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# No significant differences in soil organic carbon contents along a chronosequence of shrub willow biomass crop fields

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ABSTRACT

Shrub willow biomass crops (SWBC) have been developed and promoted for widespread deployment in northeastern and mid-western US as well as in Europe. There are concerns that the production system could reduce the soil organic carbon (SOC) over time due to soil disturbances and repeated three-year harvest cycles. This study assesses changes in SOC beneath shrub willow (*Salix x dasyclados* [SV1]) biomass crops utilizing a 0, 5, 12, 14, and 19-year old SWBC fields. The sites' management history was similar, suggesting uniform SOC contents prior to plantation establishment. SOC contents were analyzed by total (i.e. 45 cm) and by layer (i.e. 0–15 cm, 16–30 cm, and 31–45 cm) across different ages. Mean SOC contents to 45 cm depth ranged from 175 to 188 Mg $ha^{-1}$, and showed no statistically significantly differences across ages ($p = 0.15$) and no interaction between age and depth ($p = 0.19$). SOC contents differed significantly with soil depth when averaged across ages ($p < 0.0001$). Statistical analysis of SOC contents by layer, however, showed that SOC contents in the upper 15 cm depth were significantly different ($p < 0.001$). Linear contrasts of mean SOC contents for the 0–15 cm depth revealed that the 0-year old was significantly different compared with the 5, 12, 14, and 19-year old SWBC.



## 1. Introduction

Shrub willow biomass crop (SWBC) (*Salix x dasyclados* (SV1)) is one of the dedicated bioenergy crops being promoted for widespread development in Northeastern and Midwestern U.S as well as in Europe [1,2]. This perennial energy crop is known for a high biomass yield in short time period, a broad genetic base, ability to resprout after multiple harvests, and ease of propagation [2]. SWBC fields are mechanically tilled during site preparation, established in two double rows using 15–20 cm unrooted cuttings, harvested on a three-year harvest cycle, and intended to produce biomass up to 22 years [3]. It is envisioned that utilizing SWBC as a renewable source of energy could alleviate the dependency of the energy sector on the use of conventional fossil fuels [1,2]; hence, helps reduce greenhouse gases (GHG's), and other pollutants such as sulfur dioxide and potentially $NO_x$ [4]. In effect, the SWBC mitigates global warming by slowing the build-up of atmospheric GHG.

One advantage of SWBC is the low GHG potentials of the production system [1,2]. Heller et al. [1] life cycle analysis

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(LCA), based on seven three-year rotations, showed that the willow biomass production system is a low carbon fuel source with net GHG emissions of about 3.7 Mg $CO_2$ eqv. $ha^{-1}$ at the end of seven three-year rotations. This analysis assumed a constant level of soil organic carbon (SOC) over the entire life cycle of the crop, based on Ulzen-Appiah's [5] findings of no detectable differences in SOC across fields of a single willow clone (SV1). However, the assumption of stable SOC in SWBC over long-term remains debatable due to contradictory findings on SOC changes beneath short rotation woody crops (SRWC). Some authors reported an increase of SOC over time [6–8] while others reported an initial decrease followed by recovery [9–11]. There are also studies that reported no SOC changes beneath SRWC fields [4,11,12].

Observed SOC changes beneath SRWC have been attributed to soil disturbances and aboveground biomass removal [9,11,14]. Plowing and disking during site preparation enhance soil organic matter (SOM) decomposition and C losses [15] due to increased soil aeration and soil temperature that enhance microbial decomposition [16]. This leads to SOM decreases that could extend several years following plantation establishment [9,10]. Aboveground biomass harvesting reduces the amount of sequestered C and decreases soil nutrients input into the soil. This management practice removed about 499.2 Mg $CO_2$ eqv. $ha^{-1}$ at the end of seven three-year rotations [1] and exported substantial amount of soil nutrients, ranging from 75 to 86 kg N $ha^{-1}$, 10 to 11 kg P $ha^{-1}$, 27 to 32 kg K $ha^{-1}$ 52 to 79 kg Ca $ha^{-1}$, and 4 to 5 kg Mg $ha^{-1}$ [17]. Except when inorganic fertilizer is supplied to replenish exported soil nutrients, frequent harvesting could result to the decrease of soil nutrients supply and plant growth that reduces SOM inputs [18].

Effects of different management practices in SWBC on SOC had been investigated. Ulzen-Appiah [5,19] assessed SOC changes along a chronosequence of 3–12 years old SWBC (SV1) fields across New York. In this study, it was concluded that microbial biomass carbon (MBC) did not significantly change across the chronosequence. However, it remains unclear how the SOC changes over long-term (i.e. beyond 12 years), motivating the current study. Our objective was to assess SOC changes beneath SWBC following multiple three-year aboveground biomass harvesting cycles using a chronosequence of a single SWBC clone (SV1). Specifically, we (a) examine total SOC contents to 45 cm depth in SWBC that are 0, 5, 12, 14, and 19 years old, and (b) determine the vertical distribution of SOC contents by layer, at 15 cm increments to a depth of 45 cm below the soil surface. We hypothesize that there are no significant differences in SOC among the different ages and soil depths along a 19-year chronosequence.

## 2. Materials and methods

### 2.1. Site description

Four of the five different SWBC fields (ages 0, 5, 14, and 19) used in this study were located adjacent to each other at Tully (42° 47′ 30″ N and 76° 07′ 30″W); the fifth field (age 12) was located in Lafayette (42° 52′ 45″ N and 76° 06′ 22″ W), Central New York, USA. We established a new SWBC field, which we considered 0-year old, located adjacent to the 5, 14, and 19-year old willow fields. Baseline soil samples, for SOC analysis, were collected in the 0-year old field prior to plowing and disking. All fields were previously used for agricultural crops, and have comparable soil parent material, morphology, and management history. The Tully site was previously tilled and planted with corn, and subsequently been used for an aspen yield trial prior to willow establishment in 1990. The Lafayette site was also a cornfield for many years before the establishment of the willow and poplar field trials in 1997.

The soil at the Tully site is well- to excessively well drained with high sand and gravel contents from sandstone and shale (Palmyra soil series) [20], which is developed from glaciolacustrine deposits associated with proglacial lakes during glacial retreat about 14,000 years ago [21,22]. The Lafayette site is well- to moderately well drained soil, developed from glacial till deposits with a shallow limestone and a shale bedrock as close as 15 cm below the soil surface (Honeoye series) [20]. The soil texture at both sites is silt loam [4,16,20]. The climate is humid continental with cold winters and warm summers. Thirty-year mean annual temperature is 7.9 °C, and precipitation is 847 mm (www.ncdc.noaa.gov).

The planting density of the existing SWBC fields, which were used in this study, varied. The 0, 5, 12, and 14-year old willows were spaced 1.5 m between two double rows and 0.6 m within double rows (15,000 plants $ha^{-1}$). The 19-year old willow field was spaced 0.9 m between two single rows, and 0.6 m within rows (18,500 plants $ha^{-1}$) [15]. These fields have been harvested on a three-year cutting cycles. The latest harvesting activity occurred two years prior to the start of this study. Consequently, during data collection, aboveground biomass components were two years old in all fields, except the 0-year old. In contrast, the above- and belowground stool and root systems in these fields were 0, 5, 12, 14, and 19-year old. The existing aboveground biomass was harvested manually with brush saws during dormant season and the stools were allowed to resprout during the next growing season. The 0-year old willow field was used as our reference field, against which we compared the SOC of the 5, 12, 14, and 19-year old SWBC fields.

### 2.2. Sampling lay-out and soil sampling

Six measurement plots, containing 13 to 28 willow stools, were established in each field. Measurement plots were established within the untreated 8-m long border areas (buffer zones) in all SWBC fields. Dimensions of measurement plots were different due to differences in planting density. Measurements plots were 5.0 m × 3.6 m for the 5, 12 and 14-year old SWBC and 3.0 m × 4.0 m for the 19-year old SWBC. In all measurement plots, buffer zones (1.5 m wide) containing SWBC were included in each direction.

Three soil samples were collected from each measurement plot using cylindrical metal soil cores, 15 cm long × 7.5 cm diameter, with a distance of 1 m diagonally across the measurement plot. Soil cores were obtained from three depths (0–15 cm, 16–30 cm, and 31–45 cm). For the 0-year old SWBC field, we collected soil samples prior to mechanical tillage. Soil samples were composited by depth, placed in paper bags, and transported to the laboratory. While the soil sampling activity