TREE GROWTH AND CROP PRODUCTIVITY IN A HYBRID POPLAR-HARDWOOD-SOYBEAN INTERCROPPING SYSTEM IN SOUTHWESTERN QUEBEC, CANADA

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ABSTRACT

In Quebec, new strategies for improving the profitability of hardwood plantations have received little attention. Since 2000, field experiments have been established in southwestern Quebec in order to investigate the impact of introducing hybrid poplars (HP) in alternate rows with hardwood tree species. In 2004, one experimental site was converted into an intercropping system by adding a soybean crop between tree rows. Soybean was intercropped with three HP clones (NM-3729, DN-3308, TD-3230) spaced 6 (parcel A) or 8 m (parcel B) between tree rows. The growth of HP within the intercropping system was compared to sole tree treatment (disking of the alleys between tree rows). A positive effect of intercropped soybean on HP height increment was observed in parcel A, but there was no significant difference in parcel B. In parcel A, total soybean grain dry weight was significantly different between orientations with respect to tree row (east or west) and between HP clones. Total grain dry weight near the row was lower in the TD-3230 plots of parcel A, where relative photosynthetic photon flux density (*Qp*) was also lower. A decrease in both relative *Qp* and soil moisture in the upper 10 cm layer of the soil contributed to an important reduction of total grain dry weight, aboveground biomass and height of soybean plants at 2-3 versus 4-5 m from the HP rows. These results will provide vital information regarding the value of intercropping systems for improving the profitability of hardwood and HP plantations.

Keywords: Intercropping system, hybrid poplar growth, soybean productivity, tree-crop interface

INTRODUCTION

According to the final report of the Commission for the Study of Public Forest Management in Quebec, important new initiatives for planting hardwood and hybrid poplar (HP) would be necessary in the next few years in order to overcome the already insufficient availability of high-quality timber and the consequences of the recommended increase of protected forests (Commission d'études sur la gestion de la forêt publique québécoise 2004). Unfortunately, hardwood and HP plantations have always played a marginal role on the privately owned lands of southern Quebec, where their potential is the highest. For example, in the Montérégie region (11,845 km^2), where the present study is being conducted, only 70,300 hardwood seedlings (of which 1,700 were HP) were planted on privately owned lands in 2002, as compared to 1,359,200 conifers. This is disappointing since hardwood forests represent 68.5% of the total forest cover

(3,748 km^2) in this region. In order to promote hardwood and HP plantations, it is thus essential to propose productive and profitable plantation systems to producers.

Although nonexistent in Quebec so far, intercropping systems could constitute an interesting way to both stimulate hardwood and HP plantations and maximize their profitability on privately owned lands, especially those with agricultural potential. The integration of trees into the agricultural land base through tree-crop intercropping systems has already shown great potential in other temperate regions, where they can contribute to the adoption of sustainable agricultural practices (Thevathasan et al. 2004). Research activities conducted at the University of Guelph, in Ontario during the past 15 years, have demonstrated the high potential of intercropping in terms of benefits such as water-quality enhancement, carbon sequestration, and biodiversity conservation (Thevathasan and Gordon 2004).

This present study is part of a program that aims at developing intercropping systems such as hardwood-HP-soybean (*Glycine max*) associations, in southern Quebec, in order to improve the profitability of hardwood and HP plantations. The integration of a soybean crop between tree rows is seen as a potential method for improving tree growth. So far, the effects of intercropped soybean on tree growth, as compared to tree monoculture, are not well known. However, increased tree growth has already been observed in plantation mixtures of hardwood seedlings and herbaceous legumes (Haines et al. 1978; Van Sambeek et al. 1986; Dupraz et al. 1999).

After the first years of tree establishment in an intercropping system, competition for light among trees and crop can be intense, bringing an important reduction in the crop yield near the tree rows. For example, in Ontario, Simpson et al. (2003) reported that soybean yield between 2 and 6 m from the tree row was reduced to 71 and 75% of the sole cropping yield when intercropped with HP (*Populus deltoides x nigra* DN-177) and silver maple (*Acer saccharinum*), respectively. According to the authors, growth characteristics (height, leaf area, weight) of single plants were significantly correlated with available photosynthetically active radiation (PAR) and net assimilation, but were not significantly correlated with midday water potential. In a *Paulownia* - winter wheat (*Triticum* sp.) intercropping system in China, PAR levels resulting from overhead shading significantly reduced total grain weight of winter wheat (Chirko et al. 1996). On the other hand, competition for water was reported as the main determinant of crop productivity in some temperate intercropping systems in the US (Jose et al. 2004). In order to be able to recommend appropriate management strategies (e.g., row spacing, choice of tree and crop species, pruning, root-pruning, thinning) ensuring acceptable economic yields in the zone closest to the tree row, it would thus be necessary to better understand the effects of tree shading and competition for water on intercrop productivity.

Since 2000, field experiments have been established in southwestern Quebec in order to investigate the impact of introducing HP in alternate rows with hardwood tree species. Modelling (SORTIE) shows that light availability under the HP canopy depends largely on crown shape parameters (height, width and porosity), which vary according to HP types (Paquet et al. 2003). In 2004, a soybean intercrop was added to some of the established plantations, transforming them into intercropping plots.

The present study presents the first-year results of these experiments regarding the influence of a hardwood-HP-soybean intercropping system on tree growth and crop productivity. It focuses on

HP growth as related to presence or absence of the intercrop, as well as on variations in soybean productivity, depending on distance from tree row, in relation to light availability, soil moisture, and HP clone.

MATERIAL AND METHODS

Experimental Site

The study is being conducted at St-Rémi, in southwestern Quebec, Canada. The soil is a fine loam containing approximately 20% clay and 50% sand, with good soil exchange capacity (20 meq/100 g), moderately good to imperfect soil drainage conditions, and neutral pH (6.9). During the spring 2004, a soybean intercrop was added to a 4-year-old mixed plantation whose HP reached a height of approximately 5 m, while black walnut (*Juglans nigra*) and white ash (*Fraxinus americana*) varied between 1.5 et 2 m high. The cultural precedent was soybean in 1999, and corn in 1998.

Treatments and experimental design

The experimental site (3 ha) consists of 2 parcels (A et B) that are distinct regarding spacing between the rows of hardwood trees and HP (A = 6 m, B = 8 m). Within each parcel, the experimental design is a randomized block design with four blocks, each of which comprises of 5 rows of HP and 4 rows of hardwood, so that all hardwood rows have HP rows on each side. The disposition of HP and hardwood species in alternate rows should allow two productions of HP during one revolution of hardwood species. HP are spaced 2 m apart in the same row, for a total of 9 plants per row for each randomly distributed HP clone (*Populus nigra x maximowiczii* NM-3729, *Populus deltoides x nigra* DN-3308, *Populus trichocarpa x deltoides* TD-3230). These clones belong to distinct families of clones (Périnet et al., 2001). They were selected in order to provide high-quality timber. Black walnut and white ash trees were disposed in groups of 6 plants per plot (3 plants per species, randomized distribution of species) and spaced 3 m apart in the row. For tree growth analysis, each block was divided into two treatments: (1) soybean (cultivar S03-W4) intercrop, and (2) disking of the alleys between tree rows. Soybean intercrop was seeded on both sides of each randomly chosen HP row, the other rows being randomly devoted to the disking treatment. Tree rows are oriented north-south.

Tree seedlings were planted by hand during the spring of 2000. The herbaceous strata between the tree rows was cut every year from 2000 to 2003. Before sowing, on June 21, 2004, the alleys were cleared of all weed growth and plough. Soybean was sown through direct seeding at a density of 500 000 grains per ha and at a spacing of 38 cm between the rows. Standard herbicide treatment (Assure® II, Pinnacle®, FirstRate®) was applied on July 18, 2004. Strips of black plastic mulch (150 cm wide) suppressed weeds close to the trees.

Measurements

The diameter at breast height (DBH) and height growth were measured at the end of the growing season in 2003 and 2004 on each individual HP.

Soybean sampling was performed so as to permit yield evaluation in relation to orientation with respect to HP rows (on the east or on the west side of the row), distance from the row and HP clone. Within each HP plot (18 m x 12 m in parcel A or 18 m x 16 m in parcel B), three (parcel A) or four (parcel B) subplot treatments (distances from HP rows) were assigned to both the east and west sides of one selected HP row, at 2 m, 3 m, 4 m and 5 m (parcel B) from the row. Each yield plot consisted of two samples (quadrats) 4 m long and 3 rows wide (4.54 m^2). Total grain dry weight, 100-grain dry weight and number of grains per m^2 were measured. For the other parameters of soybean productivity (aboveground biomass, number of pods per m^2, number of plants per m^2), yield plot consisted of one sample 1m long and 3 rows wide (1.14 m^2). The mean height of the soybean plants was measured in three 0.5 m^2 quadrats for each subplot treatment (distance).

The effect of HP clones on relative photosynthetic photon flux density (*Qp*) (tree-shaded vs unshaded) and soil moisture at the 5-10 cm layer was measured at the same distances as those that were used for evaluating soybean productivity. The relative *Qp* was evaluated on August 16, 2004, at a height of 1 m, from diffuse light measures made with a beam fraction sensor (BF2, Delta-T Devices Ltd, Cambridge, UK) permitting the estimation of the seasonal mean of available light (Gendron et al. 1998, 2001). Soil moisture was measured once in the growing season (September 16) using a TDR soil moisture sensor (ThetaProbe ML2x, Delta-T Devices Ltd, Cambridge, UK). The choice of all the brands used in this study was made for experimental purpose and does not mean that we recommend them.

Statistical analysis

HP growth, soybean productivity, relative *Qp* and soil moisture data were subjected to analysis of variance using SAS (SAS Institute Inc. 2004). When significant treatment effects were revealed at $P = 0.05$, Tukey's range test was used for mean separation. Student's *t* test was used therefore in order to determinate significant differences for parameter values between two consecutive distances. Linear correlation analysis was performed in order to define relationships between resource availability (*Qp* and soil moisture) and soybean productivity parameters.

RESULTS

Hybrid poplar height and diameter

Height and diameter increment of HP in 2004 is shown in Figure 1. After one year of treatment, HP intercropped with soybean had a 15% higher height increment than sole HP ($P = 0.02$) in the parcel A (6 m between tree rows). However, there was no significant difference in the parcel B (8 m between tree rows). There was no significant difference between soybean intercropped plots and disked plots for HP diameter increment in both parcels. When looking at each of the three HP clones one by one, no significant differences were found for height and diameter increment in 2004.

Results are presented for two different spacings between tree rows: 6 m (parcel A) and 8 m (parcel B). Different capital letters indicate significant differences ($P < 0.05$) between hybrid poplar clones regardless of treatment; different lower case letters in two continuous columns indicate significant ($P < 0.05$) differences between treatments.

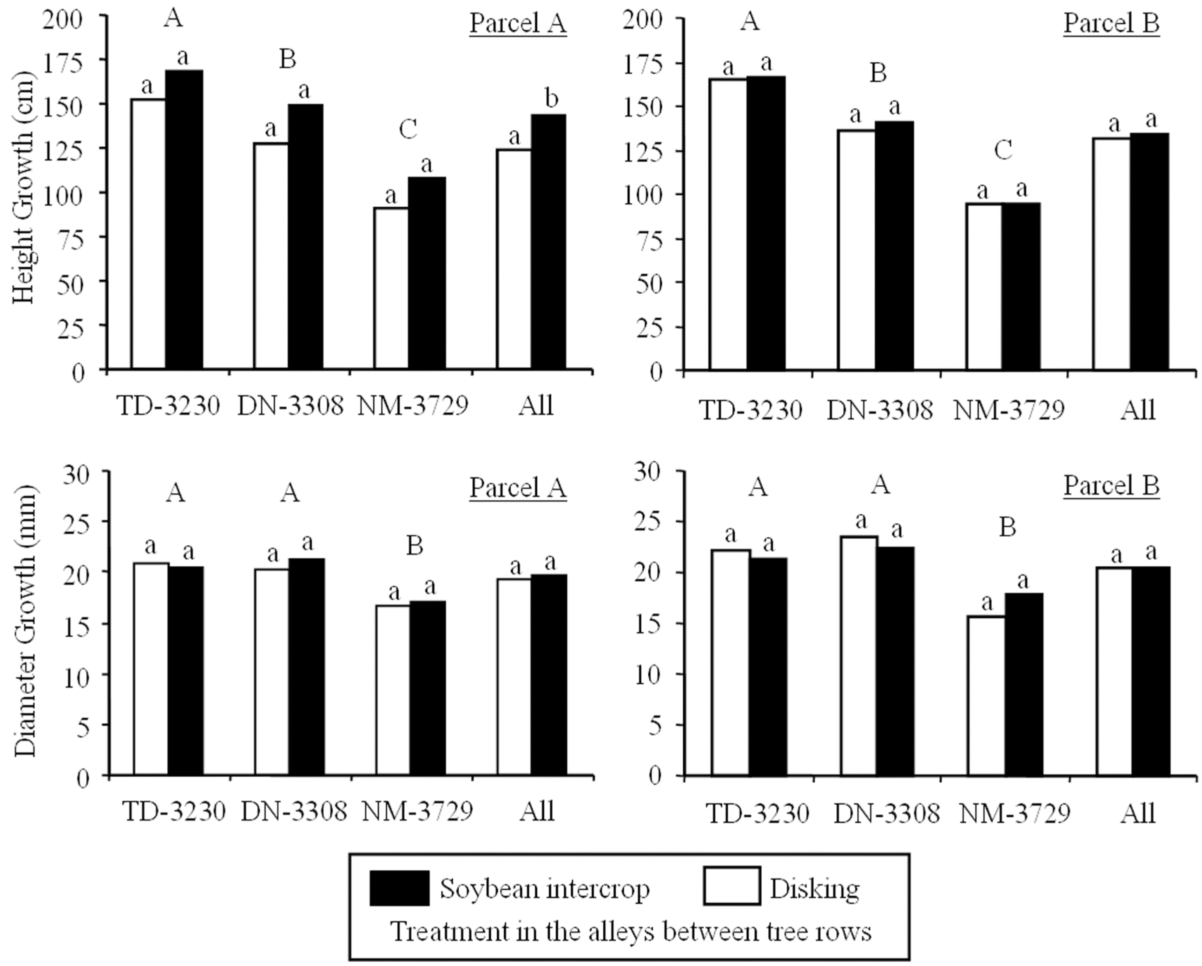

Figure 1. Mean height and diameter increment of three hybrid poplar clones (TD-3230, DN-3308, NM3729) under two alleys treatments (soybean intercrop and disking) in a hybrid poplar-hardwood plantation in southwestern Quebec, Canada, in 2004.

Regarding height and diameter of the three clones after 5 years of growth, no significant differences were found (results not shown). At the end of 2004, mean height of HP was 7.31 m in parcel A and 6.96 m in parcel B. The largest height increase in 2004 was with TD-3230, and the lowest with NM-3729 in both parcel A ($P = 0.0002$) and B ($P < 0.0001$). NM-3729 had the lowest diameter increment ($P = 0.007$ in parcel A, and $P = 0.014$ in parcel B). The interaction between treatments and HP clones was not significant.

Soybean yield as related to orientation with respect to tree row and HP clone

In parcel A, total soybean grain weight (all soybean rows included) was significantly different between orientations with respect to tree row ($P = 0.032$) and between HP clones ($P = 0.022$). On the west side of the HP rows, soybean had a 8% higher yield than on the east side. The highest soybean grain yield was obtained when intercropped with DN-3308 (Figure 2). Differences were not significant in parcel B for this variable.

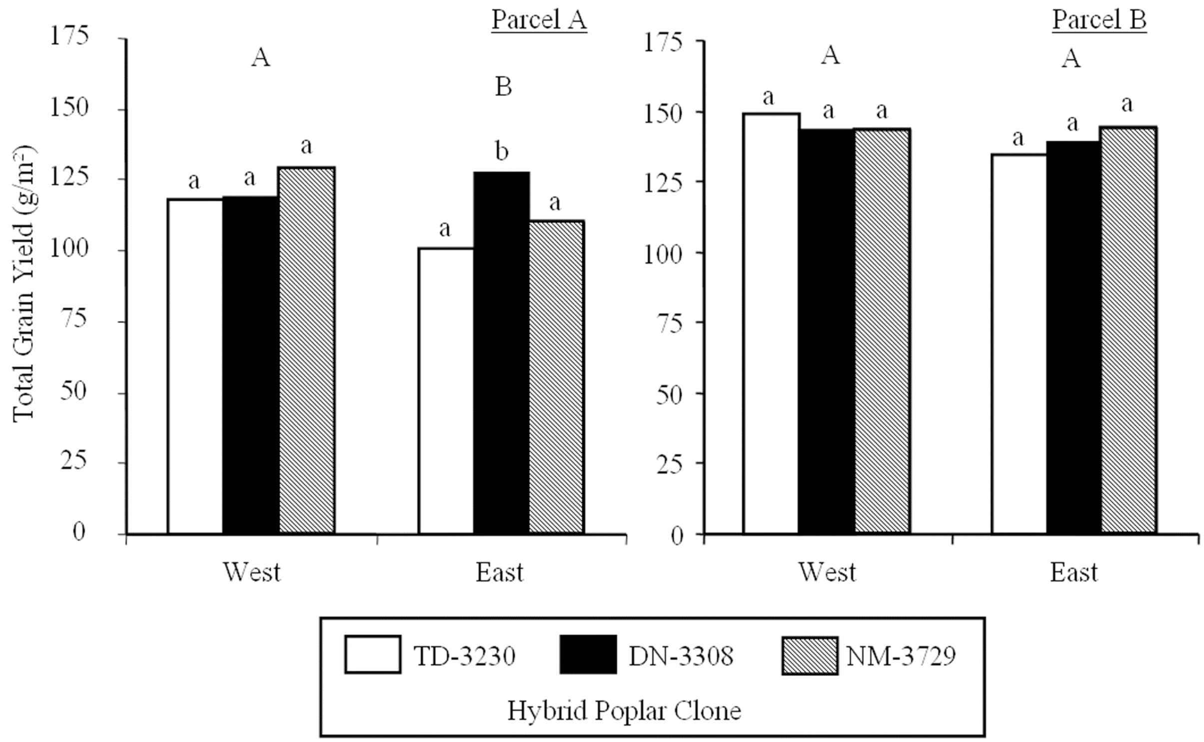

Figure 2. Total grain yield of soybean plants on the west and east sides of rows of three 5-year-old hybrid poplar clones in a hybrid poplar-hardwood-soybean intercropping system in southwestern Quebec, Canada, in 2004.

Results are presented for two different spacings between tree rows: 6 m (parcel A) and 8 m (parcel B). Different capital letters indicate significant differences ($P < 0.05$) between orientations with respect to tree rows regardless of hybrid poplar rows; different lower case letters in two continuous columns indicate significant ($P < 0.05$) differences between hybrid poplar clones.

Mean aboveground biomass ($P = 0.007$ for parcel A), number of grains per m^2 ($P = 0.022$ for parcel A), number of pods per m^2 ($P = 0.018$ for parcel A) and number of plants per m^2 ($P = 0.011$ for parcel B) were also reduced on the east side of tree rows (results not shown).

Relative photosynthetic flux density and soil moisture as related to orientation with respect to tree row and HP clone

Relative *Q*p was affected by the HP clones regardless of orientation with respect to tree row and parcel (Figure 3a). The lowest relative *Qp* was obtained with TD-3230 at 2 m from the HP row (P = 0.012), as well as at 3 m from the HP row, although not significant in this case ($P = 0.053$). At 4 and 5 m from the HP row, the relative *Q*p was similar for all HP clones. Soil moisture in the upper 10 cm of soil was unaffected by the HP clone at all distances from the tree row (Figure 3b). There was no effect related to orientation with respect to tree row for both relative *Q*p and soil moisture.

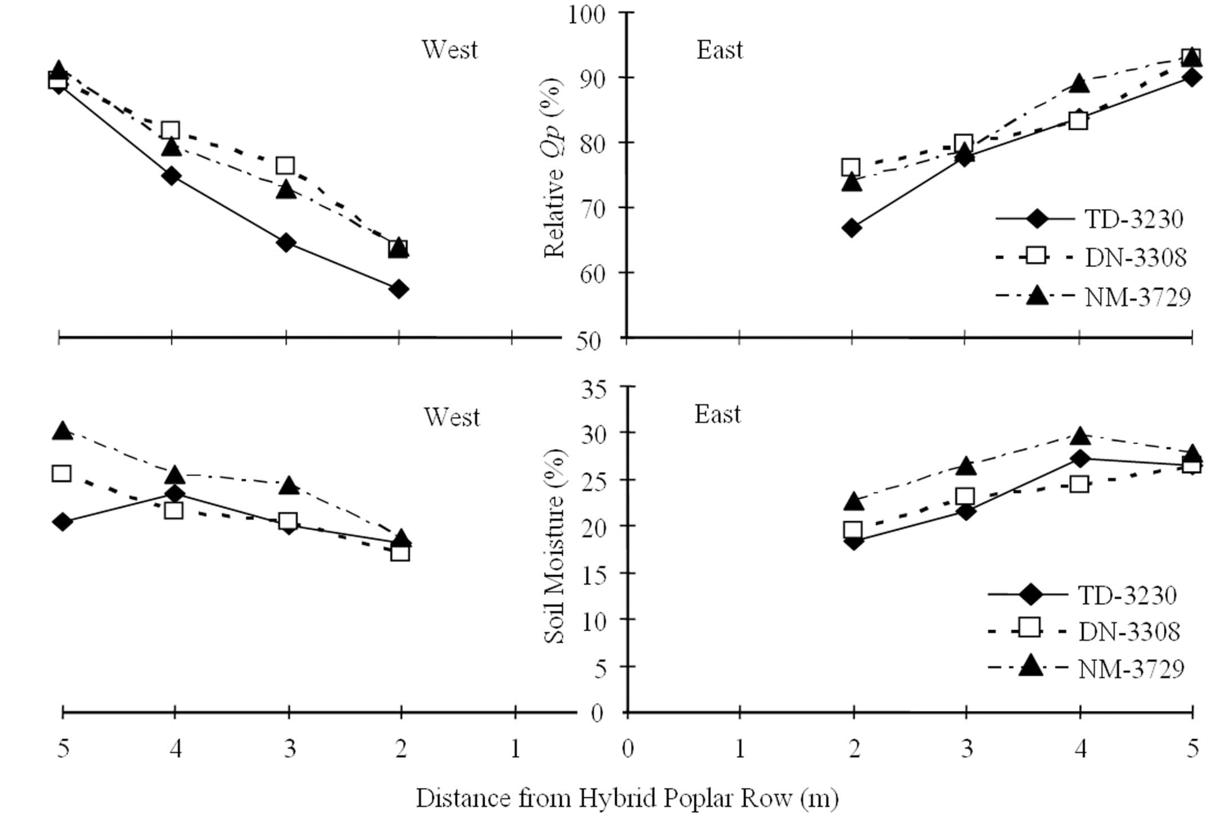

Figure 3. Variation in (a) relative photosynthetic photon flux density (*Qp*) and (b) soil moisture in the 0-10 cm soil layer in relation to orientation, distance from tree row and 5 year-old hybrid poplar clone (TD-3230, DN-3308, NM-3729) in a hybrid poplar-hardwood-soybean intercropping system in southwestern Quebec, Canada, in 2004.

Distance effects

For each HP clone, there was a highly significant increase in relative *Qp*, soil moisture and all soybean productivity parameters (except for number of plants per m^2) from 2 to 3 m from HP rows (P 0.001 in most cases) (Table 1). At 4 m, values of relative Q*p* were significantly higher than at 3 m for TD-3230 ($P < 0.0001$) and NM-3729 ($P = 0.0038$), but not for DN-3308. Soil moisture at 4 m was higher than at 3 m for TD-3230 ($P = 0.0024$), but not for NM-3729 and DN-3308. Total grain weight, number of grains per m^2 and plant height increased from 3 to 4 m from the row for each HP clone (P 0.01). Between 4 and 5 m from HP rows, significant differences were measured with NM-3729 and TD-3230 only. In the case of NM-3729, values of total grain weight ($P = 0.0087$), number of grains per m^2 ($P = 0.0062$) and plant height ($P = 0.015$) were always higher at 5 than at 4 m. Similarly, aboveground biomass ($P = 0.013$), number of pods per m^2 (P = 0,0073) and number of plants per m^2 ($P = 0.002$) were higher at 5 than at 4 m with TD-3230. Among soybean productivity parameters, 100-grain weight and number of plants per m^2 are the least affected by distance from HP rows.

Table 1. Variation in relative photosynthetic photon flux density (*Qp*), soil moisture in the 0-10 cm soil layer and parameters of soybean productivity in relation to distance from tree row and 5 year-old hybrid poplar clone (TD-3230, DN-3308, NM-3729) in a hardwood-hybrid poplar-soybean intercropping system in southwestern Quebec, Canada, in 2004.

		Distance from hybrid poplar row (m)[a]						
Parameter	**HP Clone**	**2**		**3**		**4**		**5**
Relative Qp (%)	TD-3230	62.2	*** [b]	71.2	***	79.2	NS	89.5
	DN-3308	69.7	*	78.1	NS	82.4	NS	91.1
	NM-3729	69.0	*	75.8	**	84.3	NS	92.2
Soil moisture (%)	TD-3230	18.2	**	20.8	**	25.4	NS	23.4
	DN-3308	18.3	**	21.8	NS	23.0	NS	26.0
	NM-3729	20.7	*	25.4	NS	27.6	NS	29.1
Total grain dry weight (g/m^2)	TD-3230	84.3	***	120.3	***	145.9	NS	164.8
	DN-3308	93.2	***	132.5	***	152.7	NS	151.5
	NM-3729	95.4	***	130.2	**	142.1	**	168.0
Aboveground biomass (g/m^2)	TD-3230	184.7	***	288.9	NS	279.2	*	368.2
	DN-3308	209.7	***	300.4	NS	316.9	NS	344.2
	NM-3729	219.0	***	304.2	*	265.3	NS	311.4
100-grain dry weight (g)	TD-3230	17.8	*	17.5	NS	17.3	NS	17.5
	DN-3308	18.0	***	17.3	NS	17.2	NS	17.0
	NM-3729	17.7	NS	17.5	NS	17.3	NS	17.4
Number of grains per m^2	TD-3230	472.5	***	687.6	***	845.2	NS	940.9
	DN-3308	518.1	***	766.1	***	887.9	NS	888.3
	NM-3729	537.5	***	742.2	**	820.3	**	970.2
Number of pods per m^2	TD-3230	385.9	***	613.8	NS	559.0	**	804.5
	DN-3308	414.9	***	613.3	NS	675.2	NS	768.9
	NM-3729	410.0	***	624.8	NS	581.0	NS	624.9
Number of plants per m^2	TD-3230	39.9	NS	50.3	NS	38.6	**	50,0
	DN-3308	40.7	NS	47.2	NS	41.3	NS	44.6
	NM-3729	41.9	NS	47.7	NS	42.2	NS	41.3
Plants height (cm)	TD-3230	44.3	***	51.9	***	57.1	NS	58.8
	DN-3308	47.2	***	54.7	***	57.5	NS	58.7
	NM-3729	47.2	***	54.3	**	56.7	*	57.6

[a] Regardless of orientation

[b] Significant differences between two distances from the same tree row (*i.e.* 2 vs 3 m, 3 vs 4 m, and 4 vs 5 m) are indicated by asterisks. $^{*}P$ 0.05, $^{**}P$ 0.01, $^{***}P$ 0.001, NS = non significant.

Relationships between soybean productivity, relative Qp and soil moisture

The results of linear correlation analysis are given in Table 2. At 2 m from the HP row, soil moisture in the upper 10 cm layer of the soil was correlated with total grain weight (P = 0.003), number of grains per m^2 (P = 0.007) and plant height (P = 0.002). At 3 m, soil moisture was not correlated with any of the soybean productivity parameters. However, at this distance, the relative

Q*p* was positively correlated with total grain weight (*P* = 0.013), aboveground biomass (*P* = 0.019), number of grains per m^2 (*P* = 0.019), number of pods per m^2 (*P* = 0.036) and number of plants per m^2 (*P* = 0.04).

Table 2. Correlation coefficients between various soybean productivity parameters at four distances from the hybrid poplar row and relative photosynthetic photon flux density (*Qp*) or soil moisture in the 0-10 cm soil layer in a hardwood-hybrid poplar-soybean intercropping system in southwestern Quebec, Canada, in 2004.

		Distance from hybrid poplar row (m)			
Dependant variable	**Independent variable**	**2**	**3**	**4**	**5**
Total grain dry weight	Relative *Qp*	0.25	0.36*	0.12	-0.13
(g /m^2)	Soil moisture	0.42**	-0.02	-0.08	0.09
Aboveground biomass	Relative *Qp*	0.26	0.34*	0.14	-0.11
(g/m^2)	Soil moisture	0.18	-0.01	-0.14	0.01
100-grain dry weight (g)	Relative *Qp*	0.19	0.14	-0.20	0.04
	Soil moisture	0.25	0.01	-0.16	0.03
Number of grains	Relative *Qp*	0.23	0.33*	0.16	0.12
per m^2	Soil moisture	0.38**	-0.03	-0.05	0.09
Number of pods	Relative *Qp*	0.24	0.30*	0.16	-0.23
per m^2	Soil moisture	0.10	-0.11	-0.05	-0.21
Number of plants	Relative *Qp*	0.22	0.29*	0.04	-0.14
per m^2	Soil moisture	0.08	-0.13	0.19	0.13
Plants height (cm)	Relative *Qp*	0.24	0.21	-0.10	-0.12
	Soil moisture	0.44**	0.19	0.09	0.10

* *P* 0.05, ** *P* 0.01

It is interesting to note that, at 2 m from the HP row, total grain weight was significantly correlated with soil moisture, but not with relative *Qp*, while the reverse was true at 3 m. At 4 and 5 m from the HP row, soybean productivity parameters were not correlated with either relative *Qp* or soil moisture.

DISCUSSION

In the first year of the experiment, intercropping HP with soybean resulted in a 15% increase in HP height growth in parcel A, as compared to disking of the alley. Although preliminary, this result illustrates the potential of this intercropping system for improving HP plantation profitability in southwestern Quebec. Additional investigation, however, is necessary in order to confirm this result. The beneficial effect of intercropping soybean (in rotation with other crops) on tree growth has already been reported by Dhyani and Tripathi (1999) in a humid subtropical climate. According to the authors, the faster tree growth observed in the intercropping system could be attributed to the application of fertilizers and herbicides on the agricultural crops. Since soybean, in this present study, did not receive any fertilizer application, weeding could be the main factor explaining HP height increment in parcel A in 2004. Visual assessments confirmed that spontaneous weeds covered at least 50 to 75% of the soil surface in the disked alleys from the end of July until the end of the growing season (results not shown). On the other hand, because of the use of herbicides, weed cover was generally lower than 5 to 10% in the soybean intercropped plots. The impact of this leguminous crop on nitrogen and water availability in the soil also has to be investigated. More studies will be conducted in 2005 in order to evaluate soil nitrate availability, in association with HP foliar analysis, and water balance in both treatments. Those should allow a better understanding of the influence of intercropped soybean on HP growth.

Regarding soybean productivity, it was observed that the lowest values of total grain dry weight near the row, in parcel A, were measured in TD-3230 plots, where relative *Qp* was also the lowest. However, among the three HP clones that were studied, TD-3230 was the one that showed the highest growth increment in 2004. TD-3230 could have been more efficient than the two other clones in water and nutrient uptake at the tree-crop interface, resulting in lower resources availability for soybean plants. Similar studies have shown that crop yield can vary depending on associated tree species (Dhyani and Tripathi 1999; Gillespie et al. 2000).

Although relative *Qp* and soil moisture did not seem to vary according to orientation with regard to tree row (east and west sides), several soybean productivity parameters, including total grain dry weight, were reduced on the east side of the HP rows. This result contrasts with the results of the study by Chirko et al. (1996), where no differences in wheat grain yield or kernel weight between east and west side of 12 m high Paulownia trees were found. Further studies would be needed in order to clarify this particular finding, such as comparing windspeed dynamic and its effect on evapotranspiration on both the east and west side of the HP rows.

Because of technical constraints, it was not possible to evaluate soybean productivity in a control area without any tree effect this year. Nevertheless, it is known that average soybean grain yield in the Montérégie region in 2004 varied between 220 and 250 g/m^2 (L. Bélanger, pers. comm., 2005), while it reached only 117 g/m and 142 g/m^2, respectivly, in parcels A and B. This difference could be attributed partly to tree-crop competition, but also to cultural constraints. For example, because of land irregularities, seed density was lower than recommended (50 plants/m^2), especially in parcel A (39 plants/m^2). It is important since, according to Ball et al. (2001), soybean total yield is more closely correlated to population density than to the number of grains per pod and grain weight. Moreover, a very high soil moisture level in the spring of 2004 did not allow the seeding of the soybean before June 21, resulting in a more than two-week delay as compared to recommended sowing dates for the cultivar that was used. It is well known that delayed sowing may reduce soybean grain yield (Andrete 1995).

An important gradient of soybean productivity, as well as of light and water availability, has been observed in relation to distance from the tree row. A decrease in both relative *Qp* and soil moisture contributed to a considerable reduction in total grain dry weight, aboveground biomass and height of soybean plants at 2 versus 5 m. Such a finding suggests that black walnut and white ash effects on soybean productivity are negligible at this early stage of their development as compared to HP effects. Some studies indicate that it is competition for water rather than competition for light that would be critical in defining crop productivity (Jose et al. 2000; Miller and Pallardy 2001), whereas other studies found the opposite (Chirko et al. 1996; Simpson et al.

2003). In this present study, total grain dry weight at 2 m from the HP row was significantly correlated with soil moisture, but not with relative Q*p*, while the reverse was true at 3 m. The presence of a narrow (± 10 cm) weed strip dominated by *Solidago canadensis* along black plastic mulch strips certainly contributed, in association with HP, to the reduction of soil moisture and soybean total grain dry weight at 2 m from HP rows. Foroud et al. (1993) have demonstrated that water stress can cause important decreases in soybean yield.

At 3 m from the HP row, the number of grains and the number of pods were correlated with relative Q*p*, while the 100-grain dry weight was not. Andrate and Ferreiro (1996) reported that shading during grain filling affected the number of grains more than the weight per grain. Data from the present study support these findings, since HP shade did not result in a compensatory effect on 100-grain dry weight. In this present study, the relative *Qp* and soil moisture effects on soybean productivity cannot be separated since no root barrier at the HP - soybean interface nor soybean irrigation has been installed. Thus, it is not possible to know the relative influence of each one at the moment. Further studies are needed in order to better understand below-ground and upper-ground competition at the tree-crop interface. The results of such studies would provide very useful information for evaluating the value of intercropping systems in improving the profitability of hardwood and HP plantations.

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