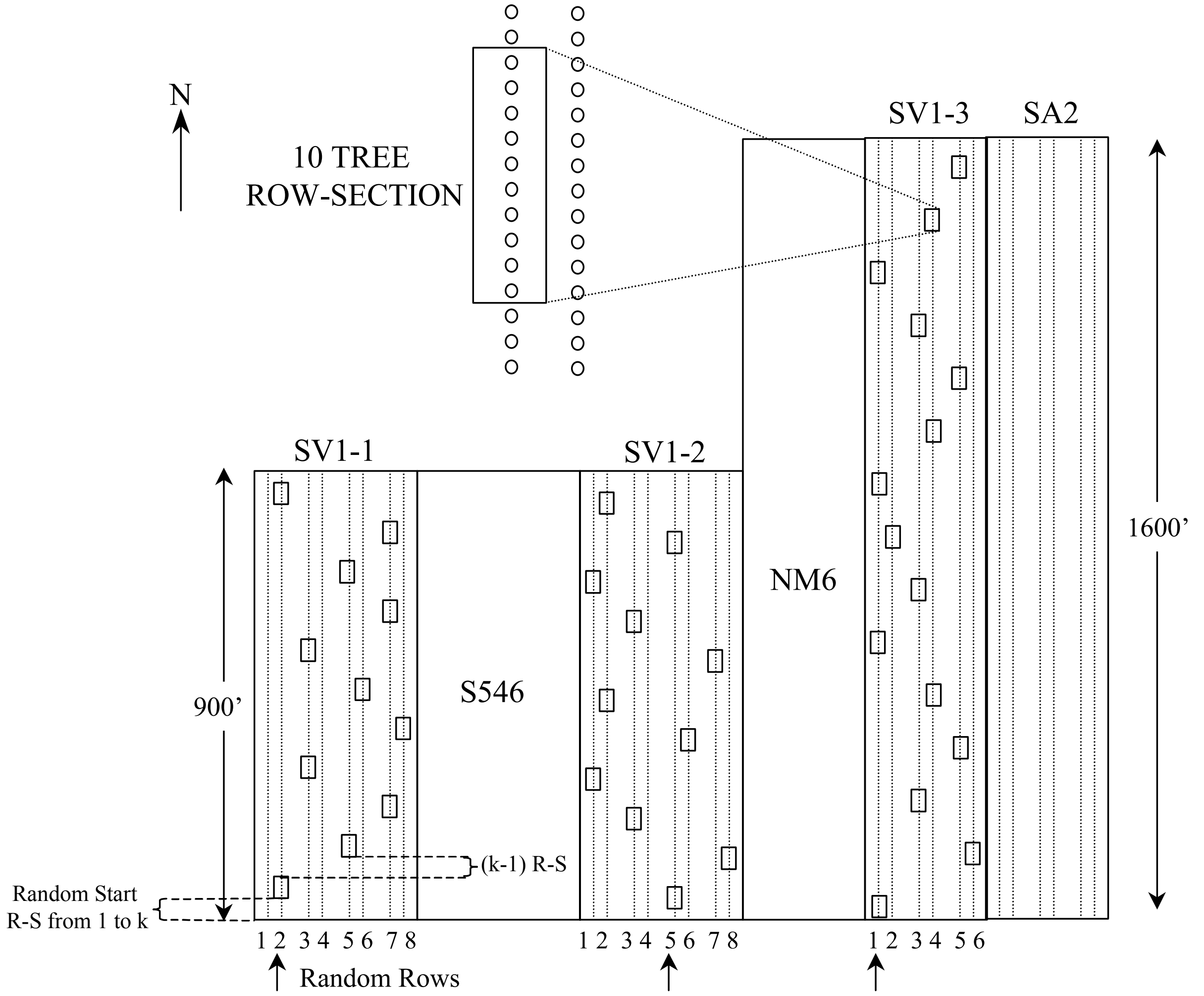

Figure 1. Example of survival sampling in a demonstration planting. Inset represents a 10 tree (20-ft., or 6-meter long) row-section in the Swedish double-row planting system.

d) Record the number of single-rows (R) *in each area, and assign a number to each row.* Determine the number of single-rows from the planting map or in the field and record the number on the data sheet. NOTE: The number of single-rows may be different for each area. Assign a number to each single-row. For this example, assume area SV1-1 and SV1-2 have 4 double-rows (8 single-rows), and area SV1-3 has 3 double-rows (6 single-rows); single-rows are then numbered from 1 to 8 and 1 to 6, respectively, from west to east.

e) Determine the number of row-sections required for each area. Divide the row length of each area (L) by 20 feet (the length of a row-section). This is the number of possible row-sections in a single row. Multiply by the number of single-rows (R) in that area. This is the total number (N) of possible row-sections in that area. Multiply by 0.03 (3%). Round to the nearest whole number. This is the number of row-sections (n) to be sampled for that area. Example calculation for area SV1-1: N = L / 20 x R = 900ft. / 20 ft. x 8 = 360;
n = N x 0.03 = 360 * 0.03 = 10.8, or 11 row-sections. NOTE: Roughly a 3-5% sample of all possible row-sections at a site is desired. If the total number of sampled row-sections in all areas is less than 30, use a 5% sample, rather than 3%.

f) Determine the number of row-sections (k) *between row-sections to be sampled.* Divide L / 20 ft. by the number of row-sections to be sampled (n) and truncate the result to obtain k. Every kth row-section will be sampled. For example, for area SV1-1: k = 900 / 20 / 11 = 4.09. or every fourth row-section. The distance from the edge (end) of one row-section to the start of the next is k-1 times 20 ft. (e.g., 4-1 = 3 x 20 = 60 ft). See Figure 2.

g) Obtain random row numbers for selecting row-sections. Select a random row number from 1 to R for each row-section to be sampled (obtain numbers from Table 1). In this example, 11 random row numbers will be needed for the 11 row-sections to be sampled in area SV1-1 (and SV1-2), and 15 random row numbers will be needed in area SV1-3. Record the *random row numbers* in the appropriate column on the data sheet.

h) Obtain a random number for the starting row-section (random start R-S). Select a random number from 1 to k, the number of row-sections between samples (e.g., 1 to 4), for each area from Table 1. Record this *random start R-S* on the data sheet.

II. OBTAINING AND RECORDING SURVIVAL DATA:

a) Locating row-sections in the field:
Use the *random row numbers* recorded on the data sheet to randomly select the starting single-row. Go to the randomly selected single-row and pace in from the edge of the field to the *random start R-S* determined in section *g* above to start the first row-section.

b) Measurements:
Record the number of live and dead stools in each row-section on the survival sampling form. There are always ten trees (either alive or dead) in a row-section. The use of a 20-ft. long drag rope, marked with 2-ft. increments, may facilitate locating trees.

c) Locating subsequent row-sections:
Subsequent row sections are located by selecting a random single-row (using the random row numbers recorded on the data sheet). Switch to the randomly selected single-row and then pace (or use a tape measure) k-1 row-section lengths (20 ft.) to the start of the next row-section and record survival data. Continue selecting row-sections in this fashion, until the last row-section for the area is selected.

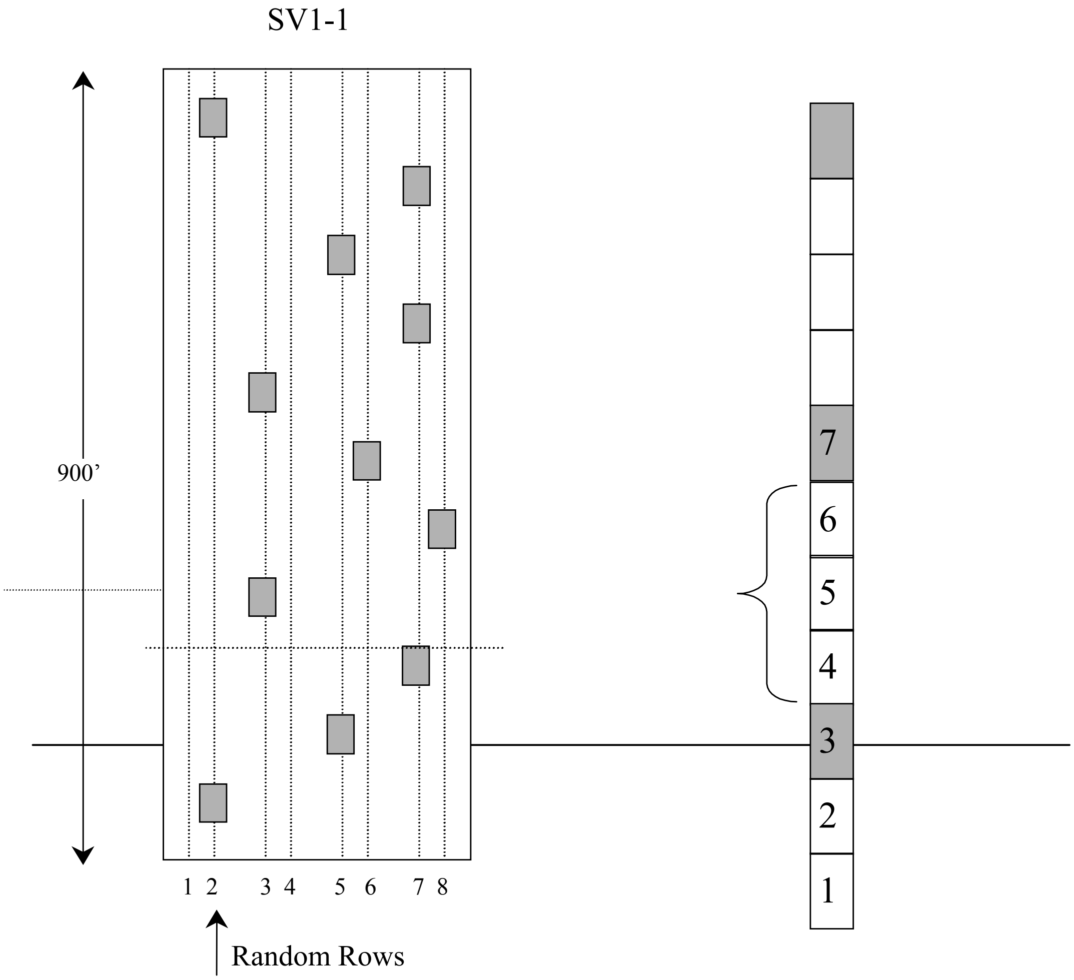

Figure 2. Area SV1-1. The random start R-S (1 to k) is 3. k = 4, so every 4th R-S is selected in randomly selected rows.