Tree-based intercropping: A land-use for greenhouse gas mitigation in Canadian agricultural systems

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Introduction

In tree-based intercropping (TBI) systems, the potential influence of trees in relation to carbon (C) sequestration and Greenhouse Gas (GHG) emissions reduction has been documented but the mechanisms remain poorly understood, especially for below-ground processes. Recently, several studies in this area were undertaken in Ontario, Canada under the auspices of Canada's involvement in the Global Research Alliance. C sequestration potential, nitrous oxide reduction potential and soil voids were quantified in a 25-year-old TBI system in southern Ontario for five tree species: hybrid poplar (*Populus* spp.), Norway spruce (*Picae abies*), red oak (*Quercus rubra*), black walnut (*Juglans nigra*), and white cedar (*Thuja occidentalis*), which were intercropped with soybean (*Glycine max*). Results were compared with a adjacent conventional agricultural system in which soybean was grown as the sole crop.

Guelph Agroforestry Research Station

Established in 1987, the Guelph Agroforestry Research Station is 30 ha of land in extent (Figure 3), intercropped with 8 hardwood and 2 coniferous trees at a tree density of 111 trees ha^{-1} on sandy loam soil. An adjacent conventional agricultural field was subject to a corn, soybean and winter wheat/barley rotation and the soil has the same soil properties. Crop management and all cultural practices are the same for both land-use systems, therefore, direct comparisons cane be made.

Figure 3. University of Guelph, Agroforestry Research Station aerial view, Guelph, Ontario, Canada

Carbon Modeling

Carbon models were constructed using five tree species within a TBI system using data from the destructive tree components. Above and belowground tree components were weighed for biomass estimations. For system level C sequestration quantification, SOC at varying distances (0.5, 1, 1.5 and 2 m) from the tree row and depths (0-20, 10-20 and 20-40 cm), annual litterfall, litter decomposition and soil respiration were measured. Results were compared with a conventional agricultural system in which soybean was grown as the sole crop.

Results:

Net C flux for poplar, spruce, oak, walnut, cedar and the soybean sole-crop were + 2.1, + 1.6, + 0.8, + 1.8, +1.4 and – 1.2 t C ha^{-1}, y^{-1}, respectively (Table 1). The results suggest a greater atmospheric CO_2 sequestration potential for all five tree species when compared to a conventional agricultural system.

Table 1. Carbon sequestration (t C ha^{-1} y^{-1}) potentials of five tree species commonly grown in tree-based intercropping systems in comparison to conventional agricultural systems in southern Ontario, Canada

Inputs	Poplar	Oak	Walnut	Spruce	Cedar	Soybean Monocrop
Aboveground tree C assimilation	0.83	0.46	0.48	0.38	0.53	
Belowground tree C assimilation	0.23	0.16	0.11	0.14	0.12	
Litterfall C inputs	1.63	1.07	1.50	1.49	0.68	
Fine root turnover	0.82	0.54	0.75	0.45	0.20	
Above and belowground Crop C input	1.22	1.22	1.22	1.22	1.22	1.40
Outputs (via decomposition)						
Litterfall C outputs	1.04	0.54	1.44	0.63	0.26	0
Root output	0.52	0.27	0.72	0.19	0.08	1.31
Crop C outputs	1.00	1.00	1.00	1.00	1.00	1.19
C leachate	0.05	0.05	0.05	0.04	0.04	0.05
Net						
Net C balance	+ 2.12	+ 1.58	+ 0.84	+ 1.81	+ 1.36	- 1.15

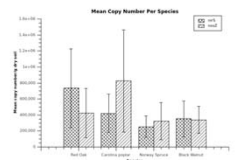

Figure 1: Influence of tree species on the abundance of key microbial groups associated with N_2O production, particularly organisms associated with denitrification, *nosZ* and *nirS*. The abundance of *nirS* was significantly higher in the Red Oak planted soil ($F = 9.94$, $p < 0.05$) and the abundance of *nosZ* was significantly higher in the poplar planted soil ($F = 8.05$, $p < 0.05$).

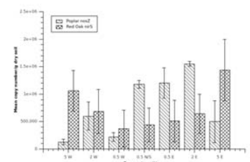

Figure 2: Influence of abundance of key microbial groups associated with N_2O production in proximity to tree spacing, particularly organisms associated with denitrification, *nosZ* and *nirS*. The transect positions on the easterly side of the poplar tree row had significantly higher abundance of *nosZ*.

Soil DNA

DNA was extracted from soil cores collected around black walnut, red oak, Norway spruce, and hybrid poplar and used for quantitative real-time PCR to determine the abundance of key functional genes in the nitrification and denitrification pathways.

Results:

From extracted DNA, results indicate that both tree species and proximity to the tree can influence the abundance of key microbial groups associated with N_2O production, particularly organisms associated with denitrification, *nosZ* and *nirS* (Figure 1 and 2). The abundance of *nirS* was significantly higher in the red oak planted soil ($F = 9.94$, $p < 0.05$) and more abundant in the transect positions within the crop alley, when compared to the positions within the tree row. The abundance of *nosZ* was significantly higher in the poplar planted soil ($F = 8.05$, $p < 0.05$) and more abundant on the East side of the poplar tree row along the transect positions.

Soil Microstructure

The top 3.5 cm of soils adjacent to black walnut, hybrid poplar, red oak, Norway spruce and soild under three types of ground chover (row crop, willow, and perennial grass tree rows) were analyzed using C-ray computer microtomography. This was used to evaluate soil void phase characteristics and heterogeneity of the soil matrix radiodensity.

Results:

X-ray µCT measured void characteristics were not significantly affected by the adjacent tree species; therefore, tree species has no effect on void characteristics at this level of observation. This can be attributed to mixed leaf litter in the system, and soils being collected under perennial (grass) vegetation. Soil void analysis showed that there was a positive correlation between x-ray bulk radio-density and soil bulk density (Figure 4), and a negative correlation between mean intra-aggregate x-ray radio-density and soil organic carbon (rs=-0.48, p=0.033), suggesting that the X-ray CT method could therefore be used to predict these soil properties. (Figure 5).

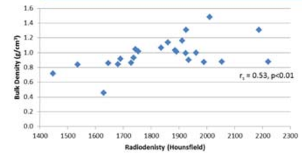

Figure 4: Bulk density plotted on y-axis, with X-ray µCT bulk radiodensity plotted on x-axis (n=24).

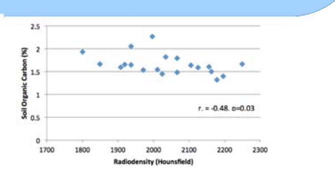

Figure 5: Soil organic carbon plotted on y-axis, with X-ray µCT solid aggregate radiodensity plotted on x-axis (n=20).

Discussion

On a systems-level scale, regardless of which species is planted within TBI systems, TBI systems show greater net C flux when compared to a conventional sole-cropping system and therefore can promote greater atmospheric CO_2 sequestration potential. From the extracted soil DNA, the abundance of *nirS* in red oak soil and abundance of *nosZ* in the poplar planted soil, indicates that tree species are associated with unique microbial communities within TBI systems and suggests that this may play a role in ecosystem functioning and N_2O emissions. Tree row soils had higher degree of structure compared to row crop soils, which had a destructive surface structure, showing more direction anisotropy. It also appears that soil organic C and soil bulk density measurements can be accurately predicted with the use of x-ray bulk radio-density as observed in this study.

Acknowledgements

The funding received from Agriculture and AgriFood Canada (AAFC) through the Agriculture Greenhouse Gases Program is greatly acknowledged.