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Biomass Crop Production: Benefits for Soil Quality and Carbon Sequestration*

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Research at three locations in the southeastern U.S. is quantifying changes in soil quality and soil carbon storage that occur during production of biomass crops compared with row crops. After three growing seasons, soil quality improved and soil carbon storage increased on plots planted to cottonwood, sycamore, sweetgum with a cover crop, switchgrass, and no-till corn. For tree crops, sequestered belowground carbon was found mainly in stumps and large roots. At the TN site, the coarse woody organic matter storage belowground was 1.3 Mg ha^{-1} yr^{-1}, of which 79% was stumps and large roots and 21% fine roots. Switchgrass at the AL site also stored considerable carbon belowground as coarse roots. Most of this carbon storage occurred mainly in the upper 30 cm, although coarse roots were found to depths of greater than 60 cm. Biomass crops contributed to improvements in soil physical quality as well as increasing belowground carbon sequestration. The distribution and extent of carbon sequestration depends on the growth characteristics and age of the individual biomass crop species. Time and increasing crop maturity will determine the potential of these biomass crops to significantly contribute to the overall national goal of increasing carbon sequestration and reducing greenhouse gas emissions.

1. INTRODUCTION

Conversion from agricultural crops to biomass crop production has been projected to have positive benefits for soil physical quality and soil carbon storage (Smith 1995, Grigal and Berguson 1998). The greatest gains in soil carbon storage are expected to occur on lands

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that were previously in agriculture or barren (Smith 1995). Hansen (1993) concluded that after a decrease in soil carbon storage during the initial years of tree crop establishment, soil carbon significantly increased over the 6-12 year rotation, primarily in the upper 30 cm. Hansen hypothesized that the initial carbon losses occurred from the clean-tilled surface soil and as a result of mineralization during the first several years of planting establishment. Makeschin (1994) found that soil carbon storage nearly doubled after three years under hybrid poplar compared to adjacent arable fields in Germany.

Johnson (1993) identified the need to determine the effects of management practices and soil properties on soil carbon storage in intensive production systems. The goal of this research was to determine changes in soil physical properties and belowground carbon sequestration during the early years of biomass crop production on sites converted from agricultural crops to short-rotation woody crops and switchgrass. A further objective of this study was to determine the contribution of cover crops to site quality and belowground carbon sequestration.

2. METHODS

On three sites in the Tennessee Valley, typical of areas having identified biomass crop potential, replicated 0.4 to 0.6 ha plots were enclosed within berms, planted to the appropriate agricultural crops or biomass crops, and instrumented for long-term monitoring to quantify differences in runoff and water quality. Sweetgum (*Liquidambar styraciflua*) with and without a cover crop between rows and switchgrass (*Panicum virgatum*) were established at a site in northern Alabama for comparison with no-till corn. Eastern cottonwood (*Populus deltoides*) was established in western Mississippi for comparison with cotton, and American sycamore (*Platanus occidentalis*) was established in western Tennessee for comparison with no-till corn. At the TN site, existing 12-year-old sycamore were included as a comparison. The Alabama (AL) site is on the Decatur silt loam soil, the Mississippi (MS) site, a Bosket silt loam soil, and the Tennessee (TN) site, a Memphis-Loring silt-loam intergrade. Soil physical characteristics of bulk density, penetration resistance, infiltration, and aggregate stability were measured on all plots at each site in 1995 at the time of establishment and again at the end of the third growing season (1997) to determine changes in soil quality over time. More detailed site descriptions, methods, and results of water quality monitoring can be found in Tolbert et al. (1998), Joslin and Schoenholtz (1998), and Thornton et al. (1998).

Belowground biomass and soil carbon were determined for each tree crop at the end of the third growing season. For each tree-crop treatment, six stumps and those roots extracted with the stumps were removed, weighed, dried, and reweighed to determine organic matter content. Replicate root cores were taken at 0 – 1.25 cm, 1.25-7.5 cm, and 7.5 – 15 cm depths to determine root biomass for both tree and switchgrass crops. Determinations of soil carbon storage under land use conversion to switchgrass were made to

30-cm depths. Additional estimates for switchgrass were made based on root distributions to greater depths for comparison with samples from CRP lands.

3. RESULTS AND DISCUSSION

Comparisons of aggregate stability from the 3-year old cottonwood and continuous cotton plots at the Mississippi (MS) site showed that the percent stability was twice as great under the tree crop after both 8 and 32 minutes of immersion and oscillation. At the Tennessee (TN) site, aggregate stability was significantly greater ($P > 0.05$) under 12-year old sycamore than under the 3-year old sycamore and no-till corn. The aggregate stability did not significantly improve under the sycamore plots at the 0- 15 cm depth over the first four years of the tree-crop rotation; significant improvements, however, were observed under the no-till corn plots. These differences at these shallow depths could be attributed to the more extensive root system of the no-till corn with a winter cover crop as compared to a less fibrous root system and less even root distribution in the sycamore.

Both penetration resistance and bulk density decreased under cottonwood compared with cotton at the MS site. After the first growing season, the soil traffic pan, which initially occurred at 15 to 30 cm, was not evident under the cottonwood but persisted under the cotton rotation. The penetration resistance dropped by half (from 3.0 to 1.5 MPa) in the upper 10 - 20 cm. At the TN site, bulk density values for the profile (from surface to 1.5 m depth) showed that significant changes occurred within the upper 30 cm depth for 12-year old sycamore plantings compared to no-till corn and the 3-year old sycamore. At a depth of 0-3 cm, the bulk density under the young sycamore showed a significant decline from year 1 to year 3. Bulk density under the 3-year old sycamore at this depth was 1.17 Mg ha^{-1}, which was comparable with the 12-year old sycamore at the same depth. Bulk density under no-till corn at the same depth was significantly greater (1.34 Mg ha^{-1}).

At the TN site, the greatest organic carbon increases occurred within 25 cm of the stem center, largely due to the contribution of coarse organic matter, particularly stumps (Fig. 1). At the MS site, the total mass of soil carbon (excluding stumps and coarse organic matter) under cottonwood was 15 Mg ha^{-1}. With stump and coarse roots included, the belowground biomass was approximately 18 Mg ha^{-1}. During the first growing season, the cottonwood that was established from cuttings did not develop a tap root, but formed a dense horizontal root system which extended across the 3.6 m distance between rows at depths of 10 to 25 cm. Approximately 60% of the soil organic carbon under the cottonwood occurred in the upper 30 cm (Fig. 2); small roots extended to depths of $\geq$ 1 m. This greater distribution of cottonwood roots in the upper 30 cm is consistent with distributions found to this depth by Tuskan (personal communication) for cottonwood (70%), sweetgum (71%), and sycamore (59%).

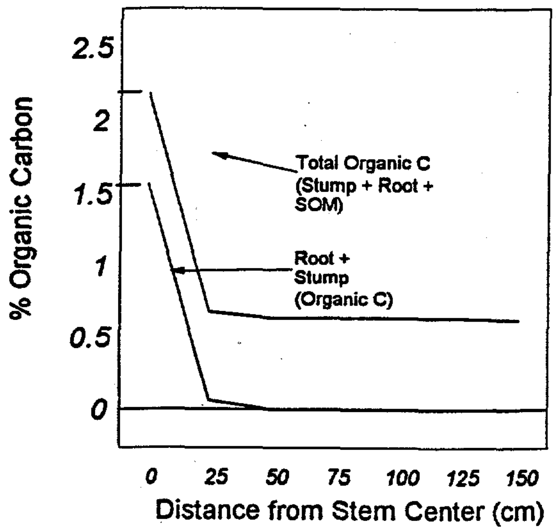

Fig. 1. Lateral distribution of soil organic C within the upper 30 cm under sycamore at t TN site.

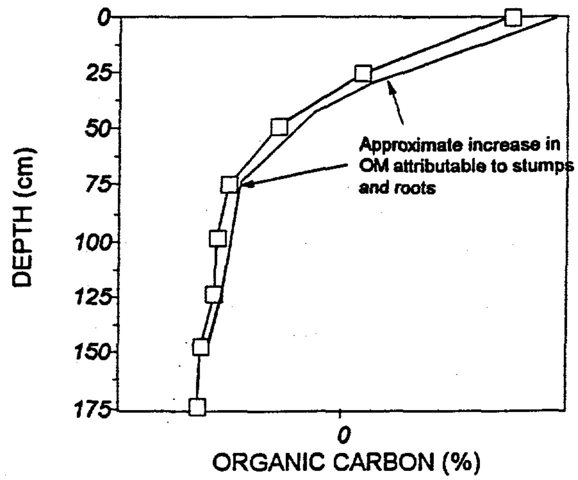

Fig. 2. Distribution of roots through the soil profile. The solid line represents th additional contribution of larger roots and coarse organic matter not passing through a 2mm sieve.

Sycamore and no-till corn established on former traditional agricultural lands at the TN site increased soil carbon in the upper 15 cm by 27 % and 34%, respectively, by the end of the third growing season. The increase in soil carbon storage under the sycamore was approximately 1.3 Mg ha^{-1} yr^{-1}. This number is similar to that found by Hansen (1993) for soil carbon accretion rates under hybrid poplar in the north-central states. Soil carbon under cottonwood at the MS site increased by 19 % by the end of the third growing season; there was no change in soil carbon for the cotton plots (Fig. 3). The increase in soil carbon on the plots converted from traditional agricultural crops to no cultivation is consistent with the projections made by Smith (1995) that reforestation of agricultural lands could increase carbon sequestration in soils.

There was a significant increase ($p \leq 0.02$) in soil carbon under switchgrass, sweetgum with a cover crop, and no-till corn over a three year period at the AL site. By contrast soil carbon in the plots of sweetgum without a cover crop actually decreased by 6% over the same period (Fig. 4). The response of the sweetgum without a cover crop treatment is consistent with Hansen's (1993) results which showed decreases in soil carbon during the first few years of tree crop establishment when clean cultivation was practiced to minimize weed competition. Soil carbon has been found to significantly increase under switchgrass across a wide range of sites from Texas through Virginia when compared with fallow plots and initial samples (McLaughlin and Walsh 1998).

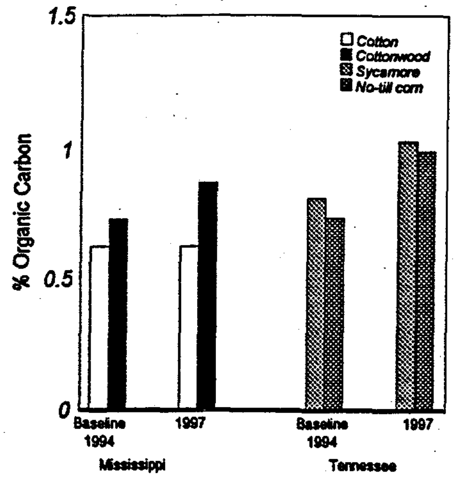

Fig. 3. Comparison of baseline soil C and soil C at the end of the third growing season at the MS and TN sites for the 0-15 cm depth increment.

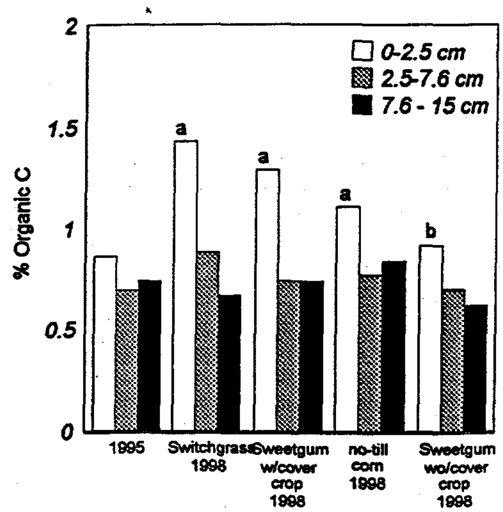

Fig. 4. Change in % organic C by depth increments at Alabama A&M after 3 years compared with baseline samples.

4. SUMMARY

Conversion of traditional agricultural lands to production of short-rotation woody and herbaceous crops as energy feedstocks offers considerable potential to sequester carbon in the belowground components of these crops. Crop rotations of 5 to 20 years for these perennial crops offer potential long-term storage of soil carbon belowground. Data from the three sites show the value of soil cover provided by switchgrass, sweetgum with a cover crop, no-till corn, sycamore, and cottonwood. The development of extensive perennial rooting systems and litter layers appear to be major factors accounting for increasing carbon sequestration. Questions still to be considered are how the vertical distribution of soil carbon within the soil column changes with time and the duration of the belowground carbon storage with conversion of sites back to agricultural crop production.

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