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# Effects of Cutting Cycle and Spacing on Carbon Content of Willow

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The influence of cutting cycle and plant spacing on carbon accumulation in willow aboveground biomass and soil were studied at Tully, New York. Willow clone SV1 was planted in 6.0×6.0 m plots at three spacing, 0.3×0.3, 0.3×0.9 and 0.6×1.1 m and harvested annually, biennially and triennialy. All plots were fertilized and irrigated. Among all treatment combinations, the greatest average annual aboveground carbon accumulation (13.6t $ha^{-1}$ $yr^{-1}$) occured in plants harvested triennially grown at 0.3×0.9 m spacing. Aboveground C content in plots harvested triennially was significantly greater than in annually harvested plots (but there was no significant difference between annually and biennially harvested plots). Aboveground C accumulation was not effected by plant spacing probably caused by competition among the plants at these dense spacings. Soil C content was not effected by harvest cycle or plant spacing.

## INTRODUCTION

With the recent concerns over increases in atmospheric $CO_2$ levels and global warming, 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, 1980; 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 decrease 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) and can be far greater than agricultural crop yield on the same land (Rutter, 1988). Furthermore, energy crops can often be grown at relatively high productivity rates on marginal cropland where the soil and climate conditions are not particularly favorable for

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growing agricultural crops (Hall et al., 1993). Within the United States a land base estimated at 40 million hectares, consisting of agricultural land recently removed from production and other marginal quality agricultural land, is potentially available for bioenergy plantations (Kopp et al., 1993). 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, controlling 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 achieve 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 $ha^{-1}$ during one growing season has been achieved experimentally (Christersson, 1987).

Short–rotation woody crops sequester large amounts C in the above– and below-ground 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., 1991; Wright et al., 1992). With the recent concerns over increases in atmospheric $CO_2$ levels and global warming, the estimation of potential for aboveground and below-ground sequestering C under short–rotation energy crops is timely.

The objective of this study was to estimate aboveground C storages and the amount of C stored in the soil as affected by cutting cycles and spacings for one willow clone SV1.

## MATERIALS AND METHODS

The field experiment was established in 1990 at the State University of New York College of Environmental Science and Forestry's Genetics Field Station near Tully, New York (42 47' 30" N, 76 07' 30" W) to determine cutting cycle and spacing effects on biomass production by willow grown with intensive culture. 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 has a gravelly loam subsoil at depths greater than 30 to 60 cm and are well drained. The water table in Palmyra soils is generally at a depth of more than 0.91 m, but may fluctuate to less than 0.91 m of the surface in spring and during wet

**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 |
|---|---|
| SV1 | *Salix daisyclados.* Branford, Ontario, Canada |
| SA22 | *S. alba.* Zagreb, Yugoslavia |
| SH3 | *S. purpurea.* Munden, Germany |

periods (Hutton and Rice, 1977)

Three willow clones (Table 1) that have been shown to produce high biomass yields in Canadian test plots were selected in consultation with the Ontario Ministry of Natural Resources. The willow clones SV1, SA22, and SH3 were planted in $6.0 \times 6.0$ m plots at three spacings, $0.3 \times 0.3$, $0.3 \times 0.9$, and $0.6 \times 1.1$ m and harvested with annual, biennial, and triennial cutting cycles. Survival of clone SH3 was poor, and many of the SA22 plots were destroyed by herbivers, so these were eliminated from the analysis. Experimental plots included two border rows around the $0.3 \times 0.3$ and $0.3 \times 0.9$ m spaced plots, and one border row around the $0.6 \times 1.1$ m spaced plots. Factorial experimental design was employed for cutting cycle and spacing study.

Site preparation began in 1989. Both Glyphosate (Roundup) and 2.4–dichlorophenoxyacetic acid (2.4D) were applied at the rate of 2.3 kg $ha^{-1}$ active ingredient, respectively, in late July, 1989. After confirmation of herbicide effectiveness, the site was plowed, disked, and raked. Oxyflorfen preemergent herbicide (Goal 1.6e) at 2.24 kg active ingredient $ha^{-1}$ was applied during the fall prior to planting to prevent weed establishment during 1990.

Unrooted stem cuttings, 25 cm in length, from willow clones were collected from one–year–old stems during winter of 1986 from an established experiment at Tully and stored at 0–4 °C until planting. Unrooted stem cuttings were planted flush with the ground during the third week of April, 1990.

In study plots, 37 kg $ha^{-1}$ of nitrogen (ammonium nitrate), 112 kg $ha^{-1}$ phosphorous (treble superphosphate), and 224 kg $ha^{-1}$ potassium (muriate of potash) were hand broadcast shortly after trees sprouted in 1991. Five nitrogen applications of 37 kg $ha^{-1}$ were applied every two weeks until mid–July for a total annual application rate of 224 kg $ha^{-1}$. Fertilization was identical in 1992. In 1993 only nitrogen was applied in six applications of 37 kg $ha^{-1}$ for a total of 224 kg N $ha^{-1}$, as in previous years.

To minimize water as a growth limiting factor during the growing seasons, all trees were irrigated during the growing season in 1991, 1992, and 1993 (second, third, and fourth growing seasons). Soil moisture tension was maintained at close to field capacity to a depth of 30 cm from May until September each year.

All trees were coppiced 2～4 cm above groundline during December, 1990, to promote multiple stem production. Biomass measurements began for annually harvested trees in 1991, and trees were harvested annually every year. Biomass measurement began for biannually harvested trees in 1992 and for triennially harvested trees in 1993. Three samples were randomly selected from each plot to estimate branch, bark, and wood carbon accumulation. After weighing the total fresh weight biomass per plot in the field, about a 1～2 kg random sub–sample of trees was taken to the laboratory for determination of moisture content. Three soil samples were collected from 0~10 cm, 10~20 cm, and 20~40 cm depth by using an Oakfield soil sampler of 10 cm 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 °C 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 sub–samples were used for organic matter analysis by loss on ignition. Soil were air–dried and sieved to pass through a 2 mm sieve. One g soil sub–samples were analyzed for organic matter concentration using the Wakely–Black wet oxidation method.

Analysis of variance using a factorial design was used to test the null hypothesis that cutting cycle and spacing had no significant effect on soil and aboveground carbon contents. 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

### Aboveground carbon storage

Aboveground C accumulation (bolewood+bolebark+branches) ranged from 14.4 to 17.4 and 16.0 to 19.9 t ha$^{-1}$ yr$^{-1}$ in the annual and biennial harvests, respectively (Table 2).

**Table 2.** Bolewood, bolebark, branch, and total aboveground carbon contents produced by willow clone SV1 grown at different spacings with two–annual and a single–biennial harvest cycle on three–year–old root stock at Tully, N. Y

| Harvest | Spacing | Stems: Bolewood t/ha | Stems: Bolewood (%)[1] | Stems: bolebark t/ha | Stems: bolebark (%) | Branch t/ha | Branch (%) | Total |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.3×0.3 | 15.05 (1.85)[2] | 86ab | 2.20 (0.26) | 13 | 0.1 (0.02) | 1 | 17.42 (2.06) |
| | 0.3×0.9 | 15.82 (0.51) | 88a[3] | 1.92 (0.48) | 11 | 0.17 (0.007) | 1 | 17.37 (0.76) |
| | 0.6×1.1 | 12.62 (1.37) | 87b | 1.50 (0.28) | 11 | 0.28 (0.14) | 2 | 14.44 (1.40) |
| 2 | 0.3×0.3 | 12.99 (2.10) | 81b | 1.69 (0.68) | 11 | 1.33 (0.66) | 8 | 16.01 (3.39) |
| | 0.3×0.9 | 16.10 (0.77) | 81a | 2.09 (0.33) | 10 | 1.92 (0.17) | 9 | 19.91 (1.51) |
| | 0.6×1.1 | 14.05 (1.13) | 80ab | 1.88 (0.28) | 11 | 1.51 (0.40) | 9 | 17.41 (1.32) |

[1] Percentage of carbon content in bolewood and bolebark of the stem; and branch of the total aboveground

[2] Values in parentheses are standard errors (n=3)

[3] Different letters indicate statistical difference in bolewood carbon content between spacings within annual or biennial cutting cycles at the 5% level

Clone SV1 planted at 0.3×0.9 m spacing in the biennial cutting cycle had the greatest aboveground C accumulation of 19.9 t $ha^{-1}$ (10 t $ha^{-1}$ $yr^{-1}$) among all treatments combinations. This was the greatest aboveground C content accumulated in the biennial harvest cycle for all spacing–cutting cycle combinations. Willow biomass production in a Swedish trial with eight willow clones and unspecified spacing yielded 15 t C $ha^{-1}$ with biennial harvest (Siren et al., 1987).

Aboveground carbon content from two annual harvests (1991 and 1992) of clone SV1 were compared with a single biennial harvest (1991~1992). There was no significant effect of cutting cycle or spacing on aboveground C content (Fig. 1) while a relatively weak cutting cycle–by–spacing interaction ($P=0.14$) existed. However, mean separation technique did not indicate that significant differences in aboveground C content existed between the annual and biennial cutting cycles within each plant spacing and similarly, carbon content among the three plant spacings within each cutting cycle were not statistically significant.

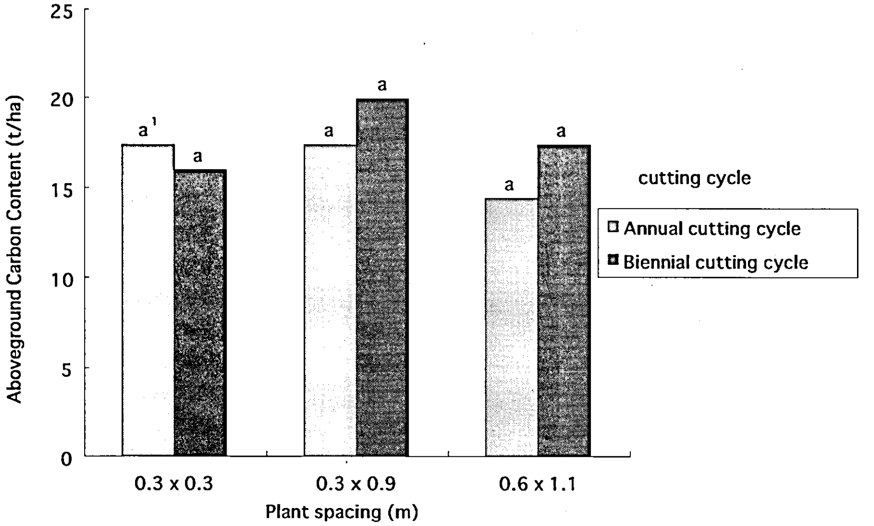


**Fig. 1.** Effect of cutting cycle and spacing on aboveground carbon accumulation by two annual or one biennial harvested willow clone SV1 used for a SRIC bioenergy plantation. [1]Different letters indicate statistical difference among plant spacings within annual or biannual cutting cycles at the 5% level. No statistical difference between cutting cycles within each spacing noted

Zavitkovski et al. (1976) and Steinbeck et al. (1972) found increased biomass production with closer spacings. However, results from the current study indicate no significant differences in aboveground C content among the three plant spacings. Willebrand et al. (1993) reported that spacing did not affect willow biomass production after the second harvest of short cycles of 1 to 3 years. DeBell et al. (1988) found that cumulative two–year yield of hybrid poplar grown at spacings of 0.18×0.18 and 0.3×

0.3 m was equalled or exceed by standing woody biomass in the 0.5×0.5 m spacings of two poplar clones and in the 1.0×1.0 m spacing of one poplar clone after planting.

Willebrand et al. (1993) and DeBell et al. (1988) attributed the small effect of plant spacing on biomass production to increased competitive stress in the denser spacings. Early findings in the current experiment by Kopp et al. (1996) found that competition among trees planted at 0.3×0.3 and 0.3×0.9 m spacings was severe even during the first growing season after coppicing; there were approximately seven- and two-times more trees at these two spacings, respectively, than at the 0.6×1.1 m spacings, but production at the two denser spacings exceeded the widest spacings by only 26%. Therefore, in the current study, it may be that due to the high resprouting capacity of willow after first year coppicing competition among plants, especially at densely planted spacings, results in stress to growth processes, and aboveground C content becomes independent of plant density.

Kennedy (1975) reported that mean annual biomass production was significantly increased with two-, three-, or four-year harvest cycles compared with one-year harvest cycles in Sycamore plantations. Also, Geyer (1988) reported silver maple (*Acer saccharium*) were more productive when harvested biennially and triennially than when harvested annually. However, the current study results were different from published reports. No significant differences in aboveground C between the two cutting cycles probably was because of rabbit damage in biennial cutting cycle plots during the winter of 1991~1992.

Aboveground C content from three annual harvests (1991, 1992, and 1993) was also compared with the aboveground C content from a single triennial harvest (1991~1993). Cutting cycle had a significant affect on aboveground C content at the end of three growing seasons with the triennial cutting cycle accumulating a significantly greater amount than three annual harvest cycles (Fig. 2).

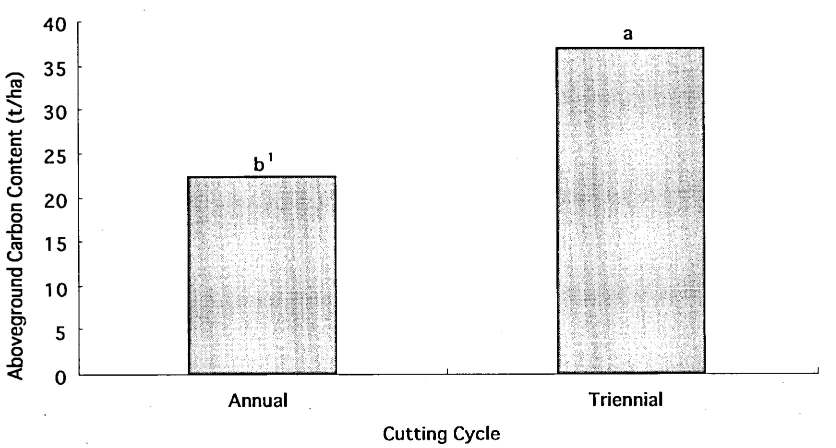


**Fig. 2.** Effect of cutting cycle on aboveground carbon accumulation by three annual or one triennial harvested willow clone SV1 used for a SRIC bioenergy plantation. [1]Different letters indicate statistical difference between cutting cycles at the 5% level

Previous research (Kennedy, 1975; McElroy et al., 1985) results agree with current results that aboveground carbon content harvested from triennial cutting cycle plots was significantly greater than three annual harvests.

Aboveground C content was greatest in middle plant spacing (0.3×0.9 m), but was not statistically significant among the three plant spacings (Table 3). As described earlier, the results support Debell et al.'s (1988) conclusion that plant spacing had a small effect on biomass production at the end of first growing season after coppicing in poplar plantations due to severe competition at dense spacings.

Triennial cycles of clone SV1 (four–year–old root) accumulated 40.87 t $ha^{-1}$ (13.6 t $ha^{-1}$ $yr^{-1}$) of aboveground C at the end of three growing seasons at 0.3×0.9 m spacing (Table 3). This aboveground C content was the greatest aboveground C content obtained in all treatment combinations in the annual and triennial harvests. The result recommends that wider spacing with longer harvest cycles be used to obtain the best yields.

**Table 3.** Bolewood, bolebark, branch, and total aboveground carbon contents produced by willow clone SV1 grown at different spacings with three–annual and a single–triennial harvest cycle on four–year–old root stock at Tully, N. Y

| Harvest | Spacing | Stems | | | | Branch | | Total |
|---|---|---|---|---|---|---|---|---|
| | | Bolewood | | bolebark | | | | |
| | | t/ha | (%)[1] | t/ha | (%) | t/ha | (%) | |
| 1 | 0.3×0.3 | 20.00 (2.52)[2] | 86 | 3.03 (0.32) | 13 | 0.23 (0.02) | 1 | 23.26 (1.80) |
| | 0.3×0.9 | 20.83 (0.78) | 87 | 2.74 (0.53) | 12 | 0.32 (0.10) | 1 | 23.89 (0.76) |
| | 0.6×1.1 | 17.63 (3.02) | 87 | 2.21 (0.49) | 11 | 0.42 (0.10) | 2 | 20.26 (1.97) |
| 3 | 0.3×0.3 | 25.94 (6.44) | 83 | 2.84 (0.90) | 9 | 2.63 (1.14) | 8 | 31.42 (8.24) |
| | 0.3×0.9 | 33.92 (2.94) | 83 | 3.40 (0.46) | 8 | 3.50 (0.83) | 9 | 40.87 (4.12) |
| | 0.6×1.1 | 30.77 (4.73) | 80 | 3.46 (0.66) | 9 | 4.26 (0.45) | 11 | 38.60 (5.83) |

[1] Percentage of carbon content in bolewood and bolebark of the stems; and branch of the total aboveground

[2] Values in parentheses are standard errors (n=3)

## Percentage of carbon content in bolebark and branch

The percentage of bark on the stems can influence the calorific value of the raw material and also the amount of nutrients removed at time of harvest (Sastry and Anderson, 1980). Anderson and Zsuffa (1975) reported 30–50% higher intrinsic nitrogen (nitrogen content per unit mass) in poplar bark than in wood. In willow, the corresponding values of nitrogen in bark and wood were found to be even more prounced (Ericsson, 1984). Therefore, reducing barkwood biomass ratio could increase the nutrient utilization efficiency (kg of dry matter/kg of nutrients) (Hansen and Baker, 1979).

Percentage of bolebark C content as the percentage of the total aboveground C content ranged from 10% to 13% in the annual and biennial combinations (Table 2). No significant spacing effect was found for percentage of bolebark C content (Table 2) (Average value :0.3×0.3 m=12%, 0.3×0.9 m=10.5%, 0.6×1.1 m=11.0%). However, Ericsson (1984) noted that decreased plant density could reduce the proportion of bark in the harvested biomass. The result of this study could be because of the greater bolewood and bolebark C content in 0.3×0.6 m spacing compared to lesser bolewood and bolebark C contents in the 0.3×0.3 m and 0.6×1.1 m spacings which, resulted similar bolewood–bolebark C content ratios. It was expected that percentage of bolebark C content as the percentage of the total C content between annual and biennial cutting cycle would be different because of possible larger stems in biennial cutting cycle plots. However, there was no significant difference in percentage of bolebark C content because of possible sampling variation (Table 2) (annual=11.7%, biennial=10.7%).

Significant cutting cycle effect on percentage of branch C content was found because of 733% higher branch C content in biennial cutting cycle (Table 2) (annual=1.3%, biennial=8.7%) due to more available lateral buds and reserved material for subsequent branch growth in the plots harvested biennially than in the plots harvested annually. No significant effect of spacing for the percentage of branch C content was found (Table 2) (0.3×0.3 m=4.5%, 0.3×0.9 m=5%, 0.6×1.1 m=5.5%).

Percentage of bolebark C content as the percentage of the total aboveground C content ranged from 9% to 13% in the annual and triennial combinations (Table 3). Significant effect of cutting cycle on percentage of bolebark C content in annual cutting cycle plots could be from 155% higher bolewood C content but 122% higher bolebark C content in triennial cutting cycle plots than in annual cutting cycle plots indicating larger stems in triennial cutting cycle plots (Table 3) (annual=12%, triennial=9.3%). Hansen and Baker (1979) recommended extending cutting cycle to reduce the bark–wood biomass ratio. No significant effect of spacing on percentage of bolebark C content was found (Table 3) (0.3×0.3 m=11%, 0.3×0.9 m=10%, 0.6×1.1 m=10%). However, the result was different from early report of Ericsson (1984) that decreased plant density could reduce the proportion of bark in the harvested biomass.

A significant effect of cutting cycle on percentage of branch C content was found (Table 3) (annual=1.3%, triennial=9.3%). There was over ten times more branch C content in the plots annually harvested due to more available lateral buds and reserved material for subsequent branch growth in the plots harvested triennially than in the plots harvested annually. A significant effect of spacing on percentage of branch C content was found in which percentage branch C content in 0.6×1.1 m spacing was significantly higher than in 0.3×0.3 m spacing (Table 3) (0.3×0.3 m=4.5%, 0.3×0.9 m=5%, 0.6×1.1 m=5.5%). Alemdag and Stiell (1982) found increased live branch weight with wider spacing (from 1.52×1.52 m to 4.27×4.27 m) at age 27 years old pine plantations.

**Soil carbon storage**

In 1992, soil samples were collected in the annual and biennial cutting cycle plots. Plant spacing had no significant affect on soil C content at all soil depths (0～10 cm, 10～20 cm, and 20～40 cm) for plots where willow clone SV1 had grown for three years (1992) and were harvested annually or biennially (Fig. 3). Cutting cycle had a significant affect on soil C contents at the 20～40 cm soil depth (Fig. 4). Soil C content at 20～40 cm depth in the biennial cutting cycle plots were significantly higher than annual cutting cycle plots.

Root mass may be the most important source of soil C in this plant spacing and cutting cycle study, because of the small amount of foliage litter on the soil surface as a

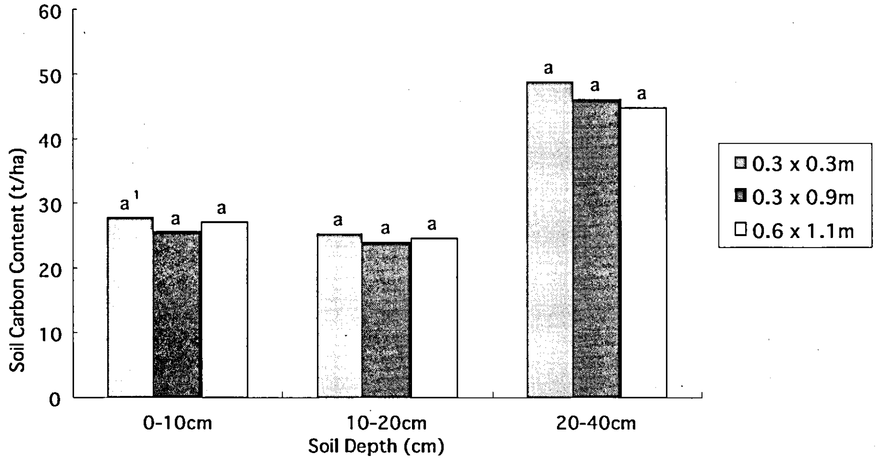


**Fig. 3.** Effect of plant spacing on soil carbon content at 0–10, 10–20, or 20–40 cm soil depths in annual and biennial harvested willow clone SV1 plots. [1]Different letters indicate statistical difference among plant spacings within annual or biannual cutting cycles within 0–10 cm, 10–20 cm, or 20–40 cm soil depths at the 5% level

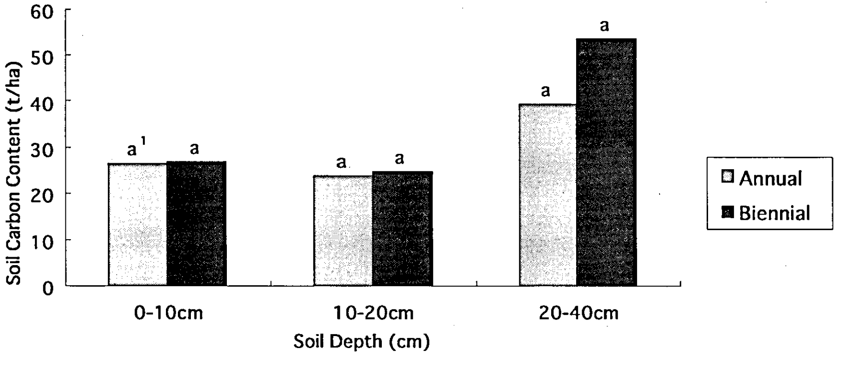


**Fig. 4.** Effect of cutting cycle on soil carbon content at 0–10, 10–20, or 20–40 cm soil depths in two annual or one biennial harvested willow clone SV1 plots. [1]Different letters indicate statistical difference between cutting cycles within 0–10 cm, 10–20 cm, or 20–40 cm soil depths at the 5% level

result of the effect of wind. Atkinson (1976) reported that the root systems of closely planted forest and fruit trees tend to be denser per unit volume of soil and grow deeper than those of widely-planted trees. However, Rennie (1974) noted little change in shoot/root biomass ratios between closely planted and widely planted trees. An interesting report by Steinbeck and Nwoboshi (1980) noted that spacing (0.3×1.2 m, 0.6×1.2 m, and 1.1×1.2 m spacings) did not affect root weight per unit land area significantly in *Platanus occidentalis* plantations 9 years after planting. Gilmore and Rolfe (1980) reported that tree spacing (four spacing between 1.2 by 1.2 m and 3 by 3 m) had a minimal effect on soil organic matter concentration for pine at age 25 years. Current results support Gilmore and Rolfe (1980)'s conclusions that spacing did not effect soil C contents at all soil sampling depths. Importantly, no significant differences in cumulative aboveground C production among the three spacings may support the assumption that small differences in detritus input to soil among the three spacings could result and it may cause small but not significant changes in the soil C contents.

Steinbeck and Nwoboshi (1980) found that rootstocks coppiced annually had significantly less rootstock mass (16.0 t $ha^{-1}$) than those harvested on longer cycles (2– and 7–year cycles). No significant difference was found between 2– and 7–year rotations, which averaged 22.8 and 25.2 tons of dry rootstock mass per hectare, respectively.

Annual harvesting may increase the decomposition rate in the surface soil layer compared to longer rotations. A more rapid decomposition rate would result in a slower increase in soil C. However, no significant differences between the two plantation years (1991～1992) may be reflected in small changes not being detected in the soil C contents. Because the effect of detritus on soil C should be less at deeper soil depth, the significant soil C contents difference between the two cutting cycle at only the 20～40 cm soil depth could be the result of site variation or sampling variation.

In 1993, soil samples were collected from annual and triennial cutting cycle plots. Plant spacing and cutting cycle had no significant affect on soil C contents at all soil sampling depth for plots where willow grown for four years and was harvested annually or triennially (Fig. 5 and 6).

There is no reason to expect significant differences in soil C contents among plant spacings with similar cumulative aboveground C content for three years as described previously in aboveground C content section. Theoritically, first–year biomass production (1991) after coppicing (1990) would be similar for all cutting cycle plots (at annual, biennial, and triennial cutting cycle plots). At the end of second growing season (1992), cumulative aboveground biomass production would be similar between biennial and triennial cutting cycle plots due to same growing conditions. As described previously in aboveground C content section, no significant cumulative biomass production between annual and triennial cutting cycle plots. At the end of three years (1993) the difference in aboveground biomass between three annual and a single triennial cycles was 320% greater in the triennial cycle plots (Table 3). However, no significant difference in soil C content between annual and triennial cutting cycles may indicate that although aboveground biomass differences between the two cycles was great, only one year had significant differences in aboveground biomass production which would not provide enough additional detritus input to the soil system to be detected in soil C content differences.

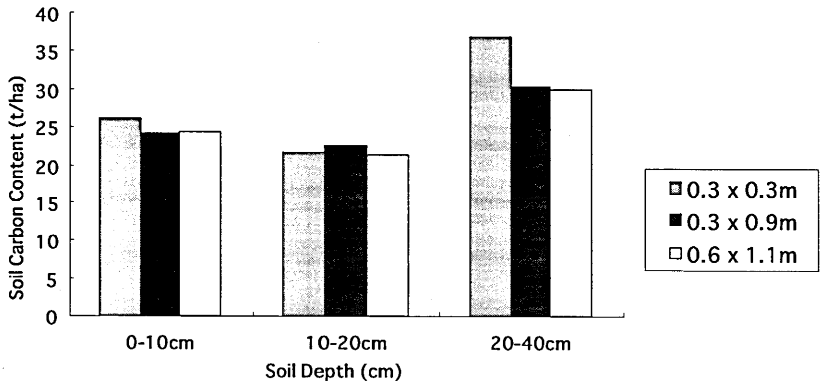


**Fig. 5.** Effect of plant spacing on soil carbon content at 0–10 cm, 10–20 cm, or 20–40 cm soil depths in three annual or one triennial harvested willow clone SV1 plots.

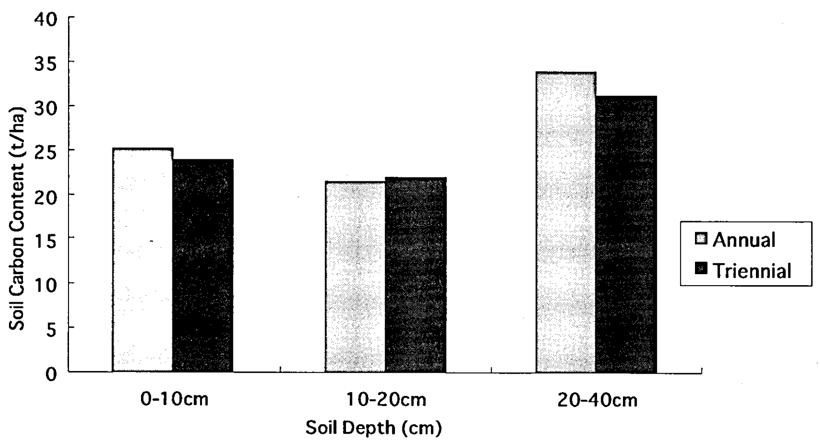


**Fig. 6.** Effect of cutting cycle on soil carbon content at 0–10, 10–20, or 20–40 cm soil depths in three annual or one triennial harvested willow clone SV1 plots.

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