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Production of soybean associated with different hybrid poplar clones in a tree-based intercropping system in southwestern Québec, Canada

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ABSTRACT

In tree-based intercropping systems, trees, especially hybrid poplars (HP), can compete with crops for light, water and nutrients, resulting in a decrease in crop production. Some tree management characteristics, such as plantation density and tree species selection, may help to partially control this competition. The aim of this study was to analyse the effect of HP competition on yield and yield components of a soybean intercrop. Soybean was added to a HP–hardwood plantation which was established in 2000 and composed of alternate rows spaced 6 m (field A) and 8 m (field B) apart. The experimental design permitted the comparison of the combined effects of HP clones (TD-3230, DN-3308, NM-3729,), orientation with respect to HP row (East, West) and distance from the HP row. A thinning was performed at the beginning of 2006 to increase the initial 2 m-spacing between HP within each row to a final 6 m-spacing. Percent total light transmittance (PTLT) was measured from soybean emergence to grain filling (VE-R6). Soil water content (WC) and soil N mineralisation (NMIN) were determined at two different periods corresponding to distinct soybean reproductive stages: (1) from flowering to pod formation (R1–R4) and (2) during grain filling (R5–R6). In 2005, PTLT, soil WC, soil NMIN (for R1–R4), soybean yield and yield components were significantly reduced near the HP row (2 m). The number of pods per m^2 contributed more to the variation in soybean yield than did the 100-seed size. Yield and number of pods per m^2 were highly correlated to PTLT, soil WC (R1–R4) and NMIN (R1–R4). An interaction between clone and orientation was found for field A. On the east side of the HP row, soybean yield with NM-3729 or DN-3308 was significantly higher than that with TD-3230, whereas it did not differ from that with the clone on the west side of the field. In field B, a significant interaction between orientation and distance was observed for PTLT and the number of pods per m^2. PTLT and number of pods per m^2 showed less variability on the west side compared to the east side. In 2006, a more regular PTLT distribution with respect to different orientations and distances from the HP row was observed and compared with that in 2005. Similarly, soil WC, soil NMIN, soybean yield and yield components were more uniform in 2006. These results suggest that HP clone selection, tree spacing within the rows, row spacing, orientation, and silvicultural treatments such as thinning may be useful to control the negative effects of HP competition on the intercrop.

1. Introduction

Results of recent studies show that certain tree-based intercropping (TBI) systems, which integrate hybrid poplars (HP) (*Populus* spp.) or hardwood species, exhibit multiple benefits for the environment, such as reducing soil erosion and N leaching, as well as increasing carbon sequestration and landscape biodiversity (Thevathasan et al., 2004; Palma et al., 2007). TBI systems, whose overall productivity depends on the sum of yields of both agricultural intercrops and tree components, also appear to be more productive and profitable than conventional agricultural or forestry systems (Graves et al., 2007).

Intercrop yield is generally unaffected by the influence of young broadleaved trees, including HP, but yield often declines with time as the trees grow (Rivest and Olivier, 2007). Reduction in crop productivity is greatest at the tree–crop interface, where competition for light (Chirko et al., 1996a,b; Newman et al., 1998), water (Jose et al., 2000; Miller and Pallardy, 2001; Wanvestraut et al., 2004) and nutrients, particularly nitrogen (Allen et al., 2004), is most critical. The magnitude of the competition for each of these resources often differs according to the pedo-climatic conditions under which the TBI system

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develops, as well as the age and species composition of the system.

In a study of a TBI association of 9- to 10-year-old HP (*P. deltoides* Bartr. ex Marsh × *P. nigra* L.) and soybean (Glycine max (L.) Merr.) established in Guelph, Canada, Reynolds et al. (2007) concluded that competition for light was the principal factor limiting soybean yield. However, their study did not distinguish the effects of this TBI system on the yield components so that the critical phases in which soybean is more sensitive to the availability of resources could be identified. According to Brun (1978) and Jiang and Egli (1995), canopy photosynthesis has a greater effect on soybean yield during the reproductive period [R1–R8 stages (Fehr et al., 1971)] than during the vegetative period (emergence to R1). Several studies have shown that light interception by artificial shade structures, at different times during the reproductive period, reduces soybean yield, principally by influencing pod number. Seed size remains unaffected (Schou et al., 1978; Board et al., 1995; Kakiuchi and Kobata, 2006). These results suggest that yield is more sensitive to shading during flowering and pod formation (R1–R4) than during seed filling (R5–R6). With respect to competition for water, Sionit and Kramer (1977) observed that water stress, when applied during seed filling, resulted in a greater reduction in yield and seed size than when a comparable stress applied during flowering. The authors emphasised that pod number was negatively affected when the water stress occurred at the beginning of pod formation.

Despite the fact that soybean productivity in TBI systems tends to decline as competition from trees increases, certain silvicultural treatments, such as the choice of tree species and clones (Dhyani and Tripathi, 1999; Puri et al., 2002; Reynolds et al., 2007) as well as plantation density (Yin and He, 1997; Shanker et al., 2005), may limit the competitive effect. Plantation density depends on the spacing between the rows of trees as well as the initial spacing of the trees within the same row. Density can also be adjusted by thinning. The association of HP and hardwood species arranged in alternate rows (Thevathasan and Gordon, 2004) appears to be a very promising system, which may help to reduce shading effects and delay crown closure.

In this study, due to the duration of time necessary for trees to grow in temperate regions, the TBI system was created by sowing soybean in an already existing tree plantation. Soybean yield and yield components were measured in 2005 at low HP spacing (2 m) in the same row. Although such a low spacing is unusual in TBI systems, we reasoned that it could help to detect quickly the possible effects of HP clone and tree row orientation, and to better understand the relative importance of HP competition for light and belowground resources. Soybean yield and yield components were re-evaluated in 2006 at higher HP-row spacing (6 m), following a HP thinning. The objectives of the present study consist of: (i) comparing the effects of three HP clones (TD-3230, DN-3308 et NM-3729), two orientations (East and West from the HP row) and various distances with respect to the HP row on the percent total light transmittance (PTLT), as well as soybean yield and the individual soybean yield components; (ii) comparing the effects of various distances with respect to the HP row on the soil water content (WC) and nitrogen mineralisation (NMIN), at two different periods corresponding to distinct soybean reproductive stages (R1–R4 and R5–R6); and (iii) determining the relationship between environmental factors (PTLT, soil WC, NMIN) and the soybean yield variables.

2. Materials and methods

2.1. Site characteristics

The study was conducted in St-Rémi (45°14′N, 73°40′W; altitude, 53 m), in southwestern Québec. Between 1971 and 2000, an average annual temperature of 6 °C, an average annual number of degree-days (above 5 °C) totalling 2031 and an average annual precipitation of 1027 mm were recorded in the St-Rémi region (Environment Canada, 2008). Over the two years of the study, in 2005 and 2006, average monthly temperature between June and October represented 100 and 103% of the 30-years monthly average (15.4 °C), respectively. Average monthly precipitation between June and October represented 107 and 94% of the monthly average (96 mm) in 2005 and 2006, respectively. The soil is classified as an orthic melanic brunisol (Agriculture Canada Expert Committee on Soil Survey, 1987) with a loam soil texture (19% clay, 34.5% silt and 46.5% sand) with moderate to imperfect drainage, a cation exchange capacity of 20.6 cmolc kg^{-1}, a total N content of 3 g kg^{-1}, a total C content of 30 g kg^{-1}, and a pH_{water} of 6.9 in the 0–15 cm layer.

2.2. Vegetative material, experimental design and treatments

The original experimental design, established in 2000, was composed of two adjacent fields (A and B) separated by a distance of 20 m. The fields differed in the spacing between rows of hardwoods and HP (A = 6 m and B = 8 m). Each of the fields contained five HP rows and four rows of hardwoods. A row of HP was present on both sides of each hardwood row. The rows of trees were oriented at 310° (NW–SE), which corresponds to the orientation of the fields in the study region. Each field (A and B) was divided into four experimental blocks perpendicular to the direction of the slope. Each block consisted of three plots arranged in the direction of the slope. Each plot contained one of the three clones being evaluated: TD-3230 (*P. trichocarpa* Torr. & Gray × *P. deltoides* cv. Boelare), DN-3308 (*P. deltoides* × *P. nigra* cv. Regenerata Bâtard d'Hauterive), NM-3729 (*P. nigra* × *P. maximowiczii* A. Henry cv. Max 5). Typically, TD-3230 clone has a dense, narrow crown of moderately rising branches. DN-3308, in contrast, is characterised with a narrowly cylindrical crown of short rising branches, but often tends to be broadly rounded and irregular as it grows. NM-3729 has a large, narrowly egg-shaped crown of long, gently to sharply rising branches (Eckenwalder, 2001). The clones were randomly assigned to the plots. From 2004 to 2006, a soybean crop was integrated into the plantation. In the present study, each experimental plot was bounded on each side by a row of hardwood species, with two alleys separated in the middle by one row of HP (Fig. 1).

In each row, 20-cm long rooted cuttings of HP were planted at 2 m spacing. Nine cuttings of each clone were planted adjacent to each other. The HP were pruned twice (2003 and 2005) with the goal of releasing the top third and top half of their boles in 2003 and 2005, respectively. A thinning, in the winter of 2006, permitted the spacing between HP in each row to be increased from 2 to 6 m, thereby decreasing their density from 417 to 139 stems ha^{-1} in field A and from 313 to 104 stems ha^{-1} in field B. The hardwood tree species, black walnut (*Juglans nigra* L.) and white ash (*Fraxinus americana* L.), were planted at 3 m spacing in the rows, in groups of 3 seedlings per species. However, given that the hardwoods were smaller (average height of 2.4 and 3.2 m in 2005 and 2006, respectively) than the HP, their influence was considered to be negligible over the course of this study. For this reason, the treatment combinations were planned to isolate the effects of the HP clone, the orientation with respect to the HP row and the distance from the HP row.

The soybeans (cv. S03-W4) were sowed on June 11, 2005 and July 3, 2006. The 2006 sowing was delayed because of abundant precipitation in June. Following superficial (0–10 cm) soil preparation, the soybeans were sowed with a no-till planter at a density of 50 plants m^{-2} with spacing of 38 cm between rows.