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GROWING WOODY BIOMASS FOR BIOENERGY IN SOUTHERN ONTARIO, CANADA - A CASE STUDY USING TREE-BASED INTERCROPPING

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Abstract: During the spring of 2006, three willow varieties from SUNY-ESF (SV1, SX67 and 9882-41) were established on a marginal land in an agroforestry tree-intercropping arrangement where plots of short rotation willow were planted between rows (spaced 15 m apart) of 20-year-old mixed tree species. As a control, the same varieties were established on an adjacent piece of land without established tree rows. The study investigated the distribution of carbon and nitrogen pools, fine root biomass and clone yields in both tree-based intercropping (agroforestry) and conventional monocropping systems. Willow biomass yield was significantly higher in the agroforestry field, 4.86 and 3.02 odt ha^{-1} y^{-1} for the agroforestry and control fields, respectively. SV1 and SX67 had the highest yields and 9882-41 had the lowest. Willow fine root biomass in the top 20 cm of soil was significantly higher in the intercropping system (3000 kg ha^{-1}) than in the conventional system (2500 kg ha^{-1}). Differences in fine root biomass between clones followed the same order that was observed for differences in biomass yield: SV1>SX67>9882-41. Leaf input was higher in the intercropping system (1900 kg ha^{-1}) than in the monocrop system (1700 kg ha^{-1}). Clonal differences in leaf inputs followed the same trends as those for root biomass and yield: SV1>SX67>9882-41. Soil organic carbon was significantly higher in the agroforestry field (1.94%) than in the control field (1.82%). A significant difference was found between the three clones; 9882-41 had the lowest soil organic carbon of 1.80%. In December 2009, both fields were harvested (1st cycle) with Anderson bio-baler harvester. Harvesting process and bale yield data, harvest moisture content, field drying and loss of moisture etc. will also be discussed.

Keywords: Willow, woody biomass, bioenergy, agroforestry

INTRODUCTION

A general principle of tree-crop complementarity is to grow trees with crops that each takes advantage of spatially- or temporally-separated resources (Gordon and Newman 1997, Ong and Huxley 1996). Given the potential for competition between intercropped tree rows and crop plants, it is important to maximize complementary interactions and minimize any competitive interactions

(Thevathasan et al., 2004). One way to achieve this is by understanding parameters such as the minimal distance required between intercropped tree rows and crop plants to avoid significant competition for light and nutrients.

Results from experiments conducted at the University of Guelph Agroforestry Research Station (GARS) over the last 24 years suggest two distinct zones across a 15 m wide tree-intercropping alley with temperate mixed species. The first zone – the competitive zone – is the area within 2 m of tree rows. The second zone – the complementary zone – is the remaining area in the centre of the alley, which is 11 m wide. The competitive zone is characterized by direct competition for nutrients, moisture and light. The complementary zone is characterized by favorable growing conditions, where the following processes are enhanced: nutrient cycling, nitrogen mineralization, soil organic carbon addition, earthworm activity, low soil temperature, higher moisture availability through less evapotranspiration and carbon assimilation (Reynolds et al. 2007, Thevathasan and Gordon 2004, Clinch et al., 2009). The two zones are depicted in Figure 1.

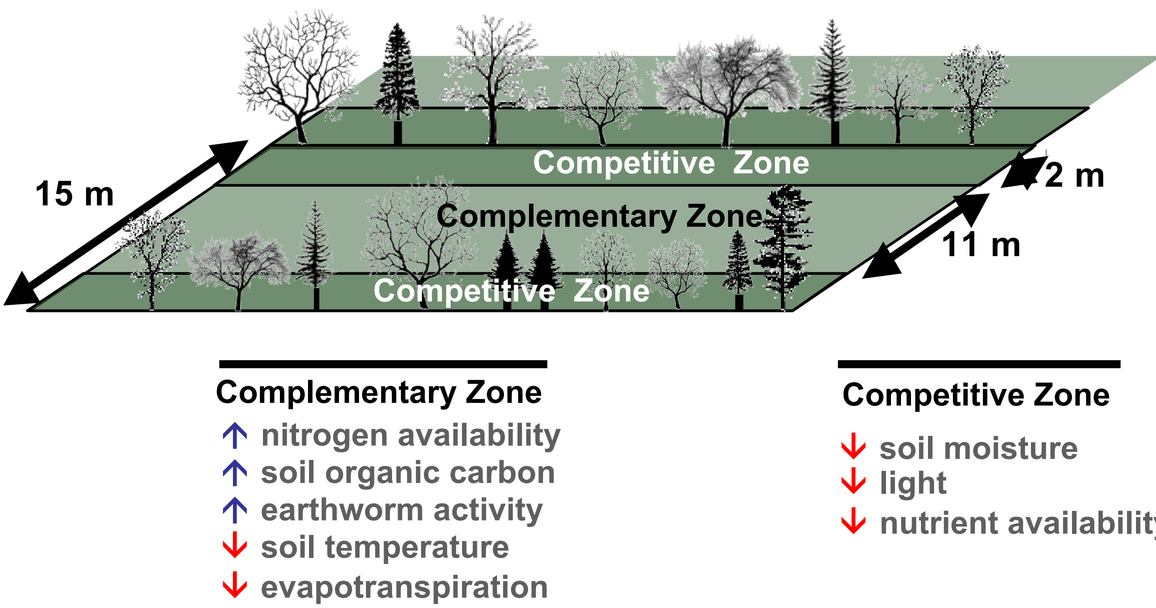

Figure 1. Schematic showing the competitive and the complementary zones in the tree-based intercropping field at the GARS, Guelph, Ontario, Canada

The Ontario greenhouse industry, worth about US$ 2.3 billion per year, is seeking alternative energy sources to oil and natural gas since about 25% of the operating costs for greenhouses are for heating (Picchi et al., 2006). Emissions from greenhouses are currently unregulated, but if emission standards and/or carbon trading strategies come into play, a move towards cleaner bioenergy from Short Rotation Woody Crops (SRWC) and other wood residues would become economically attractive. Given this recent demand for alternative green energy source by the Ontario greenhouse industry, this study was design to investigate the potentials and possibilities of growing hybrid willow crops in the complementary zone in order to maximize woody biomass production for bioenergy in a tree-based intercropping system in southern Ontario, Canada.

MATRIALS AND METHODS

Field Location and Design

The experimental field sites were located at the University of Guelph's Agroforestry Research Station in Guelph, Ontario (latitude 43° 32' 28" N, longitude 80° 12' 32" W). The soils were classified as Gray Brown Luvisols with a fine sandy loam texture. Willow plots were located in two fields, one with tree-based intercropping (agroforestry field), and one without trees (the control/monocrop field). The area of the agroforestry field used for this study consisted of 20-year-old mixed tree species (predominantly *Juglans nigra* L. with some *Quercus rubra* L., *Fraximus Americana* L. and *Robinia pseudoacacia* L.) planted in 370 m long rows with 6 m spacing between trees in a row, and 15 m width between tree rows (the crop alley or alleyway). Tree rows were oriented northwest to southeast. Willow plots were located within the alleyways between the large tree rows with a 2 m buffer on either side, placing them in the central 11 m of the alleyways (within the 11 m – wide complementary zone). The control field had no established tree rows, and plots were separated by at least a 2 m buffer.

Plots of three willow varieties (*Salix dasyclados* SV1, *S. miyabeana* SX67 and *S. purpurea* 9882-41), from SUNY-ESF, Syracuse, New York, were randomly arranged with four replications within each field, for a total of 12 plots in each field. Plot dimensions were 10 m x 50 m with 5 double rows and alternating inter-row distances of 0.75 m and 1.5 m. Spacing between cuttings in a row was 0.55 m, resulting in a planting density of approximately 20 000 stools ha^{-1}.

Soil characteristics

Table 1. Summary of soil characteristics (0-20 cm depth) at the two field sites, Guelph, Ontario, Canada. [None of the measured soil parameters were significantly different between the two fields (t-test, p>0.05)]. Soil density was about 1.2g cm^{-3}.

Field	Texture Sand, Silt, Clay (%)	Carbon Tot., In.org., Org (%)	pH	Electrical Conductivity ($mS.m^{-1}$)
Agroforestry	51.1, 34.7, 14.2	3.15, 1.84, 1.31	7.4	95.8
Control	53.4, 33.0, 13.6	3.29, 1.86, 1.43	7.5	89.9

Willow biomass yield

Two samples of four trees per plot were harvested, at about 10 cm above soil. The location was determined through randomization. The sample area was 3.105 $m^{2.}$ Willow biomass samples were oven dried at 65 ^{0}C for 5 days in order to obtain dry biomass yields.

Willow root biomass

Four randomized core samples per plot were taken out in June, 2009 : two in the large inter-row (1.5 m) and two in the smaller inter-row (0.75 m). Each sample was divided in to four subsamples, in order to study the root distribution: 0-5cm, 5-10cm, 10-15cm, 15-20cm. Soil samples were stored at 4°C until washing, in order to prevent root decomposition. Roots were washed out from soil manually using sieves and tweezers, and then dried in an oven at 65°C for 2 days.

Willow leaf input

Forty-eight leaf litter traps were manufactured and put in the two fields. Two traps per plot were used, one in the larger inter-row and one in the smaller inter-row. The location was determined through randomization. The trap diameter was 30cm, and they were 50cm high. Leaves were collected every two weeks, from June to November. Leaves collected from June 5th to September 11th corresponded to a leaf turnover during the growing season, whereas leaves collected from September 11th to November 20th corresponded to leaf drop during the fall season.

Soil C determination

Soil samples were collected from 0 to 20cm depth and were analyzed for total C, inorganic and organic C using Leco CR-12 carbon analyzer. Sample preparation was done by adopting standard procedures as outlined in Carter and Gregorich, 2008.

Statistical analysis

Analysis of variance was conducted using PROC MIXED in SAS v.9.1 (SAS Institute, Cary NC, USA) with a Type I Error rate of α=0.05.

RESULTS

Willow biomass yield

ANOVA on willow biomass yield (Table 2) was significant between the two fields (Agroforestry > Control), and also between the three clones (SV1=SX67 > 9882-41), when both fields were analyzed together.

Table 2. Biomass yields of three willow clones, three years after coppice. Values represent least squares means. Same letters are not significantly different based on Tukey's HSD test (p>0.05). * Field averages are significantly different (p<0.05).

Field and Clone	Willow biomass (odt ha^{-1} y^{-1}) (odt = oven dry ton)	
Agroforestry		4.86 *
9882-41	2.82 b	
SV1	5.64 ac	
SX67	6.12 a	
Control		3.02 *
9882-41	2.24 b	
SV1	4.50 c	
SX67	2.31 b	

Willow root biomass

ANOVA on root biomass (Figure 2) was significantly different between the two fields ($p<0.05$). In the top 20cm of soil, root biomass was 3000 kg ha^{-1} in the agroforestry field, and 2500 kg ha^{-1} in the control field (planting density was about 20 000 stools ha^{-1}).

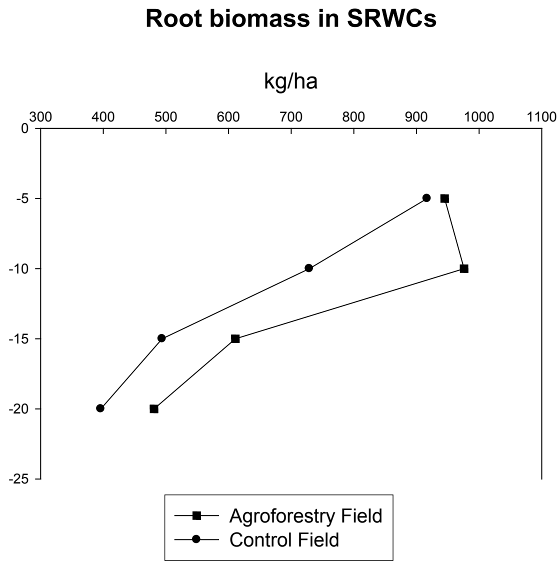

Figure 2. Willow root biomass distribution in the agroforestry field and monocropping field, three years after coppice in 2009, GARS, Ontario, Canada.

Leaf biomass inputs to soil

ANOVA on leaf litter inputs (Figure 3) throughout the season was found significantly different ($p<0.05$) between the tested fields. In the agroforestry field, willow leaf input was about 2000kg ha^{-1}, and was about 1700kg ha^{-1} in the control field, from June to November. But in the agroforestry field, there was also a leaf input from the larger intercropped trees, estimated at about 450kg ha^{-1} y^{-1} (this estimation does not represent the total leaf input from these trees, but represents leaf input collected within the sample plots, 2m to 6m from the tree row).

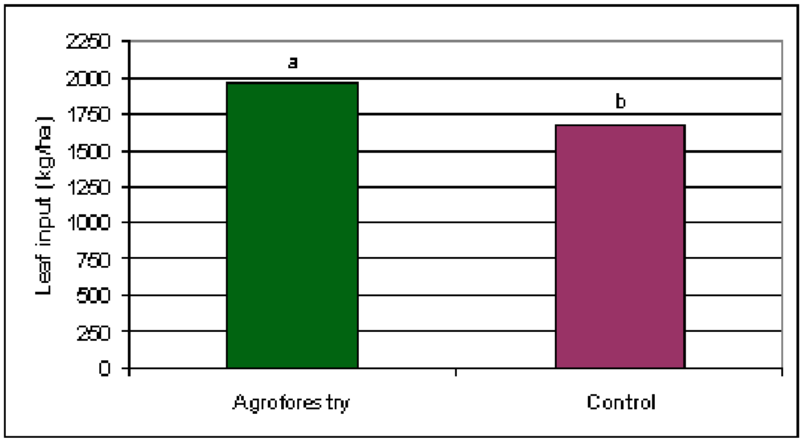

Figure 3. Willow leaf biomass inputs from agroforestry and monocropped test sites in 2009, three years after coppice. Notation of different letters indicate that the mean values are significantly different. ($p < 0.05$).

Soil organic carbon

ANOVA on soil organic carbon data (Table 3) showed a significant variation between the two tested fields. The soil organic carbon in the agroforestry field was significantly higher than the control or monocropped field.

Table 3. Soil organic carbon as influenced by three clones of willow grown in an agroforestry intercropping system and in a monocropping system in 2009 after three years of coppice. Values represent least squares means. Those with the same letters are not significantly different based on Tukey's HSD test ($p>0.05$). * Field averages are significantly different ($p<0.05$).

Field and Clone		Organic Carbon (%)	se
Agroforestry	1.94 *		0.04717
9882-41		1.85 ab	0.04007
SV1		1.98 a	0.04007
SX67		1.99 a	0.04007
Control	1.82 *		0.04742
9882-41		1.74 b	0.04007
SV1		1.80 b	0.04283
SX67		1.91 a	0.04007

Willow mechanical harvest, 2009

In December 2009, both test sites were harvested with Anderson Biobaler harvester, the very first Canadian made willow bale harvester (Figure 4).

Figure 4. Anderson biobaler harvester in operation, GARS, southern Ontario, Canada

The average wet bale weight was around 350 kg with moisture content of 52%. The bales were left in the field for winter drying during the winter of 2010 and were transported to a pelletizing plant in May 2010. At the time of transportation the bales were at about 10 to 12% moisture content. The bale harvest rate was about 31 bales per hour. The biobaler should be operated with a tractor having a minimum power of 100 kW.

DISCUSSION

Tree-based intercropping is one of the temperate agroforestry land-use systems. During the early stages of temperate intercropping, annual crops are grown in the alleys. As the trees mature and light become a limiting factor due to shading, shade-tolerant crops should be introduced in the alleys. Due to the current interest in biomass for bioenergy, in this study, we introduced and promoted willow as an alternative crop to be successfully grown in the alleys of mature (25 years) tree-based intercropping systems. This is also a new temperate agroforestry concept - trees within trees - but willow is considered as a crop due to the short harvest cycle of three years.

As discussed in the introduction, past studies (Thevathasan and Gordon, 2004, Reynolds et al., 2007, Clinch et al., 2009) in the agroforestry test site clearly demonstrated complementary growth promoting interactions in the middle of cropping alleys as influenced by the presence of mature trees along the tree rows (Figure 1). It appears that these growth promoting interactions or processes have positively enhanced willow biomass yield in the agroforestry site when compared to monocropping site (Table 2). Significantly higher biomass yield in the agroforestry has also proportionally resulted in significantly higher root and leaf biomass inputs to the soil (Figures 2 and 3) in the agroforestry than recorded in the monocropping or control site. This enhanced addition of biomasses in the agroforestry did significantly increase the soil organic carbon by 48% in the agroforestry site but only 27% in the monocropping site when compared with baseline soil organic carbon values for both sites (Table 1).

Given the current political will and climate change mitigation strategies promoting bioenergy, Short Rotation Woody Crops (SRWC) production in mature tree-based intercropping systems in the temperate region could be a viable option. In order to scale-up such SRWC systems in the temperate region, infrastructure (planters, harvesters, conversion technologies etc.) needed to support such systems in the temperate region should be developed. In this context, it is encouraging that Canada has now produced its first commercial willow harvester.

LITERATURE CITED

Carter, M.R., Gregorich, E.G. (eds.). 2008. Soil Sampling and Methods of Analysis (2nd ed.), Canadian Society of Soil Science, CRC Press, Boca Raton, Florida, pp. 228-229.

Clinch, R.L., Thevathasan, N.V., Gordon, A.M., Volk, T.A. and Sidders, D. 2009. Biophysical interactions in a short rotation willow intercropping system in southern Ontario, Canada. Agri Ecosys. Env.

Gordon, A.M., Newman, S.M. 1997. Temperate Agroforestry Systems. CAB International Press, Wallingford, UK., 269 pp.

Ong C.K. and Huxley P. 1996. Tree-crop interactions: A physiological approach. CAB International, Wallingford, UK, 386 pp.

Picchi, G., Gordon, A.M., Thevathasan, N.V. 2006. Feedstock to Furnace: Bioenergy Systems for the Ontario Greenhouse Industry. Available from the Department of Environmental Biology, University of Guelph, Guelph, ON, 75 pp.

Reynolds, P.E., Simpson, J.A., Thevathasan, N.V., Gordon, A.M. 2007. Effects of tree competition on corn and soybean photosynthesis, growth, and yield in a temperate tree-based agroforestry intercropping system in southern Ontario, Canada. Ecol. Eng. 29, 362-371.

Thevathasan, N.V., Gordon, A.M. 2004. Ecology of tree intercropping systems in the North temperate region: Experiences from southern Ontario, Canada. Agroforest. Syst. 61, 257-268.