SOIL CARBON POOLS IN SHORT ROTATION WILLOW (*Salix dasyclados*) PLANTATION FOUR YEARS AFTER ESTABLISMENT

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ABSTRACT

Soil carbon (C) pools, i.e., whole soil (WSC), and particle size fractions; sand (SaC), silt (SiC), and clay (ClC), within 0-60 cm soil depth of willow [*Salix dasyclodos* (SV 1)] short rotation intensive culture (SRIC) plantation were compared with adjacent non-woody vegetation (control) plots four years after plantation establishment. The sites had similar management history and by assumption similar soil C levels prior to plantation establishment. Particle size fractions were obtained using physical fractionation procedures. Carbon, determined by wet oxidation, did not differ significantly ($P > 0.05$) between willow and non-woody vegetation plots in concentration (g/kg), mass (g C/kg fraction), and enrichment (E = % fraction C/% soil C). We hypothesized that SRIC systems could impact soil organic matter (SOM) pools differently. The general increasing trend for pool C concentration was SaC < WSC = SiC < ClC and for mass SaC < ClC < SiC. Sand was C depleted whilst silt and clay were C enriched. We conclude that four years of tree presence maintained or caused no decline in initial soil C pools.

"Keywords:" Carbon concentration; Carbon mass; Carbon enrichment; Willow (*Salix dasyclados*); Short rotation intensive culture.

INTRODUCTION

Worldwide, interest in biomass and energy from short rotation intensive culture (SRIC) systems is increasing and cogent. Beneficial attributes associated with SRIC include sequestration of carbon (C) in aboveground biomass and soil, and conservation of fossil fuels, which could reduce atmospheric CO_2 enrichment and associated negative impacts on global climate. Soil C sequestration in SRIC systems is important because soil organic matter (SOM) is an important ecosystem component (Paul, 1984), contributes significantly to soil fertility, influences many soil properties (Swift and Woomer, 1993), and is an important soil quality indicator (Sikkora and Stott, 1996). Hence, knowledge of soil C sequestration and turnover would aid our understanding of soil productivity and sustainability in SRIC systems and their potential to act as a C sink.

Soil organic matter is composed of labile or actively cycling and stable recalcitrant fractions (Ellert and Gregorich, 1995) that have different rates of turnover due to the degree of physical and chemical protection (Stevensen and Elliot, 1989). Labile and recalcitrant SOM may be impacted differently under SRIC systems. There are a variety of biological and physical methods for studying SOM distribution and dynamics. Physical fractionation of soil into sand, silt and clay-size fractions separates SOM according to origin and degree of transformation. Partially decomposed organic matter of recent origin is associated with sand-size fraction and microbially processed organic matter is associated with silt and clay-size fractions (Chesire and Mundie, 1981). Particulate organic matter (POM) or organic matter associated with sand-size fraction is a good indicator of soil quality and responds rapidly and selectively to changes in land use and soil management (Camberdella and Elliot, 1992). Carbon enrichment ratios or factors (E) relate particle size fraction C to soil C and exclude effects of differences in soil C. Ratios greater than one indicate size fraction C enrichment, whereas ratios less than one indicate depletion (Christensen, 1992; Amelung et al., 1998). Therefore, the impact of SRIC on soil C pools can be evaluated by monitoring changes in C concentration, mass and enrichment.

Soil C pools have not been widely reported for willow and hybrid poplar SRIC systems. We determined the impact of four years of willow (*Salix dasyclados*-SV1) plantation growth on soil C pools within three soil depths (i.e. 0-20, 20-40, and 40-60 cm). We measured pool C concentration, mass and enrichment. Our specific objectives were to compare the distribution of C among pools: sand carbon (SaC); silt carbon (SiC); clay carbon (ClC), and whole soil (WSC) individually and combined between willow and non-woody vegetation (control) plots. The hypotheses tested for each sampling depth were: a) WSC, SaC, SiC, and ClC pools under willow and non-woody vegetation (control) plots are equal; and b) distribution of C among pools does not differ between willow and non-woody vegetation.

MATERIALS AND METHODS

Study Description

The study was superimposed on a 14-clone willow biomass site trial at Massena, New York (44° 58'N, 74° 51'W). The soils belong to the Rhinebeck series, an Aeric Ochraqualf subgroup, and are deep and somewhat poorly drained with a silt loam A horizon (0-30 cm) and a mottled silty clay loam and silty clay B2 horizon (30-75 cm). A mean annual temperature of 6.4^{0}C and mean annual precipitation of 84.7 cm characterize the area.

Non-woody vegetation (native grasses and shrubs) occupied the experimental area (0.16 ha) for more than a decade. The site was prepared using no-till chemical weed control. In the spring of 1993, unrooted dormant willow cuttings were planted in double-rows. Tree spacing was 0.6 m within rows, 0.7 m between single rows, and 1.5 m between double rows (15,500 trees/ha). The adjacent non-woody vegetation area serves as a control. All trees were cut back after the first growing season during December 1993. During early spring 1994 the plantation was fertilized with N, P, and K at elemental rates of 112, 34, and 78 kg/ha, respectively.

Soil Sampling

Soil samples were collected by depth (0-20, 20-40, and 40-60 cm) from willow and non-woody vegetation plots in November 1997 using a soil auger. Three replicate plots generated nine composite samples for each treatment. Samples were air-dried and sieved through a 2-mm sieve before laboratory analyses.

Soil Analyses

The procedure for particle size fractionation was adapted from methods outlined by Jackson (1956) and Gregorich and Ellert (1993). A 50-g soil sub-sample was dispersed with sodium hexamethaphosphate. The sand size fraction (>53μm) was obtained by wet sieving using a 53 μm sieve. The silt size fraction (2-53 μm) was obtained through successive sedimentation-decanting cycles. The clay fraction (< 2-μm) was obtained from the decanted supernatant by flocculation with $CaCl_2$ and centrifuging. Dry weights of soil fractions were obtained at 40°C and samples ground in a mortar to pass a 0.5-mm sieve screen. Carbon was determined within particle size fractions and whole soil using the Walkley Black procedure (Bickelhaupt and White, 1982).

Statistical Analysis

Sand, silt, clay and whole soil C concentration (g/kg soil) and mass (g C/kg fraction) data were analyzed in a split plot ANOVA with treatment (willow and non-woody vegetation) as whole plot factor and soil depth as a sub-plot factor. Fractional C mass was derived as the product of fraction dry weight and fraction C concentration. Fractional C enrichment ratios (E=[% C in fraction]/[% C in whole soil]) were computed for both willow and non-woody vegetation plots for each depth and compared using Student's t-test.

RESULTS AND DISCUSSION

Size Fraction Distribution

Generally, within 0-60 cm soil depth of willow and non-woody vegetation plots, sand and clay increased while silt decreased with depth. The proportional distribution of particle size fractions averaged: clay (7% in 0-20 cm and 20% in 40-60 cm) < sand (26% in 0-40 cm and 29% at 40-60 cm) < silt (67% in 0-20 cm and 51% in 40-60 cm) depth. Recovery of particle size fractions following fractionation averaged 99.5% indicating negligible losses during fractionation.

Soil Carbon Pools

Concentration and Mass. Four years after plantation establishment, soil C pools (WSC, SaC, SiC and ClC) within 0-60 cm soil depth between willow clone SV1 and non-woody vegetation plots did not differ significantly ($P > 0.05$) in concentration and mass. However, soil C pool concentrations for both vegetation types decreased significantly ($P < 0.001$) by depth. Beneath willow plots, C pool concentration values from the three depths ranged from 38 g kg^{-1} to 11 g kg^{-1} for WSC, 18 g kg^{-1} to 3 g kg^{-1} for SaC, 38 g kg^{-1} to 10 g kg^{-1} for SiC and 50 g kg^{-1} to 15 g kg^{-1} for ClC (Fig. 1.).

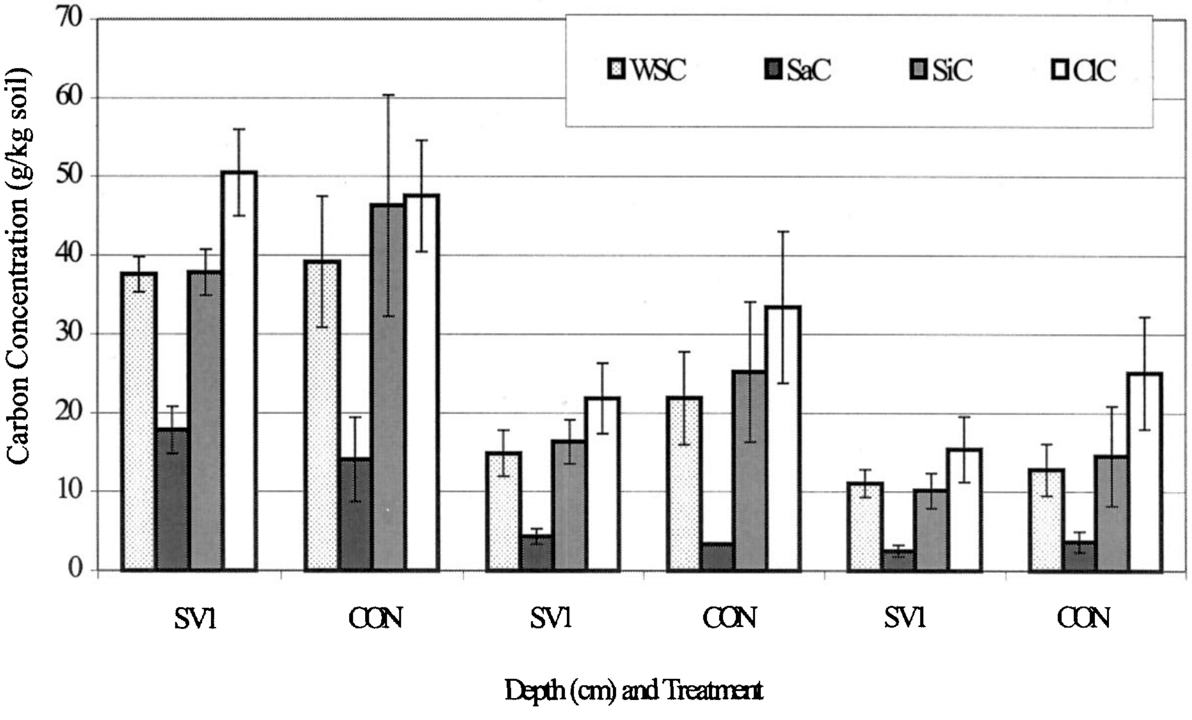

Figure 1. Soil C pool concentrations within 0-60 cm soil depth of willow clone SV1 and non-woody vegetation (Control = CON) plots. Whole soil carbon =WSC, sand carbon = SaC, silt carbon = SiC and clay carbon = ClC. (Bars represent one standard error).

For both vegetation types, SaC and SiC mass differed significantly by depth ($P < 0.001$) but not ClC mass. Beneath willow plots, values of fractional C mass from 0-20 cm to 40-60 cm were: SaC, 2 to 0.3 g C/ g kg^{-1} sand; SiC, 12.9 to 2.7 g C/ g kg^{-1} silt, and ClC, 1.7 to 1.3 g C/ g kg^{-1} clay (Fig. 2.).

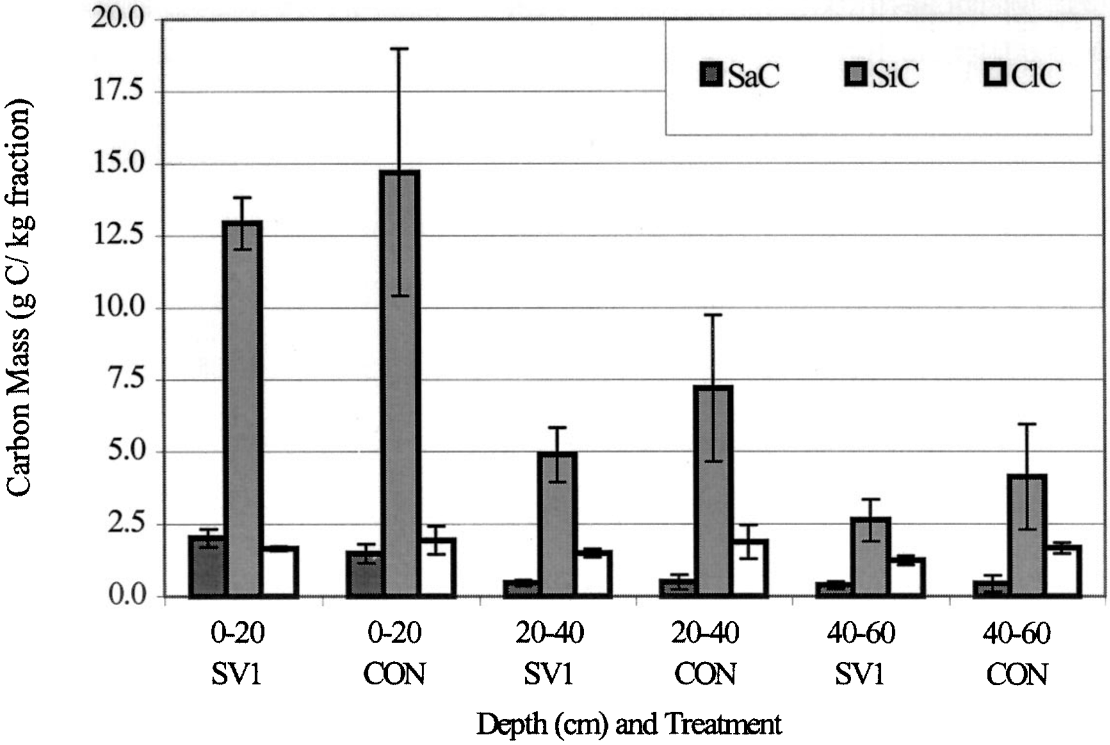

Figure 2. Fraction C mass within 0-60 cm soil depth of willow clone SV1 and non-woody vegetation (Control = CON) plots. Sand C = SaC, silt C = SiC, and clay C = ClC. (Bars represent one standard error).

These results indicate no significant changes in WSC, SaC, SiC and ClC concentrations, and SaC, SiC and ClC mass within 0-60 cm soil depth of willow plots four years after plantation establishment. Therefore, by implication, four years of tree presence maintained or caused no declines in soil C pools based on the assumption both willow and non-woody vegetation plots had similar management history and soil C pools at the commencement of the study. Soil C in willows and poplars have mostly been compared with agricultural row crops and other vegetation types with no consistent trends. Hansen (1993) reported soil C loss in young poplar plantations (4-6 years) compared to adjacent row crop and grass plots and attributed it to rapid decomposition from exposed clean-tilled surface. Park (1996) found soil C concentration was greater in grassland plots than in willow plots (6-7 years), which was greater than corn plots. Mehdi et al., (1999) reported higher soil C in willow bioenergy plots compared to corn and switchgrass three years after establishment. However, soil C declined in all systems after five years but willow plots on a more fertile site had significantly higher soil C.

Site preparation for willow biomass plantations involves a combination of conventional tillage (CT) practices and chemical methods of weed control. No-till (NT) chemical weed control was used to prepare this study site. Many studies have reported NT favors SOM build-up because of reduced losses from decomposition and soil erosion. Also, soil texture influences SOM loss, which is in the order: silt < whole soil < clay < sand (Christensen, 1987). Soil texture at the site is silt loam to silty clay and physical fractionation yielded high silt and clay proportions (approx. 70%).

We think the four-year period is probably too short for tree presence to significantly influence soil C pools. The no-till method of site preparation and high proportion of silt and clay may have also slowed the rate of soil C loss. Soil organic matter variability is naturally high as such SOM studies may require large sample sizes to capture natural variability and detect changes. We estimated that a sample size ($n = 154$), compared to our sample size ($n = 18$) is required to estimate a mean WSC concentration within 10% of the true mean.

Distribution. Pool C concentrations for both vegetation types generally increased in the order SaC < WSC < SiC < ClC for each sampling depth (Fig. 1.). This corroborates similar trends in C in particle size fractions reported for Danish arable soils (Christensen, 1985). Others have reported high C concentrations in clay (Genrich and Bremner, 1974; Christensen, 1987), and lower C concentrations in sand (Amelung et al., 1998; Barrios et al., 1996).

Size fraction C mass for both vegetation types generally increased in the order SaC < ClC < SiC for each sampling depth (Fig. 2). We attribute low SaC mass to relatively low proportion of sand (26% to 29%) combined with a lower SaC concentration (3 g kg^{-1} to 18 g kg^{-1}) compared to SiC (10 g kg^{-1} to 38 g kg^{-1}) and ClC (15 g kg^{-1} to 50 g kg^{-1}) (Fig. 1). Sand C is also more labile and actively cycling organic matter than SiC and ClC (Tiessen and Stewart, 1983; Gregorich et al., 1988; Camberdella and Elliot, 1992; Gregorich and Ellert, 1993) and could have been re-distributed to other fractional pools or decomposed. Clay C mass was intermediate between SiC and SaC mass and could be due to low proportion of soil clay (7% to 20%) even though ClC concentrations (15 g kg^{-1} to 50 g kg^{-1}) were highest. High SiC mass could be attributed to higher silt proportion (51% to 67%) combined with a relatively high SiC concentration of 10 g kg^{-1} to 38 g kg^{-1} (Fig. 1). High SiC mass could result from a combination of factors including: lower decomposition rates of silt-associated organic matter relative to clay, the transfer to silt of stabilized decomposition products from other size separates, and the accumulation of more stable soil organic matter (Christensen, 1992).

Carbon Enrichment. Four years after plantation establishment, fraction pool E did not differ significantly ($P < 0.05$) between willow and non-woody vegetation plots but varied with depth (Fig. 3.). Thus, similar to results of soil C pool concentration and mass above, four years of tree presence maintained or caused no decline in size fraction E. Generally, within 0-60 cm soil depth in both willow and non-woody vegetation plots, sand was C depleted whilst silt and clay were C enriched. The magnitude of E tended to be higher for clay than for silt. Beneath willow plots, the range in E values were: SaC ($E = 0.22$ to 0.47) < SiC ($E = 0.99$ to 1.14) < ClC ($E = 1.34$ to 1.55) (Fig. 3.). Fractional values of E less than one indicate C depletion and values greater than one indicate C enrichment (Amelung et al., 1998).

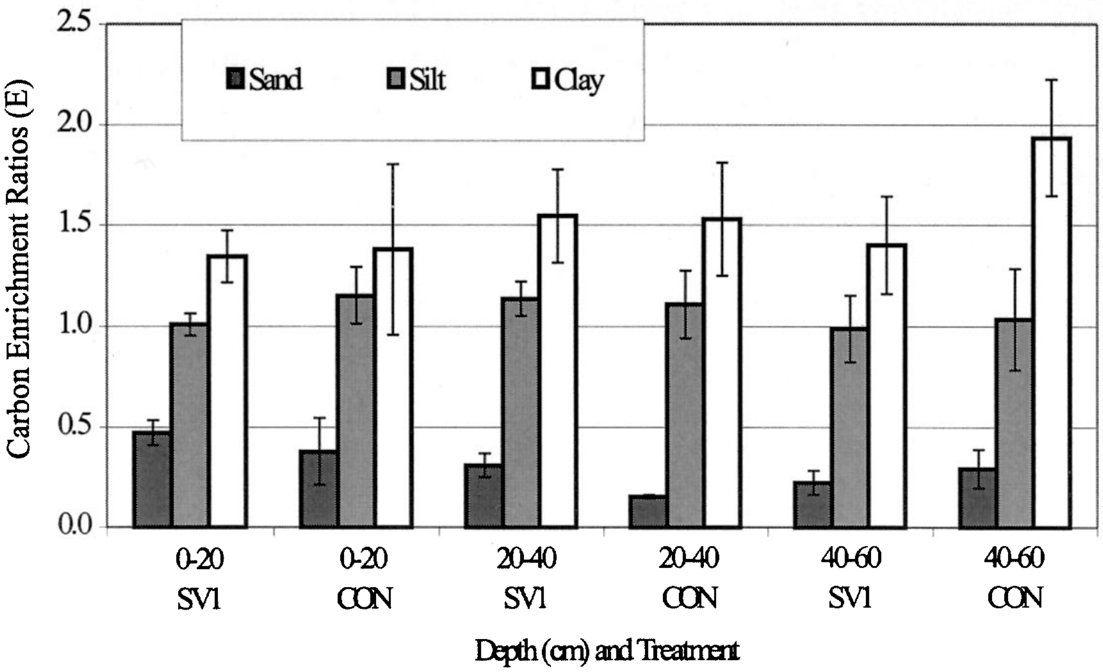

Figure 3. Carbon enrichment ratios (E) for sand, silt, and clay fractions within 0-60 cm soil depth of willow clone SV1 and non-woody vegetation (Control = CON) plots. (Bars represent one standard error).

These results corroborate other reports of higher E for clay (< 2μm) than for silt (2-20μm) and C depletion for sand (20-250 μm) (Christensen, 1985; 1987; Amelung et al., 1998). We note slightly different criteria for silt and sand in these reports. As discussed earlier, sand associated organic matter is more labile and could result in SaC depletion. Carbon enrichment of silt and clay could be due to protection of SOM from decomposition and SOM re-distribution among particle size fractions, which depletes labile fractions to fine silt and coarse clay (Tiessen and Stewart, 1983).

With higher site silt proportion and slower rates of organic matter loss compared to clay, silt E is lower than clay E because silt E is not influenced by silt content but by the extent to which silt active sites are occupied by organic matter (Christensen, 1985; 1987). We note that SiC concentration is lower than ClC concentration. With lower clay proportion, and higher ClC concentration, clay E is higher than silt E because of higher ClC concentration and occlusion of organic matter by clays offering protection from microbial processing and loss. Christensen (1985), (1987), reported that clay E is influenced by clay content, organic matter binding capacity and the extent to which clay active sites are occupied by organic matter.

CONCLUSIONS

Four years after willow SRIC plantation establishment, there were no detectable changes in: a) WSC, SaC, SiC and ClC concentration; b) SaC, SiC and ClC mass, and c) SaC, SiC and ClC enrichment within 0-60 cm soil depth of willow and non-woody vegetation (control) plots. Based on our initial assumptions of similar soil C pool levels prior to plantation establishment due to similar site management history, we can conclude tree presence for four years has not depleted soil C pools. A number of factors may have contributed to this: the short period of tree growth; the no-till site preparation; protection of SOM from decomposition and losses by high site silt and clay proportions, and high site SOM variability.

Carbon concentration, mass, and enrichment differed among soil C pools. The general trends were: (a) for concentration, SaC < SC < SiC < ClC; (b) for mass, SaC < ClC < SiC; and (c) for enrichment, silt < clay whilst sand was depleted. These trends may be due to differences in patterns of organic matter loss and re-distribution among pools. We conclude that particle size fractions define soil C pools and can be monitored to advance our understanding of SOM dynamics. Changes in total SOM due to land use or management is usually slow and difficult to detect until several years after changes in land use or management. Active SOM pools respond quickly to changes. Research is needed to assess the impacts SRIC systems on soil C sequestration and soil sustainability and productivity. Such an effort requires long-term systematic studies of SOM dynamics in SRIC systems. Particle size C pools may be monitored to assess the negative or positive impacts.

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