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Effects of Fertilization and Clone on Aboveground and Soil Carbon Storages in a Willow(*Salix* spp.) Bioenergy Plantation[1]

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ABSTRACT

The influences of fertilizer treatment and clones of five willows and one hybrid poplar on above ground and soil carbon (C) accumulations in a willow bioenergy plantation were studied. The aboveground and soil samples were collected in the winter of 1992 and 1993 from the previously established willow plantation at Tully, New York, U.S.A. in 1987. Half of the plots were fertilized annually with 336kg/ha N, 112kg/ha P, and 224kg/ha K. All trees were harvested annually. The most productive clone, willow clone SV1 with fertilization, accumulated 5.4 and 6.8 t/ha/yr aboveground C contents during the sixth(1992) and seventh(1993) growing seasons, respectively. The average percentage of C in bolewood, bolebark, and branches for the five willow clones and one hybrid poplar clone ranged from 57.1 to 57.5, from 54.0 to 55.4, and from 55.6 to 56.5, respectively, among all treatment combinations. Only two of the six clones(SA22 and SA2) responded significantly to the addition of fertilizer by increasing the amount of aboveground C accumulated for the 1992 sampling period(clone-by-fertilizer interaction). No fertilization effect, on aboveground C content, was noted for the 1993 sampling period. No significant fertilization effect on soil C accumulation for all soil sampling depths(0-10, 10-20, and 20-40cm) was found in 1992 and 1993 sampling years. Little clone effect on soil C content was found in 1992 and 1993 sampling years, except at 0-10cm soil depth in 1992. The significant clonal effect on soil C content at 0-10cm soil depth could be because of stone content variation rather than clonal effect. The significant clone-by-fertilizer treatment interaction observed requires that evaluation of response to fertilization by willows be made for each clone individually.

Key words : Salix *spp.*, Populus *spp.*, *aboveground and soil carbon, fertilization*

要約

지상부 및 토양중 탄소축적에 미치는 시비의 효과와 클론간(5개의 버드나무 클론과 1개의 잡종 포플러 클론)의 특성을 규명하기 위한 목적으로, 목재에너지 공급을 위해 1987년 미국 뉴욕주립대 연습림에 조성된 버드나무(Salix spp.) 조림지를 대상으로 1992년과 1993년 겨울에 분석용 지상부와 토양 시료를 채취하여 탄소축적량을 측정하였다. 시비구에 매년 N(336kg/ha), P(112kg/ha) 및 K(224kg/ha)를 시비하였으며, 조림지에 식재된 모든 공시목은 매년 벌채되었다. 시비처리된 버드나무 클론

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SV1의 지상부 탄소축적량은 5.4t/ha/yr(6년생뿌리)와 6.8t/ha/yr(7년생뿌리)로써 전체 클론중 가장 높게 나타났다. 전체 클론에 대한 부위별 평균 탄소함량은 수간목부에서 57.1~57.5%, 수피에서 54.0~55.4%, 그리고 생지에서 55.6~56.5%로 분포하였다. 시비처리에 의한 지상부 탄소축적량의 증가가 1992년에 전체 클론 중 2개 클론(SA2, SA22)에서만 있었으며(시비와 클론간 交互作用), 1993년에는 대조구와 시비구간에는 유의적인 차이가 없었다. 토심별(0-10, 10-20, 20-40cm) 토양중 탄소축적량은 대조구와 시비구간에 차이가 없었다. 클론간 토양 탄소축적량은 1992년 0-10cm 토심에서만 유의적인 차이가 있는 것으로 나타났는데, 이것은 클론에 의한 영향보다는 토양중 자갈함량의 차이에 의한 것으로 사료된다. 본 연구에서 나타난 클론과 시비간 交互作用 때문에 지상부 탄소축적에 대한 시비처리효과의 평가는 각 클론내에서 실시되어야 할 것으로 사료된다.

INTRODUCTION

After the earth's average air temperature reached an all-time high recently, many scientist expressed concern about the potential for significant global warming as a result of the increased carbon dioxide(CO_2) and other greenhouse gases (CFCs, CH_4, and N_2O) within the coming century(Schlesinger, 1991 ; Hansen, 1993). Even small changes in temperature can have dramatic impacts on the earth's complex atmosphere, ocean, land, and life systems(Hair and sampson, 1992). Increasing population and economic activity will increase the concentration of CO_2 in the atmosphere and may accerelate changes in global climate which may have important consequences for the earth's ecology.

Forests have received considerable attention because they are a major sink for C and play an important role in the global C cycle. Most proposals for reducing global warming have focused on large-scale reforestation or afforestation that increase the forested area that actively sequesters C(Sedjo, 1989 ; Vitousek, 1991). Little attention has been paid to the replacement of fossil fuel energy sources with fuels from biomass that can reduce the input of fossil C into the atmosphere. If biomass is grown for energy, with the amount grown equal to that converted to energy for a given period, there would be no net build-up of CO_2 in the atmosphere because the amount released in conversion to energy would be compensated for by the amount released by the biomass during photosynthesis(Hall et al., 1991). Reductions in fossil fuel C conservation also decreases the rate at which inactive fossil fuel C enters the active biosphere C cycle.

High rates of biomass production are necessary for efficient C sequestration. All woody plant systems can be used for biofuels, but short-rotation woody crops have an advantage as a primary source of bioenergy because of high annual productivity. Yields obtained with short-rotation woody crops are two to five times greater and more frequent than yields currently obtained in natural forests(Wright et al., 1992 ; Hall et al., 1991). While the aboveground biomass could be used as an energy source to reduce the use of fossil fuel, short-rotation woody plantations also store C in the roots and litter added to the soil. The soil functions as a C sink and thus helps ameliorate increases in atmospheric C.

Short-rotation woody crops can be harvested annually or more typically on three-to ten-year cycles, with planting densities of 1,000 to 440,000 trees per hectare. Hardwoods are preferred for short-rotation woody crops because of the advantage of coppicing from stumps and rapid juvenile growth. Short-rotation woody crop systems employ intensive techniques to attain maximum biomass, e.g., optimizing nutrient and water conditions, controling pests, and using genetically improved plants(Anderson et al., 1983). These techniques promote rapid juvenile growth rates in selected species allowing maximum yields at various ages depending on initial spacing, species, and climate(Wright et al., 1992).

Many fast-growing hardwood genera have been assessed for their biomass production potential. Willows, as fast growing tree species, have been extensively used in short-rotation cultures in U.S.A., Sweden, New Zealand, Ireland, and

Canada because of their rapid growth, resprouting capacity, and ease of vegetative propagation (Ericsson, 1984). Controlled pollination and interspecific hybridization of willows is relatively easy to achive compared with most forest tree genera (Kopp et al., 1993). Many species flower as early as two years of age. Willow biomass production as high as 40 dry t/ha during one growing season has been achieved experimentally(Christersson, 1987).

Short-rotation woody crops sequester large amounts C in the above- and belowground biomass. However, most researchers working to reduce atmospheric CO_2 with energy crops have focused on the use of short-rotation energy crops (Dixon et al., 1994 ; Sedjo, 1989 ; Vitousek, 1991) and the harvestable aboveground biomass productivity(Hall et al., 1991 : Wright et al., 1992). With the recent concerns over increases in atmospheric CO_2 levels and global warming, the estimation of potential for soil and belowground sequestering C under short-rotation woody crops is timely.

The objective of this study was to estimate the annual aboveground C storage and the amount of C stored in the soil as affected by fertilization treatment and clones of fast-growing trees, five willows(*Salix* spp.) and one hybrid poplar(*Populus* spp.).

MATERIALS AND METHODS

The field experiment was established in 1987 at the SUNY College of Environmental Science and Forestry's Genetics Field Station near Tully, New York(42° 47′ 30″ N, 76° 30″ W) to determine the effect of willow clones and fertilization on biomass production. The soil is a Palmyra gravelly silt loam(Glossoboric Hapludalf), an agricultural soil representative of significant acreage that potentially is available for energy plantation establishment in the Northeastern United States. The soil have a gravelly loam subsoil at depths greater than 30 to 60cm and are well drained. The water table in Palmyra soils is generally at a depth of more than 0.91m, but may fluctuate to less than 0.91m of the surface in spring and during wet periods(Hutton and Rice, 1977).

Five willow clones(Table 1) that have been shown to produce high biomass yields in Canadian test plots were selected in consulation with the Ontario Ministry of Natural Resources. The hybrid poplar clone selected had performed exceptionally well in ultrashort rotations at a location near the planting site and was included for comparison purposes.

Site prepararion was done mechanically and chemically in 1986. Glyphosate(Roundup), with surfactant, was applied at the rate of 2.3kg active ingredient per hectare in late August, 1986 to kill vegetation. After confirmation of glyphosate effectiveness, the site plowed, disked and raked. To prevent weed establishment during the first part of the 1987 growing season, simazine was applied in October, 1986 at the rate of 4.5kg active ingredient per hectare.

Unrooted stem cuttings, 25cm in length, were collected from the one-year-old stems of six clones during winter 1986 from nursery stool beds at Kemptville, Ontario, Canada and stored at 0℃ before planting. Cuttings were hand planted flush with the ground, using steel planting dibbles from April 6 to 9, 1987.

Five willow clones and one hybrid poplar clone were planted at 0.3×0.3m spacing in 6.0×6.0m plots including two exterior border rows in 1987.

Table 1. Origin of clones planted at SUNY Genetic Field Station at Tully, New York to determine the biomass production potential of willows.

Clone	Origin
NM5	Populus nigra X P. maximowiczii, Munden, Germany
SV1	Salix dasyclados. Branford, Ontario, Canada
SA22	S. alba. Zagreb, Yugoslavia
SA2	S. alba Var. sanguinea. Novi Sad, Yugoslavia
SAM3	S. X rubens. Toronto, Ontario, Canada
SH3	S. purpurea. Munden, Germany

The treatments included fertilized and non-fertilized, with three replications(6 clones×2 fertilizer treatments×3 replications) with a total of 36 plots providing 256 measurement per plot. A split-plot design with three replications per treatment for the main-plot factor was employed (Peterson, 1985). Fertilization treatment was the main-plot factor and clone was the sub-plot factor.

In study plots, three of the replications received annual applications of 336kg/ha nitrogen(ammonium nitrate), 112kg/ha phosphorous(treble superphosphate), and 224kg/ha potassium(muriate of potash) for five years. From 1987 to 1989 and 1991, the entire amount of P and K, and first application of 56kg ha/N was hand broadcast every three weeks after the first application. In 1990 fertilization of P and K was identical as in previous years, except N was applied as urea through an irrigation system. No fertilizer was applied in 1992, and only N was applied at the rate of 224kg/ha in six equal applications during 1993.

To minimize water as a growth limiting factor during the 1989-1993 growing seasons, study plots were irrigated with a drip irrigation system. Soil moisture tension was maintained at close to field capacity to a depth of 30cm from May until September each year.

All aboveground woody biomass was harvested during November each year using a power scythe, cutting within 5cm of the ground. After weighing the total fresh weight biomass per plot in the field, about a 1-2kg random subsample of trees was taken to the laboratory for determination of moisture content. Three aboveground samples were randomely selected from each plot to estimate branch, bark, and wood carbon accumulation from November to December, 1992 and 1993. Three soil samples were also randomely taken in each plot for soil carbon. At each sampling point, samples were collected from 0-10cm, 10-20cm, and 20-40cm depth by using an Oakfield soil sampler of 10cm diameter. Bulk density samples at these depths were collected using the excavation method.

All soil and aboveground woody biomass samples were analyzed by methods detailed by Bickelhaupt and White(1982). Aboveground biomass samples were dried at 65℃ in a forced-air drying oven. The branch, bark, and bole samples were ground in a Wiley mill to pass through a 1-mm stainless steel sieve and subsamples were used for organic matter analysis by loss on ignition. Soil were air-dried and sieved to pass through a 2mm sieve. One g soil subsamples were analyzed for organic matter concentration using the Wakely-Black wet oxidation method.

Analysis of variance using a split-plot design with three replications was used to test the null hypothesis that fertilization(main effect) and clone(sub-plot factor) had no significant effect on soil and aboveground carbon content for the 1992 and 1993 data, respectively. Tukey's HSD test were used to statistically separate means. The SAS computer software system was used in this study. Test of significance were at the 0.05 level unless otherwise stated. Test of significance for interaction was set at the 0.15 level (Stehman and Meredith, 1995).

RESULTS AND DISCUSSION

1. Aboveground carbon storage

One-year-old stems were harvested from six-(1992) and seven-year-old(1993) root stocks. Persons(1992) reported that carbon percentage in wood and bark was about 50 and 47 for willow and cottonwood, respectively. In the current study, the average percentage of carbon in bolewood, bolebark, and branches for five willow clones and one hybrid poplar clone ranged from 57.1 to 57.5, from 54.0 to 55.4, and from 55.6 to 56.5, respectively, among all treatment combinations(Table 2). There were little clonal differences in bolewood, bolebark, and branch carbon concentration(each clonal carbon percentage was applied to the clonal C accumulation). Also, the C concentration among bolewood, bolebark, and branches was not greatly different. Therefore, the differences in total aboveground C accumulation among clones or between fertilized and non-fertilized trees were mainly from differences in biomass production.

The aboveground C(bolewood + bolebark + branches)(t/ha/yr) accumulated annually ranged from 1.4 to 5.4t/ha/yr in 1992 and from 1.1 to 6.8t/ha/yr in 1993(Tables 3). The most productive clone SV1, with fertilization, accumulated 5.4 and 6.8t ha/yr aboveground carbon content during the 1992 and 1993 growing seasons, respectively. In Scotland and Nothern Ireland willow clones grown in high-yielding short rotation research plots accumulated 4.5 to 5(one-year-old roots) and 4 to 8.5 t C ha/yr(one- to three-year-old roots), respectively(Cannell, 1988).

It was expected that fertilization would increase annual aboveground C accumulation. However, only two of the six clones(SA2 and SA22) responded significantly to the addition of fertilizer by increasing the amount of aboveground C accumulated for the 1992 sampling period(six-year-old root stock)(Table 3). No fertilization effect, on aboveground C content, was noted for the 1993 sampling period(seven-year-old root stock).

Table 2. The percent carbon(%) in bolewood, bolebark, and branch of the five willow clones and one hybrid poplar clone plots.

Clone	Bolewood	Bolebark	Branch
SV1	57.5(0.02)[1]	54.8(0.25)	56.5(0.92)
SH3	57.5(0.29)	54.4(0.28)	55.6(0.31)
NM5	57.1(0.25)	54.6(0.06)	---[2]
SA22	57.3(0.34)	54.0(1.47)	56.5(0.03)
SAM3	57.5(0.06)	55.4(0.37)	56.5(0.51)
SA2	57.5(0.06)	55.4(0.15)	56.1(0.09)

Note : [1] Values in parentheses are standard errors (n=2).

[2] No branch found.

The nutrient requirements of the willow and hybrid poplar clones used in this study area may have been satisfied by the existing soil nutrient conditions. The soil of this study site was a Palmyra gravelly silt loam(Glossoboric Hapludalf), a good quality agricultural soil(Hutton and Rice, 1977). Hansen and Tolsted(1985) reported that fertilization of a moderately fertilized silt loam soil increased hybrid poplar biomass production during years two and three but not during years one, four, or five, while a less fertilized site responded to fertilization during all five years of their study. Kopp et al.(1993) reported that fertilization significantly increased biomass production during years two and three of the current study but not during years one, four, or five.

Clonal comparison among the fertilized plots indicates that clones SV1, SA2, SH3, and NM5 accumulated more carbon than SAM3 during the 1992 growing season(Table 3). Similar results were observed in the non-fertilized plots where clones SH3 and SV1 accumulated the most aboveground carbon with SAM3 and SA22 accumulating the least(Table 3). During the 1993 growing season aboveground C content accumulated by clones SV1, SH3, NM5, and SA2 was significantly greater than the amount accumulated by clones SA22, and SAM3(Fig. 1).

The differences in the amount of aboveground C accumulated among clones during the two growing seasons within fertilized and non-fertilized plots was most likely due to genetic differences in yield among the clones. Clonal dif-

Table 3. Annual aboveground carbon contents(t/ha/yr) produced by coppiced five willow clones and one hybrid poplar clone grown on six- and seven-year-old root with fertilizer treatment.

Clone	1992		1993	
	F	NF	F	NF
NM5	4.22(0.11)a	4.23(0.41)ab	5.67(0.15)a	6.05(0.50)a
SAM3	2.39(0.58)b	1.42(0.38)c	2.60(1.92)a	1.73(0.37)a
SA2	4.79(0.24)a*	3.20(1.34)bc*	6.07(0.53)a	4.81(0.14)a
SA22	3.61(1.51)ab*	1.62(0.61)c*	1.60(0.82)a	1.08(0.42)a
SH3	4.57(0.28)a	5.27(0.35)a	5.58(0.28)a	5.68(0.08)a
SV1	5.38(0.38)a	5.11(0.15)a	6.79(0.59)a	5.97(0.89)a

Note : Values in the same colums followed by a different letter are different at p=0.05.

* indicates statistical difference between fertilized and non-fertilized treatment within each clone within 1992 and 1993 at p=0.05.

ferences can be a significant source of variation in yield as illustrated by clonal productivity comparisons of 450 willows(McElroy et al., 1985).

2. Soil carbon storage

Effect of N, P, and K fertilizer of five willow clones and one hybrid poplar clone on soil C content(Mg/ha) at three different soil depths(0-10, 10-20, and 20-40cm) are discussed. No significant fertilization effect for all soil depths was found in 1992 and 1993 sampling years(Table 4). However, there was significant clone effect on soil C content at 0-10cm soil depth in 1992. Soil C content in clone SH3 plot was signficantly greater than in clones NM5 and SV1 plots(Table 5).

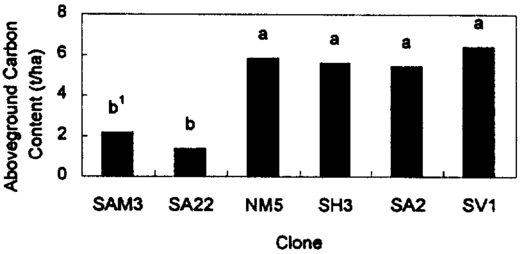

Fig. 1. Aboveground C accumulation by annually coppiced five willow clones and one hybrid poplar clone on seven-year-old root stock(1993).

[1] Different letter indicates statistical difference among clones at p=0.05.

According to Johnson(1992) and Henderson(1995) fertilization usually causes an increase in soil C. This is expected because of the increase in primary productivity associated with fertilization. However, the current results were different from other published reports because fertilization did not effect soil carbon content at all soil sampling depth for both years.

Nutrient status of the willow strongly effect the production of leaves with improved nutritional status increasing leaf production in relation to

Table 4. Mean soil C contents(Mg/ha) at three soil depths in fertilized(F) and non-fertilized(NF) five willow clones and one hybrid poplar clone plots.

Year	Treatment	0 - 10cm	10 - 20cm	20 - 40cm
1992	F	21.1(2.43)a	18.6(1.79)a	29.0(6.19)a
	NF	23.1(3.48)a	18.0(2.09)a	31.7(5.91)a
1993	F	23.5(3.08)a	19.0(1.97)a	33.5(7.70)a
	NF	25.0(2.31)a	18.0(1.68)a	29.5(5.07)a

Note : Values in the same column followed by a different letter are different within 1992 and 1993 at p=0.05.

Table 5. Mean soil C contents(Mg/ha) at three soil depths in five willow clones and one hybrid poplar clone plots.

Year	Clone	0 - 10cm	10 - 20cm	20 - 40cm
1992	NM5	20.5(1.34)b	18.5(2.22)a	33.8(5.68)a
	SAM3	23.2(3.16)ab	18.4(1.72)a	29.4(3.40)a
	SA2	22.1(3.31)ab	17.4(2.48)a	28.1(4.73)a
	SA22	22.3(2.95)ab	18.9(2.54)a	30.1(7.37)a
	SH3	24.3(3.86)a	19.1(1.08)a	30.4(10.1)a
	SV1	20.2(2.56)b	17.5(1.24)a	30.1(4.13)a
1993	NM5	23.0(2.09)a	19.4(2.43)a	37.1(8.43)a
	SAM3	24.9(1.15)a	18.7(1.95)a	33.5(5.04)a
	SA2	24.6(2.52)a	17.0(1.32)a	30.1(5.90)a
	SA22	24.9(3.01)a	18.1(1.03)a	30.4(4.32)a
	SH3	24.9(3.01)a	19.2(1.48)a	26.4(7.70)a
	SV1	22.3(3.15)a	18.4(2.38)a	31.7(5.53)a

Note : Values in the same column followed by a different letter are different within 1992 and 1993 at p=0.05

stems and roots(Ericsson, 1984). Also, research conducted by Adegbidi(1994) showed in a 1993 study, on the same site, that fertilized trees produced more litter than non-fertilized trees, except clone SV1. According to his calculation, six years of increased litter production would be required to increase soil C 0.035%, where soil C concentration was 3.22% in fertilized plots and 3.29% in non-fertilized plots at 0-10㎝ soil depth. This small difference in litterfall was too small to be detected in soil C concentration at the end of seven growing seasons. There was no evidence of a litter layer at the willow experimental site. The lack of a litter layer could be because of the effect of wind on the foliage litterfall. After the annual harvest during late fall tremendous amounts of the current litter may be removed by strong winds before canopy closure the next year and even during canopy closure. Also, small plot size(6m×6m), with open areas between the plots, may increase the effect of wind on the amount of foliage litterfall C input to the soil surface. Annual cutting may increase soil temperature and the decomposition rate at soil surface layer. A rapid decomposition rate would result in less C content and also decrease the effect of the foliage litterfall C input to soil surface.

Another potential reason for no differences in soil C content between the fertilized and non-fertilized plots involves differences in root growth. Differences in root production between the fertilizer treatment and control may be explained by root/shoot partitioning. Assimilates are used preferentially by the shoots if conditions limit photosynthesis, and preferentially by the roots if conditions limit nutrient or water uptake(Cannell, 1988). As a result, high levels of nutrients increase shoot growth relative to root growth in both herbaceous and woody species(Ledig, 1983). Altered root biomass and productivity have been reported after N fertilization of willow(Ericsson et al., 1981) where properly fertilized willow plants, grown in nutrient solution, expends less of their photosynthetic products on root growth compared to nutrient-deficient plants. Decreased root production after fertilization was also reported by Linder and Axelsson(1982), but Binkley(1986) reported that fertilization had no effect on root production. Vogt and Bloomfield(1991) noted that as nutrient availability decreases, the contribution by senesced roots to carbon and nutrient cycling in the soil increases while that of aboveground litterfall decreases.

In this study, according to early research by Kopp et al.(1993), annual fertilization significantly increased aboveground biomass production during only second and third growing season(on average, 26% and 28% more production in fertilized plots) due to original adequate soil nutrient conditions, as described earlier. Therefore, if functional equilibrium could be adaptive to our willow experiment trees(changed root production by fertilized treatment), the response of root growth change to fertilization would be adapted to second and third growing season. However, the relatively small aboveground biomass differences between fertilized and non-fertilized plots may not indicate much difference in root production between the two treatment plots. Possible small differences in root production for only two years could result in small differences in root detritus input that are difficult to detect in soil C concentration between the two treatments. Fertilization effect on soil C content in this study plots was non-significant because of small differences in root turnover between fertilized and non-fertilized plots combined with the small amounts of litterfall input to the soil.

Significant clonal effect on soil C content at 0-10㎝ soil depth only in 1992 could be because of stone content variation rather than clonal effect. That is, no significant clonal differences in soil C concentration(%) was found at 0-10㎝ soil depth. Also, the differences were not detected in 1993. Because soil C content could be stable for one year, no significant differences in soil C content between fertilized and non-fertilized plots in 1993 may support the hypothesis that the significant clonal differences could be from inherent site variation.

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