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CARBON SEQUESTRATION POTENTIAL OF A 27-YEAR-OLD TREE-BASED INTERCROPPING SYSTEM IN SOUTHWESTERN ONTARIO

Amy Wotherspoon[1], Idris Mohammed[1], Naresh V. Thevathasan[1], Andrew M. Gordon[1], and R. Paul Voroney[1]

[1]School of Environmental Sciences, University of Guelph, Guelph, ON, Canada, N1G 2W1

Contact: awothers@uoguelph.ca

ABSTRACT

This study aimed to quantify carbon (C) pools and fluxes in a 27-year-old tree-based intercropping (TBI) system as compared to a conventional agricultural system at the University of Guelph's Agroforestry Research Station (43° 16'N 89° 26'W) (established 1987). Tree species quantified during this study include poplar hybrid (*Populus* spp.), Norway spruce (*Picea abies*), red oak (*Quercus rubra*), black walnut (*Juglans nigra*), and white cedar (*Thuja occidentalis*). In the TBI system, above- and belowground biomass, along with soil organic carbon (SOC) concentrations, litterfall, litter decomposition and soil respiration were quantified. In the conventional agricultural field, SOC, litter decomposition and soil respiration were quantified. Preliminary results indicated higher C sequestration potential rate with faster growing species such as poplar, and slower potential rate for slower growing species such as spruce and cedar. SOC accumulation was highest in the predominant wind direction (east), closest to the tree rows (0.5 m), and at shallower depths (10-20 cm) for all species. SOC accumulation was highest under poplar tree, followed by spruce, oak and walnut. Quantities of litterfall followed similar pattern and decomposition rates are still being analyzed. Soil respiration rates were higher in TBI systems and at distances closer to the tree row. Further results will be presented on the total measured C pools and fluxes and the importance of C sequestration potential of a 27-year-old TBI system to sequester atmospheric C and mitigate climate change. Accumulation of SOC can also have implications on crop yields and long term stability of TBI soils.

Keywords: agroforestry, soil organic carbon, litterfall, litter decomposition, soil respiration

INTRODUCTION

With an increase of 30% atmospheric carbon dioxide (CO_2) in the last 50 years (IPCC, 2001), and its associated increased in temperature, anthropogenic emission sources from agricultural practices contribute one quarter of these contributions to global warming (Duxbury *et al.* 1993). In attempt to mitigate these CO_2 emissions, efforts to reclaim some of this forested land have been put into effect, including tree-based intercropping (TBI). TBI, a form of agroforestry land use management, consists of widely spaced tree rows planted among agricultural crops. These trees provide additional above- and belowground biomass to sequester atmospheric carbon and return nutrients to the soil in the form of litterfall. Along with economic and ecological benefits, TBI systems can act as a long term carbon (C) sink and enhance nutrient cycling. These additional nutrients also reduce our dependence on fossil fuels for fertilizer, and thus greenhouse gas (GHG) emissions.

This study aimed to quantify (C) pools and fluxes in a 27-year TBI system as compared to conventional agricultural. Research was conducted at the University of Guelph's 30 ha Agroforestry Research Station located in Guelph, Ontario (43^o 16'N 89^o 26'W). Established in 1987 on calcareous parent material, this site has a sandy loam soil and tree density of 111 ha^{-1}. Tree species quantified during this study include *Populus* spp. (poplar hybrid) *Picea abies* (Norway spruce), *Quercus rubra* (red oak), *Juglans nigra* (black walnut), and *Thuja occidentalis* (white cedar), species commonly found in TBI and other agroforestry systems.

MATERIALS AND METHODS

Above- and Belowground Carbon Pools

In order to quantify above- and belowground carbon pools from biomass, three replicates of the five tree species were destructively harvested at the TBI site. Tree components were divided into categories of leaves, twigs, primary and secondary branches, trunk and belowground roots. These were weighed for oven dry biomass, and analyzed for carbon concentration, as outlined by Gordon *et al.* (2005).

To quantify belowground soil organic carbon (SOC) pools, three replicates were collected at the TBI site in the east and west direction, at 0.5, 1.0, 1.5 and 2.0 m from the tree row to a depth of 0-10 cm, 10-20 cm, and 20-40 cm for all tree species. Soils collected at a conventional agricultural field were collected in the same respective pattern. Soils were sieved to 2 mm to remove fine root matter and then further ball milled to 0.125 mm. Soil was then fumigated with 12 M hydrochloric acid (HCl) for seven days to remove inorganic carbon (IC) and then analyzed for organic carbon (OC) with the LECO CR-12 Carbon Analyzer (LECO Corporation, MI, USA).

Litterfall and Litter Decomposition

Litterfall was measured using 1 m^2 litter traps (mesh size 0.2 cm^2) placed at various distances from the tree row in the TBI site to suit tree orientation and spacing. For poplar, walnut and oak species, litter traps were placed at 1 m in the north, east, south and west direction and at 4 m in the east and west direction. For spruce trees, litter traps were placed at 1 m in all directions, and for cedar trees litter traps were placed at 1 m in the east and west direction. Annual litterfall was collected between September and December, 2012 and weighed for oven dry biomass.

Litter decomposition was measured at both sites with 30 cm^2 decompositions bags (mesh size 0.2 cm^2), filled with a known oven dry mass of litter from each tree species and buried at ~20 cm below the soil surface. Decomposition bags were retrieved seven times a year between October 2012 and September 2013, cleaned, dried and reweighed to compare mass loss. Upon final collection, decomposition rates will be expressed as a decay function of remaining mass over time.

Soil Respiration

CO_2 evolution of both systems was quantified using the soda lime (lime $Ca(OH)_2$) with 5-20% sodium hydroxide (NaOH)) absorption method, outlined by Edwards (1982). Three replicates of respiration chambers were placed at 0.0 m (within the tree row), 2.0 m and 4.0 m into the alley crop row for poplar, walnut and spruce trees in the TBI site. Respiration chambers in the conventional agricultural field were set up at the same corresponding distances. Measurements were taken at least once per month between June 2012 and May 2013.

RESULTS AND DISCUSSION

Above- and Belowground Carbon Pools

C content, as determined by the concentration of C (%) multiplied by the oven dry biomass (kg) was determined for each tree species. Aboveground tree components had higher C concentration (%) when compared to belowground by 1 – 3%, but all ranged between 43 – 55%. Poplar had significantly higher C content, both above- and belowground as compared to walnut, oak and spruce, all of which were also significantly higher than the C content of cedar. While these results can be expected, they aid us in determining which trees have higher sequestration potential – an important factor when establishing TBI systems (Peichl *et al.* 2006).

SOC concentrations were consistently found to be higher in the east direction (the predominant wind direction), at distances closer to the tree row (0.5 m) and at shallower depths (0-10 cm). Overall, poplar had the highest SOC concentration, followed by spruce, oak and walnut (cedar concentrations are still to be determined). As SOC accumulation is a result of input from litterfall and fine root turnover, it is expected that trees such as poplar, with higher growth and assimilation rates would have higher SOC concentrations than slower growing species such as spruce (Peichl *et al.* 2006). SOC concentrations in the control field were found to be higher than the TBI system at a depth of 10-20 cm depth. While this is unexpected, it could be due to smaller sample sizes, and different land management practices and crop rotations than the TBI site. Peichl *et al.* (2006) and Bambrick *et al.* (2010) found SOC levels to be 0.6 and 12% higher, respectively, in the same TBI site under poplar trees when compared to conventional agricultural systems at 17 and 21 years after establishment. For this reason, re-sampling will occur to verify current data. By accumulating long term SOC accumulation, this will allow TBI systems to continue to support nutrient cycling and uptake for agricultural crops and allow for crops yields comparable to conventional agriculture. This SOC accumulation contributes to overall ameliorated soil conditions and long term soil stability.

Litterfall and Litter Decomposition

Higher amounts of litterfall biomass were found in the east direction (the predominant wind direction), and within the first metre surrounding the tree. In 2006, Oelbermann *et al.* found C input to be significantly higher at 1 m from the tree row compared to 11.5 m from the tree row. While this study does not account for as far into the crop alley, we expect higher concentrations at 1 m as well. Litter decomposition rates are still being analyzed but are expected to follow a constant decay rate which will help to determine the rate at which nutrients are being released back into the soil in order to contribute to long term SOC accumulation.

Soil Respiration

Preliminary analysis of soil respiration rates indicated higher respiration between July and December. At the same site at 13 years after establishment, Gordon *et al.* (2005) found annual yearly emissions to be 732.50 ($\pm$ 31.0) g/m^2) and 400.65 ($\pm$ 17.2) g/m^2) for the TBI and conventional agricultural system, respectively. Similar results can be expected from this study, as respiration rates are expected to be higher most likely due to the presence of trees. Trees provide higher C inputs from leaf litter which favour higher tree root respiration and microbial respiration and therefore CO_2 evolution (Brady and Weil 1996, Matteucci *et al.* 2000, Peichl *et al.* 2006).

Next Steps: Allometric Equations and C Modeling

Data presented in this study will next be applied to the improvement and accuracy of allometric equations and C modeling systems. These equations and models are currently in place to account for site characteristics, biophysical properties of tree species, and quantification of C pools and fluxes to predict biomass measurements and total C sequestration potential. While allometric equations currently exist for natural forest systems, their application for agricultural systems is questionable due to the forms of management and species presence (Kuyah *et al.* 2012). In addition to allometric equations, data can also help to refine C models, such as that presented in Peichl *et al.* (2006). These models can now be run with data from a 27-year-old system where certain tree species, such as poplar, have reached maturity and are at the end of their life cycle. By modeling amounts of C being sequestered in a TBI system and comparing it to conventional agriculture, we can put a monetary value on the benefits of TBI systems to mitigate climate change. This can provide support for the implementation of carbon credits and tax incentives from the government to landowners to increase the adoptability of TBI systems.

CONCLUSIONS

Conventional agricultural systems are known to clear natural forests, degrade land, and contribute to GHG emissions through excessive use of fertilizers. TBI systems may be the solution to slow these effects by providing a natural source of nutrients back into the soil and sequestering atmospheric CO_2 to act as a C sink and a form of land remediation. It can be concluded that the incorporation of fast growing tree species can sequester a significant amount of CO_2 emissions caused by the clearing of natural forests for agriculture. The accumulation of C in the soil, via litterfall, otherwise absent in conventional agricultural systems, can help to slow land degradation as a result of agricultural practices. TBI systems not only provide ecological and economic benefits, but will almost become more attractive with the idea of carbon credits, which will provide monetary compensation and thus more incentive for landowners to invest in C storage alongside agriculture.

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