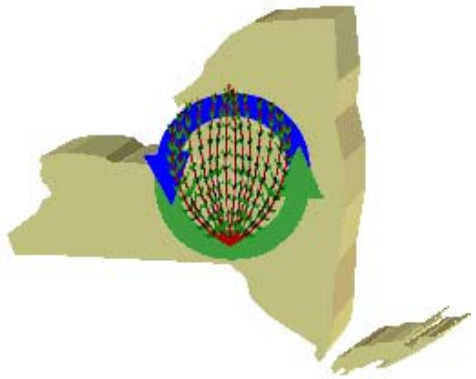

Short-Rotation Woody
Crops Program
at
State University of New York
College of Environmental Science & Forestry

Biomass Power for Rural Development
Technical Report:

USE OF BIOSOLIDS AS ORGANIC SOIL AMENDMENT IN WILLOW BIOENERGY PLANTATIONS
Interim Program Report

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TABLE OF CONTENTS

NOTICE **1**

ABSTRACT **1**

INTRODUCTION AND LITERATURE REVIEW **2**

INTRODUCTION 2
OBJECTIVES 3
LITERATURE REVIEW 3
Systems of biomass crop for energy *3*
Willow biomass for energy in Central New York: the SUNY-ESF project *4*
Fertilization of short-rotation biomass crops *4*
Wastewater and sewage sludge fertilization of short-rotation biomass crops *4*
Utilization of residuals as soil amendments in agriculture *5*
Sewage sludge and wastewater 5
Animal wastes 6
Utilization of residuals as soil amendments in forest ecosystems *6*
Sewage sludge and wastewater 6
Other residues utilization in forest ecosystems 7
Nitrogen addition to soil via residuals application *7*
Mineralization of sewage sludge nitrogen 7
Mineralization of poultry manure 8
Environmental problems associated with land application of residuals *9*
Nitrate and phoshorus considerations 9
Trace metals, toxic organics and pathogenic considerations 9
Slow-release fertilizers in crop production *10*
Ion-Exchange resins *10*

GREENHOUSE STUDY **12**

INTRODUCTION 12
MATERIALS AND METHODS 12
Biomass response *12*
Nitrogen movement *13*
Nitrogen mass balance *19*
Laboratory procedures *19*
Soil and plant materials 20
Ammonium-N and nitrate-N determination 20
Statistical analyses *20*
RESULTS 21
Biomass production *21*
First growing cycle 21
Second growing season 27
Resin-captured NH_4-N and NO_3-N *27*
Resin-captured NH_4-N 27
Resin-captured NO_3-N 36
Nitrogen release *37*
DISCUSSION 41
Biomass production *41*
Resin-captured NH_4-N and NO_3-N *44*
Resin-captured NH_4-N 44
Resin-captured NO_3-N 45
Net contributions of treatments to resin-captured NO_3-N 45
Nitrogen release *46*
Mass loss of organic materials during mineralization 46
Percent nitrogen release: gross mineralization rate 46
Gross and available amounts of N release 46
CONCLUSION 47

REFERENCES **47**

APPENDICIES **59**

LIST OF TABLES

TABLE 2.1. CHARACTERISTICS OF ORGANIC MATERIALS USED AS SOIL AMENDMENTS DURING THE FIRST AND SECOND GROWING SEASONS IN THE GREENHOUSE STUDY 14
TABLE 2.2. TREATMENTS APPLIED IN THE GREENHOUSE STUDY TO DETERMINE GROWTH RESPONSE OF WILLOW CLONE SV1 TO ORGANIC AMENDMENTS AT THE SUNY-ESF LAFAYETTE ROAD STATION. 15
TABLE 2.3. CHEMICAL CHARACTERISTICS OF SOIL USED AS POTTING MATERIAL IN THE GREENHOUSE STUDY. 16
TABLE 2.4. TREATMENTS USED IN THE GREENHOUSE STUDY TO DETERMINE NITROGEN AVAILABILITY AND MINERALIZATION, AND NITROGEN MASS BALANCE AT THE SUNY-ESF LAFAYETTE ROAD STATION. 18
TABLE 2.5. WILLOW CLONE SV1 STEM, FOLIAGE AND ROOT BIOMASS AS PERCENTAGES OF TOTAL BIOMASS PRODUCED DURING THE FIRST GROWING SEASON IN THE GREENHOUSE STUDY. 23
TABLE 2.6. LINEAR CONTRASTS AND P-VALUES ASSOCIATED WITH THE NULL HYPOTHESIS OF NO DIFFERENCE FOR TREATMENT EFFECTS ON STEM, FOLIAGE, ROOT AND TOTAL BIOMASS PRODUCED BY WILLOW CLONE SV1 DURING THE FIRST GROWING SEASON IN THE GREENHOUSE STUDY. 24
TABLE 2.7. CORRELATION AMONG STEM, FOLIAGE AND ROOT BIOMASS PRODUCED BY WILLOW CLONE SV1 DURING THE FIRST GROWING SEASON IN THE GREENHOUSE STUDY. 26
TABLE 2.8. WILLOW CLONE SV1 STEM, FOLIAGE AND ROOT[A] BIOMASS AS PERCENTAGES OF TOTAL BIOMASS PRODUCED DURING THE SECOND GROWING SEASON IN THE GREENHOUSE STUDY (NUMBERS OF OBSERVATIONS PER TREATMENT ARE IN PARENTHESES). 29
TABLE 2.9. STEM, FOLIAGE AND ROOT BIOMASS PRODUCED BY WILLOW CLONE SV1 AFTER THE SECOND GROWING SEASON IN THE GREENHOUSE STUDY (NUMBERS OF OBSERVATIONS PER TREATMENT ARE IN PARENTHESES). 30
TABLE 2.10. T-TEST COMPARISONS AMONG TREATMENTS FOR FOLIAGE, STEM AND ROOT BIOMASS PRODUCED AFTER THE SECOND GROWING SEASON IN THE GREENHOUSE STUDY. 31
TABLE 2.11. LINEAR CONTRASTS AND P-VALUES ASSOCIATED WITH THE NULL HYPOTHESIS OF NO DIFFERENCE FOR TREATMENT EFFECTS ON RESIN-CAPTURED NH4-N AND NO3-N IN NON-PLANTED POTS FROM JULY 1996 TO JULY 1997 IN THE GREENHOUSE STUDY. 33
TABLE 2.12. RESIN-CAPTURED NO3-N AND NH4-N IN PLANTED POTS FROM JULY 1996 TO JULY 1997 IN THE GREENHOUSE STUDY 34
TABLE 2.13. T-TEST COMPARISONS OF RESIN-CAPTURED NH4-N AND NO3-N IN PLANTED POTS FROM JULY 1996 TO JULY 1997 IN THE GREENHOUSE STUDY 35
TABLE 2.14. T-TEST COMPARISONS BETWEEN NON-PLANTED POTS AND PLANTED POTS (WHICH GREW), OF RESIN-CAPTURED NH4-N AND NO3-N FROM JULY 1996 TO JULY 1997 IN THE GREENHOUSE STUDY. 35
TABLE 2.15. NET CONTRIBUTIONS OF APPLIED TREATMENTS TO RESIN-CAPTURED NH4-N AND NO3-N IN NON-PLANTED POTSA (STANDARD ERRORS OF MEANS ARE IN PARENTHESES). 36
TABLE 2.16. LINEAR CONTRASTS AND P-VALUES ASSOCIATED WITH THE NULL HYPOTHESIS OF NO DIFFERENCE FOR WEIGHT LOSS AND NITROGEN RELEASE BY DECOMPOSITION OF ORGANIC AMENDMENTS FROM DECEMBER 1996 TO JULY 1997 IN THE GREENHOUSE STUDY. 39
TABLE 2.17. T-TEST COMPARISONS OF INITIAL AND FINAL NITROGEN CONCENTRATIONS OF TOP-DRESSED ORGANIC AMENDMENTS FROM DECEMBER 1996 TO JULY 1997 IN THE GREENHOUSE STUDY. 41

LIST OF FIGURES

FIGURE 2.1. LAYOUT OF THE GREENHOUSE STUDY AT LAFAYETTE ROAD STATION, SYRACUSE , NY. 17
FIGURE 2.2. DETAILED LAYOUT OF THE GREENHOUSE STUDY (REP X AND REP Y EACH, REPRESENTS ONE BLOCK OF THE PLANTED POTS; REP Z REPRESENTS ONE BLOCK OF THE NON-PLANTED POTS). 17
FIGURE 2.3. CROSS-SECTION OF A POT IN THE GREENHOUSE STUDY SHOWING ION-EXCHANGE RESIN COLUMNS, TOP-DRESSED ORGANIC AMENDMENT AND MASS BALANCE RING. 19
FIGURE 2.4. STEM BIOMASS OF WILLOW CLONE SV1 IN THE GREENHOUSE AFTER THE FIRST GROWING SEASON. 22
FIGURE 2.5. FOLIAGE BIOMASS OF WILLOW CLONE SV1 IN THE GREENHOUSE AFTER THE FIRST GROWING SEASON. 25
FIGURE 2.6. ROOT BIOMASS OF WILLOW CLONE SV1 IN THE GREENHOUSE AFTER THE FIRST GROWING SEASON. 26
FIGURE 2.7. TOTAL BIOMASS OF WILLOW CLONE SV1 IN THE GREENHOUSE AFTER THE FIRST GROWING SEASON. 28
FIGURE 2.8. MEAN NH4-N CAPTURED BY RESIN COLUMNS IN PLANTED AND NON-PLANTED POTS FROM JULY 1996 TO JULY 1997 IN THE GREENHOUSE STUDY. 32
FIGURE 2.9. MEAN NO3-N CAPTURED BY RESIN COLUMNS IN PLANTED AND NON-PLANTED POTS FROM JULY 1996 TO JULY 1997 IN THE GREENHOUSE STUDY. 37

FIGURE 2.10. MASS DECREASE BY DECOMPOSITION OF ORGANIC AMENDMENTS (ESTIMATED BY MASS LOSS) IN THE GREENHOUSE STUDY FROM DECEMBER 1996 TO JULY 1997. (EACH BAR REPRESENTS ONE STANDARD ERROR). 38
FIGURE 2.11. NITROGEN CONCENTRATION OF TOP-DRESSED ORGANIC AMENDMENTS AT THE APPLICATION (DECEMBER 1996) AND AT THE END (JULY 1997) OF THE GREENHOUSE STUDY. (EACH BAR REPRESENTS ONE STANDARD ERROR). 40
FIGURE 2.12. AMOUNTS OF NITROGEN RELEASED BY DECOMPOSITION OF ORGANIC AMENDMENTS (ESTIMATED BY MEANS OF MASS AND CONCENTRATION CHANGES) IN THE GREENHOUSE STUDY FROM DECEMBER 1996 TO JULY 1997. (EACH BAR REPRESENTS ONE STANDARD ERROR). 42
FIGURE 2.13. PERCENTAGE OF INITIAL TKN RELEASED BY DECOMPOSITION OF ORGANIC AMENDMENTS (ESTIMATED BY MEANS OF MASS AND CONCENTRATION CHANGES) IN THE GREENHOUSE STUDY FROM DECEMBER 1996 TO JULY 1997. (EACH BAR REPRESENTS ONE STANDARD ERROR). 43

LIST OF APPENDICES

APPENDIX 1. AMMONIUM AND NITRATE RECOVERY TESTS OF RESIN 59
APPENDIX 2. STEM, FOLIAGE AND ROOT BIOMASS PRODUCTION DURING THE FIRST GROWING SEASON IN THE GREENHOUSE EXPERIMENT AT LAFAYETTE ROAD STATION, SYRACUSE, NY 60
APPENDIX 3. STEM, FOLIAGE AND ROOT BIOMASS PRODUCTION DURING THE SECOND GROWING SEASON IN THE GREENHOUSE EXPERIMENT AT LAFAYETTE ROAD STATION, SYRACUSE, NY 64
APPENDIX 4. MASS LOSS AND NITROGEN RELEASE BY DECOMPOSITION OF ORGANIC RESIDUALS IN THE GREENHOUSE EXPERIMENT AT LAFAYETTE ROAD STATION, SYRACUSE, NY (NON-PLANTED POTS). 66
APPENDIX 5. MASS LOSS AND NITROGEN RELEASE BY DECOMPOSITION OF ORGANIC RESIDUALS IN THE GREENHOUSE EXPERIMENT AT LAFAYETTE ROAD STATION, SYRACUSE, NY (PLANTED POTS). 67
APPENDIX 6. RESIN-CAPTURED AMMONIUM-N AND NITRATE-N IN THE GREENHOUSE EXPERIMENT AT LAFAYETTE ROAD STATION, SYRACUSE, NY. 68
APPENDIX 7. STEM BIOMASS PRODUCTION (O.D.T/HA) OF WILLOW CLONE SV1 IN THE FIELD STUDY AT TULLY, NY. 69
APPENDIX 8. RESIN-CAPTURED NITRATE-N IN THE FIELD STUDY AT TULLY, NY. 70
APPENDIX 9. STANDARD OPERATING PROCEDURES FOR SAMPLING WILLOW FOLIAGE FOR NUTRIENT CONCENTRATION MEASUREMENTS 71
APPENDIX 10. STANDARD OPERATING PROCEDURES FOR SAMPLING STEM MOISTURE CONTENT AND NUTRIENTS IN HARVESTED PLOTS 72
APPENDIX 11. INITIAL AND FINAL AMMONIUM-N AND NITRATE-N MEASURED IN ORGANIC RESIDUALS, SAND, SOIL SOLUTION AND RESIN IN THE GROWTH-CHAMBER EXPERIMENT AT WARREN, PA. 73

NOTICE

This report was originally submitted by Hector G. Adegbidi as part of a thesis in partial fulfillment of the requirements for the Master of Science Degree at the State University of New York College of Environmental Science and Forestry.

ABSTRACT

Willow biomass crops have potential as a source of renewable energy. To achieve this potential, genetic materials and cultural systems should be developed that maximize biomass yields at the lowest possible cost of production. High yields equate with high nutrient demands and fertilization costs. The utilization of organic residuals such as sludge and manures can supply nutrients, particularly N and P, reduce production costs and provide a safe disposal for the residuals. This study, conducted in three experiments, examined the effects of organic residuals' application on (1) willow clone SV1 biomass production and (2) soil nitrogen dynamics. In the greenhouse experiment, stem biomass production increased by an average of 90% with the application of 250 m^3/ha of sewage sludge, composted sewage sludge, lime-stabilized sewage sludge or composted poultry manure. The incorporation of organic residuals at planting time produced more biomass than the application as top-dressing after coppicing. Gross amounts of N released by decomposition, seven months after residuals application, ranged from 75 to 550 kg N/ha. Ammonium-N leaching was insignificant. Actively growing plants limited NO_3-N leaching to 4 kg N/ha while 140 kg N/ha were leached in pots with no plant growth. In the field experiment, top-dressing of 250 m^3/ha of composted poultry manure and lime-stabilized sludge increased stem biomass production by an average of 33%. Stem biomass production was similar between organically amended plots and plots fertilized with 300 kg N/ha of slow-release fertilizer, with an average annual growth rate of 11.6 o.d.t/ha over a three-year period. Net mineral N contributed to soil by organic residuals averaged 100 and 170 kg/ha for composted poultry manure and lime-stabilized sludge, respectively. The growth-chamber experiment showed that temperature significantly affects N mineralization from sewage sludge and composted poultry manure. Nitrogen mineralization was the highest around 20-25^{0}C, with approximately 3% of total N mineralized after 31 days of incubation. There were discrepancies between estimated amounts of N calculated from the incubation-derived mineralization rates and the actual amounts of N observed in the field and greenhouse experiments, attributed to differences of conditions between controlled and non-controlled environments, and the variability of the resin data.

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

The economy of the world and particularly that of western countries is dependent upon the consumption of fossil fuels. For example, 85% of U.S. energy needs are met by these energy sources (Brower, 1994). In the quest for development and economic growth, emphasis is put on industrialization in the Third World, which in turn calls for more use of petroleum and coal. This situation underscores the dependency of human civilization upon fossil fuels, dependency that on the long run might also be the cause for a collapse of our world as we know it today. It is obvious to all that world fossil fuel reserves will not last indefinitely.

The heavy dependency of global economy on fossil fuels poses a problem that is compounded by the role these fuels play in damaging the global environment. Emissions of gases resulting from the burning of fossil fuels are changing atmospheric composition with consequences of climate change, global warming and acid rain (Macdonald, 1990).

In recent decades, the increasing consciousness about environmental issues and the dependency vis-à-vis fossil fuels has led to the development of alternative renewable energy sources such as biomass, wind, photo-voltaic and hydroelectric energies. Hall (1997) reported that among these renewable energy sources, biomass energy is likely to play a more significant role than any other source in the next century. Scientists throughout the world have been working to identify plant species and clones and, to design management techniques capable of producing greater amounts of biomass at economically sustainable costs in order to replace fossil fuels. Species of willow (*Salix* spp.) and hybrid poplar (*Populus* spp.) grown in short-rotation intensive cultural (SRIC) systems have the potential to meet that goal in the northeastern and mid-western United States.

In Sweden, willow biomass production for energy is already a commercial activity. In the United States, wood biomass production for energy has not yet reached that stage. However, starting in 1986, the State University of New York College of Environmental Science and Forestry, in partnership with various organizations within the Salix Consortium, has developed a willow biomass crop program. During the last decade, the program has conducted research on developing clones and cropping systems to meet the objective of making biomass crop production a successful and profitable agricultural activity.

One obstacle to the development of wood biomass production as an alternative agricultural activity is the high cost of production. In SRIC systems of willow biomass production, annual biomass yields of 12 to 18 oven-dry tons (o.d.t.) per ha are expected (in non-irrigated conditions) (Abrahamson *et al.,* 1998). Such yield requires that nutrient removals by periodic woody biomass harvest be replenished to assure the sustainability of the production system. Fertilizer cost is an important component of the economics of production and has been calculated by various authors to represent 20 to 30% of the cost of production of biomass crops (Johansson and Rosenqvist, 1995; Kelkjoer, 1995; Strauss, 1995).

Human activities generate organic residuals that contain the requisite nutrients to fertilize biomass crop production systems. Materials such as sewage sludge, farm animal manures, waste water and paper mill sludge can inexpensively provide plant nutrients and organic amendments beneficial to soil physical properties. The utilization of these materials in biomass crop systems would considerably reduce the production costs while providing for disposal of waste materials.

Various research programs, including Pack Forest Sludge Demonstration Program of the University of Washington (Henry and Cole, 1986), Savannah River Plant Sludge Application Program (Corey *et al.*, 1986) and Penn State's "living filter" Program (Sopper, 1986) have investigated the use of municipal sewage for forest fertilization. Colletti *et al*. (1993) observed a 30% biomass increase following sewage sludge application in biofuels systems of Iowa. In Sweden, United Kingdom and Canada, research using sludge to fertilize willow plantations has been conducted (Labrecque *et al.*, 1994; Riddell-Black, 1994a; Kowalik and Randerson, 1994). Teodorescu *et al*. (1993) applied sewage sludge containing 200 kg N/ha to pot-grown *Salix viminalis* and *S. discolor* and observed four and five-fold increases in stem biomass production, respectively. Nielsen (1994a) and Hodson *et al*. (1994) also reported biomass increase in willow plantations following the use of sewage sludge.

Nevertheless, research is still needed to improve our understanding of the beneficial and potential negative effects of wastes application in tree plantations.

OBJECTIVES

This project was undertaken to assess the potential use of various organic residuals as soil amendments and nutrient sources for willow biomass crops in northeastern United States. For that purpose, three different experiments were conducted. The objective of experiment # 1, a greenhouse study, was to evaluate the effects of various amendments applied (a) by top-dressing and (b) by incorporation into surface soil at different rates on willow biomass production and nitrogen movement in the soil. The objective of experiment # 2, a field study, was to measure the effect of organic amendments and inorganic slow-release N fertilizer on willow biomass production. The objective of experiment # 3, an incubation study conducted in growth-chambers, was to study N mineralization dynamics of organic residuals destined to be utilized as soil amendments in willow biomass plantations. These three experiments are intended to provide an integrated assessment of the potential use of organic amendments in the willow bioenergy production system.

LITERATURE REVIEW

Systems of biomass crop for energy

About 15% of world energy supplies come from biomass. In industrialized countries, biomass supplies only 3% of the total primary energy, whereas, 35% of the total primary energy in developing countries is supplied by biomass (Winrock, 1997). Some developing countries, like Brazil, started wood for energy programs in the 1960's. In industrial countries, one had to wait for the 1970's and increasing concerns over carbon dioxide emission, global warming and economic dependence on fossil fuels, to see the increase of interest in renewable energy resources such as wind, sunlight and biomass. Among those resources, wood biomass has great potential. By 1992 in Sweden, over 6,000 ha of commercial willow plantations had been established for the purpose of district heating (Winrock, 1997).

In the 1970's, the U.S. Department of Energy (DOE) launched the Biofuels and Municipal Waste (BMW) program to expand the availability and use of biomass as an energy source. The BMW was organized into regional programs (Walter, 1990; Wood, 1990). The program identified dedicated energy crops having the potential to be major sources of renewable fuels. Additional benefits include establishment of domestic energy independence, reduction of carbon dioxide emissions from fossil fuel use, reduction of over-production in the agricultural sector, reduction of water pollution and increased rural income (Cooper *et al.*, 1998). Plants identified as suitable energy crops in the United States of America include: Bahia grass, Bermuda grass, switchgrass, tall fescue, reed canary grass, alfalfa and crown vetch as herbaceous species, and hybrid poplar, black locust, eucalyptus, silver maple, sweetgum and sycamore as woody species (Robertson and Shapouri, 1993). Various biomass for energy projects were initiated throughout the USA in the mid-1980's and early 1990's. As feedstock, the focus was put on switchgrass, elephantgrass and sugar cane in the Midwest and the Southeast (Bransby *et al.* 1993; Stricker *et al.* 1993; Cooper *et al.* 1998). Willow and hybrid poplar were the choice species in the northeast and the Great Lakes regions (White *et al.* 1993; Kroll and Downing, 1995) while eucalyptus was the feedstock being experimented with in Hawaii (Winrock, 1997).

Wood biomass produced for energy is mostly burned in power plants to produce energy. Wiltsee *et al.* (1993) distinguished 2 major biomass combustion systems for power production: the dedicated wood-fired power plants and the co-firing retrofitted utility plants. The dedicated wood-fired power plants include direct combustion in a stoker or fluidized-bed boiler driving a steam turbine generator, advanced direct combustion firing in a gas-fired combustion turbine and advanced gasification/combined cycle or fuel cell power plant. The co-firing plants combine biomass feedstocks with coal in retrofitted utility steam boilers.

In biomass for energy plantations, high yields are sought. Stricker *et al.* (1993) observed 36-45 Mg/ha/yr and 43-56 Mg/ha/yr for fertilized elephant grass and fertilized sugar cane respectively, in Florida. Parrish *et al.* (1995) reported a range of 12 to 20 Mg/ha/yr for fertilized switchgrass in the Upper Southeast. Production figures of 11 to 24 Mg/ha/yr were reported for willow in New York State (Kopp *et al.* 1997), and 7 to 20 Mg/ha/yr for hybrid poplar in the Pacific Northwest USA (Downing and Tuskan, 1995; Winrock, 1997).

Willow biomass for energy in Central New York: the SUNY-ESF project

In 1983, a Fast-Growing Hardwoods Program was initiated at the State University of New York College of Environmental Science and Forestry (White *et al*., 1993). The objective of the program was to investigate cultural systems for the establishment, tending and harvesting of short-rotation hybrid poplar clones. In 1986, studies were initiated to ascertain the potential of *Salix* as a high yielding biomass feedstock. *Salix* clones developed with the collaboration of the University of Toronto were screened and used in various trials.

Current research topics of this biomass program include the effect of slow-release nitrogen fertilizer on biomass production, the use of organic residuals as soil amendments, the investigation of alternative site preparation methods, the effects of clonal deployment patterns on productivity and pests, the collection of native willow for clonal improvement and clonal development, and the determination of clone-site relationships (Abrahamson *et al.* 1997). Kopp *et al.* (1993) and Kopp *et al.* (1996) studied the effects of N, P and K fertilization on biomass production of various willow clones harvested annually and planted at high density (> 100,000 trees/ha) and observed yields as high as 16 Mg/ha/yr. Kopp *et al.* (1997), reporting on the effects of cutting cycle and spacing on willow biomass production, found that a 3-year cutting cycle associated with a spacing of 0.3 x 0.9 m produced the greatest biomass yields. Annual biomass yields of 24 Mg/ha were observed in irrigated and fertilized plots of these trials. Sahm (1995) applied 10 to 20 Mg/ha of wood ash to willow and did not observe any significant effect of the application on biomass production. Abrahamson *et al.* (1998) addressing the issues of sustainability and environment impacts associated with willow bioenergy development in New York State, reported that current knowledge indicates that production and utilization systems of willow are environmentally and ecologically sustainable. They stated that only economic constraints related to the cost of production remain to be overcome.

Fertilization of short-rotation biomass crops

The achievement of high yields in biomass for energy plantations requires that nutrients be adequately supplied to plants, from the soil reserves or from added fertilizers and organic soil amendments. Studies of nutrient removals at harvest by various willow clones in the SUNY-ESF biomass project showed that for annual biomass production of 15 to 26 Mg/ha, as much as 75-100, 10-12, 25-40 kg/ha of N, P and K respectively, are exported annually (unpublished data). In Sweden, Ericsson (1994) reported N, P and K total accumulations (in roots, leaves and stems) of 270, 42 and 200 kg/ha, respectively, by 3 year-old *Salix viminalis* stands with a total biomass of 22.4 Mg/ha. In Poland, Kowalik and Randerson (1994) found that harvested willow stems remove 23 and 10 kg of N and P respectively, for every 10 Mg of biomass.

In Finland, Hytonen (1984, 1992), Hytonen *et al*. (1987) and Lumme and Tormala (1987) observed positive biomass response of willow to fertilizer (particularly N) application. They recommended fertilization rates of 100-200, 20-40 and 100-200 kg/ha/yr of N, P and K, respectively. Ericsson (1981, 1984) reported that 200 kg/ha/yr of N would be needed to sustain an annual biomass production of 10 Mg/ha. In Sweden, Ledin (1986) observed that fertilization requirements depend on soil nutrient status, method of culture, frequency and time of harvest, and degree of plant utilization. This same author recommended an application of 60 kg/ha of N in the planting year and 80-120, 30 and 80 kg/ha of N, P and K, respectively, in subsequent years. Kopp *et al.* (1993) obtained annual yields of 8.5 to 16.3 Mg/ha with the application of 336, 112 and 224 kg/ha/yr of N, P and K, respectively.

Wastewater and sewage sludge fertilization of short-rotation biomass crops

In many studies, short-rotation biomass plantations have been used as means for wastewater renovation and sludge disposal because short-rotation biomass plantations have high nutrient requirements (Hansen and Baker, 1979). Kowalik and Randerson (1994) irrigated plantations of four *Salix* clones (*amygdalina, viminalis, americana and purpurea*) with wastewater at the rate of 100 or 200 mm per week. They observed removal efficiencies of 85, 39 and 46% for five-day biochemical oxygen demand (BOD_5), N and P, respectively. Irrigation with wastewater increased annual biomass yield by 50% (9.6 to 14.4 Mg/ha/yr) in *S. amygdalina* plots but did not have any effect on the biomass of the other clones. Kutera and Soroko (1994) reported removal efficiencies of 96, 78 and 87% for BOD_5, N and P respectively, in a poplar plantation irrigated with wastewater by flooding technique at a single rate of 250 mm. They observed, at age seven, a wood volume of 140 m^3/ha in irrigated plots

compared to 20 m^3/ha in non-irrigated plots. Similar removal efficiencies were found by Obarska-Pempkowiak *et al.* (1994).

Nielsen (1994a) applied sewage sludge to willow plantations in amounts equivalent to 300 and 600 kg N/ha on a peat soil, a sandy soil and a clay soil. He reported that due to drought stress, the sludge application failed to make any difference with regard to biomass production on the sandy and peat soils. On the clay soil, where water supply was adequate, biomass production increased from 5.8 Mg/ha/yr in the control plots to 7.4 and 8.9 Mg/ha/yr for the 300 and 600 kg N/ha treatments, respectively. Hodson *et al.* (1994) showed that the biomass of a tree, at first year cut back, doubled and quadrupled following applications of sludge combined with lime, equivalent to 100 and 300 kg N/ha, respectively. Colletti *et al.* (1993) applied sewage sludge, as fertilizer, to alley-cropping biofuels systems in Iowa and observed a 30% biomass increase compared to the control. Teodorescu *et al.* (1993) applied an equivalent of 200 kg N/ha as sewage sludge to pot-grown *Salix discolor* and *S. viminalix* and observed that biomass increased from 39 to 167 g/tree (*S. viminalis*) and from 27 to 145 g/tree (*S. discolor)*.

Several investigators studied metal tolerance and uptake of willows (Dickinson *et al.* 1994; Goransson and Phillipot, 1994; Riddell-Black, 1994b; Labrecque *et al.* 1994). Dickinson *et al.* (1994) observed that *Salix cinerea*, *S. caprea* and *S. fragilis* have the ability to accumulate Cd, Cu, Zn and Pb. Landberg and Greger (1994) studied accumulation of Cu, Zn and Cd by 105 different clones and species of willow, and identified metal accumulator species that can be used as vegetation filters. Riddell-Black (1994b) found that evidence in support of specific willow varieties being used in the renovation of metal contaminated land is poor, despite existing indications of metal tolerance.

Riddell-Black (1994a) wrote that, overall the use of wastewaters and sewage sludge as fertilizer in short-rotation biomass plantations is beneficial. These materials have the advantages of being a slow-release, low cost and long-term source of nutrients, which make them more efficient than mineral fertilizers. Nielsen (1994b) stated that environmental aspects of the wastewater and sewage sludge use have proved to be mainly positive.

Utilization of residuals as soil amendments in agriculture

Prior to the invention of chemical fertilizers to enhance crop production, farmers depended solely on various organic products and wastes. These organic wastes and products included farm animal litters and manures, household biodegradable wastes, sewage sludge and even human manure in some societies. That utilization of sewage waste on land for enhancement of crop production is an age-old practice (Clapp *et al.* 1994a). Prior to modern times, organic residuals were usually applied directly to the land without processing, although some residuals may have been composted. Burd (1986) cited a book by Elsner (1912) reporting that sludge was sold to farmers who used it to fertilize their crops. After the invention of mineral fertilizers, the utilization of organic residuals as soil amendments decreased.

Sewage sludge and wastewater

During the current century, concerns about environmental contamination and health hazards from raw wastes led to less utilization of organic residuals, particularly sewage sludge, in agriculture. However, in the past three decades, the even greater environmental impacts of sewage dumping in oceans and water bodies has prompted society to rethink the application of sewage sludge on land.

Sewage sludge contains nutrients required for plant growth and thereby has the potential to be beneficial to cropping systems and environmentally safe when applied at adequate rates. Rudolfs and Gehm (1942) documented agronomic attributes of sludges. Page and Chang (1994) observed that as many as 876 references were published on the subject of land application of sewage sludge from 1970 to March 1993. Lue-Hing *et al.* (1994) reported that the amount of sewage sludge applied to land increased from 0.86 million dry metric tons (20% of U.S. total sludge production) in 1972 to 2.34 million dry metric tons (33.9% of U.S. total sludge production) in 1989. They cited various programs throughout the US (Metropolitan Water reclamation District of Greater Chicago, Madison Metropolitan Sewerage District, Milwaukee Metropolitan Sewerage District) where municipal sewage sludge in solid or liquid form was applied with success to farmlands.

Pierzynski (1994) reviewed the plant nutrient aspects of sewage sludge. He commented on the concepts of "potentially available nitrogen (PAN)" and "potentially mineralizable nitrogen (PMN)". The PAN is the sum of

sludge initial NO_3-N, the portion of sludge initial NH_4-N that does not volatilize and the portion of organic N expected to mineralize (PMN). Clapp *et al.* (1994b) reported on yields, nutrient uptake and, soil and water quality in Rosemount, Minnesota. After 20 years of experiment, they found that corn grain, fodder, and reed canarygrass yields were higher in sludge treated areas than in control areas. Total soil N, organic matter and extractable P were higher in sludge treated areas. Although they found high levels of N and P in soil water of sludge treated areas, deep groundwater was not affected.

Animal wastes

Farm animal litters and manures are used more often than sewage sludge, as fertilizers to produce crops. On animal production farms, the manures generated by the animals are used to produce the various crops that constitute animal diets. Many authors studied and reported on the use of animal manures in solid, slurry and liquid forms as fertilizers. Liu *et al.* (1997) applied swine lagoon effluent to a field of bermudagrass and ryegrass, and observed a yield increase of 57 to 74% compared to the control. N'Dayegamiye (1996) applied dairy manure and observed significant increase of silage corn and wheat yields.

In recent years, the increase in demand for low-cholesterol meat has led to increased poultry production. Moore *et al.* (1995) estimated that about 13 million Mg of poultry litter and manure were produced in the U.S. in 1990. Land application offers the best solution to managing that enormous amount of waste. They advised alum addition and composting of poultry manure to stabilize the manure and avoid ammonia volatilization. Poultry litter is generally considered the most valuable of animal manures for use as fertilizer, due mainly to its low water content. The application of poultry litter was shown by many authors to increase yields of orchardgrass, bermudagrass, tall fescue, corn, wheat and rice (Adams *et al.* 1994; Moore *et al.* 1995).

Utilization of residuals as soil amendments in forest ecosystems

Various residuals, including pulp and paper mill sludges, ash, industrial residues, sewage sludge and wastewater, are utilized to enhance growth in forest ecosystems. The enactment of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) fostered a surging interest in land application, not only of treated municipal wastewater and sludge as mentioned by Sopper and Moeller (1979), but also of all sorts of organic residues. Most programs for land application of residuals started as projects of wastewater renovation and alternative disposal for wastes rather than soil amendment projects (Breuer *et al.*, 1979).

Sewage sludge and wastewater

Forest land application of sludge as fertilizer was common until it became an issue in England in 1857, due to sanitation problems (Burd, 1986). When the Clean Water Act was passed by the U.S. Congress in 1972, it very much intended that the beneficial use of sludge and wastewater be promoted (Burd, 1986). In various experiments conducted during the 1970's, quantities of wastewater and sludge were applied/dumped into forestlands for the purpose of renovation and disposal.

Sopper and Kerr (1979) reported on the Penn State experiment of wastewater renovation where municipal sewage effluent was sprayed in several ecosystems. While the forests were efficient in removing wastewater P, lysimeters installed at 120 cm depth showed high nitrogen concentration in groundwater. In the Pack Forest program reported by Henry *et al.* (1994), quantities as high as 470 Mg/ha of sewage sludge were applied to forestland. This experiment showed that excess available nitrogen was transformed into nitrate and leached into the groundwater causing the concentration of nitrate to be in excess of EPA standards. However in both experiments, there were positive responses of the vegetation to the applications. In the 1980's, public concerns about toxic substances inflicted a setback to land application programs.

Henry *et al*. (1994) wrote that forests are the place of choice for the recycling of wastewater and sludge for many reasons including deficiency in major nutrients found in the sludges, non-food production, soil properties (high organic carbon and infiltration, minimum erosion) and extensive areas. However, social circumstances and results of early experiments brought foresters to re-examine the concept of land application. Cole (1997) distinguished land application, which is done for the benefit of the soil and the vegetation, from the disposal of unwanted residues in forests. He wrote that a successful application program should consider both the ability of the soils to store and

process the residuals without unwanted losses and the ability of the vegetation to utilize the available nutrients contained in the applied materials. Burd (1986) pointed out the issues that were to be addressed by land application, starting in the 1980's. They included (1) understanding the dynamics of N, P and metals (environmental safety), (2) solving the practical aspects (economics, field operation) and (3) addressing the social issues (public acceptance).

Cole (1997) observed a growth response of 50% with applied sludge, compared to 25% with 200 kg N/ha as urea in well-established Douglas-fir sites. Henry (1997) reviewing the N dynamics of applied wastes, wrote that during the first year after application, 10-40% and nearly 100% of organic-N mineralize from solid and liquid sewage sludge, respectively. Robinson and Polglase (1997) applied 30 Mg/ha of sludge to pine plantations in Australia and found that 58 to 78% of the total N applied in the sludge was unaccounted for (leached, taken up, denitrified or volatilized) after 116 weeks.

Sewage sludge and wastewater are also used for the reclamation of devastated sites and mine areas (Griebel *et al.* 1979; Mathias *et al.* 1979; Kardos *et al.* 1979). Berry (1986) reported that sewage sludge was used to reclaim devastated sites in the Tennessee Copper Valley. This latter author found that compared to the recommended NPK rate, applications of 34 Mg/ha of dried sludge generated 45% or more height growth and 50% or more diameter growth in 10-year-old loblolly pine.

Other residues utilization in forest ecosystems

In 1995, 5.1 million Mg of sludges and 4.0 million Mg of boiler ash were generated by the U.S. paper industry (Vance, 1997). Despite successes observed with pulp sludge application on pine growth in Mississippi and Florida, attributed to the phosphorus supplied by the sludge-ash mixture, caution was advised because of possible N immobilization due to high C/N ratios of pulp sludge (Vance, 1997). Macyk (1997) and Sarigumba (1997) also reported improved tree growth with paper mill sludge. In British Columbia, Prescott *et al.* (1997) used fish silage, pulp sludge and wood ash to fertilize cedar-hemlock plantations. At five years of age, trees treated with the combination of fish silage-pulp sludge had 50% more height than the control trees. Wood ash and iron slags are applied as liming agents in forest plantations (Lundkvist and Eriksson, 1997; Jacobson, 1997; Guerrini *et al.* 1997).

Nitrogen addition to soil via residuals application

The application of residuals, such as animal manures and sewage sludge, to soil brings additional N into the soil. However, much of that added N is in organic form, and is mineralized to plant-available forms. Mineralization is the process of transformation of organically bound N into mineral forms (mainly NH_4^+ and

NO_3^-). Immobilization is the opposite process, which consists in the transformation of inorganic forms of N into organic forms.

The first step of the mineralization process is the ammonification or transformation of organic N into ammonium. The ammonification process is mediated by heterotrophic organisms. The formed ammonium can be either fixed by soil colloids or lost to the atmosphere by volatilization of ammonia, or converted to nitrate by autotrophic bacteria that mediate the nitrification process. Nitrate can be taken up by plants, lost to atmosphere by the process of denitrification or leached to groundwater.

The processes of N mineralization and immobilization are affected by physico-chemical conditions of the soil medium such as temperature, pH, moisture and aeration. At any time in the soil, mineralization and immobilization occur simultaneously. Whether the net effect is an increase or a decrease in the mineral N available to plants depends primarily on the C/N ratio of the organic material under decomposition (Brady and Weil, 1999).

Mineralization of sewage sludge nitrogen

Page and Chang (1994) wrote that during the past two decades, the multiple research projects conducted on land application improved our understanding of the physical, chemical and biological processes that control N transformations in relation to soil and sludge properties.

Many investigators who studied the N mineralization of sewage sludge reported different mineralization rates depending on the type and form of the sludge, the temperature and time of the incubation, but also on the

properties of the soil receiving the sludge and the application rate. Barbarika *et al.* (1985), Douglas and Magdoff (1991) and Sims (1990) reported that organic N mineralization rate was negatively correlated with C/N ratio of the organic material. Bernal *et al.* (1998) applied composts at different stages of maturation and different C/N ratios to soil and observed immobilization of N occurring with immature composts having C/N ratios greater than 21/1. With regard to the rates of application, mixed effects are reported in the literature. While Ryan *et al.* (1973), Garau *et al.* (1986) and Fine *et al.* (1989) found that mineralization rate of organic N decreased with increasing application rates, Epstein *et al.* (1978), Boyle and Paul (1989) and Barbarika *et al.* (1996) observed increasing mineralization rates with increasing application rates in their studies.

The type and form of the sludge affect the rate of mineralization. For anaerobically digested sludge, mineralization rate of organic N was reported to be 15% after 16 weeks of incubation at 23^0C (Parker and Sommers, 1983), 16-41% after 16 weeks of incubation at 30^0C (Garau *et al.,* 1986) and 23-41% after 10 weeks of incubation at 25^0C (Douglas and Magdoff, 1991). Higher rates were reported for aerobically digested sludge: 19-50% after 16 weeks of incubation at 30^0C (Garau *et al.* 1986) and 41-50% after 10 weeks of incubation at 25^0C (Douglas and Magdoff, 1991). With dewatered sludge, Ryan *et al.* (1973) observed that 4 to 48% of organic N mineralized after 16 weeks of incubation. Organic N in liquid digested sludge generally has a higher mineralization rate than other forms of sludge: rates up to 50%, 40-42% and up to 54% were reported by Kelling *et al.* (1977), Epstein *et al.* (1978) and Magdoff and Amadon (1980), respectively. Parker and Sommers (1983) observed, after 16 weeks of incubation at 23^0C, organic N mineralization rates of 40 and 25% for waste-activated and raw sludges, respectively. Epstein *et al.* (1978) reported 36-46% for organic N mineralization rate with raw sludge incubated at 35^0C for 15 weeks.

Compared to non-composted sludge, composted sludge has a lower rate of organic N mineralization. Sims (1990), Douglas and Magdoff (1991) and Bernal *et al.* (1998) observed nitrogen immobilization (negative mineralization rate) that they mostly explained by high C/N ratios of composts. Epstein *et al.* (1978) observed rates of 7-9% and 4-5% for composted digested and composted raw sludge respectively, incubated during 15 weeks at 35^0C. Parker and Sommers (1983) found a rate of 8% for composted digested sludge after 16 weeks of incubation at 23^0C.

The effects of soil properties on mineralization of sludge organic N were studied by various authors. Babarika *et al.* (1985) applied sewage sludge to 2 different types of soil and observed that the rate of N mineralization depended on total N and C/N ratio of soil. Chae and Tabatabai (1986) incorporated a variety of waste materials in various soil substrates and found a wide range of organic N mineralization rates (1 to 58%) depending on soil types. Garau *et al.* (1986) observed different rates of organic N mineralization for the same treatments of sludge applied to 2 different soils.

Mineralization of poultry manure

Mineralization of poultry manure and litter organic N has been shown by many studies to depend on the characteristics of the organic material but also on the physico-chemical conditions prevailing in the decomposition medium. Sims (1986) used three types of poultry manure in an incubation study and found different organic N mineralization rates that he explained by the different proportions of excreta and litter that formed the 3 manures. He stated that a higher proportion of excreta in the litter would lead to a higher rate of mineralization. That result confirmed the observation of Castellanos and Pratt (1981) who wrote that mineralization of manure organic N has a rapid and exponential phase (corresponding to excreta mineralization) followed by a slow release and linear phase (corresponding to litter mineralization). Cabrera *et al.* (1993) incubated the fine portion, obtained from sieving poultry litter, during 5 weeks at 25^0C, and observed that organic N mineralization rate was as high as 60 to 77% due to the high proportion of excreta in that fine portion. However, they also found that 50 to 60% of mineralized N was volatilized as NH_3. Cabrera *et al.* (1994) made the same observation on the fine fraction when they compared mineralization rates of whole poultry litter (44.5%) and its fine fraction (51.5%).

Poultry manure organic N mineralization rate also depends on whether the organic material is composted or not. Lower rates of mineralization are generally reported for composted materials. Bitzer and Sims (1988) recorded a mineralization rate of 66% for non-composted poultry litter during 20 weeks of incubation at 23^0C. Castellanos and Pratt (1981) observed organic N mineralization rates of 45 and 28% with poultry manure and composted poultry manure respectively, after 10 weeks of incubation at 23^0C. Tyson and Cabrera (1993) observed an early

immobilization of N in composted poultry litter, after 4 weeks of incubation at 25^0C. But these authors also found later (after 8 weeks of incubation) in the same experiment, that organic N mineralization rates were 0.4 to 5.8% and 25.4 to 39.8% for composted and non-composted poultry litter, respectively. Hadas and Portnoy (1994) and Hadas *et al.* (1996) observed 11 to 29% organic N mineralization rate for composted manures after an incubation period of 32 weeks at 30^0C. N'Dayegamiye *et al.* (1997) reported a much lower rate (less than 3%) for composted farm animal manures after 20 weeks of incubation at 25^0C.

Sims (1986) and Pathak and Sarkar (1995) observed that poultry litter organic N mineralization rate depended on moisture conditions. They reported that higher moisture conditions generated higher mineralization rates. With regard to temperature conditions, Sims (1986) and Robinson and Sharpley (1995) found that organic N mineralization increased with increasing temperature. However, they added that high temperature also favored volatilization of mineralized N as NH_3.

Environmental problems associated with land application of residuals

Various environmental problems are associated with the land application of residuals. These problems include N and P pollution of surface and ground waters, trace metals pollution of soils and waters, toxic organics and pathogens.

Nitrate and phoshorus considerations

Nitrate and P movements are the most important considerations concerning land application of organic residuals. Several studies have been conducted on P loss from fields receiving surface applications of wastes, especially poultry litter and manure (Sharpley *et al*, 1993; Sharpley *et al.* 1994; Edwards and Daniel, 1993; Robinson and Sharpley, 1995). Robinson and Sharpley (1995) estimated by means of rainfall simulations that as much as 40% of mineralized P leached in one rainfall event. Moore *et al.* (1995) mentioned that P concentration in runoff from poultry litter treated plots could reach 1.5-3.6 mg/L. Edwards and Daniel (1993) observed that 80-90% of P runoff from treated pastures is dissolved organic P, which is bioavailable and responsible for eutrophication in surface waters. Most investigators recommend that particular attention be paid to the timing of the application, to minimize P loss.

In the drinking water guidelines defined by United States Environmental Protection Agency (U.S. EPA), the maximum concentration of NO_3-N in groundwater has been set to 10 ppm (parts per million). Groundwater concentration of nitrate-N is one of the first indicators of groundwater contamination following land application of waste products. Nitrate-N leaching following land application of sewage sludge and animal wastes has also been extensively studied in various systems (Kelling *et al.* 1977; Liebhardt *et al.* 1979; Sopper and Kerr, 1979; Henry and Cole, 1986; Adams *et al.* 1994; Robinson and Sharpley, 1995; Robinson and Polglase, 1997). Henry and Cole (1986) estimated that 1052 kg N/ha leached with an application of 188 Mg/ha of sludge in Douglas-fir stands. Average monthly and annual nitrate concentrations of soil water consistently ranged from 10 to 28 mg/L at 120 cm depth in a mixed hardwood forest irrigated with municipal wastewater at 2.5 cm/wk, exceeding the 10 mg/L, EPA Drinking Water Standards (Sopper and Kerr, 1979). Kelling *et al.* (1977) observed soil solution NO_3-N exceeding 100 mg/L at 120-150 cm depth when rates greater than 30 Mg/ha of liquid digested sludge were applied. Soil solution nitrate-N concentrations higher than 10 mg/L were also observed with application of animal wastes (Liebhardt *et al.* 1979, Adams *et al.* 1994).

Most investigators agree that the majority of the NO_3-N leaching happens in the first few weeks after the application as a result of the combined effects of nitrification of initial NH_4-N in the residual material and mineralization of the highly degradable part of the organic-N and minimal plant uptake occurring in early spring. They stressed the importance of the rates and the timing of applications.

Trace metals, toxic organics and pathogenic considerations

Trace metals of concern in organic residuals are arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), molybdenum (Mo), lead (Pb), selenium (Se), mercury (Hg), nickel (Ni) and zinc (Zn). Moore *et al.* (1995) mentioned that As, Cu and Zn are commonly included in poultry diet. Chaney (1994) wrote that the potential health risks to feed- and food-chains from trace elements in municipal sewage sludge applied to land exist and have been extensively studied. However, he added that it is now established that for most trace elements, treated sewage with the appropriate industrial pretreatment is not likely to cause adverse effects to humans, livestock, plants or wildlife when less than

1000 Mg/ha is applied. Nonetheless successive applications, on the same site over a long period of time, is likely to present some health risks. Page and Chang (1994) reported that recent studies showed that crops grown on sludge-amended soils would not accumulate As, Cr, Cu, Pb, Hg, Ni or Zn in amounts considered sufficient to be harmful to consumers. However, they pointed out that depending on the soil conditions Cd, Mo and Se could potentially be taken up by crops in amounts harmful to humans and animals. Harrison *et al.* (1997) studied the fate of metals in treatments of 500 and 25-60 Mg/ha of applied sewage sludge. Their study showed that while surface soil total metal concentrations in the high sludge rate were higher than the control, water-soluble concentrations were very low and most of the trace metals were in forms unavailable to plants and did not leach from the profile.

O'Connor (1994) mentioned that numerous man-made toxic organics (TOs) are found in sewage sludges. He added that many sludge-borne TOs are so strongly sorbed to the soil-sludge matrix that their bioavailability is negligible. They do not constitute much of a concern with regard to leaching and groundwater contamination.

A wide variety of pathogenic organisms including bacteria, viruses, fungi and parasites have been isolated from raw wastewater, sludge and animal manure (Edmonds, 1979; Angle, 1994; Moore *et al.,* 1995). Primary treatment of raw sewage reduces the organism load of sewage by >90%, thereby decreasing risk. Further treatments reduce more of the count of organisms in the sludge. However, organisms that remain in land applied sludge have a wide range of survival time in soil varying from 8 days (fecal coliforms) to more than 1000 days (helminth eggs) suggesting that there is a human health hazard associated with land application (O'Connor, 1994).

Slow-release fertilizers in crop production

As awareness and concerns increased about nitrate contamination of groundwater from agricultural production areas, improvements in fertilizer production technology were made. Fertilizer manufacturers developed slow-release (also called controlled-release) N fertilizers (SRFs) coated with various chemicals such as resins, waxes, sulfur and polymers. Slow-release fertilizers slowly release the nutrient over an extended duration so that the release coincides with plant nutrient demand, minimizing potential leaching losses (Paramasivam and Alva, 1997a). Alva (1992), in a leaching column experiment, compared NO_3-N leaching from various blends of SRFs (Meister, Osmocote, Nutralene, Isobutylidene Urea) and soluble N fertilizers (ammonium nitrate and calcium nitrate). After the columns were leached with 26 cm of rainfall, he observed that less that 4% of NO_3^- and NH_4^+ contained in the SRF leached while 88 to 100% of NO_3^- and NH_4^+ contained in the soluble fertilizers leached.

Wang and Alva (1996) applied Meister, Isobutylidene Urea and ammonium nitrate to sandy soils and observed that leaching losses were 12%, 27-32% and 88-100% for Meister, Isobutylidene Urea and Ammonium Nitrate, respectively. They added that N release from SRFs depended on soil temperature and moisture content. Paramasivam and Alva (1997b) confirmed the effect of soil temperature on SRFs N release but found that soil moisture had little effect on SRFs N release. These latter authors also wrote that N release depended on thickness of coatings whereas pH and microbial activity had little effect on N release. With regard to the mode of application, a study by Cox (1993) found that N leaching losses were even less when SRFs were surface-applied compared to incorporated into soil. All investigators of SFRs agreed on the fact that SRFs offer an important capability to minimize leaching losses and maximize N fertilization return and efficiency.

Ion-Exchange resins

Being able to estimate (1) the amounts of certain ions present in available forms in the soil and (2) the amounts of certain chemicals leaching below certain levels in soils, is very important in plant nutrition and environmental studies. Ion-exchange resins (IERs) have been used to achieve those objectives in many studies. Skogley and Dobermann (1996) stated that the process of ion exchange was first reported to occur in soils in 1950, and synthetic ion-exchangers were developed in the 1930s. While they distinguished many types of IERs, they reported that most of them are solid organic polymers with an electrostatic charge that is neutralized by a selected counter-ion of opposite charge. Ion-exchange resins have internal surface areas that can exceed 100,000 m^2/kg and capacities between 50 and 500 $cmol_c$/kg. In a study of nitrogen leaching, Schnabel (1983) wrote that compared to lysimeters and suction extractors which require an independent means of estimating total solute fluxes, IERs were a simple method that could yield the total mass of inorganic nutrients leached continuously over a span of time.

Many investigators used ion-exchange resins to study N availability and leaching in soils. Binkley and Matson (1983) compared IER method to six other methods of assessing N availability in soils. These researchers observed correlations between IER method and the other methods ranging between 0.71 and 0.87. Discrepancies between greenhouse and field assays led them to conclude that IER method is sensitive to on-site factors. Schnabel (1983) and Binkley (1984) observed that soil solute percolation rate affected the efficiency of cation-exchange resin whereas anion-exchange resin efficiency was not affected. Binkley (1984) reported that beside a significant effect of N levels in soil solution, ion charge and concentration of other chemical species did not affect N accumulation by resin. Wyland and Jackson (1993) observed that above a threshold of 400 mg NO_3-N/l IER accumulation of N significantly decreases, confirming these results. Schnabel (1983) and Subler *et al.* (1995) raised the concern of soil and flow patterns disturbance associated with the installation of IER bags in soil, leading to changes in dynamic soil processes.

Various methods have been reported with regard to the extraction of IER-adsorbed N for analysis. One extraction by shaking and filtering with a solution of 1M KCl was reported by Binkley (1984) and Binkley and Matson (1983), while one extraction with solutions of 1M NaCl, 1N HCl and 2M KCl were mentioned by Hubner *et al.* (1991), Lundell (1989) and Schnabel (1983), respectively. With one 2M KCl extraction, Kolberg *et al.* (1997) observed a consistent recovery rate of 55% of IER-adsorbed NH_4^+ and NO_3^- and subsequently corrected their results using that factor. For a maximum recovery of IER-adsorbed N, Wyland and Jackson (1993) and Dobermann *et al.* (1997) proposed 3 sequential extractions and Kolberg *et al.* (1997) recommended 5 sequential extractions with a solution of 2M KCl.

GREENHOUSE STUDY

INTRODUCTION

Various studies have reported on the advantages of using organic residuals as soil amendments in biomass energy plantations (Teodorescu *et al.,* 1993; Kowalik and Randerson, 1994; Labrecque *et al.*, 1994; Riddell-Black, 1994a). However, the utilization of organic residuals raises environmental concerns with regard to nitrogen management and contamination of groundwater and soil by heavy metals, pathogens and antibiotics. Thus, the associated negative environmental effects and consequent unfavorable public reaction imply that caution should be exercised while applying organic residuals, even at a reduced scale in field experiments.

Conducting experiments in a greenhouse confers the advantage of a controlled environment thus minimizing environmental contamination. Greenhouse experiments also allow for a greater control over environmental conditions, i.e. growth medium, temperature, irrigation and photo-period and, can be used to shorten the length of an experiment.

In order to assess the potential use of organic residuals as soil amendments and as sources of nutrients for willow biomass crops, a greenhouse study was initiated in 1996. The objectives of the study were to (1) determine the biomass response of a selected clone of willow to a variety of organic waste products and application rates and, (2) determine the fate of the nitrogen contained in the applied materials. The following hypotheses were tested.

1. The application of organic residuals has no effect on willow biomass production.

2. Willow biomass production is independent of the application rate of organic residuals.

3. The modes of application of organic residuals (incorporated at planting or surface applied after first-year cutback) do not affect coppice biomass production.

4. Leaching of nitrogen from organic residuals applied to actively growing willow biomass plants, is minimal with appropriate application rates.

5. Organic residuals provide, by the means of mineralization, as much inorganic nitrogen as mineral N fertilizers.

MATERIALS AND METHODS

This experiment was conducted in the greenhouse of the Lafayette Road Experiment Station of SUNY-ESF (State University of New York College of Environmental Science and Forestry) at Syracuse, NY. Various treatments of organic residuals and mineral N fertilizers were applied to pot-grown willow plants. The experiment was organized in three studies: biomass response, nitrogen movement and nitrogen mass balance.

Biomass response

Willow clone SV1, a *Salix dasyclados* clone developed by the genetics program of the University of Toronto and successfully used in trials by the SUNY-ESF biomass crops program, was grown from cuttings in pots. Five organic amendments were applied at various rates using two modes of application: incorporated with cutting stock at time of planting or top-dressed on coppice stock after cutback. The trial consisted of two growing seasons of approximately 20 weeks each. At the end of the first growing season, the plants were cut back to induce the growth of multiple shoots. Then top-dressed treatments were applied. The organic amendments were:

- New York City dewatered anaerobically digested sewage sludge (NYC) obtained from Alternative Resources, Inc., New York, NY,

- Syracuse dewatered anaerobically digested sewage sludge (SYR) obtained from the Metro wastewater treatment plant in Syracuse,

- Composted sewage sludge (SLC) obtained from the composting facility of Lockport, NY,

- Composted poultry manure (PMC) obtained from the Wegmans poultry egg farm in Wolcott, NY,

- Lime-stabilized sewage sludge (LMB) from “N-Viro Organics” in Syracuse, NY.

The chemical characteristics of the waste materials are shown in Table 2.1.

The sewage sludge treatments (NYC, SYR and LMB) were applied in quantities equivalent to 2.50 cm thickness. Composts (SLC and PMC) were applied in quantities equivalent to 1.25, 2.50 and 3.75 cm thickness. Two sources of mineral nitrogen fertilizer, ammonium nitrate (NCF) and sulfur coated urea slow-release fertilizer (NSR), were applied at 200 kg N/ha as top-dressing on coppice stock after cutback. The experimental design was a completely randomized block design of twenty treatments, each replicated eight times (Table 2.2).

A clay-loam topsoil, scrapped off a construction site on the SUNY-ESF campus and stored at the Lafayette Road Station, was used as growing substrate. To achieve homogeneity, this clay-loam soil was sieved through a 2.50cm mesh and separated into two components: fine and coarse aggregates, which were stored in two different bins. The two soil components were recombined in the proportions of 4 fine to 1 coarse, thoroughly mixed and used as potting soil. Chemical characteristics of the soil are presented in Table 2.3.

Thirty-nine liter capacity black plastic pots, 45 cm diameter by 38 cm deep, were used to grow willow plants. A 5 cm layer of quartz gravel and sand was laid at the bottom of each pot to insure adequate drainage. The pots were filled with a layer of potting soil of approximately 25 cm and placed in the greenhouse, in rows with distances of 2 cm between pots in a row and 30 cm between rows (Figures 2.1 and 2.2). A network of plastic pipes was installed to provide drip irrigation outlets for each pot.

In mid-July 1996, each pot in the planted treatment received one 25 cm cutting of willow clone SV1 (*Salix dasyclados*). Prior to planting, incorporated treatments were applied. For pots receiving incorporated amendments, the top 10 cm of soil were scooped out, thoroughly mixed with the appropriate quantity of organic material and returned to the pots. Pots were watered by drip irrigation 3 times a day at a rate of 2.8 L/day. During the fourth week of November 1996, after the completion of the first 20-week growing season, the eight pots of each treatment were harvested and the aboveground biomass (foliage and stem) of each plant was oven-dried and weighed. Four blocks (blocks A, C, E and G) were sacrificed for the measurement of root biomass, leaving four blocks to remain for the second growing season. Pots sacrificed for root biomass measurement were stored outside of the greenhouse from December 1996 to April 1997. In April of 1997, the soil was washed off the roots of each plant using pressurized water. Roots were washed again with distilled water, dried at 65^0C and weighed.

During the first week of December 1996, top-dressed treatments of organic amendments and mineral fertilizers were applied (beginning of the second growing season). Pots were watered 3 times a day at the rate of 3.4 L/day. During the winter, daylight was prolonged daily for 3 to 4 hours by artificial greenhouse lights. Temperature inside the greenhouse was set at 25^0C. The plants did not resprout for 1 to 16 weeks after they were coppiced, consequently the second growing season extended to 36 weeks (third week of July 1997). Finally, foliar and stem biomass of the plants that resprouted and grew during that second season were harvested, oven-dried and weighed. Plant roots were subsequently collected, using pressurized water to wash off soil. Roots were later washed again with distilled water, dried at 65^0C and weighed.

Nitrogen movement

Ion-exchange resin columns were used to assess leaching of nitrogen in pots resulting from the application of organic residuals and mineral fertilizers. Seven top-dressed treatments plus the control were selected for installation of the resin columns (Table 2.4). For the selected treatments, four pots without plants were prepared and placed in the greenhouse along with the planted pots (Figures 2.1 and 2.2). The experimental design was a 2 x 8 factorial with 2 levels for plant (planted and non-planted) and 8 levels for amendment (NYC, SYR, PMC, SLC, LMB, NCF, NSR and CTRL). The treatments were arranged in 4 blocks.

For the selected treatments, two resin columns (one for anion-exchange and one for cation-exchange) were inserted in each of the four non-planted pots and the four planted pots (replicates B, D, F and H) that were not sacrificed for root biomass measurement after the first growing season (Figure 2.3). Each ion-exchange resin column was constructed of 7 cm diameter plastic pipe at the bottom of which was inserted another 2.50 cm high by 6.30 cm diameter plastic pipe closed at both ends with nylon stocking and containing 23-25 g of either anion-exchange resin or cation-exchange resin. The resin chamber at the bottom of each column was designed to act as a sink for nitrogen ions

Table 2.1. Characteristics of organic materials used as soil amendments during the first and second growing seasons in the greenhouse study.

	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
	First growing season																
NYC Sludge	373	35.2	0.00	4.5	23.1	0.9	30.5	8.1	1241	1192	26.2	202.6	5.6	74.8	11.3	8.5	0.19
Syracuse Sludge	370	44.3	0.00	5.6	24.4	1.2	33.4	5.5	647	432	20.9	74.9	18.6	63.8	16.0	7.2	0.10
Composted Sludge	384	15.3	0.4	2.0	5.8	1.7	21.0	8.5	328	375	57.2	59.8	4.1	282.7	2.8	6.3	0.21
Composted Poultry Manure	379	14.4	0.00	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	0.00	0.00	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 Nitrogen
NO_3-N and NH_4-N: 2M KCl extraction
Other elements: 6N HCl digested extraction
Dens. = density

Table 2.2. Treatments applied in the greenhouse study to determine growth response of willow clone SV1 to organic amendments at the SUNY-ESF Lafayette Road Station.

(Mg/ha)	Thickness of application (cm)	TKN[c] application (kg/ha)	Mode of application	
1- New York City sewage sludge (NYC)	46.75	2.5	1880	INC-Cutting[a]
2- New York City sewage sludge (NYC)	46.75	2.5	1880	TD-Coppice[b]
3- Syracuse sewage sludge (SYR)	25.75	2.5	1150	INC-Cutting
4- Syracuse sewage sludge (SYR)	25.75	2.5	1150	TD-Coppice
5- Composted sewage sludge (SLC)	25.9	1.25	484	INC-Cutting
6- Composted sewage sludge (SLC)	25.9	1.25	484	TD-Coppice
7- Composted sewage sludge (SLC)	51.75	2.5	968	INC-Cutting
8- Composted sewage sludge (SLC)	51.75	2.5	968	TD-Coppice
9- Composted sewage sludge (SLC)	77.6	3.75	1452	INC-Cutting
10- Composted sewage sludge (SLC)	77.6	3.75	1452	TD-Coppice
11- Composted poultry manure (PMC)	34.6	1.25	668	INC-Cutting
12- Composted poultry manure (PMC)	34.6	1.25	668	TD-Coppice
13- Composted poultry manure (PMC)	69.25	2.5	1336	INC-Cutting
14- Composted poultry manure (PMC)	69.25	2.5	1336	TD-Coppice
15- Composted poultry manure (PMC)	103.9	3.75	2004	INC-Cutting
16- Composted poultry manure (PMC)	103.9	3.75	2004	TD-Coppice
17- Lime-stabilized sewage sludge (LMB)	129.5	2.5	1400	TD-Coppice
18- NH4-NO3 fertilizer (NCF)	0.588	-	200	TD-Coppice
19- Slow-release N fertilizer (NSR)	0.526	-	200	TD-Coppice
20- Control (CTRL)	-	-	0	-

a: INC = Incorporated at time of planting.

b: TD = Top-dressed at beginning of second season after coppice cut.

c: Total Kjeldahl Nitrogen.

Table 2.3. Chemical characteristics of soil used as potting material in the greenhouse study.

Characteristics	
pH	7.7
OM (g/kg)[a]	61.3
TKN (g/kg)[b]	1.8
NO3-N (g/kg)[c]	1.2
NH4-N (g/kg)[c]	0.02
P (mg/kg)[d]	21.8
K (mg/kg)[e]	69
Ca (mg/kg)[e]	208.5
Mg (mg/kg)[e]	345
CEC (cmolc/kg)[f]	14.8

a: Loss on ignition

b: Total Kjeldahl Nitrogen

c: 2M KCl extraction

d: Truog

e: Ammonium acetate extraction at pH 7

f: Ammonium saturation

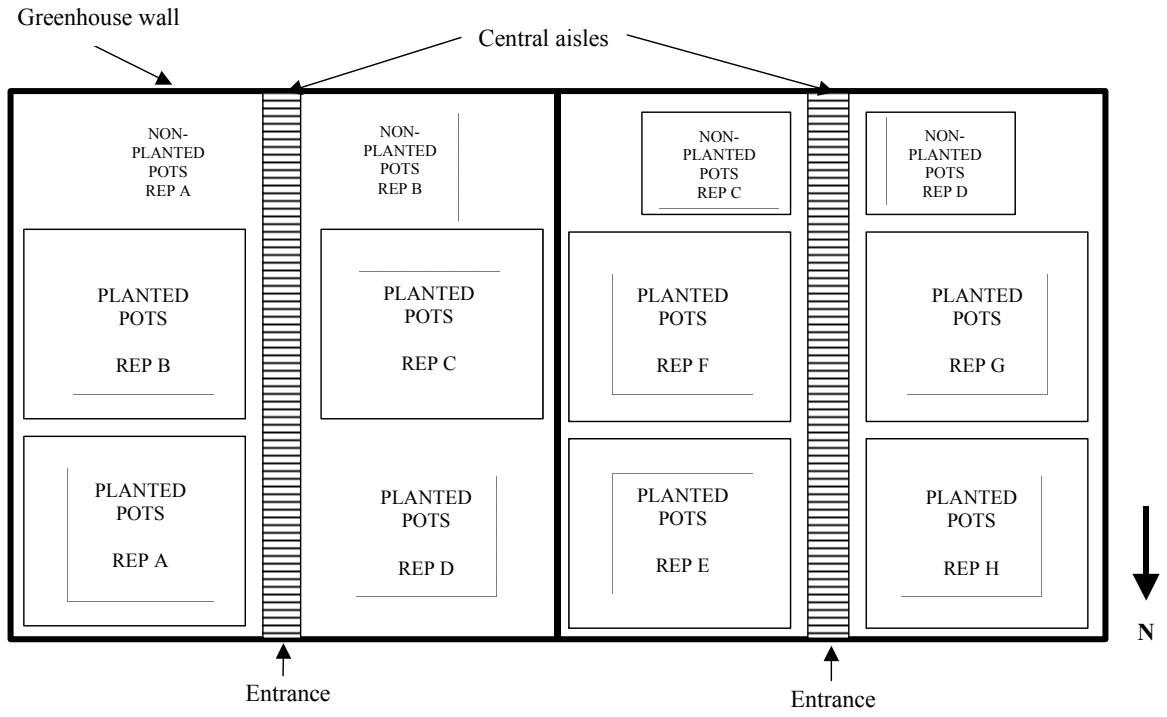

Figure 2.1. Layout of the greenhouse study at Lafayette Road Station, Syracuse , NY.

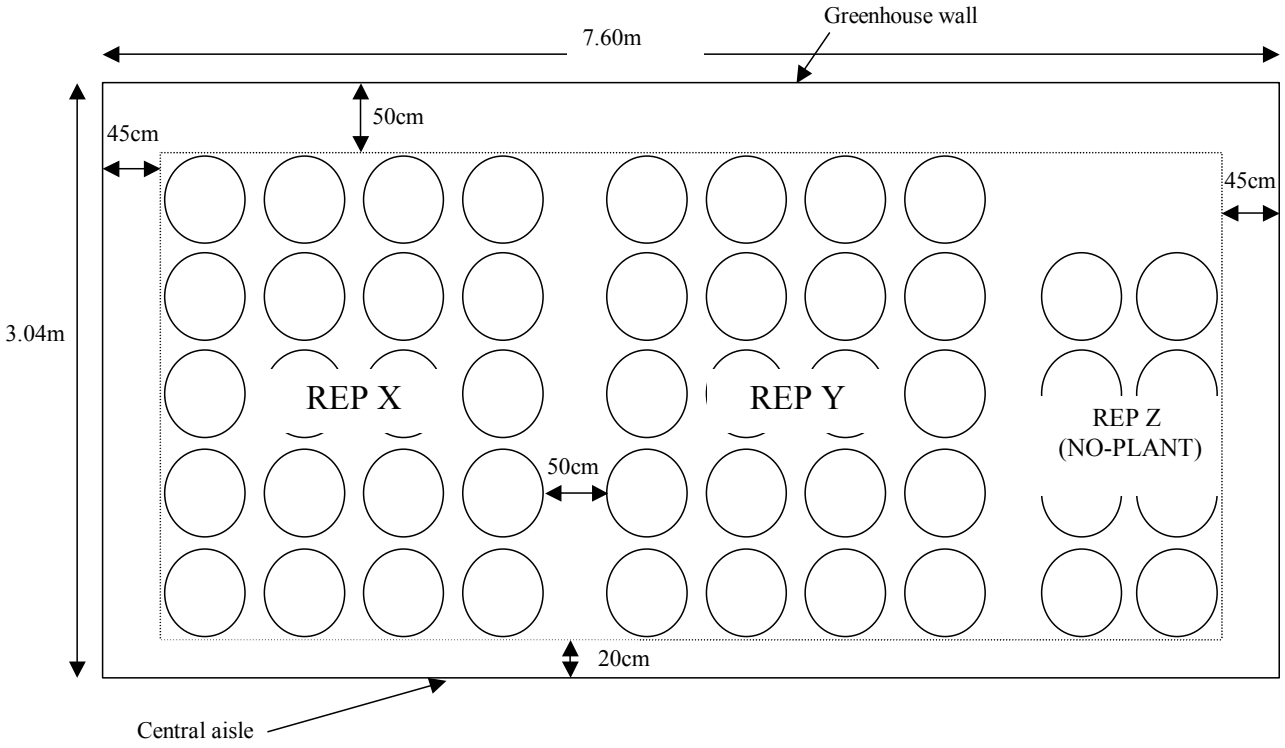

Figure 2.2. Detailed layout of the greenhouse study (REP X and REP Y each, represents one block of the planted pots; REP Z represents one block of the non-planted pots).

Table 2.4. Treatments used in the greenhouse study to determine nitrogen availability and mineralization, and nitrogen mass balance at the SUNY-ESF Lafayette Road Station.

Treatment (Mg/ha)	Application rate Mode of application	
2- New York City sewage sludge (NYC)**	46.75	TD plus plant (inside previous design)[a]
2'- New York City sewage sludge (NYC)**	46.75	TD no plant[b]
4- Syracuse sewage sludge (SYR)**	25.75	TD plus plant (inside previous design)
4'- Syracuse sewage sludge (SYR)**	25.75	TD no plant
8- Composted sewage sludge (SLC)**	51.75	TD plus plant (inside previous design)
8'- Composted sewage sludge (SLC)**	51.75	TD no plant
14- Composted poultry manure (PMC)**	69.25	TD plus plant (inside previous design)
14'- Composted poultry manure compost (PMC)**	69.25	TD no plant
17- Lime-stabilized sewage sludge (LMB)	129.5	TD plus plant (inside previous design)
17'- Lime-stabilized sewage sludge (LMB)	129.5	TD no plant
18- NH4-NO3 fertilizer (NCF)	200 kg N/ha	TD plus plant (inside previous design)
18'- NH4-NO3 fertilizer (NCF)	200 kg N/ha	TD no plant
19- Slow-release N fertilizer (NSR)	200 kg N/ha	TD plus plant (inside previous design)
19'- Slow-release N fertilizer (NSR)	200 kg N/ha	TD no plant
20- Control (CTRL)	-	with plant (inside previous design)
20'- Control (CTRL)	-	no plant

[a]: top-dressed with plant (i.e. resin tubes inserted in pots of previous design)

[b]: top-dressed with no plant

**: Rings installed for nitrogen release study.

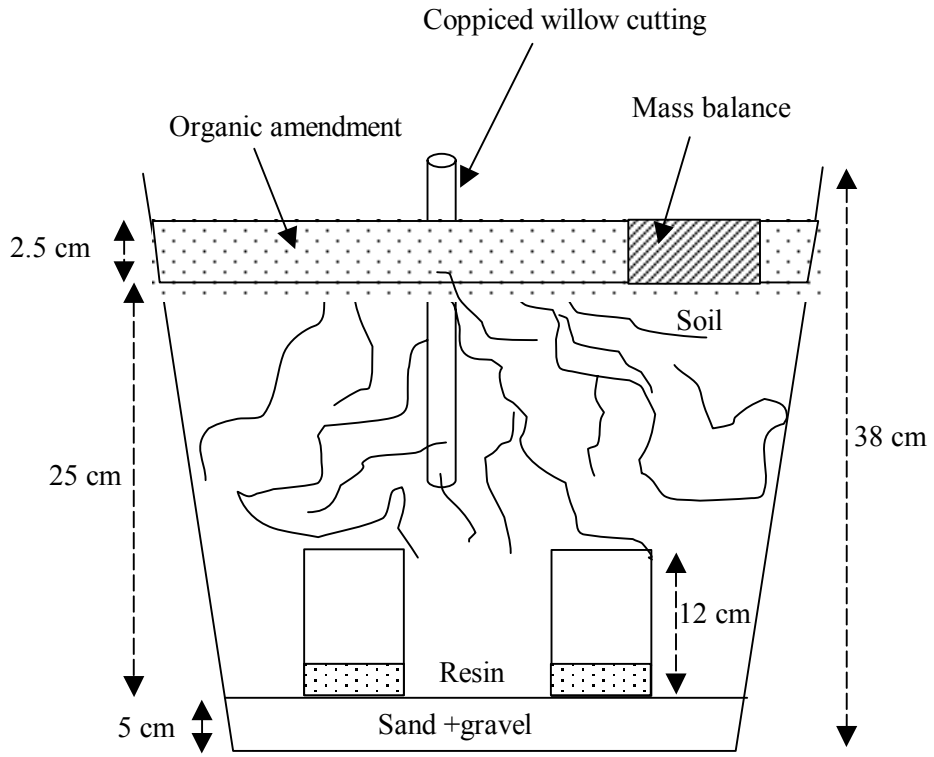

Figure 2.3. Cross-section of a pot in the greenhouse study showing ion-exchange resin columns, top-dressed organic amendment and mass balance ring.

(NO_3^- for anion-exchange resin and NH_4^+ for cation-exchange resin) contained in the soil solution leaching through the soil column. The cation exchange resin was J. T. Baker manufactured Dowex HCR-W2, H^+ form spherical beads) (16-40 mesh) and the anion exchange resin was J. T. Baker manufactured IONAC A-554, Cl^- form, Type II beads (16-50 mesh). At the end of the second growing season (July 1997), the resin columns were retrieved and the amounts of adsorbed NH_4^+ and NO_3^- were determined.

Throughout the experiment, air and soil temperatures were recorded continuously. Three Onset Stow-Away temperature loggers were used: one recorded air temperature and the other two, installed with their sensors buried at 10 cm depth in the soil, recorded soil temperature (one in a PMC pot and the second in a SYR pot).

Nitrogen mass balance

In order to assess the state of organic amendment decomposition, plastic rings of 2.50 cm height by 6.30 cm diameter were constructed. In December 1996, while the top-dressed treatments of organic materials were being applied, the plastic rings were also filled with known masses of organic materials corresponding to the rate of material application. The rings were then closed at both ends with nylon stocking and installed inside the top-dressed treatment of organic materials, on the surface of the soil in the pot (Figure 2.3). The rings were retrieved in July 1997 and weighed. The amount of N remaining was calculated to estimate total nitrogen released during the experiment. The rings were installed in planted as well as non-planted pots of top-dressed treatments of New York City sewage sludge (NYC), Syracuse sewage sludge (SYR), poultry manure compost (PMC) and sewage sludge compost (SLC), applied at 2.50 cm thickness (Table 2.4). The experimental design was a 2 x 4 factorial with 2 levels for plant (planted versus non-planted) and 4 levels for amendment (NYC, SYR, PMC and SLC). The treatments were arranged in 4 blocks.

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).

Soil and plant materials

Prior to laboratory analyses, soil samples were air-dried, ground with ceramic mortar and pestle, and sieved through a 2 mm sieve. Plant and organic materials were dried at 65^0C to constant weight and ground with a Wiley mill. When applicable, the weights before and after drying were recorded to calculate the moisture content of the samples.

Total nitrogen concentration of samples was determined with the macro-Kjeldahl methodology. Organic matter and ash content were determined by heating samples at 470^0C. For samples of biomass and organic materials, the ash was digested with a 6N HCl solution and the extract was diluted to a final volume of 100 ml. For soil samples, cations were extracted using a 2N ammonium acetate solution. Concentrations of K, Ca and Mg in the sample extracts were determined by atomic adsorption spectrophotometry using a Perkin-Elmer 3030B. Concentrations of trace elements (Ni, Zn, Cu, Mo, Cd, Cr and Pb) were determined by Inductively Coupled Plasma (ICP) Spectrophotometry using a Perkin-Elmer Optima 3300DV. Phosphorus in soil was extracted using the Truog procedure with 0.002N sulfuric acid and determined by colorimetry with a Milton Roy Company Spectronic 1201. Acidity (pH) was determined in water solution of 2:1 and 10:1 respectively for mineral soil and organic material samples.

Ammonium-N and nitrate-N determination

After retrieval from the soil, ion-exchange resin columns were stored at -4^0C when they could not be processed immediately. First, resin chambers were thoroughly washed with deionized distilled water (DDW) to remove soil particles still adhering to the nylon stocking covers. Then they were air-dried, the nylon stocking covers were cut and the resin beads were collected into two 250 ml Erlenmeyer flasks for each resin column. A volume of 100 ml of a 2M KCl solution was added to the resin in each flask that was subsequently closed with a rubber stopper. Flasks were shaken for one hour on a platform shaker. The extracts obtained after the shaking were filtered into 100 ml volumetric flasks and brought to exact volume with additional 2M KCl solution. Finally, the extracts were analyzed for nitrate or ammonium. Nitrate concentrations were determined in 1/50 diluted extracts with a Dionex DX20 anion analyzer. Ammonium concentrations were determined in 1/10 diluted samples with a Wescan Autoanalyzer. First, NH_4^+ and NO_3^- concentrations of resin columns were corrected with the recovery factors obtained from a test of recovery initially performed to assess the efficiency of the 2M KCl extraction procedure (see Appendix 1). Then the concentrations were converted to contents of NO_3-N or NH_4-N per resin chamber. The contents were subsequently expanded to an area basis using the soil area sampled by a resin chamber.

The same extraction and analysis procedures were used to determine concentrations of NH_4-N and NO_3-N in soil and organic amendment samples. Ammonium and nitrate concentrations of organic amendments were determined on oven-dried (65^0C) and ground samples while concentrations in soil were determined on air-dried samples.

Statistical analyses

The SAS program was used to perform all the statistical analyses. Analysis of variance was used to evaluate treatment effects on plant biomass, resin-captured NH_4-N and NO_3-N, and nitrogen release. The general linear model with fixed effects was used for the analysis of variance. For biomass variables, the data were 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 ith amendment treatment

μ = overall mean of all observations

τ_i = added effect of the ith treatment measured as deviation from μ

β_j = effect of the jth block

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

For resin-captured N and nitrogen release variables, the physical layout of the pots shows that, within each block, pots were arranged together as group of planted or non-planted pots. So, a first attempt was made to analyze the

data as a randomized block split-plot with plant/non-plant as whole plot factor and the amendments as subplot factor. This analysis showed that the main effect of plant/no plant factor was not significant. Then, the groups of planted pots and non-planted pots were analyzed separately, each one as a randomized complete block design. The models were identical as written earlier for biomass variables.

Correlations among stem, foliage and root biomass productions were computed. Linear contrasts among treatments and groups of treatments were tested with the Student t-test. Statistical significance was assessed at $\propto = 0.05$ for simple effects and $\propto = 0.20$ for interactions.

RESULTS

Biomass production

First growing cycle

After the first 20-week growing cycle in the greenhouse, stem production ranged from 8.8 to 30.7 o.d.g (oven-dry grams)/plant (Figure 2.4). Based on the data from the four pots completely harvested per treatment, stem biomass accounted for 24 to 30% of the total biomass produced (Table 2.5). Treated pots (pots with incorporated organic materials) produced significantly more stem biomass than non-treated pots (Table 2.6). Within the sludges, New York City sludge significantly produced more stem biomass than Syracuse sludge ($p<0.01$). Within the composts, composted poultry manure treatments produced more stem biomass than composted sewage sludge treatments ($p<0.01$). No significant difference was observed between (1) the compost and non-compost treatments, all rates pooled ($p = 0.07$) and (2) the composted sewage sludge (all rates pooled) and the Syracuse sludge ($p = 0.78$). The incorporated New York City sludge treatment had the greatest stem biomass production of all treatments. Though there seemed to be an increasing stem biomass production with increasing rates of application of composted poultry manure and composted sewage sludge, there was no significant difference between the highest (3.75 cm) and the lowest (1.25 cm) rates of compost treatments.

Average leaf biomass production after the first growing season ranged from 8.7 to 24.3 o.d.g/plant (Figure 2.5). Based on the data from the four pots completely harvested per treatment, foliar biomass accounted for 21 to 26% of total biomass (Table 2.5). There was a strong positive correlation between leaf biomass and stem biomass in the greenhouse experiment ($r = 0.98$ and $p <0.01$) (Table 2.7). Contrasts (Table 2.6) showed that pots treated with incorporated amendments produced significantly more foliar biomass than non-treated pots ($p < 0.01$). New York City sewage sludge treated pots had greater foliar biomass than the Syracuse sewage sludge treated pots ($p < 0.01$). Plants growing in pots receiving non-composted organic amendments had greater foliar biomass than plants growing in compost-treated pots ($p < 0.01$). Comparing among composts, the composted poultry manure treated plants had the greatest foliar biomass ($p < 0.01$). There was no significant difference between (1) the Syracuse sewage sludge and the composted sewage sludge treatments ($p = 0.31$) and (2) the highest (3.75 cm) and the lowest (1.25 cm) rates of composts treatments. New York City sewage sludge treated plants produced more foliar biomass than any other treatment plants.

Average root biomass production during the first growing season ranged from 19.0 to 49.9 o.d.g/plant (Figure 2.6). Root biomass was greater than either stem biomass or foliar biomass for every treatment. Based on the data from the four pots completely harvested per treatment, roots represented between 46 and 53% of total biomass produced during the first growing season (Table 2.5). Contrasts (Table 2.6) showed that plants grown in treated pots had significantly more root biomass than plants from non-treated pots ($p < 0.01$). The New York City sewage sludge treated plants had greater root biomass than the Syracuse sewage sludge treated plants ($p = 0.05$) and the composted sewage sludge treated plants ($p = 0.02$). There were no significant differences between (1) the non-composts and the composts ($p = 0.26$), (2) the composted sewage sludge and the composted poultry manure ($p = 0.32$), and (3) the highest (3.75 cm) and the lowest (1.25 cm) rates of compost treatments ($p = 0.84$). Root biomass was also positively and highly correlated with foliar biomass ($r = 0.91$ and $p < 0.01$) and stem biomass ($r = 0.91$ and $p < 0.01$) (Table 2.7).

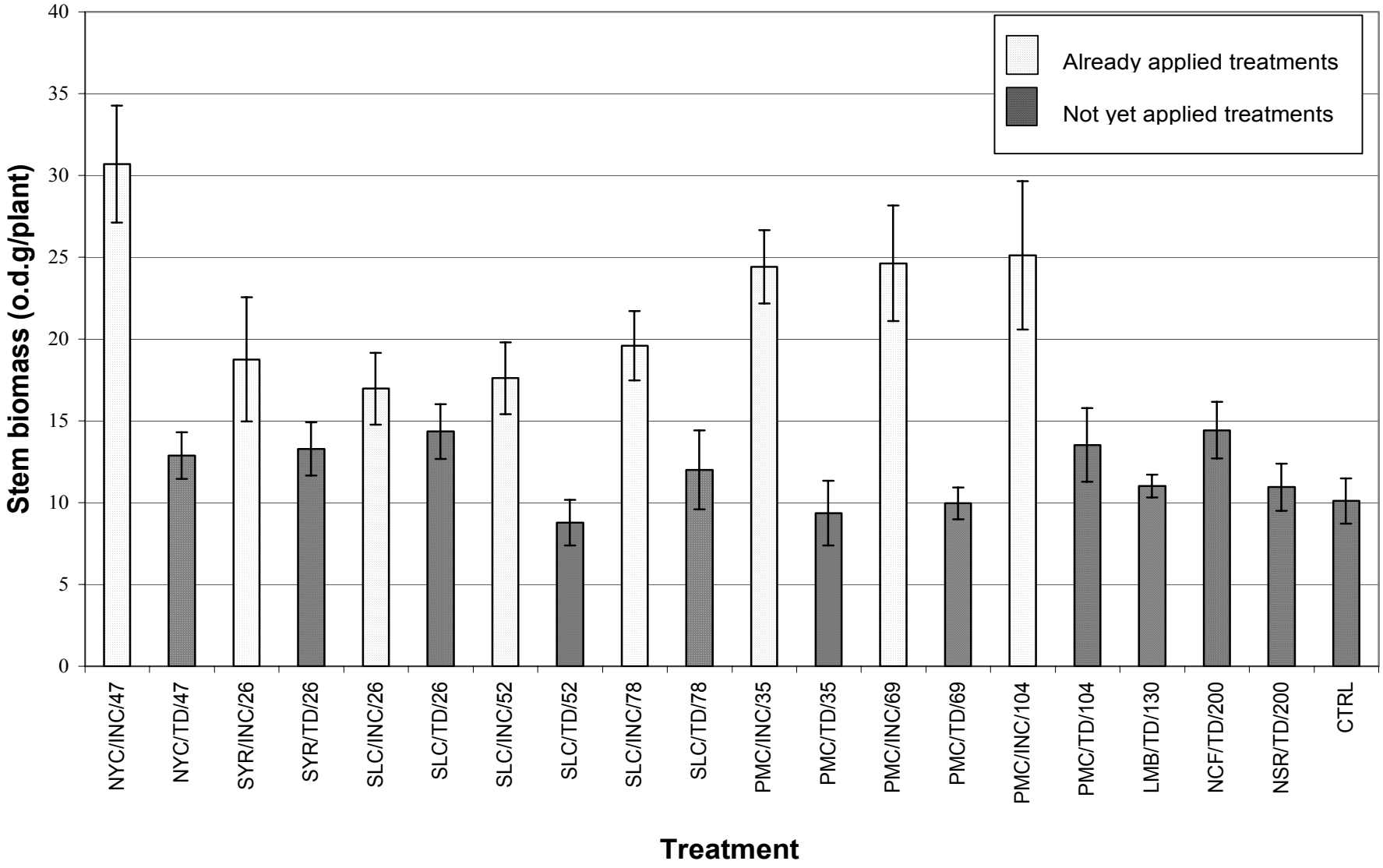

Figure 2.4. Stem biomass of willow clone SV1 in the greenhouse after the first growing season.
INC= incorporated; TD= top-dressed; NYC= NYC sludge; SYR= Syracuse sludge; SLC= Composted sludge; PMC= Composted poultry manure; LMB= Lime-stabilized sludge; NCF= ammonium nitrate fertilizer; NSR= Slow-release N fertilizer; CTRL= Control. (Treatment labels correspond to treatments listed in Table 2. Each bar represents one standard error.)

Table 2.5. Willow clone SV1 stem, foliage and root biomass as percentages of total biomass produced during the first growing season in the greenhouse study.

Notation	Fertilizer/Amendment (o.d.g/plant)	Mode %	Rate %	Total[a] %	Stem	Foliage	Root
NYC/INC/47	NYC sewage sludge	Incorporated	2.50 cm	98.9	27	23	50
NYC/TD/47	NYC sewage sludge	Top-dressed	2.50 cm	49.7	27	25	48
SYR/INC/26	Syracuse sewage sludge	Incorporated	2.50 cm	69	26	24	50
SYR/TD/26	Syracuse sewage sludge	Top-dressed	2.50 cm	47	27	25	48
SLC/INC/26	Composted sewage sludge	Incorporated	1.25 cm	73.1	27	22	51
SLC/TD/26	Composted sewage sludge	Top-dressed	1.25 cm	51	25	22	53
SLC/INC/52	Composted sewage sludge	Incorporated	2.50 cm	52.6	26	23	51
SLC/TD/52	Composted sewage sludge	Top-dressed	2.50 cm	39.4	24	25	51
SLC/INC/78	Composted sewage sludge	Incorporated	3.75 cm	72.5	27	23	50
SLC/TD/78	Composted sewage sludge	Top-dressed	3.75 cm	44.7	24	24	52
PMC/INC/35	Composted poultry manure	Incorporated	1.25 cm	70.2	29	24	47
PMC/TD/35	Composted poultry manure	Top-dressed	1.25 cm	40.5	25	25	50
PMC/INC/69	Composted poultry manure	Incorporated	2.50 cm	93.1	27	21	52
PMC/TD/69	Composted poultry manure	Top-dressed	2.50 cm	48.1	25	24	51
PMC/INC/104	Composted poultry manure	Incorporated	3.75 cm	68.3	29	25	46
PMC/TD/104	Composted poultry manure	Top-dressed	3.75 cm	48.7	26	24	50
LMB/TD/130	Limed-stabilized sludge	Top-dressed	2.50 cm	47.2	27	25	48
NCF/TD/200	NH4-NO3 fertilizer	Top-dressed	200 kg N/ha	47.6	30	23	47
NSR/TD/200	Slow-release N fertilizer	Top-dressed	200 kg N/ha	39.9	27	24	49
CTRL	Control	--	--	38.1	25	26	49

[a]: Total based on the 4 replicates that were totally harvested (stem, foliage, and root) in each treatment.

Table 2.6. Linear contrasts and p-values associated with the null hypothesis of no difference for treatment effects on stem, foliage, root and total biomass produced by willow clone SV1 during the first growing season in the greenhouse study.

	Stem	Foliage	Root	Total biomass				
Contrast	Estimate (g/plant)	p-value (g/plant)	Estimate (g/plant)	p-value (g/plant)	Estimate	p-value	Estimate	p-value
Treated – Non treated	10.5	<0.01	7.3	<0.01	15	<0.01	29.6	<0.01
New York Sludge – Syracuse Sludge	12	<0.01	7.9	<0.01	16.9	0.05	29.9	<0.01
Composts – Non-Composts	-3.4	0.07	-3.5	<0.01	-5.5	0.26	-12.3	0.19
Sludge Compost – Poultry Compost	-6.7	<0.01	-4.2	<0.01	-4.9	0.32	-11.1	0.23
Syracuse Sludge – Sludge Compost	-0.7	0.78	-1.7	0.31	-0.5	0.94	3	0.82
New York Sludge – Sludge Compost	12.7	<0.01	9.5	<0.01	16.4	0.02	32.9	0.01
Rate 3.75 cm – Rate 1.25 cm	1.7	0.45	1.2	0.39	-1.2	0.84	-1.2	0.91

Treated = all …/INC/…; Non-treated = all …/TD/… + Control;
New York Sludge = NYC/INC/47;
Syracuse Sludge = SYR/INC/26;
Composts = SLC/INC/26 + SLC/INC/52 + SLC/INC/78 + PMC/INC/35 + PMC/INC/69 + PMC/INC/104;
Non-Composts = SYR/INC/26 + NYC/INC/47;
Sludge compost = SLC/INC/26 + SLC/INC/52 + SLC/INC/78;
Poultry compost = PMC/INC/35 + PMC/INC/69 + PMC/INC/104;
Rate 3.75 cm = PMC/INC/104 + SLC/INC/78;
Rate 1.25 cm = PMC/INC/35 + SLC/INC/26;

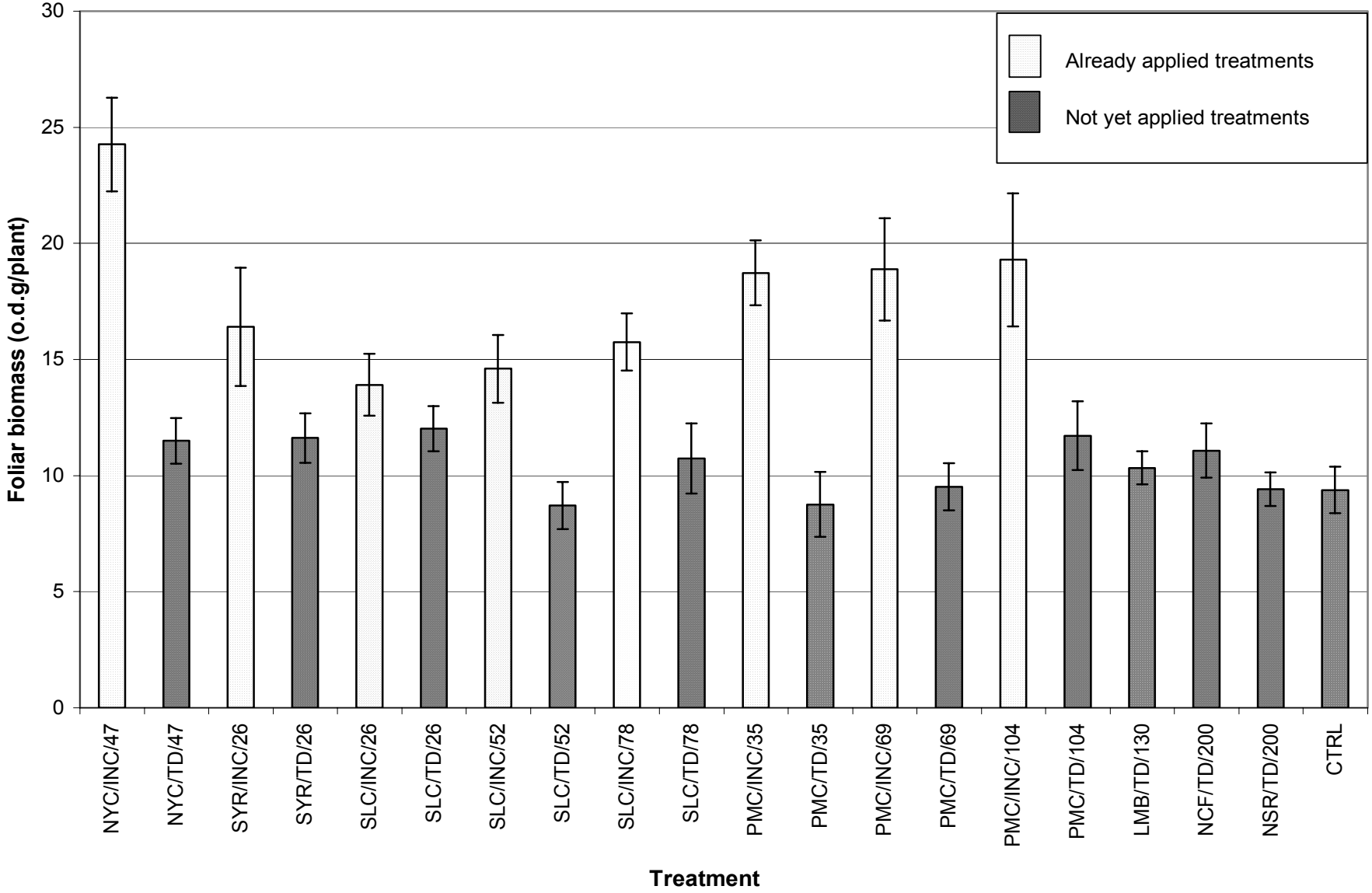

Figure 2.5. Foliage biomass of willow clone SV1 in the greenhouse after the first growing season.
INC= incorporated; TD= top-dressed; NYC= NYC sludge; SYR= Syracuse sludge; SLC= Composted sludge; PMC= Composted poultry manure; LMB= Lime-stabilized sludge; NCF= ammonium nitrate fertilizer; NSR= Slow-release N fertilizer; CTRL= Control. (Treatment labels correspond to treatments listed in Table 2. Each bar represents one standard error.)

Table 2.7. Correlation among stem, foliage and root biomass produced by willow clone SV1 during the first growing season in the greenhouse study.

	Pearson correlation coefficient (r)	p-value
Stem – Leaf	0.98	<0.01
Stem – Root	0.91	<0.01
Leaf – Root	0.91	<0.01

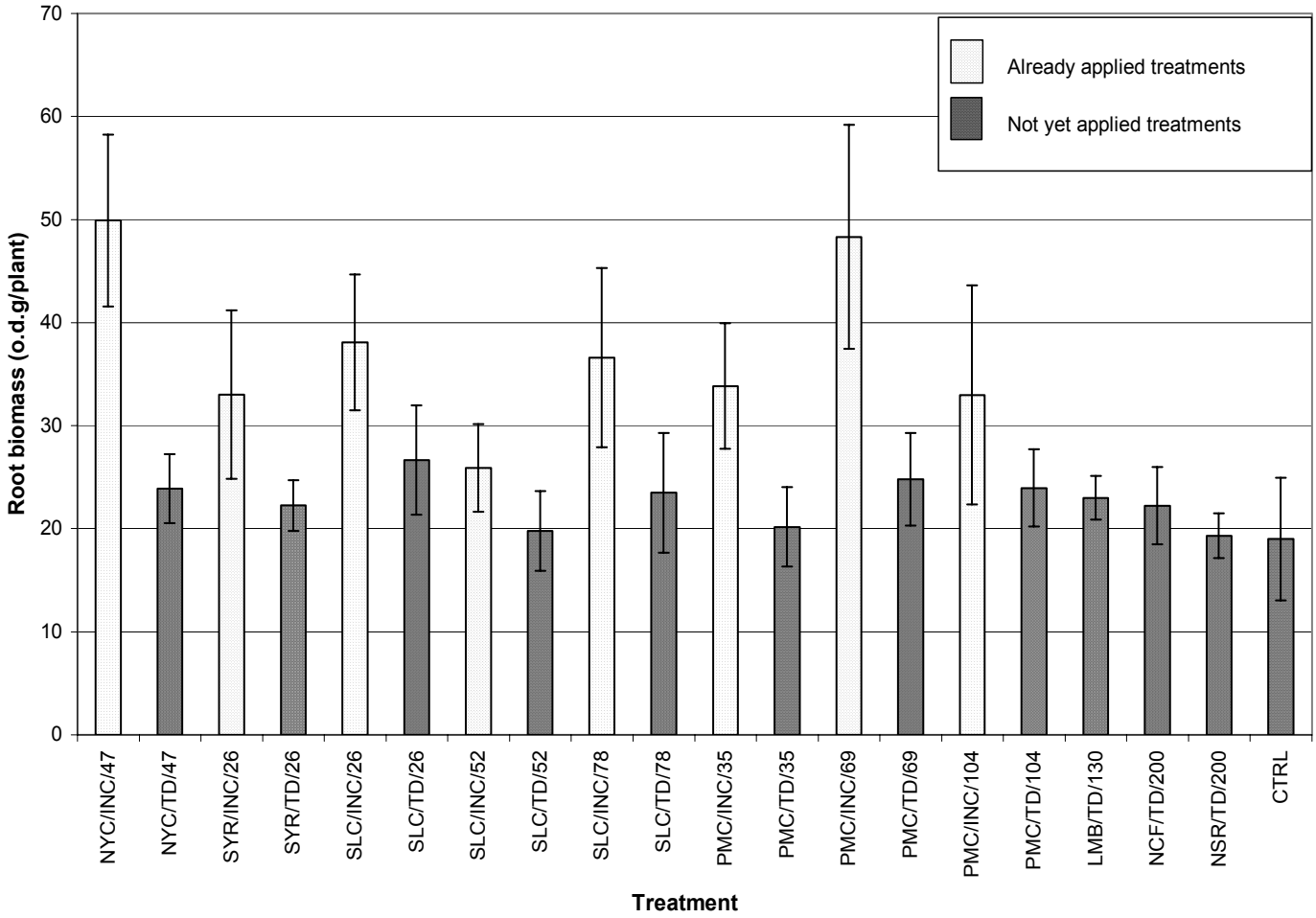

Figure 2.6. Root biomass of willow clone SV1 in the greenhouse after the first growing season. INC= incorporated; TD= top-dressed; NYC= NYC sludge; SYR= Syracuse sludge; SLC= Composted sludge; PMC= Composted poultry manure; LMB= Lime-stabilized sludge; NCF= ammonium nitrate fertilizer; NSR= Slow-release N fertilizer; CTRL= Control. (Treatment labels correspond to treatments listed in Table 2. Each bar represents one standard error.)

After the first 20 weeks in the greenhouse experiment, average total plant biomass ranged from 38 to 99 o.d.g/plant (Figure 2.7 and Table 2.5). Plants in treated pots had significantly greater biomass than plants in non-treated pots ($p < 0.01$). There was no significant difference between (1) the non-composts and the composts treatments ($p = 0.19$), (2) the composted sewage sludge and the composted poultry manure treatments ($p = 0.23$), and (3) the highest (3.75 cm) and the lowest (1.25 cm) rates of compost treatments ($p = 0.91$). New York City sewage sludge produced the greatest amount of biomass of all treatments.

Second growing season

After the first 20-week growing season, 80 plants (four replicates per treatment) were coppiced to induce sprouting of multiple stems. However, only 21 plants grew. This failure to resprout was due to a lack of dormancy period in the greenhouse. Total biomass (based on 18 observations due to 3 missing root data), after 36 weeks of growth, ranged from 220 to 637 o.d.g/plant (Table 2.8). Stem biomass ranged from 112 to 422 o.d.g/plant (Table 2.9) representing 46 to 66% of total biomass (Table 2.8). Foliage biomass ranged from 40 to 116 o.d.g/plant (Table 2.9) and accounted for 13 to 24% of total biomass (Table 2.8). Root biomass ranged from 33 to 196 o.d.g/plant (Table 2.9) and represented 15 to 37% of total biomass (Table 2.8). Compared to the first growing season, stem biomass increased in proportion of the total biomass whereas foliage and root biomass decreased in proportion of the total biomass.

The lack of replicates for most treatments precluded thorough evaluations of treatment effects. However, comparisons could be made among groups of treatments (Table 2.10). Incorporated treatments produced greater total biomass ($p = 0.03$), greater stem biomass ($p < 0.01$) and greater foliage biomass ($p < 0.01$) than top-dressed treatments. Within composted sewage sludge treatments, incorporated treatments produced more stem biomass than top-dressed treatments ($p = 0.01$). There was no significant difference between (1) plants grown in the composted poultry manure and plants grown in the composted sewage sludge, (2) plants grown in the Syracuse sewage sludge and plants grown in any of the compost treatments. Among individual treatments that had more than one replicate, thus allowing a T-test, comparisons were made. Except for one significant contrast showing that plants grown in the composted sewage sludge incorporated at 2.50 cm rate had greater root biomass than plants grown in the composted sewage sludge top-dressed at 2.50 cm rate ($p = 0.01$), none of the tested contrasts showed any significance.

Resin-captured NH_4-N and NO_3-N

Resin-captured NH_4-N

A large variability was observed for resin-captured NH_4-N data (CV: 20-88%). In non-planted pots, resin-captured NH_4-N ranged from 0.4 to 1.5 kg/ha (Figure 2.8). The test of specific contrasts of interest between the various treatments and groups of treatments did not show any significant differences (Table 2.11). There was no significant difference between (1) treated and control pots ($p = 0.20$), (2) organic amendments and mineral N treatments ($p = 0.42$) and (3) composts and non-compost organic amendments ($p = 0.72$). Also, there was no significant difference between (1) the two types of compost ($p = 0.44$), (2) the two types of sewage sludge ($p = 0.10$) and (3) the two-types of mineral N fertilizer ($p = 0.59$).

In planted pots, resin-captured NH_4-N ranged from 0.3 to 1.6 kg/ha in pots where plants grew and from 0.9 to 1.8 kg/ha in pots where plants did not grow (Table 2.12). Results of the comparisons between individual treatments or groups of treatments that had enough replicates to allow for T-test are shown in Table 2.13. There was no significant difference between (1) planted pots with growth and planted pots without growth ($p=0.75$) and (2) the composted poultry manure and the composted sewage sludge for plants that grew ($p = 0.48$).

T-test comparisons made between non-planted pots and planted pots that grew (Table 2.14) showed that non-planted pots had less NH_4-N than planted pots ($p = 0.01$). Also for composted sewage sludge treatments, non-planted pots had lower NH_4-N than planted pots that grew ($p = 0.02$). For composted poultry manure treatments, there was no significant difference between non-planted pots and planted pots that grew ($p = 0.13$).

In non-planted pots, the net effect of each treatment was calculated by deducting, within each block, the value obtained for the control from the value obtained for the treatment. Net NH_4-N due to treatments ranged from 0 to 1.1 kg/ha (Table 2.15).

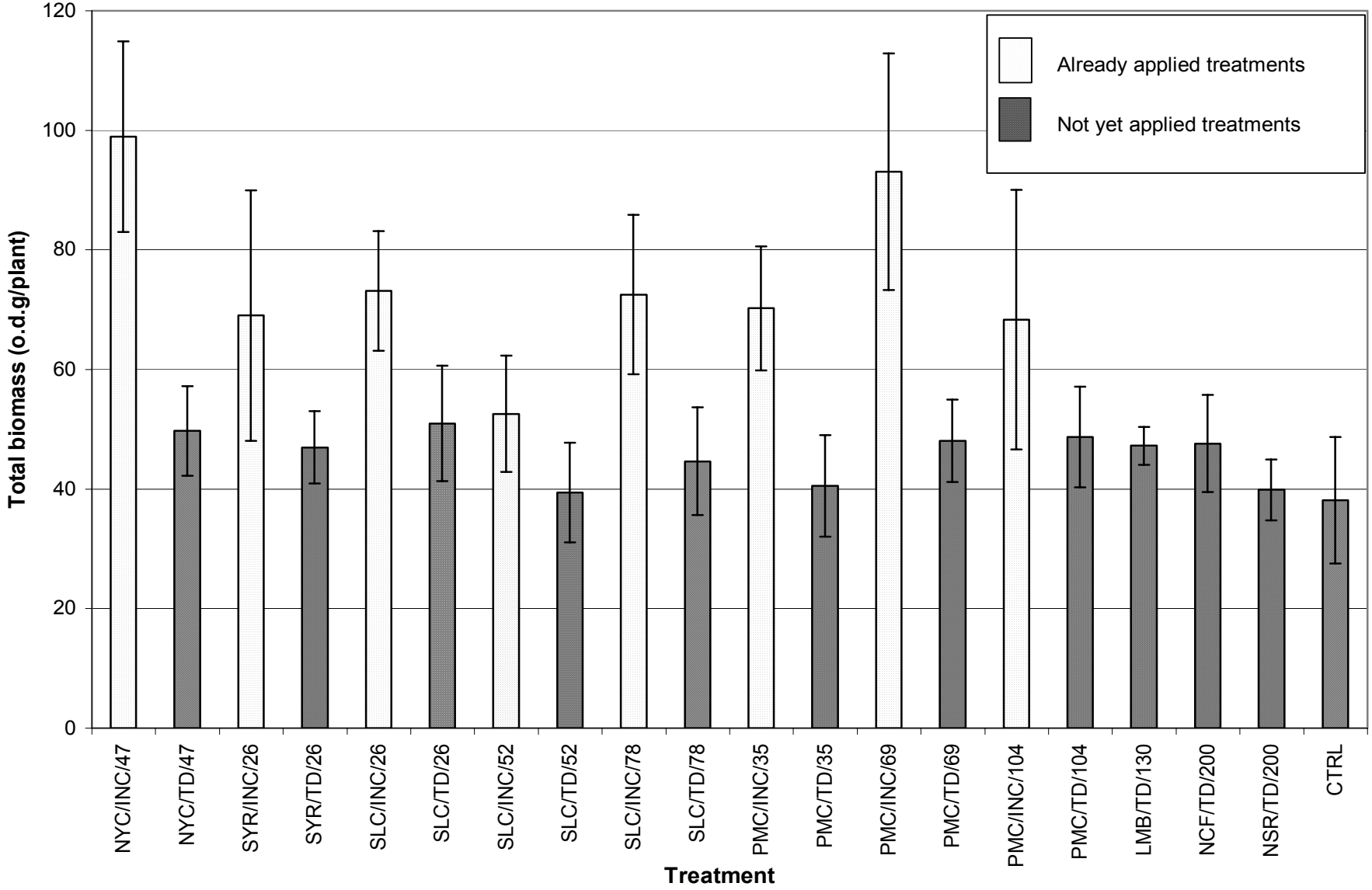

Figure 2.7. Total biomass of willow clone SV1 in the greenhouse after the first growing season.
INC= incorporated; TD= top-dressed; NYC= NYC sludge; SYR= Syracuse sludge; SLC= Composted sludge; PMC= Composted poultry manure; LMB= Lime-stabilized sludge; NCF= ammonium nitrate fertilizer; NSR= Slow-release N fertilizer; CTRL= Control. (Treatment labels correspond to treatments listed in Table 2. Each bar represents one standard error.)

Table 2.8. Willow clone SV1 stem, foliage and root[a] biomass as percentages of total biomass produced during the second growing season in the greenhouse study (Numbers of observations per treatment are in parentheses).

Notation	Fertilizer/Amendment (g/plant)	Mode %	Rate %	Total %	Stem	Foliage	Root
NYC/INC/47	NYC sewage sludge	Incorporated	2.50 cm	0 (0)	--	--	--
NYC/TD/47	NYC sewage sludge	Top-dressed	2.50 cm	0 (0)	--	--	--
SYR/INC/26	Syracuse sewage sludge	Incorporated	2.50 cm	538.0 (1)	56	21	23
SYR/TD/26	Syracuse sewage sludge	Top-dressed	2.50 cm	220.1 (1)	61	24	15
SLC/INC/26	Composted sewage sludge	Incorporated	1.25 cm	271.5 (1)	57	21	22
SLC/TD/26	Composted sewage sludge	Top-dressed	1.25 cm	255.6 (1)	52	23	25
SLC/INC/52	Composted sewage sludge	Incorporated	2.50 cm	444.1 (2)	59	15	26
SLC/TD/52	Composted sewage sludge	Top-dressed	2.50 cm	324.5 (2)	55	18	27
SLC/INC/78	Composted sewage sludge	Incorporated	3.75 cm	513.6 (2)	60	18	22
SLC/TD/78	Composted sewage sludge	Top-dressed	3.75 cm	0 (0)	--	--	--
PMC/INC/35	Composted poultry manure	Incorporated	1.25 cm	636.6 (1)	66	18	16
PMC/TD/35	Composted poultry manure	Top-dressed	1.25 cm	250.2 (2)	61	19	20
PMC/INC/69	Composted poultry manure	Incorporated	2.50 cm	0 (0)	--	--	--
PMC/TD/69	Composted poultry manure	Top-dressed	2.50 cm	385.3 (2)	46	17	37
PMC/INC/104	Composted poultry manure	Incorporated	3.75 cm	0 (0)	--	--	--
PMC/TD/104	Composted poultry manure	Top-dressed	3.75 cm	0 (0)	--	--	--
LMB/TD/130	Limed-stabilized sludge	Top-dressed	2.50 cm	474.9 (1)	48	17	35
NCF/TD/200	NH4-NO3 fertilizer	Top-dressed	200 kg N/ha	611.0 (1)	55	13	32
NSR/TD/200	Slow-release N fertilizer	Top-dressed	200 kg N/ha	0 (0)	--	--	--
CTRL	Control	--	--	243.6 (1)	57	16	27

[a]: Root data are missing for 3 of the 21 plants that grew during the second growing season.

Table 2.9. Stem, foliage and root biomass produced by willow clone SV1 after the second growing season in the greenhouse study (Numbers of observations per treatment are in parentheses).

Notation	Fertilizer/Amendment (g/plant)	Mode (g/plant)	Rate (g/plant)	Stem	Foliage	Root
NYC/INC/47	NYC sewage sludge	Incorporated	2.50 cm	0 (0)	0 (0)	0 (0)
NYC/TD/47	NYC sewage sludge	Top-dressed	2.50 cm	0 (0)	0 (0)	0 (0)
SYR/INC/26	Syracuse sewage sludge	Incorporated	2.50 cm	303.8 (-1)	110.8 (-1)	123.4 (-1)
SYR/TD/26	Syracuse sewage sludge	Top-dressed	2.50 cm	135.4 (-1)	52 (-1)	32.7 (-1)
SLC/INC/26	Composted sewage sludge	Incorporated	1.25 cm	156.2 (-1)	56.3 (-1)	59 (-1)
SLC/TD/26	Composted sewage sludge	Top-dressed	1.25 cm	133.5 (-1)	59.5 (-1)	62.6 (-1)
SLC/INC/52	Composted sewage sludge	Incorporated	2.50 cm	241.8 (-2)	64.4 (-2)	138 (-2)
SLC/TD/52	Composted sewage sludge	Top-dressed	2.50 cm	157.2 (-3)	61.8 (-3)	84.1 (-2)
SLC/INC/78	Composted sewage sludge	Incorporated	3.75 cm	286.9 (-2)	91.4 (-2)	135.3 (-2)
SLC/TD/78	Composted sewage sludge	Top-dressed	3.75 cm	105.9 (-1)	54.2 (-1)	0 (0)
PMC/INC/35	Composted poultry manure	Incorporated	1.25 cm	422(-1)	115.5 (-1)	99.1 (-1)
PMC/TD/35	Composted poultry manure	Top-dressed	1.25cm	112 (-2)	43.7 (-2)	94.5 (-2)
PMC/INC/69	Composted poultry manure	Incorporated	2.50 cm	0 (0)	0 (0)	0 (0)
PMC/TD/69	Composted poultry manure	Top-dressed	2.50 cm	172.6 (-3)	62.2 (-3)	117.4 (-2)
PMC/INC/104	Composted poultry manure	Incorporated	3.75 cm	0 (0)	0 (0)	0 (0)
PMC/TD/104	Composted poultry manure	Top-dressed	3.75 cm	0 (0)	0 (0)	0 (0)
LMB/TD/130	Limed-stabilized sludge	Top-dressed	2.50 cm	228.6 (-1)	79.3 (-1)	164 (-1)
NCF/TD/200	NH4-NO3 fertilizer	Top-dressed	200 kg N/ha	336.3 (-1)	78.9 (-1)	195.8 (-1)
NSR/TD/200	Slow-release N fertilizer	Top-dressed	200 kg N/ha	0 (0)	0 (0)	0 (0)
CTRL	Control	--	--	138.7 (-1)	39.5 (-1)	65.3 (-1)

Table 2.10. T-test comparisons among treatments for foliage, stem and root biomass produced after the second growing season in the greenhouse study.

[a]Null hypothesis Ho: $\mu_1 - \mu_2 = 0$ Alternate hypothesis Ha: $\mu_1 - \mu_2 > 0$	Foliage		Stem		Root		Total biomass	
	Estimate (g/plant)	p-value	Estimate (g/plant)	p-value	Estimate (g/plant)	p-value	Estimate (g/plant)	p-value
Main effect application mode:								
Incorporated vs. Top-dressed	24.6	<0.01	111.4	<0.01	13.6	0.3	132.4	0.03
Incorporated vs. Top-dressed (within Composted sludge treatments)	13.7	0.08	100.6	0.01	44.1	0.06	135.9	0.06
Main effect organic residual:								
Syracuse sludge vs. Composted sludge	14.7	0.18	27.2	0.34	-26.5	0.23	-7.4	0.47
Syracuse sludge vs. Composted poultry manure	16.5	0.28	25.6	0.4	-26.6	0.31	-2.5	0.49
Composted poultry manure vs. Composted sludge	-1.8	0.44	1.5	0.49	0	0.5	-4.9	0.48
Simple effects:								
PMC/TD/69 vs. PMC/TD/35	18.4	0.18	60.6	0.09	22.9	0.4	135	0.19
SLC/INC/78 vs. SLC/INC/52	26.9	0.09	45.2	0.3	-2.7	0.47	69.5	0.27
SLC/INC/52 vs. SLC/TD/52	2.6	0.41	84.6	0.13	53.8	0.01	119.7	0.16
PMC/TD/69 vs. SLC/TD/52	0.3	0.49	15.5	0.33	33.3	0.31	60.8	0.29

[a]: μ_1 denotes the mean of the first mentioned treatment and $\mu 2$ denotes the mean of the second mentioned treatment

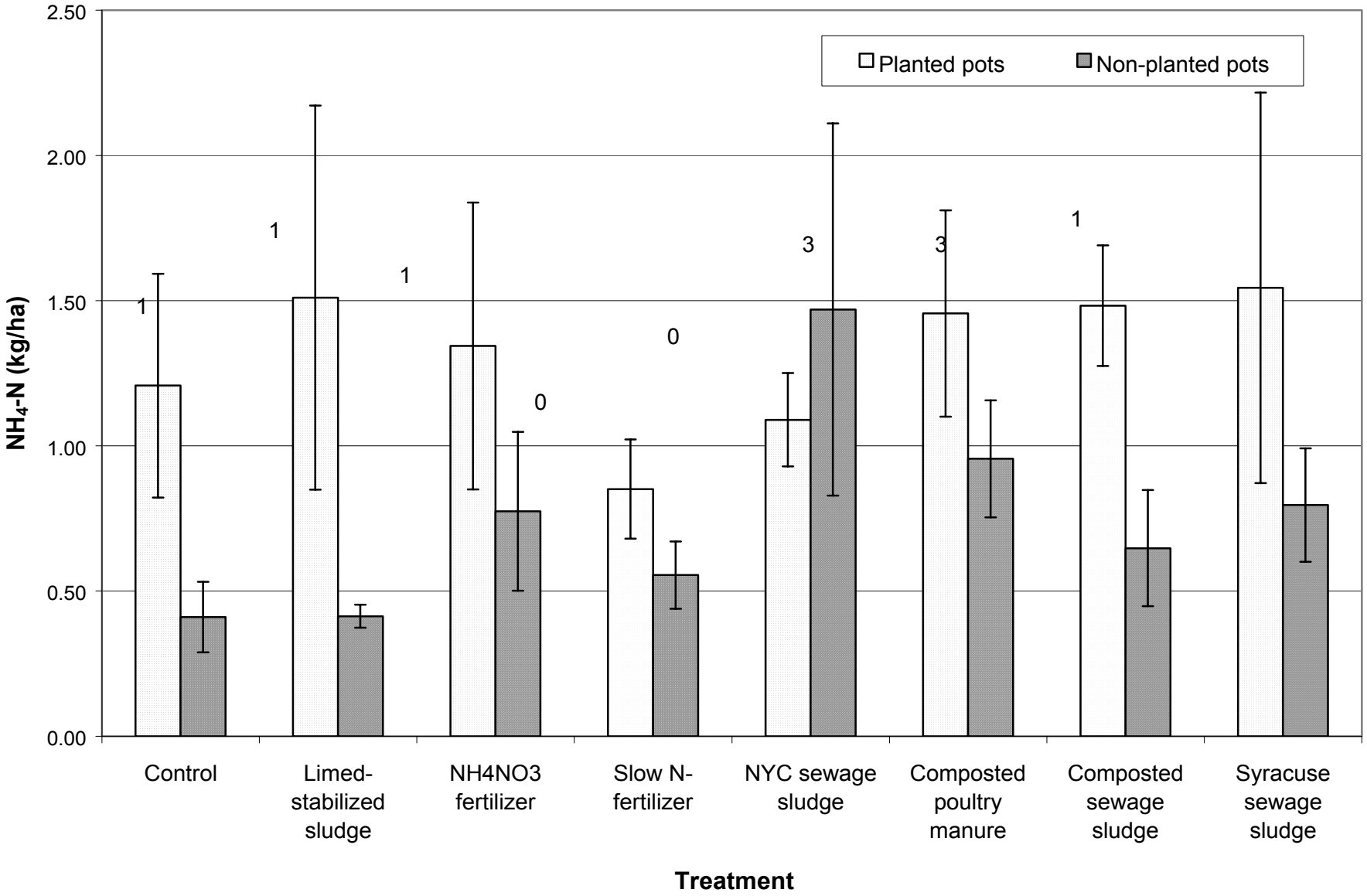

Figure 2.8. Mean NH4-N captured by resin columns in planted and non-planted pots from July 1996 to July 1997 in the greenhouse study. (Number of plants that grew out of the 4 replicates are marked on top. Each bar represents one standard error).

Table 2.11. Linear contrasts and p-values associated with the null hypothesis of no difference for treatment effects on resin-captured NH4-N and NO3-N in non-planted pots from July 1996 to July 1997 in the greenhouse study.

	NH4-N		NO3-N	
Contrast	Estimate (kg N/ha)	p-value	Estimate (kg N/ha)	p-value
Treated – Control	0.4	0.2	13.4	0.7
Slow-release N – NH4NO3-N	-0.2	0.59	58.7	0.2
New York sludge – Syracuse sludge	0.7	0.1	-56.2	0.22
Organic amendment – Mineral N	0.2	0.42	-8.9	0.74
Composted poultry manure – Composted sewage sludge	0.3	0.44	-28.5	0.53
Composts – Organic non-composts	-0.1	0.72	-30.6	0.3
Sludge – Composted sewage sludge	0.5	0.17	35.3	0.37
Sludge – Lime-stabilized sludge	0.7	0.05	56.8	0.16

Treated = Slow-release N + NH4NO3-N + New York sludge + Syracuse sludge + Composted poultry manure + Composted sewage sludge + Lime-stabilized sludge.

Organic amendment = New York sludge + Syracuse sludge + Composted poultry manure + Composted sewage sludge + Lime-stabilized sludge.

Mineral N = Slow-release N + NH4NO3-N.

Composts = Composted poultry manure + Composted sewage sludge.

Organic non-composts = New York sludge + Syracuse sludge + Lime-stabilized sludge.

Sludge = New York sludge + Syracuse sludge.

Table 2.12. Resin-captured NO3-N and NH4-N in planted pots from July 1996 to July 1997 in the greenhouse study

(Numbers of observations in each category are in parentheses).

	NH4-N (kg/ha)			NO3-N (kg/ha)		
Treatment	All pots	P. with growth	P. without growth	All pots	P. with growth	P. without growth
Control	1.2 (4)	0.3 (1)	1.5 (3)	76.1 (4)	2.4 (1)	101. 0 (3)
Lime-stabilized sludge	1.5 (4)	0.8 (1)	1.8 (3)	110.1 (4)	0.0 (1)	147.2 (3)
NH4-NO3 fertilizer	1.3 (4)	0.9 (1)	1.5 (3)	108.7 (4)	0.0 (1)	145.3 (3)
Slow-release N fertilizer	0.9 (4)	-- (0)	0.9 (4)	159.6 (4)	-- (0)	159.6 (4)
NYC sewage sludge	1.1 (4)	-- (0)	1.1 (4)	148.2 (4)	-- (0)	148.2 (4)
Composted Poultry manure	1.5 (4)	1.6 (3)	1.2 (1)	40.4 (3)[a]	12.1 (2)	97.1 (1)
Composted sewage sludge	1.5 (4)	1.6 (3)	1.2 (1)	47.3 (4)	4.1 (3)	176.7 (1)
Syracuse sludge	1.5 (4)	1.2 (1)	1.7 (3)	90.1 (3)[a]	0.0 (1)	135.9 (2)
Average		1.2 (10)	1.3 (22)		4.3 (9)	140.8 (21)

[a] : One missing observation in each of these categories due to torn resin chamber.

Table 2.13. T-test comparisons of resin-captured NH4-N and NO3-N in planted pots from July 1996 to July 1997 in the greenhouse study.

[a]Null hypothesis Ho: $\mu_1 - \mu_2 = 0$ Alternate hypothesis Ha: $\mu_1 - \mu_2 > 0$	NO_3-N Estimate (kg/ha)	NO_3-N p-value	NH_4-N Estimate (kg/ha)	NH_4-N p-value
Planted pots without growth vs. Planted pots with growth	136.5	<0.01	0.1	0.75
Composted Poultry Manure[b] vs. Composted sewage sludge[b] (tested only for pots with growth)	8	0.23	0	0.48

[a]: μ_1 denotes the mean of the first mentioned treatment and μ_2 denotes the mean of the second mentioned treatment.

[b]: Only treatments to allow for t-test, having had more than one replicate to grow during the second growing season.

Table 2.14. T-test comparisons between non-planted pots and planted pots (which grew), of resin-captured NH4-N and NO3-N from July 1996 to July 1997 in the greenhouse study.

[a]Null hypothesis Ho: $\mu_1 - \mu_2 = 0$ Alternate hypothesis Ha: $\mu_1 - \mu_2 > 0$	NO_3-N Estimate (kg/ha)	NO_3-N p-value	NH_4-N Estimate (kg/ha)	NH_4-N p-value
Non-planted pots vs. Planted pots with growth	133	<0.01	-0.4	0.01
Composted Poultry manure[b]: Non-planted pots vs. Planted pots with growth	89.7	0.03	-0.6	0.13
Composted sewage sludge[b]: Non-planted pots vs. Planted pots with growth	128.2	<0.01	-0.9	0.02

[a]: μ_1 denotes the mean of the first mentioned treatment and μ_2 denotes the mean of the second mentioned treatment.

[b]: Only treatments to allow for t-test, having had more than one replicate to grow during the second growing season.

Table 2.15. Net contributions of applied treatments to resin-captured NH4-N and NO3-N in non-planted potsa (Standard errors of means are in parentheses).

Treatment	NH_4-N (kg/ha)	NO_3-N (kg/ha)
NYC sewage sludge	1.1 (0.58)	13.9 (34.3)
Syracuse sewage sludge	0.4 (0.10)	70.1 (34.4)
Composted sewage sludge	0.2 (0.27)	6.8 (28.3)
Limed sewage sludge	0.0 (0.13)	-14.8 (9.7)
Composted poultry manure	0.5 (0.31)	-21.8 (23.4)
NH4-NO3 fertilizer	0.4 (0.23)	-9.6 (28.5)
Slow-release N fertilizer	0.1 (0.15)	49.1 (51.8)

[a]: Lack of growth in planted pots does not allow to calculate net effect.

Resin-captured NO_3-N

Resin-captured NO_3-N data also exhibited a high variability (CV: 9-183%). In non-planted pots, NO_3-N ranged from 103.8 to 195.7 kg/ha (Figure 2.9). There were no significant differences between (1) treated and control pots ($p = 0.70$), (2) organic amendments and mineral N treatments ($p = 0.74$) and (3) composts and non-compost organic amendments ($p = 0.30$) (Table 2.11). Also, there were no significant differences between (1) the two types of compost ($p = 0.53$), (2) the two types of sewage sludge ($p = 0.22$) and (3) the two-types of mineral N fertilizer ($p = 0.20$) (Table 2.11).

Within planted pots, distinction should be made between the ones where plants grew and the others where plants did not grow. Resin-captured NO_3-N ranged from 0 to 12 kg/ha in pots where plants grew and, from 97 to 177 kg/ha in pots where plants did not grow (Table 2.12). Table 2.13 shows the results of the comparisons between individual treatments or groups of treatments that had enough replicates to allow for T-test. Planted pots without growth had significantly higher NO_3-N than planted pots with growth ($p < 0.01$). For pots with growth, there was no significant difference between the composted poultry manure and the composted sewage sludge ($p = 0.23$).

T-test comparisons made between non-planted pots and planted pots that effectively grew (Table 2.14) showed that non-planted pots generated more NO_3-N than planted pots ($p < 0.01$). Also for composted sewage sludge and composted poultry manure treatments, non-planted pots had higher NO_3-N than planted pots that grew ($p < 0.01$ and $p = 0.03$, respectively).

In non-planted pots, the net effect of each treatment was calculated by deducting, within each block, the value obtained for the control from the value obtained for the treatment. Net NO_3-N contribution of treatments ranged from 0 to 70 kg/ha (Table 2.15). The treatments of lime-stabilized sludge, composted poultry manure and NH_4-NO_3 fertilizer had negative NO_3-N contribution. This observation is probably due to the excessive variability of the data.

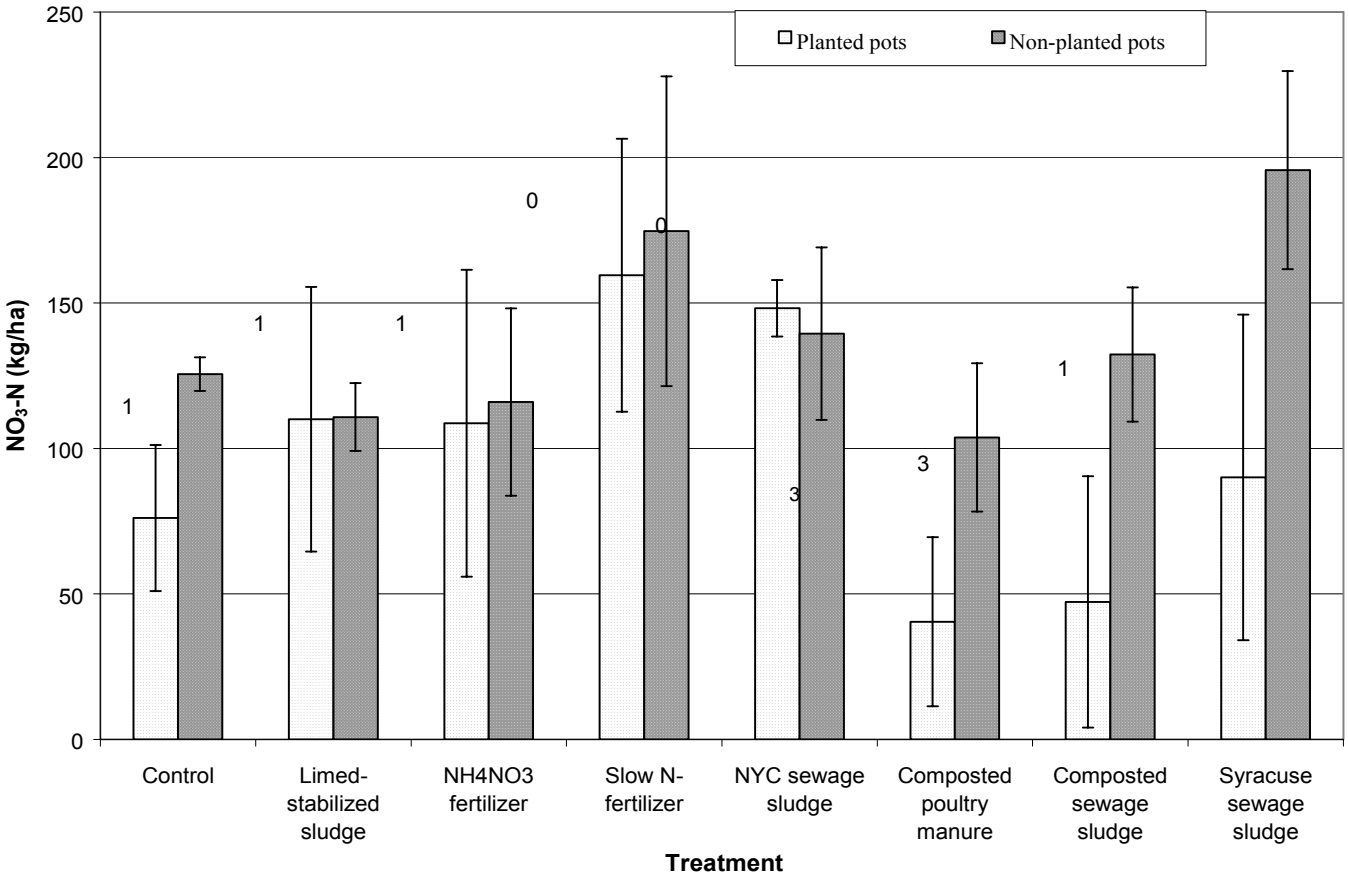

Figure 2.9. Mean NO3-N captured by resin columns in planted and non-planted pots from July 1996 to July 1997 in the greenhouse study.
(Number of plants that grew out of the 4 replicates are marked on top. Each bar represents one standard error).

Nitrogen release

Total nitrogen released by treatments of NYC sewage sludge, Syracuse sewage sludge, composted poultry manure and composted sewage sludge, all top-dressed at the rate of 2.50 cm thick, was determined. Total nitrogen release of each treatment was calculated as the difference between initial and final N contents of the applied treatment computed from the mass and TKN (Total Kjeldahl Nitrogen) concentration at the beginning and the end of the experiment.

After 36 weeks (first week of December 1996 to third week of July 1997) in the greenhouse, mass loss of applied organic material, expressed as a percentage of the initial applied mass, ranged from 25 to 52% in non-planted pots and 20 to 47% in planted pots (Figure 2.10). Mass loss was greater in non-planted pots than in planted pots, for the Syracuse sludge and the composted sewage sludge treatments. A priori contrasts (Table 2.16) showed that within both planted pots and non-planted pots, (1) Syracuse sludge had greater mass loss than NYC sludge ($p < 0.01$), (2) composted poultry manure lost more mass than composted sewage sludge ($p < 0.01$) and non-compost treatments lost more mass than composts ($p < 0.01$).

Nitrogen concentrations of the organic amendments varied from the beginning to the end of the experiment (Figure 2.11). For the compost treatments (composted poultry manure and composted sewage sludge), nitrogen concentration increased. Nitrogen concentration of composted poultry manure significantly increased for both planted and non-planted pots by 0.50 and 0.34%, respectively (Table 2.17). The increase of nitrogen concentration in composted sewage sludge was significant only for planted pots. In contrast, nitrogen concentration decreased for the non-compost treatments (Syracuse sewage sludge and NYC sewage sludge). For the Syracuse sewage sludge, N concentration significantly decreased in both planted and non-planted pots by 0.74 and 0.86%, respectively. For the NYC sewage sludge the decreases of nitrogen concentration were not statistically significant (Table 2.17). There was no difference between planted and non-planted pots with regard to the final concentrations of organic amendments.

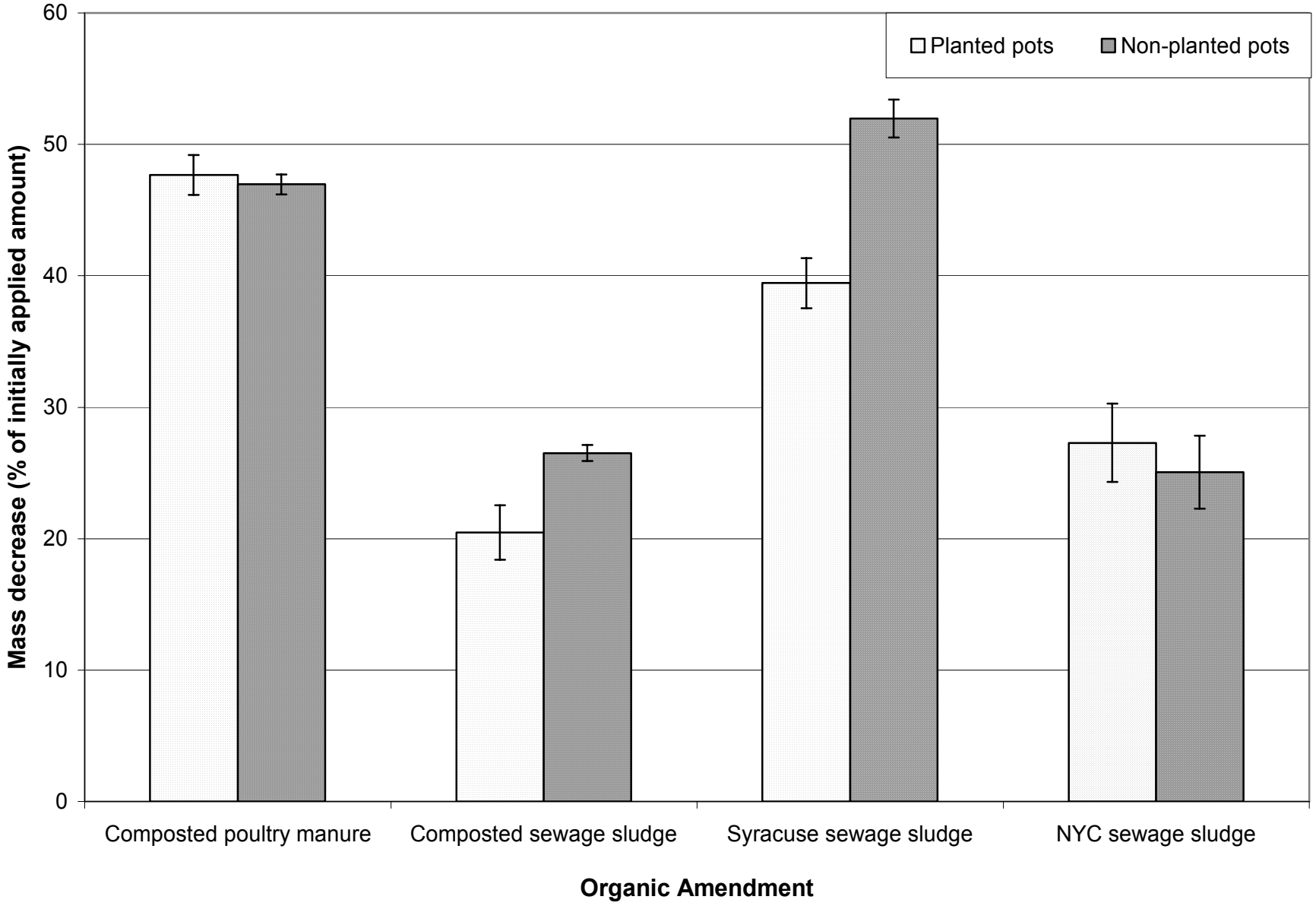

Figure 2.10. Mass decrease by decomposition of organic amendments (estimated by mass loss) in the greenhouse study from December 1996 to July 1997. (Each bar represents one standard error).

Table 2.16. Linear contrasts and p-values associated with the null hypothesis of no difference for weight loss and nitrogen release by decomposition of organic amendments from December 1996 to July 1997 in the greenhouse study.

Contrasts	Mass loss Estimate (% of initial)	p-value	N release Estimate (kg/ha)	p-value	N release Estimate (% of initial)	p-value
Non-planted pots:						
NYC sludge – Syracuse sludge	-26.9	<0.01	-156.8	0.1	-33.8	<0.01
Comp. poultry manure – Comp. Sludge	20.5	<0.01	214.6	0.03	15.3	0.08
Sludge: Non-composted – Composted	12	<0.01	392.4	<0.01	26.7	<0.01
Planted pots:						
NYC sludge – Syracuse sludge	-12.1	<0.01	-8.19	0.9	-19.91	<0.01
Comp. poultry manure – Comp. Sludge	27.2	<0.01	267.4	<0.01	24.8	<0.01
Sludge: Non-composted – Composted	12.9	<0.01	458.5	<0.01	36.6	<0.01

Comp. : Composted

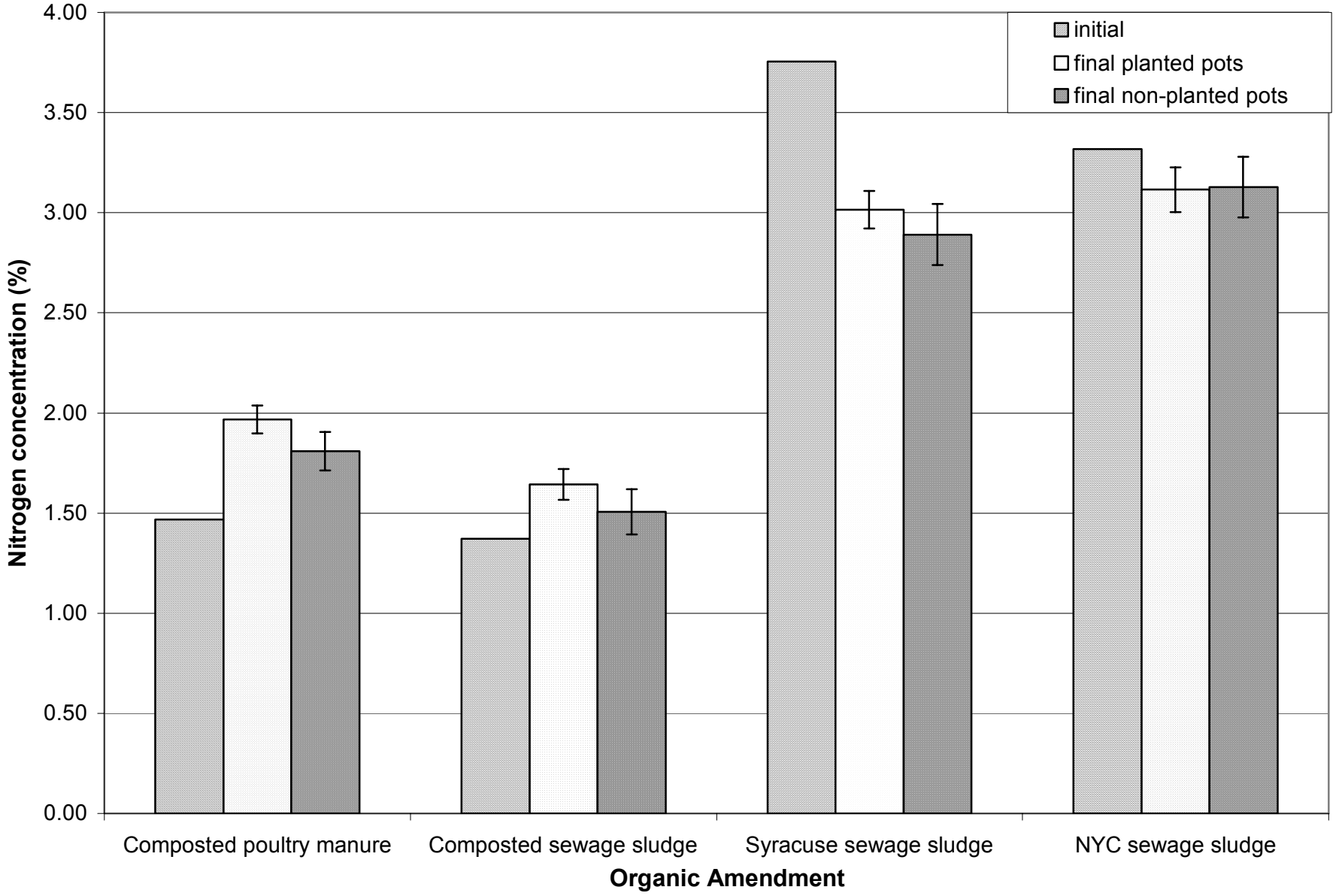

Figure 2.11. Nitrogen concentration of top-dressed organic amendments at the application (December 1996) and at the end (July 1997) of the greenhouse study. (Each bar represents one standard error).

Table 2.17. T-test comparisons of initial and final nitrogen concentrations of top-dressed organic amendments from December 1996 to July 1997 in the greenhouse study.

	Planted pots		Non-planted pots	
Amendment	Estimate %	p-value	Estimate %	p-value
Composted poultry manure	0.5	<0.01	0.34	0.04
Composted sewage sludge	0.27	0.04	0.13	0.32
Syracuse sewage sludge	-0.74	<0.01	-0.86	0.01
NYC sewage sludge	-0.2	0.16	-0.19	0.3

μ_{final} denotes mean nitrogen concentration at the end of the experiment and $\mu_{initial}$ denotes mean nitrogen concentration at the beginning of the experiment.

Null hypothesis: Ho: $\mu_{final} - \mu_{initial} = 0$

Alternate hypothesis: Ha: $\mu_{final} - \mu_{initial} \neq 0$

Nitrogen release (decrease of organic amendment N pool) ranged from 137 to 608 kg N/ha in non-planted pots and 35 to 498 kg N/ha in planted pots (Figure 2.12). There was no difference between the two sludge (Syracuse and New York City) treatments within either planted pots ($p = 0.90$) or non-planted pots ($p = 0.10$) (Table 2.16). Non-compost treatments released more nitrogen than compost treatments in both planted pots and non-planted pots ($p < 0.01$). A comparison of the composts showed that composted poultry manure released more nitrogen than composted sewage sludge in both planted pots and non-planted pots ($p < 0.01$ and $p = 0.03$ respectively).

Nitrogen release, expressed as a percentage of initially applied TKN, ranged from 29 to 63% in non-planted pots and 4 to 51% in planted pots (Figure 2.13). Percent N release was the highest with the Syracuse sludge treatment and the lowest with the composted sewage sludge treatment within both planted and non-planted pots. A priori contrasts (Table 2.16) showed that for either planted pots or non-planted pots (1) percent N released by NYC sewage sludge was less than in Syracuse sewage sludge ($p < 0.01$) and (2) percent N release by non-composts treatments was lower than in composts treatments ($p < 0.01$). In planted pots, percent N release was higher for composted poultry manure than composted sewage sludge ($p < 0.01$) in non-planted pots, there was no difference between the two compost treatments ($p = 0.08$).

DISCUSSION

Biomass production

The low stem biomass production (9-31 o.d.g/plant), observed for the first growing season in the greenhouse, is typical of establishment year production. For willow planted at wood-grass spacing (+100,000 plants/ha), Kopp *et al.* (1993) observed a maximum of 1.4 o.d.t/ha, equivalent to 11 o.d.g/plant, during the establishment year. The total biomass produced during the first growing season (38 to 99 o.d.g/plant) was similar to the range of 27 to 147 o.d.g/plant observed with pot-grown and sludge fertilized *Salix discolor* and *Salix viminalis* reported by Teodorescu *et al*. (1993). Coppice stem biomass production (second season) ranged from 220 to 637 o.d.g/plant and was much higher than that of the first season. That stem biomass production would correspond to 6.5-18.9 o.d.t/ha at the planting density equivalent to the spacing of the pots in the greenhouse, somewhat comparable to the good production range of 11.5 to 18 o.d.t/ha/yr reported by Abrahamson *et al.* (1998).

Comparing the establishment season to the coppice season, the proportion of stem biomass increased from 27 to 56% on average of the total biomass, at the expense of root and foliage biomass (Tables 2.5 and 2.8). The proportional distribution of root biomass decreased from an average of 50 to 25% and the proportion of leaf

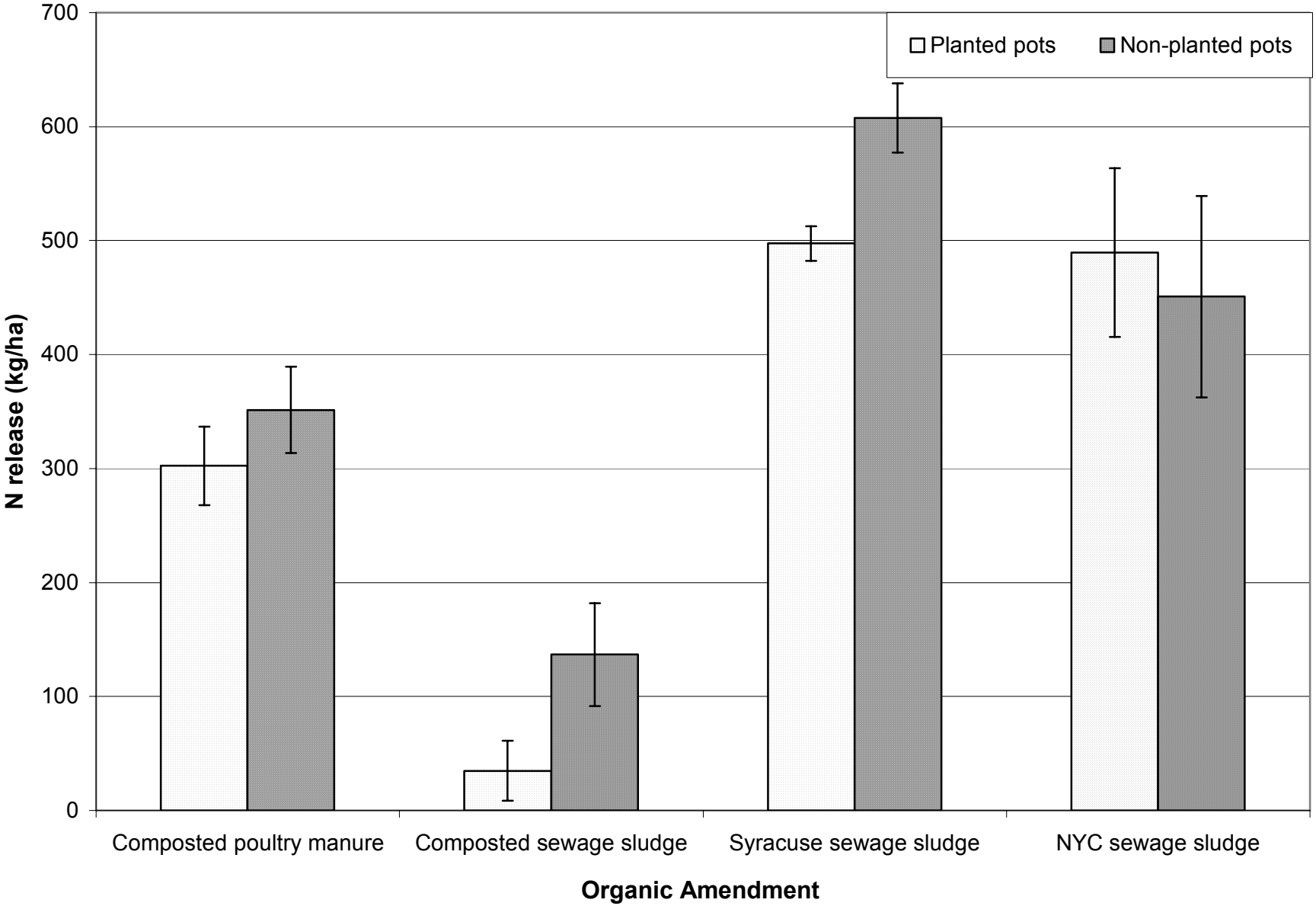

Figure 2.12. Amounts of nitrogen released by decomposition of organic amendments (estimated by means of mass and concentration changes) in the greenhouse study from December 1996 to July 1997. (Each bar represents one standard error).

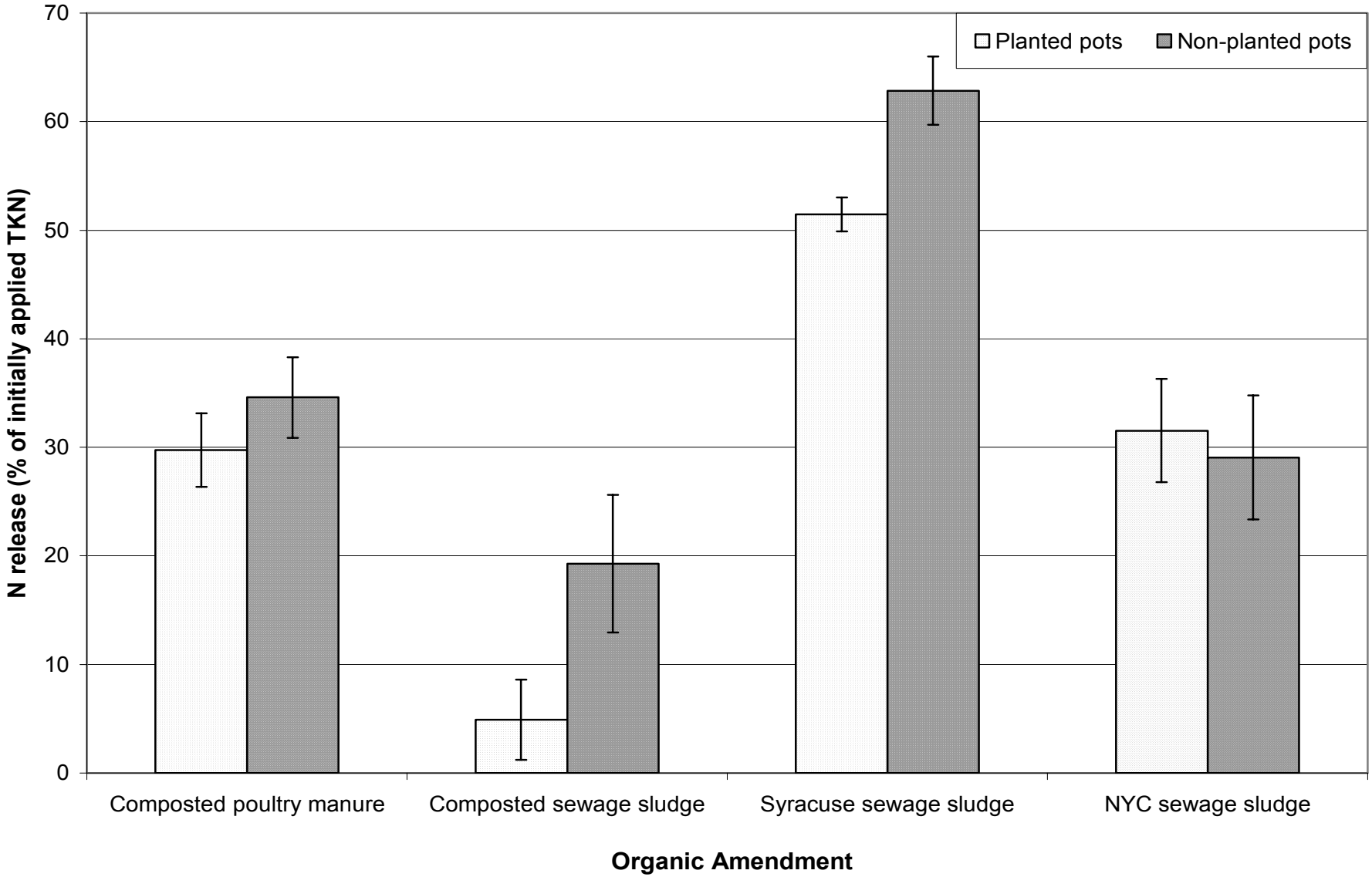

Figure 2.13. Percentage of initial TKN released by decomposition of organic amendments (estimated by means of mass and concentration changes) in the greenhouse study from December 1996 to July 1997. (Each bar represents one standard error).

biomass decreased from an average of 24 to 18%. Various authors have reported the decrease of root biomass proportion, in coppice systems (Dickmann and Pregitzer, 1992). The high proportion of root biomass during the establishment season confirmed the well-known fact that the plants, being raised from cuttings, primarily allocate their production to their root system to get established, before they begin to put on aboveground biomass. The proportion of root biomass observed for the coppice season was similar to that reported by Chapman (1992) who found that roots account for 28% of the total biomass for a one-year shoot on two-year root stock of *Salix purpurea*. Elowson and Rytter (1984) observed that 30% of the total biomass was root biomass for one-year shoot on three-year root of *Salix viminalis*. Ericsson (1984) found that roots accounted for 17% of the total biomass of a two-year shoot on three-year root of *Salix dasyclados*.

During the first season, as proposed by the first hypothesis of this study, organically amended plants produced significantly more stem, foliage and root biomass than non-treated plants (Table 2.6). Nielsen (1994a), Hodson *et al.* (1994) and Teodorescu *et al*. (1993) also found increased willow biomass production following sewage sludge application. Of all organic amendments tested, the NYC sewage sludge had the greatest effect probably due to the fact that its total nitrogen input (1880 kg/ha) was the highest of all amendments examined (because it had the highest density). The minimal growth of the plants during the establishment season might explain why there was no effect of the application rate for the treatments of composted poultry manure and composted sewage sludge, since the plants did not require a great amount of nutrients at that stage.

The comparison of the mode of application of organic amendments (incorporated at planting versus top-dressed on coppice) showed that incorporated treatments had higher stem and leaf biomass than top-dressed treatments (Table 2.10). Incorporating the organic amendments when planting results in higher first year coppice biomass than top-dressing the organic amendments after cutback. This observation indicates that the mode of application of organic residuals does affect coppice biomass production. However, in order to decide between the two practices, one should (1) consider the environmental implications of the practices and (2) address the persistence of differential biomass response over several harvests. Since not much biomass is produced during the establishment year, most of the nutrients made available by the incorporated organic amendment would leach, Table 2.12 showing that as much as 140.8 kg N/ha leached from planted pots with no growth. The advantage of a higher stem and foliar biomass after the first coppice season (with incorporated treatments) is not worth the adverse cost of leaching. Moreover, given a longer coppice rotation length, the effects of top-dressed treatments (more recent treatments) on biomass would persist longer than those of the incorporated treatments, allowing biomass production of the top-dressed treatments to catch up and even surpass the incorporated treatments. Top-dressing of organic amendments after cutback is the most advantageous of the two modes of application investigated. To conclude, it can be said that contrary to the statement of the third hypothesis, the mode of application does affect production: incorporation of organic residuals at planting increases biomass production but it also adversely affects the environment.

With regard to coppice season biomass, there was no difference among the various organic amendments, and also no difference among the various rates of application (Table 2.10). The number of observations (at most two per treatment) and the consequent limited degrees of freedom for the statistical tests made it impossible to thoroughly test the second hypothesis of the study. No correlation could be established between coppice biomass production and the rates of application of organic amendments.

Resin-captured NH_4-N and NO_3-N

Resin-captured NH_4-N

The N leaching data exhibited a high degree of variability probably due to soil disturbance and preferential flow channels created by the installation of the resin columns. The sample size (one column of 6 cm of diameter per pot) was too small in light of the high level of variability. Resin-captured NH_4-N was very low in either planted or non-planted pots. Two different processes can account for these low levels: ammonia volatilization and nitrification. Brady and Weil (1999) wrote that ammonia volatilization is favored by surface application of fertilizers and organic residuals, and alkaline soil conditions. Also nitrification is favored by good soil aeration and moisture, soil temperature ranging from 25 to 35^{0}C, and the abundance of base-forming cations. In this experiment, resin columns were installed in pots of top-dressed treatments and the soil substrate pH was 7.7,

indicating favorable conditions for ammonia volatilization. On the other hand, the temperature inside the greenhouse was maintained around 25^0C, there was good soil drainage and abundance of base-forming cations (Table 2.3) and most of the amendments were basic, indicating favorable conditions for nitrification. Both processes likely contributed to the low levels of resin-captured NH_4-N.

The low amounts of resin-captured NH_4-N associated with the high variability of the data resulted in failure to detect treatment effects for NH_4-N among treatments (Table 2.11). The same reason also accounts for the lack of difference between pots where plants grew and pots where plants did not grow, within treatments (Table 2.13). However comparison between non-planted pots and planted pots where plants grew (Table 2.14) showed a significantly lower NH_4-N in planted pots with growth. This observation indicates that actively growing willow plants reduced NH_4-N leaching. Overall, the data showed that NH_4-N leaching is minimal in every case and should not be a concern when organic residuals are applied to willow crops.

Resin-captured NO_3-N

The NO_3-N data also exhibited a high variability for the same reasons as NH_4-N. Estimates of resin-captured NO_3-N in non-planted pots were high, 104-196 kg N/ha (Figure 2.9). These estimates were indicative of the potential adverse environmental effect that could be caused by the application of organic residuals in the absence of vegetative nutrient uptake. There was no significant difference among the various treatments, probably due to the high variability of the data (Table 2.11). Sample size calculations suggest that in order to detect treatment effects within 20% of observed values at 95% confidence interval, 10-40 samples (depending on the treatment) would be needed.

In planted pots, many of the plants did not grow, complicating analysis of the data. No significant difference could be found between treatments of composted poultry manure and composted sludge that were the only two treatments with enough replicates to allow for statistical testing (Table 2.13). Nevertheless, the low number of replicates limited the capacity to detect a difference. One interesting finding from the comparisons of resin-captured NO_3-N in planted pots was the difference between planted pots where plants did grow and planted pots where plants did not grow. Resin-captured NO_3-N was on average 4.3 kg N/ha in planted pots with willow growth compared to an average of 140.8 kg N/ha in planted pots without willow growth (Table 2.12). A test of the difference between these two groups showed that they were significantly different with regard to NO_3-N leaching (Table 2.13). The significant contrasts between non-planted pots and planted pots with growth (Table 2.14) reinforced the point made above that actively growing plants significantly reduced the risks of NO_3-N leaching. This observation confirmed that leaching of nitrogen from organic residuals applied at rates used in the current study to actively growing willow plants, is minimal and should not be a concern at the various rates applied in the current experiment.

Net contributions of treatments to resin-captured NO_3-N

Control pots where amendments were not applied also had measurable amounts of resin-captured NO_3-N (Figure 2.9). Deducting NO_3-N captured in control from that captured in other treatments gave the net contributions of the treatments (Table 2.15). The raw sludge treatments seemed to have the highest contributions whereas composts and the lime-stabilized sludge treatments had the lowest contributions. The higher contributions of the raw sludge treatments would be attributed to their higher content of readily decomposable organic compounds. In contrast, composts are made up of more stable organic compounds that decompose more slowly. These nitrogen mineralization dynamics are well-documented by various authors (Epstein *et al.* 1978; Castellanos and Pratt, 1981; Bitzer and Sims, 1988; Hadas *et al.*, 1996; Bernal *et al.*, 1998). These authors reported that mineralization of organic N from raw organic residuals has an initial rapid and exponential phase followed by a slow linear release phase, in contrast to mineralization of organic N from composts that might show an initial immobilization of N before the slow release and linear phases. Negative values observed for the net contributions of the treatments of lime-stabilized sewage sludge, composted poultry manure and NH_4-NO_3 fertilizer indicated that variability between resin columns was high. Sims (1990) found that immobilization of N could be a serious problem with the use of composts.

Nitrogen release

Mass loss of organic materials during mineralization

Thirty-six weeks after application of organic amendments in the greenhouse, 20 to 50% of the mass initially applied was decomposed. For either planted pots or non-planted pots, mass decrease was significantly higher in non-compost amendments than in composts (Table 2.16). This could be explained by the fact that sludges have more readily decomposable compounds than composts. The greater mass loss of the Syracuse sludge compared to the NYC sludge probably resulted from the fact that Syracuse sludge was much less dense than NYC sludge (Table 2.2) and could have still contained higher quantities of volatile organic compounds. Composted poultry manure, which had finer particles, also had a greater mass loss than composted sewage sludge that contained more coarse wood debris.

Percent nitrogen release: gross mineralization rate

Percent N release, equivalent to organic N gross mineralization rate, ranged from 4 to 63%. Magdoff and Amadon (1990) also reported large variation (4 to >50%) for N mineralization rate in sludge. The Syracuse sludge treatment had the highest rates (52-63%) consistent with its low C:N ratio (8:1, Table 2.1). Lindemann and Gardenas (1984) observed 56 to 72% of gross mineralization rate for sewage sludge after 32 weeks of incubation. The NYC sludge, with a 10:1 C:N ratio, had mass loss rates of 28 to 32%, close to the 25% rate reported by Parker and Sommers (1983) after 16 weeks of incubation of raw and primary sludge. These observations suggest that gross mineralization rates of sewage sludge are specific to the utilized sludge and the experimental conditions as has been found by many authors (Barbarick *et al.*, 1996; Garau *et al.*, 1986; Chae and Tabatabai, 1986).

Gross N disappearance rates of composted sewage sludge in the current study (C:N ratio = 25:1) ranged from 4 to 18%. Parker and Sommers (1983) found a mineralization rate of 8% for composted sludge incubated at 23^0C for 16 weeks. The composted poultry manure had relatively high N mineralization rates (30-34%) in contrast to what would be suggested by its C:N ratio of 26:1. We can speculate that perhaps there was some physical loss of materials from the rings of composted poultry manure due to the fine size of the particles of that compost, loss that would have caused the observed mass variation to be high. Tyson and Cabrera (1993) observed N mineralization rates of 0.4 to 5.8% for composted poultry manure after 56 days of incubation at 25^0C. Hadas and Portnoy (1994) reported N mineralization rates of 11 to 29% for poultry and dairy manure derived composts incubated during 32 weeks at 30^0C. These observations also suggest that N mineralization rates of composts are specific to the materials utilized and the experimental conditions. As one would expect, on average, non-compost amendments had higher mineralization rates than composts in this study (Table 2.16). The fact that some plants did not grow among the group of planted pots did not allow for the analysis of the effects of plants on gross N mineralization rates.

Gross and available amounts of N release

Gross amounts of nitrogen released by mineralization of organic amendments ranged from 137 to 608 kg N/ha. Non-composted amendments released more N than composted treatments and the composted poultry manure released more N than the composted sewage sludge (Table 2.16). A comparison of the sludges showed that although the Syracuse sludge had the greatest gross N mineralization rate, its N release was not different from that of the NYC sludge because this latter had a higher N loading. It should be stressed here that the amounts reported represent gross N release, accounting for both soil mineral N increase and N loss through volatilization and denitrification. Fine *et al.* (1989) found that as much as 87% of mineralized N could be lost by ammonia volatilization in an experiment with activated sewage sludge. Cabrera *et al.* (1993) observed that 50 to 60% of total N applied in fresh poultry litter was loss through volatilization during the first five weeks of incubation.

In a study of ammonia volatilization from anaerobically digested liquid sludge, Beauchamp *et al.* (1978) observed that 21-22% of total N applied was lost as NH_3 during the first week of decomposition. Assuming and applying the 20% volatilization loss to the current study, volatilization loss would be 376 and 230 kg N/ha respectively for the NYC sludge and the Syracuse sludge. When those figures of loss are deducted from the gross amounts of N release, available amounts of mineral N are found to be on average 80 and 320 kg N/ha respectively for the NYC sludge and the Syracuse sludge.

Brinson *et al.* (1994) observed that 0 to 0.24% of the applied N in composted poultry litter was lost through NH_3 volatilization and they attributed that low rate to the very nature of the composts. Literature data on NH_3 volatilization loss of composted sewage sludge are not available. Assuming that there was no NH_3 loss from both composts in this experiment, net amounts of N release would be, on average, 320 and 90 kg N/ha for the composted poultry manure and the composted sewage sludge treatments respectively. From these observations, it appeared that organic amendments supplied 80 kg/ha or more of net N by decomposition. This supports the hypothesis that organic amendments could provide as much N to biomass crops as the annual rate of 80 kg N/ha recommended by IEA (1995).

CONCLUSION

Organic residuals used as soil amendments and nitrogen sources for pot-grown willow plants significantly increased both above- and below-ground biomass production of the plants. Due to the lack of resprouting of most plants after cutback, the effects of the rates of organic amendments on biomass production could not be assessed. Results of first coppice season biomass showed that incorporating the organic amendments at the time of planting produces greater biomass than top-dressing the organic amendments after the establishment season. However, figures of NO_3-N losses suggest that the incorporation will cause the greater leaching of mineral N during the establishment season.

The investigation of nitrogen leaching with ion-exchange resin showed that ammonium-N leaching is negligible. Nitrate-N leaching in organically amended plots could be significantly high. However, the results obtained in this experiment showed that when the organic amendments are applied to actively growing willow plants, nitrate-N leaching is substantially reduced.

The nitrogen mineralization study showed that the amounts of available nitrogen released by the organic amendments examined in this experiment were equivalent and sometimes greater than the N fertilization rate recommended for short-rotation woody plantations. Applied as top-dressing at the rate of 2.50 cm thick material, the organic amendments investigated in this experiment can be substituted for mineral N fertilizer to grow willow clone SV1 biomass crops.

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APPENDICIES

Appendix 1. Ammonium and nitrate recovery tests of resin

In order to assess the efficiency of the 2M KCl solution in recovering the resin-captured ammonium and nitrate, tests of recovery were performed.

- Ammonium recovery: 1.94 g of ammonium chloride was dissolved in 60 ml of DDW making a solution of 36.26 meq of total NH_4^+. Fifteen milligrams of cation-exchange resin were left to soak in the prepared solution for a total of 8 hours with periodic shakings every 30 minutes. At the end of the soaking period, resin beads and residual solution were separated. Ammonium concentration and content of the residual solution were determined. The residual solution content was deducted from the total content initially in the solution to determine the amount of ammonium theoretically captured by the resin. Then the resin was extracted with 2M KCl and its ammonium concentration and content were determined. The ammonium content thereby determined was compared with the theoretical content previously calculated. The ratio of resin content as determined by analysis, to the resin theoretical content as determined by calculation, was calculated and retained as the recovery efficiency of the 2M KCl extraction method for ammonium. This procedure was repeated two times and yielded an average recovery efficiency of 78.5% (+/- 5% standard deviation). Consequently, all resin extraction results of ammonium were corrected according to that factor.

Nitrate recovery: 2.22 g of potassium nitrate were dissolved in 60 ml of DDW making a solution of 24.45 meq of total NO_3^-. Fifteen milligrams of anion-exchange resin were let to soak in the prepared solution for a total of 8 hours with periodic shakings every 30 minutes. At the end of the soaking period, resin beads and residual solution were separated. Nitrate concentration and content of the residual solution were determined. The residual solution content was deducted from the total content initially in the solution to determine the amount of nitrate theoretically captured by the resin. Then the resin was extracted with 2M KCl and its nitrate concentration and content were determined. The nitrate content thereby determined was compared with the resin theoretical content previously calculated. The ratio of resin content as determined by analysis, to the resin theoretical content as determined by calculation, was calculated and retained as the recovery efficiency of the 2M KCl extraction method for nitrate. This procedure was repeated two times and yielded an average recovery efficiency of 56% (+/- 2% standard deviation). Consequently, all resin extraction results for nitrate were corrected according to that factor.

NH4+ RECOVERY TEST OF ION-EXCHANGE RESIN

	Replicate 1	Replicate 2
Initial total NH4+ content of solution (meq)	36.26	36.26
NH4+ content of residual solution after soaking (meq)	14.95	14.86
Theoretical NH4+ captured by resin (meq)	21.31	21.4
Resin NH4+ recovered with extraction procedure (meq)	17.45	16.04
NH4+ recovery factor (%)	81.87	74.95

Average = 78.5 %
Standard error = 3.5%

NO3- RECOVERY TEST OF ION-EXCHANGE RESIN

	Replicate 1	Replicate 2
Initial total NO3- content of solution (meq)	21.96	21.96
NO3- content of residual solution after soaking (meq)	5.94	5.85
Theoretical NO3- captured by resin (meq)	16.02	16.11
Resin NO3- recovered with extraction procedure (meq)	8.77	9.24
NO3- recovery factor (%)	54.74	57.36

Average = 56%
Standard error = 1.3%

Appendix 2. Stem, foliage and root biomass production during the first growing season in the greenhouse experiment at Lafayette Road Station, Syracuse, NY.

Treatment	Mode	Rate	Replicate	Leaf Biomass (g)	Stem Biomass (g)	Root Biomass (g)	Total (g)
NYC sewage sludge	Incorporated	2.5 cm	A	15.71	15.94	27.36	59.01
NYC sewage sludge	Incorporated	2.5 cm	B	22.16	25.76		
NYC sewage sludge	Incorporated	2.5 cm	C	18.85	21.07	47.9	87.82
NYC sewage sludge	Incorporated	2.5 cm	D	21.67	27.41		
NYC sewage sludge	Incorporated	2.5 cm	E	25.21	35.42	59.18	119.81
NYC sewage sludge	Incorporated	2.5 cm	F	32.6	47.35		
NYC sewage sludge	Incorporated	2.5 cm	G	29.42	34.48	65.2	129.1
NYC sewage sludge	Incorporated	2.5 cm	H	28.46	38.25		
NYC sewage sludge	Top-dressed	2.5 cm	A	11.79	14.23	22.71	48.73
NYC sewage sludge	Top-dressed	2.5 cm	B	10.93	10.08		
NYC sewage sludge	Top-dressed	2.5 cm	C	8.26	7.23	15.76	31.25
NYC sewage sludge	Top-dressed	2.5 cm	D	11.1	15.79		
NYC sewage sludge	Top-dressed	2.5 cm	E	13.13	12.89	25.12	51.14
NYC sewage sludge	Top-dressed	2.5 cm	F	7.44	8.94		
NYC sewage sludge	Top-dressed	2.5 cm	G	16.12	19.62	31.98	67.72
NYC sewage sludge	Top-dressed	2.5 cm	H	13.18	14.19		
Syracuse sewage sludge	Incorporated	2.5 cm	A	12.1	11.38	27.38	50.86
Syracuse sewage sludge	Incorporated	2.5 cm	B	15.04	19.65		
Syracuse sewage sludge	Incorporated	2.5 cm	C	16.62	17.65	31.6	65.87
Syracuse sewage sludge	Incorporated	2.5 cm	D	10.83	12.53		
Syracuse sewage sludge	Incorporated	2.5 cm	E	7.51	6.43	17.32	31.26
Syracuse sewage sludge	Incorporated	2.5 cm	F	22.62	22.8		
Syracuse sewage sludge	Incorporated	2.5 cm	G	30.3	42.07	55.81	128.18
Syracuse sewage sludge	Incorporated	2.5 cm	H	16.25	17.58		
Syracuse sewage sludge	Top-dressed	2.5 cm	A	8.12	8.91	16.21	33.24
Syracuse sewage sludge	Top-dressed	2.5 cm	B	11.87	15.12		
Syracuse sewage sludge	Top-dressed	2.5 cm	C	10.13	9.95	20.33	40.41
Syracuse sewage sludge	Top-dressed	2.5 cm	D	10.86	11.18		
Syracuse sewage sludge	Top-dressed	2.5 cm	E	13.51	17.37	25.36	56.24
Syracuse sewage sludge	Top-dressed	2.5 cm	F	16.16	20.27		
Syracuse sewage sludge	Top-dressed	2.5 cm	G	14.61	16.33	27.07	58.01
Syracuse sewage sludge	Top-dressed	2.5 cm	H	7.7	7.18		
Composted sewage sludge	Incorporated	1.25 cm	A	17.53	24.76	45.85	88.14
Composted sewage sludge	Incorporated	1.25 cm	B	10.42	12.77		
Composted sewage sludge	Incorporated	1.25 cm	C	16.68	21.06	51.97	89.71
Composted sewage sludge	Incorporated	1.25 cm	D	11.08	12.78		
Composted sewage sludge	Incorporated	1.25 cm	E	15.94	19.89	31.48	67.31
Composted sewage sludge	Incorporated	1.25 cm	F	18.88	23.96		
Composted sewage sludge	Incorporated	1.25 cm	G	11.82	12.45	23	47.27
Composted sewage sludge	Incorporated	1.25 cm	H	8.96	8.03		
Composted sewage sludge	Top-dressed	1.25 cm	A	9.6	10.79	19.63	40.02
Composted sewage sludge	Top-dressed	1.25 cm	B	14.91	20.92		
Composted sewage sludge	Top-dressed	1.25 cm	C	6.95	6.08	18.48	31.51
Composted sewage sludge	Top-dressed	1.25 cm	D	11.28	11.56		
Composted sewage sludge	Top-dressed	1.25 cm	E	15.14	18.49	41.53	75.16

Appendix 2. cont'd.

Treatment	Mode	Rate	Replicate	Leaf Biomass (g)	Stem Biomass (g)	Root Biomass (g)	Total (g)
Composted sewage sludge	Top-dressed	1.25 cm	F	12.72	14.72		
Composted sewage sludge	Top-dressed	1.25 cm	G	13.3	16.98	26.96	57.24
Composted sewage sludge	Top-dressed	1.25 cm	H	12.28	15.24		
Composted sewage sludge	Incorporated	2.5 cm	A	16.52	20.55	33.09	70.16
Composted sewage sludge	Incorporated	2.5 cm	B	17.41	20.94		
Composted sewage sludge	Incorporated	2.5 cm	C	5.34	5.24	14.41	24.99
Composted sewage sludge	Incorporated	2.5 cm	D	15.87	19.19		
Composted sewage sludge	Incorporated	2.5 cm	E	14.14	16.29	24.75	55.18
Composted sewage sludge	Incorporated	2.5 cm	F	15	16.63		
Composted sewage sludge	Incorporated	2.5 cm	G	13.6	15.05	31.34	59.99
Composted sewage sludge	Incorporated	2.5 cm	H	18.9	26.96		
Composted sewage sludge	Top-dressed	2.5 cm	A	14.76	16.63	30.31	61.7
Composted sewage sludge	Top-dressed	2.5 cm	B	6.32	5.51		
Composted sewage sludge	Top-dressed	2.5 cm	C	5.55	3.79	11.82	21.16
Composted sewage sludge	Top-dressed	2.5 cm	D	6.91	6.2		
Composted sewage sludge	Top-dressed	2.5 cm	E	9.03	8.99	19.47	37.49
Composted sewage sludge	Top-dressed	2.5 cm	F	8.22	8.51		
Composted sewage sludge	Top-dressed	2.5 cm	G	9.13	10.6	17.58	37.31
Composted sewage sludge	Top-dressed	2.5 cm	H	9.81	10.07		
Composted sewage sludge	Incorporated	3.75 cm	A	17.98	24.31	60.12	102.41
Composted sewage sludge	Incorporated	3.75 cm	B	12.76	13.66		
Composted sewage sludge	Incorporated	3.75 cm	C	15.95	20.7	24.19	60.84
Composted sewage sludge	Incorporated	3.75 cm	D	13.68	17.49		
Composted sewage sludge	Incorporated	3.75 cm	E	20.51	25.3	39.36	85.17
Composted sewage sludge	Incorporated	3.75 cm	F	16.78	19.59		
Composted sewage sludge	Incorporated	3.75 cm	G	9.81	9.22	22.67	41.7
Composted sewage sludge	Incorporated	3.75 cm	H	18.56	26.48		
Composted sewage sludge	Top-dressed	3.75 cm	A	5.84	3.91	10.43	20.18
Composted sewage sludge	Top-dressed	3.75 cm	B	7.1	6.48		
Composted sewage sludge	Top-dressed	3.75 cm	C	11.17	11.37	26.81	49.35
Composted sewage sludge	Top-dressed	3.75 cm	D	7.45	6.95		
Composted sewage sludge	Top-dressed	3.75 cm	E	12.2	14.27	19.06	45.53
Composted sewage sludge	Top-dressed	3.75 cm	F	19.53	25.78		
Composted sewage sludge	Top-dressed	3.75 cm	G	11.31	14.55	37.68	63.54
Composted sewage sludge	Top-dressed	3.75 cm	H	11.31	12.76		
Composted poultry manure	Incorporated	1.25 cm	A	15.43	19.96	27.35	62.74
Composted poultry manure	Incorporated	1.25 cm	B	24.67	32.3		
Composted poultry manure	Incorporated	1.25 cm	C	16.02	17.96	36.11	70.09
Composted poultry manure	Incorporated	1.25 cm	D	17.39	24.61		
Composted poultry manure	Incorporated	1.25 cm	E	12.9	14.47	22	49.37
Composted poultry manure	Incorporated	1.25 cm	F	21.87	29.03		
Composted poultry manure	Incorporated	1.25 cm	G	21.37	27.37	49.93	98.67
Composted poultry manure	Incorporated	1.25 cm	H	20.21	29.63		
Composted poultry manure	Top-dressed	1.25 cm	A	8.67	9.36	20.32	38.35
Composted poultry manure	Top-dressed	1.25 cm	B	13.51	16.59		

Appendix 2. cont'd.

Treatment	Mode	Rate	Replicate	Leaf Biomass (g)	Stem Biomass (g)	Root Biomass (g)	Total (g)
Composted poultry manure	Top-dressed	1.25 cm	C	5.41	4.2	10.09	19.7
Composted poultry manure	Top-dressed	1.25 cm	D	5.13	5.14		
Composted poultry manure	Top-dressed	1.25 cm	E	10.88	10.65	21.48	43.01
Composted poultry manure	Top-dressed	1.25 cm	F	3.47	2.46		
Composted poultry manure	Top-dressed	1.25cm	G	14.24	17.92	28.82	60.98
Composted poultry manure	Top-dressed	1.25 cm	H	8.72	8.63		
Composted poultry manure	Incorporated	2.5 cm	A	25.58	39.35	75.47	140.4
Composted poultry manure	Incorporated	2.5 cm	B	20.97	26.85		
Composted poultry manure	Incorporated	2.5 cm	C	18.82	21.13	52.09	92.04
Composted poultry manure	Incorporated	2.5 cm	D	9.43	10.43		
Composted poultry manure	Incorporated	2.5 cm	E	23.69	30.23	42.52	96.44
Composted poultry manure	Incorporated	2.5 cm	F	22.77	30.62		
Composted poultry manure	Incorporated	2.5 cm	G	9.35	10.91	23.2	43.46
Composted poultry manure	Incorporated	2.5 cm	H	20.43	27.49		
Composted poultry manure	Top-dressed	2.5 cm	A	13.12	14.55	32.7	60.37
Composted poultry manure	Top-dressed	2.5 cm	B	7.03	6.23		
Composted poultry manure	Top-dressed	2.5 cm	C	10.21	10.69	18.34	39.24
Composted poultry manure	Top-dressed	2.5 cm	D	7.39	9.38		
Composted poultry manure	Top-dressed	2.5 cm	E	14.07	12.88	32.35	59.3
Composted poultry manure	Top-dressed	2.5 cm	F	9.75	9.72		
Composted poultry manure	Top-dressed	2.5 cm	G	8.52	9.14	15.78	33.44
Composted poultry manure	Top-dressed	2.5 cm	H	6.03	7.15		
Composted poultry manure	Incorporated	3.75 cm	A	17.56	19.22	35.12	71.9
Composted poultry manure	Incorporated	3.75 cm	B	28.44	39.79		
Composted poultry manure	Incorporated	3.75 cm	C	4.58	4.63	5.23	14.44
Composted poultry manure	Incorporated	3.75 cm	D	13.97	15.12		
Composted poultry manure	Incorporated	3.75 cm	E	14.82	17.11	34.5	66.43
Composted poultry manure	Incorporated	3.75 cm	F	22.48	31.21		
Composted poultry manure	Incorporated	3.75 cm	G	26.53	36.93	57.05	120.51
Composted poultry manure	Incorporated	3.75 cm	H	26.02	36.87		
Composted poultry manure	Top-dressed	3.75 cm	A	13.38	16.43	30.75	60.56
Composted poultry manure	Top-dressed	3.75 cm	B	17.43	21.89		
Composted poultry manure	Top-dressed	3.75 cm	C	7.86	6.51	16.73	31.1
Composted poultry manure	Top-dressed	3.75 cm	D	4.49	3.91		
Composted poultry manure	Top-dressed	3.75 cm	E	10	9.42	18.22	37.64
Composted poultry manure	Top-dressed	3.75 cm	F	13.37	14.86		
Composted poultry manure	Top-dressed	3.75 cm	G	15.52	19.87	30.07	65.46
Composted poultry manure	Top-dressed	3.75 cm	H	11.66	15.34		
Lime-stabilized sludge	Top-dressed	2.5 cm	A	10.98	11.46	21.48	43.92
Lime-stabilized sludge	Top-dressed	2.5 cm	B	10.53	10.7		
Lime-stabilized sludge	Top-dressed	2.5 cm	C	10.93	12.42	20.84	44.19
Lime-stabilized sludge	Top-dressed	2.5 cm	D	6.91	7.5		
Lime-stabilized sludge	Top-dressed	2.5 cm	E	13.72	13.6	29.34	56.66
Lime-stabilized sludge	Top-dressed	2.5 cm	F	10.36	10.03		
Lime-stabilized sludge	Top-dressed	2.5 cm	G	10.91	12.89	20.33	44.13

Appendix 2. cont'd.

Treatment	Mode	Rate	Replicate	Leaf Biomass (g)	Stem Biomass (g)	Root Biomass (g)	Total (g)
Lime-stabilized sludge	Top-dressed	2.5 cm	H	8.27	9.51		
NH4-NO3 fertilizer	Top-dressed	200 kg N	A	12.1	16.03	19.28	47.41
NH4-NO3 fertilizer	Top-dressed	200 kg N	B	15.82	21.57		
NH4-NO3 fertilizer	Top-dressed	200 kg N	C	11.15	13.5	24.21	48.86
NH4-NO3 fertilizer	Top-dressed	200 kg N	D	10.09	11.44		
NH4-NO3 fertilizer	Top-dressed	200 kg N	E	5.45	7.86	13.88	27.19
NH4-NO3 fertilizer	Top-dressed	200 kg N	F	10.1	9.71		
NH4-NO3 fertilizer	Top-dressed	200 kg N	G	14.89	20.53	31.58	67
NH4-NO3 fertilizer	Top-dressed	200 kg N	H	9.01	14.79		
Slow-release N fertilizer	Top-dressed	200 kg N	A	11.68	16.27	24.13	52.08
Slow-release N fertilizer	Top-dressed	200 kg N	B	9.51	9.01		
Slow-release N fertilizer	Top-dressed	200 kg N	C	6.99	6.23	14.49	27.71
Slow-release N fertilizer	Top-dressed	200 kg N	D	5.9	6.01		
Slow-release N fertilizer	Top-dressed	200 kg N	E	10.46	9.59	17.1	37.15
Slow-release N fertilizer	Top-dressed	200 kg N	F	9.45	12.22		
Slow-release N fertilizer	Top-dressed	200 kg N	G	9.59	11.45	21.54	42.58
Slow-release N fertilizer	Top-dressed	200 kg N	H	11.7	16.8		
Control	-	-	A	7.75	6.45	11.94	26.14
Control	-	-	B	10.23	9.71		
Control	-	-	C	4.23	3.17	7.99	15.39
Control	-	-	D	9.71	10.72		
Control	-	-	E	13.45	13.84	34.73	62.02
Control	-	-	F	8.98	11.22		
Control	-	-	G	12.18	15.44	21.34	48.96
Control	-	-	H	8.53	10.3		

Appendix 3. Stem, foliage and root biomass production during the second growing season in the greenhouse experiment at Lafayette Road Station, Syracuse, NY.

Treatment	Mode	Rate	Replicate	Leaf Biomass (g)	Stem Biomass (g)	Root Biomass (g)
NYC sewage sludge	Incorporated	2.5 cm	B	0	0	39.55
NYC sewage sludge	Incorporated	2.5 cm	D	0	0	24.98
NYC sewage sludge	Incorporated	2.5 cm	F	0	0	66.85
NYC sewage sludge	Incorporated	2.5 cm	H	0	0	52.38
NYC sewage sludge	Top-dressed	2.5 cm	B	0	0	37.3
NYC sewage sludge	Top-dressed	2.5 cm	D	0	0	19.57
NYC sewage sludge	Top-dressed	2.5 cm	F	0	0	-
NYC sewage sludge	Top-dressed	2.5 cm	H	0	0	20.28
Syracuse sewage sludge	Incorporated	2.5 cm	B	0	0	21.5
Syracuse sewage sludge	Incorporated	2.5 cm	D	0	0	11.83
Syracuse sewage sludge	Incorporated	2.5 cm	F	0	0	43.39
Syracuse sewage sludge	Incorporated	2.5 cm	H	110.84	303.8	123.41
Syracuse sewage sludge	Top-dressed	2.5 cm	B	0	0	59.81
Syracuse sewage sludge	Top-dressed	2.5 cm	D	51.98	135.41	32.67
Syracuse sewage sludge	Top-dressed	2.5 cm	F	0	0	-
Syracuse sewage sludge	Top-dressed	2.5 cm	H	0	0	18.88
Composted sewage sludge	Incorporated	1.25 cm	B	0	0	16.43
Composted sewage sludge	Incorporated	1.25 cm	D	56.27	156.22	58.97
Composted sewage sludge	Incorporated	1.25 cm	F	0	0	27.61
Composted sewage sludge	Incorporated	1.25 cm	H	0	0	17.2
Composted sewage sludge	Top-dressed	1.25 cm	B	0	0	28.11
Composted sewage sludge	Top-dressed	1.25 cm	D	0	0	31.38
Composted sewage sludge	Top-dressed	1.25 cm	F	59.51	133.45	62.64
Composted sewage sludge	Top-dressed	1.25 cm	H	0	0	22.26
Composted sewage sludge	Incorporated	2.5 cm	B	77.28	315.16	141.28
Composted sewage sludge	Incorporated	2.5 cm	D	51.56	168.35	134.64
Composted sewage sludge	Incorporated	2.5 cm	F	0	0	40.36
Composted sewage sludge	Incorporated	2.5 cm	H	0	0	-
Composted sewage sludge	Top-dressed	2.5 cm	B	61.13	186.42	92.14
Composted sewage sludge	Top-dressed	2.5 cm	D	67.22	165.94	76.1
Composted sewage sludge	Top-dressed	2.5 cm	F	57.09	119.09	-
Composted sewage sludge	Top-dressed	2.5 cm	H	0	0	18.51
Composted sewage sludge	Incorporated	3.75 cm	B	86.85	295.4	105.55
Composted sewage sludge	Incorporated	3.75 cm	D	0	0	20.09
Composted sewage sludge	Incorporated	3.75 cm	F	95.87	278.44	165.07
Composted sewage sludge	Incorporated	3.75 cm	H	0	0	27.71
Composted sewage sludge	Top-dressed	3.75 cm	B	0	0	16.93
Composted sewage sludge	Top-dressed	3.75 cm	D	54.23	105.86	-
Composted sewage sludge	Top-dressed	3.75 cm	F	0	0	58.65
Composted sewage sludge	Top-dressed	3.75 cm	H	0	0	73.34
Composted poultry manure	Incorporated	1.25 cm	B	115.5	421.96	99.14
Composted poultry manure	Incorporated	1.25 cm	D	0	0	22.65
Composted poultry manure	Incorporated	1.25 cm	F	0	0	29
Composted poultry manure	Incorporated	1.25 cm	H	0	0	29.98
Composted poultry manure	Top-dressed	1.25 cm	B	0	0	19.4

Appendix 3. cont'd.

Treatment	Mode	Rate	Replicate	Leaf Biomass (g)	Stem Biomass (g)	Root Biomass (g)
Composted poultry manure	Top-dressed	1.25 cm	D	32.85	106.72	34.6
Composted poultry manure	Top-dressed	1.25 cm	F	54.64	117.26	154.37
Composted poultry manure	Top-dressed	1.25 cm	H	0	0	29.73
Composted poultry manure	Incorporated	2.5 cm	B	0	0	30.54
Composted poultry manure	Incorporated	2.5 cm	D	0	0	22.36
Composted poultry manure	Incorporated	2.5 cm	F	0	0	24.76
Composted poultry manure	Incorporated	2.5 cm	H	0	0	42.09
Composted poultry manure	Top-dressed	2.5 cm	B	81.18	220.39	174.8
Composted poultry manure	Top-dressed	2.5 cm	D	65.35	168.73	60.06
Composted poultry manure	Top-dressed	2.5 cm	F	39.95	128.8	-
Composted poultry manure	Top-dressed	2.5 cm	H	0	0	16.68
Composted poultry manure	Incorporated	3.75 cm	B	0	0	31.25
Composted poultry manure	Incorporated	3.75 cm	D	0	0	17.77
Composted poultry manure	Incorporated	3.75 cm	F	0	0	31.26
Composted poultry manure	Incorporated	3.75 cm	H	0	0	29.8
Composted poultry manure	Top-dressed	3.75 cm	B	0	0	24.91
Composted poultry manure	Top-dressed	3.75 cm	D	0	0	11.62
Composted poultry manure	Top-dressed	3.75 cm	F	0	0	36.76
Composted poultry manure	Top-dressed	3.75 cm	H	0	0	19.6
Lime-stabilized sludge	Top-dressed	2.5 cm	B	0	0	19.85
Lime-stabilized sludge	Top-dressed	2.5 cm	D	0	0	17.08
Lime-stabilized sludge	Top-dressed	2.5 cm	F	79.25	228.6	164.04
Lime-stabilized sludge	Top-dressed	2.5 cm	H	0	0	16.93
NH4-NO3 fertilizer	Top-dressed	200 kg N	B	78.91	336.31	195.78
NH4-NO3 fertilizer	Top-dressed	200 kg N	D	0	0	18.81
NH4-NO3 fertilizer	Top-dressed	200 kg N	F	0	0	-
NH4-NO3 fertilizer	Top-dressed	200 kg N	H	0	0	31.1
Slow-release N fertilizer	Top-dressed	200 kg N	B	0	0	39.63
Slow-release N fertilizer	Top-dressed	200 kg N	D	0	0	-
Slow-release N fertilizer	Top-dressed	200 kg N	F	0	0	-
Slow-release N fertilizer	Top-dressed	200 kg N	H	0	0	40.97
Control	-	-	B	39.53	138.77	65.27
Control	-	-	D	0	0	31.48
Control	-	-	F	0	0	-
Control	-	-	H	0	0	16.46

Appendix 4. Mass loss and nitrogen release by decomposition of organic residuals in the greenhouse experiment at Lafayette Road Station, Syracuse, NY (non-planted pots).

Treatment	Replicate	Initial mass Applied (o.d.g/ring)	Final mass Collected (o.d.g/ring)	Initial N (%)	Final N (%)	Mass Loss (%)	Mass Loss (kg/ha)	Nitrogen Release (kg/ha)	Nitrogen Release (% of Applied TKN)
NON-PLANTED POTS									
Composted poultry manure	AA	27.04	13.76	1.47	1.85	49.1	34004.59	365.69	35.99
Composted poultry manure	BB	27.08	14.54	1.47	1.96	46.3	32063.2	288.22	28.37
Composted poultry manure	CC	27.09	14.75	1.47	1.9	45.56	31549.01	299.26	29.45
Composted poultry manure	DD	27.07	14.38	1.47	1.53	46.88	32461.24	452.52	44.54
Composted sewage sludge	AA	20.15	15.07	1.37	1.81	25.21	13047.88	8.88	1.25
Composted sewage sludge	BB	20.21	15	1.37	1.28	25.78	13339.96	219.72	30.95
Composted sewage sludge	CC	20.16	14.68	1.37	1.44	27.18	14067.82	167.98	23.66
Composted sewage sludge	DD	20.17	14.55	1.37	1.5	27.86	14419.71	150.8	21.24
Syracuse sewage sludge	AA	10.01	4.78	3.75	2.86	52.25	13453.8	615.34	63.64
Syracuse sewage sludge	BB	10.09	4.65	3.75	2.67	53.91	13880.7	649.81	67.21
Syracuse sewage sludge	CC	10	4.61	3.75	2.7	53.89	13876.88	645.82	66.8
Syracuse sewage sludge	DD	10.06	5.25	3.75	3.33	47.83	12317.22	519.58	53.74
NYC sewage sludge	AA	18.09	13.18	3.32	2.77	27.14	12688.41	606.98	39.13
NYC sewage sludge	BB	18.19	14.52	3.32	3.32	20.18	9434.62	312	20.11
NYC sewage sludge	CC	18.04	12.27	3.32	2.99	31.98	14952.83	600.3	38.7
NYC sewage sludge	DD	18.3	14.47	3.32	3.43	20.91	9777.68	284.05	18.31

Appendix 5. Mass loss and nitrogen release by decomposition of organic residuals in the greenhouse experiment at Lafayette Road Station, Syracuse, NY (planted pots).

Treatment	Replicate	Initial mass Applied (o.d.g/ring)	Final mass Collected (o.d.g/ring)	Initial N (%)	Final N (%)	Mass Loss (%)	Mass Loss (kg/ha)	Nitrogen Release (kg/ha)	Nitrogen Release (% of Applied TKN)
PLANTED POTS									
Composted poultry manure	B	27.04	15.24	1.47	1.92	43.65	30225.53	268.64	26.44
Composted poultry manure	D	27.07	13.85	1.47	1.9	48.83	33817.16	344.37	33.89
Composted poultry manure	F	27.08	14.25	1.47	2.18	47.39	32815.95	222.92	21.94
Composted poultry manure	H	27	13.28	1.47	1.89	50.82	35192.66	373.31	36.74
Composted sewage sludge	B	20.19	16.38	1.37	1.43	18.87	9765.44	110.47	15.56
Composted sewage sludge	D	20.17	16.62	1.37	1.67	17.58	9098.41	-0.57	-0.08
Composted sewage sludge	F	20.17	16.37	1.37	1.69	18.82	9739.98	-0.46	-0.07
Composted sewage sludge	H	20.21	14.84	1.37	1.79	26.59	13758.9	30.04	4.23
Syracuse sewage sludge	B	10.09	5.6	3.75	3.19	44.48	11452.95	510.5	52.8
Syracuse sewage sludge	D	10.03	6.49	3.75	3.05	35.32	9094.88	459.01	47.47
Syracuse sewage sludge	F	10.09	6.23	3.75	2.75	38.24	9847.69	529.89	54.81
Syracuse sewage sludge	H	10.17	6.13	3.75	3.07	39.74	10232.16	490.62	50.74
NYC sewage sludge	B	18.37	14.57	3.32	3.16	20.7	9677.36	380.26	24.51
NYC sewage sludge	D	18.21	13.88	3.32	3.38	23.77	11111.82	347.85	22.43
NYC sewage sludge	F	18.04	12.14	3.32	3.09	32.71	15289.72	579.55	37.36
NYC sewage sludge	H	18.3	12.44	3.32	2.84	32.01	14964.54	649.6	41.88

Appendix 6. Resin-captured ammonium-N and nitrate-N in the greenhouse experiment at Lafayette Road Station, Syracuse, NY.

Treatment	Non-planted Pots			Planted Pots		
	Replicate	Nitrate-N (kg/ha)	Ammonium-N (kg/ha)	Replicate	Nitrate-N (kg/ha)	Ammonium-N (kg/ha)
Control	AA	137.26	0.64	B	2.43	0.26
Control	BB	125.95	0.6	D	86.09	1.65
Control	CC	109.82	0.16	F	107.43	0.93
Control	DD	129.23	0.24	H	108.58	1.99
Lime-stabilized sludge	AA	142.66	0.32	B	145.21	0.71
Lime-stabilized sludge	BB	86.73	0.5	D	212.66	3.48
Lime-stabilized sludge	CC	104.62	0.44	F	-1.23	0.75
Lime-stabilized sludge	DD	109.25	0.39	H	83.58	1.11
NH4-NO3 fertilizer	AA	212.46	0.54	B	-1.23	0.87
NH4-NO3 fertilizer	BB	88.93	1.59	D	121.64	2.75
NH4-NO3 fertilizer	CC	80.72	0.39	F	247.8	1.25
NH4-NO3 fertilizer	DD	81.68	0.58	H	66.49	0.5
Slow-release N fertilizer	AA	194.77	0.35	B	117.86	0.5
Slow-release N fertilizer	BB	316.98	0.86	D	90.12	1.31
Slow-release N fertilizer	CC	101.68	0.4	F	297.71	0.86
Slow-release N fertilizer	DD	85.25	0.62	H	132.52	0.74
NYC sewage sludge	AA	89.41	1.17	B	149.59	1.48
NYC sewage sludge	BB	90.87	3.34	D	147.23	0.69
NYC sewage sludge	CC	209.2	0.46	F	124.31	1.08
NYC sewage sludge	DD	168.39	0.91	H	171.64	1.11
Composted poultry manure	AA	99.77	0.85	B	-	1.7
Composted poultry manure	BB	72.38	0.44	D	0.89	0.65
Composted poultry manure	CC	66.01	1.36	F	23.26	2.3
Composted poultry manure	DD	177.11	1.18	H	97.11	1.17
Composted sewage sludge	AA	105.55	0.82	B	10.23	1.57
Composted sewage sludge	BB	144.86	0.27	D	0.17	1.15
Composted sewage sludge	CC	191.52	1.13	F	1.97	2.04
Composted sewage sludge	DD	87.32	0.37	H	176.68	1.18
Syracuse sewage sludge	AA	146.76	1.31	B	191.66	0.92
Syracuse sewage sludge	BB	295.05	0.86	D	-1.44	1.2
Syracuse sewage sludge	CC	157.45	0.39	F	-	0.53
Syracuse sewage sludge	DD	183.44	0.63	H	79.98	3.52

Appendix 7. Stem biomass production (o.d.t/ha) of willow clone SV1 in the field study at Tully, NY.

Treatment	Block	Year-1 (1996)	Year-2 (1997)	Year-3 (1998)
Control	1	5.06	11.28	22.5
Control	2	6.41	15.85	26.85
Control	3	5.6	13.47	26.09
100N	1	12.35	22.51	35.36
100N	2	7.75	16.64	26.93
100N	3	12.47	19.74	32.19
200N	1	8.12	16.98	26.1
200N	2	8.69	17.64	25.94
200N	3	11.99	19.47	29.37
300N	1	12.75	21.84	27.69
300N	2	14.21	25.02	38.25
300N	3	12.69	23.44	34.58
Plastic Mulch	1	5.68	12.4	20.78
Plastic Mulch	2	8.7	19.22	29.55
Plastic Mulch	3	4.3	12.16	22.08
Lime-stabilized sludge	1	14.29	25.89	39.12
Lime-stabilized sludge	2	9.31	19.45	28.61
Lime-stabilized sludge	3	11.39	20.37	30.77
Lime-stabilized sludge + plastic mulch	1	12.14	20.62	35.5
Lime-stabilized sludge + plastic mulch	2	12.61	23.21	37.42
Lime-stabilized sludge + plastic mulch	3	9.51	20.99	31.11
Composted poultry manure	1	10.78	22.69	32.53
Composted poultry manure	2	12.93	25.83	38.41
Composted poultry manure	3	10.49	21.03	33.52

Appendix 8. Resin-captured nitrate-N in the field study at Tully, NY.

Treatment	Block	Year-1 (1996)	Year-2 (1997)	Year-3 (1998)
Control	1	-1.23	79.76	123.11
Control	2	57.59	4.31	39.99
Control	3	25.96	20.62	208.87
100N	1	29.54	55.66	53.03
100N	2	407.08	96.28	118.8
100N	3	349.49	57.66	17.78
200N	1	492.6	884.95	161.63
200N	2	258.52	50.72	33.25
200N	3	259.53	153.21	71.24
300N	1	107.18	133.95	44.41
300N	2	200.32	295.37	26.73
300N	3	57.14	48.4	12.84
Lime-stabilized sludge	1	467.58	220.13	44.19
Lime-stabilized sludge	2	459.31	118.59	167.94
Lime-stabilized sludge	3	206.69	236.55	167.31
Composted poultry manure	1	16.51	231.6	114.91
Composted poultry manure	2	54.17	260.12	292.21
Composted poultry manure	3	69.07	318.41	95.12

Appendix 9. 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.

SOP No. 1
8/98

Appendix 10. 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 content and moisture content determination.
6) As soon as possible after chipping: weigh the bag of chips, to two decimal places using a digital scale (e.g., Metler 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°C to a constant temperature (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 (2mm) sieve.
10) After grinding, split the sample (as many times as needed) to fit into the small brown/clear sample bottles; be sure to label bottles.
11) Follow lab procedures for nutrient analyses.

SOP No. 3
11/98

Appendix 11. Initial and final ammonium-N and nitrate-N measured in organic residuals, sand, soil solution and resin in the growth-chamber experiment at Warren, PA.

Treatment	Temperature (degree C)	Replicate	Initial TKN Applied (g)	Initial NO3-N In Sand (mg)	Final NO3-N In Solution (mg)	Final NO3-N In Sand (mg)	Final NO3-N In Resin (mg)	Initial NH4-N In Sand (mg)	Final NH4-N In Solution (mg)	Final NH4-N In Sand (mg)	Final NH4-N In Resin (mg)
Composted poultry manure	10	A	0.39	0	0.005	0	0.726	4.658	0.263	7.832	4.409
Composted poultry manure	10	B	0.39	0	0.012	0	0.524	4.658	0.299	5.363	4.506
Composted poultry manure	10	C	0.39	0	0.007	0	0.645	4.658	0.111	6.632	4.1
Sewage sludge	10	A	0.48	0	0.005	0	1.21	4.658	1.071	13.907	2.829
Sewage sludge	10	B	0.48	0	0.004	0	0.887	4.658	0.407	25.182	4.21
Sewage sludge	10	C	0.48	0	0.006	0	1.169	4.658	0.75	23.23	2.04
Control	10	A	-	0	0.003	0	0.524	4.658	0.154	3.406	1.101
Control	10	B	-	0	0.01	0	0.323	4.658	0.241	2.009	1.055
Control	10	C	-	0	0.006	0	0.726	4.658	0.171	1.818	0.973
Composted poultry manure	20	A	0.39	0	0.018	0	6.935	4.658	0.955	6.449	3.534
Composted poultry manure	20	B	0.39	0	0.025	0	3.75	4.658	0.83	4.16	3.762
Composted poultry manure	20	C	0.39	0	0.044	0	5.605	4.658	0.461	8.879	5.592
Sewage sludge	20	A	0.48	0	0.006	0	2.903	4.658	0.844	15.337	3.495
Sewage sludge	20	B	0.48	0	0.067	0	2.661	4.658	1.007	18.999	3.913
Sewage sludge	20	C	0.48	0	0.057	0	1.694	4.658	0.857	8.665	4.4
Control	20	A	-	0	0.025	0	1.129	4.658	0.021	2.709	1.078
Control	20	B	-	0	0.056	0	1.008	4.658	0.103	2.414	1.369
Control	20	C	-	0	0.139	0	0.806	4.658	0.086	2.139	1.118
Composted poultry manure	30	A	0.4	0	0.084	0	5.484	0.633	4.729	3.266	3.607
Composted poultry manure	30	B	0.4	0	0.077	0	5.605	0.633	2.253	2.263	4.685
Composted poultry manure	30	C	0.4	0	0.11	0	4.556	0.633	2.974	3.052	4.238
Sewage sludge	30	A	0.44	0	0.166	0	4.637	0.633	0.974	7.92	3.494
Sewage sludge	30	B	0.44	0	0.26	0	5.161	0.633	1.054	3.557	3.817
Sewage sludge	30	C	0.44	0	0.102	0	3.831	0.633	0.602	6.837	5.877
Control	30	A	-	0	0.078	0	3.065	0.633	0.205	0	1.102
Control	30	B	-	0	0.082	0	2.661	0.633	0.038	0.307	1.23
Control	30	C	-	0	0.139	0	2.419	0.633	0.09	1.061	1.534

Appendix 11. cont'd.

Treatment	Temperature (degree C)	Replicate	Initial TKN Applied (g)	Initial NO3-N In Sand (mg)	Final NO3-N In Solution (mg)	Final NO3-N In Sand (mg)	Final NO3-N In Resin (mg)	Initial NH4-N In Sand (mg)	Final NH4-N In Solution (mg)	Final NH4-N In Sand (mg)	Final NH4-N In Resin (mg)
Composted poultry manure	30/10	A	0.4	0	0.056	0	2.46	0.633	1.599	6.125	5.677
Composted poultry manure	30/10	B	0.4	0	0.157	0	1.774	0.633	2.288	7.264	3.106
Composted poultry manure	30/10	C	0.4	0	0.166	0	1.694	0.633	1.525	5.63	4.768
Sewage sludge	30/10	A	0.44	0	0.027	0	2.702	0.633	0.632	4.386	2.277
Sewage sludge	30/10	B	0.44	0	0.007	0	1.653	0.633	1.146	2.946	3.391
Sewage sludge	30/10	C	0.44	0	0.045	0	2.218	0.633	0.565	11.94	2.553
Control	30/10	A	-	0	0.141	0	1.25	0.633	0.04	0	0.876
Control	30/10	B	-	0	0.081	0	1.371	0.633	0.069	4.004	0.848
Control	30/10	C	-	0	0.141	0	1.089	0.633	0.028	0.376	1.161