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Nutrient accumulation and carbon sequestration in 6-year-old hybrid poplars in multiclonal agricultural riparian buffer strips

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ABSTRACT

Riparian vegetation has a critical role to play in non-point source pollution abatement and water quality protection within watersheds in agricultural areas. In addition to their water quality function, riparian buffers also have the potential to sequester large amounts of carbon (C). In this study, the C and nutrient sequestration by five unrelated hybrid poplar (*Populus* spp.) clones growing in the riparian zone of four southern Quebec (Canada) agroecosystems is measured aboveground after 6 years of growth and compared to free-growing (unmanaged) herbaceous buffer strips. Very large differences in C sequestration and nutrient accumulation in hybrid poplar buffers were observed across the four agricultural riparian sites. For all variables measured in this study, the largest effect detected by the ANOVA was the Site effect. While C sequestration, N and P accumulation in total aboveground biomass were, respectively 52 t ha^{-1}, 770 kg ha^{-1} and 82 kg ha^{-1} at the Bromptonville site, these values were as low as 6.4 t ha^{-1}, 90 kg ha^{-1} and 10 kg ha^{-1} at the Magog site. Site fertility, in terms of NO_3 supply rate, was the main factor controlling biomass growth, and consequently C sequestration and nutrient accumulation in hybrid poplars. Although Site effect was by far the largest effect in this study, the Clone effect was also important, with clone 3729 (*Populus nigra* L. × *Populus maximowiczii* A. Henry) being the most effective for C and nutrient sequestration. Across the four study sites, total aboveground C sequestration, N and P accumulation at the site level could be, respectively enhanced by 31–37%, 29–41% and 30–38% with the sole use of clone 3729. Site × Clone interactions for the variables tested in this study were generally not significant, or significant but small in magnitude compared to main effects (Site and Clone). Important C and nutrient accumulation differences exist after 6 years of growth between hybrid poplar buffers and unmanaged herbaceous buffers. Compared to an unmanaged herbaceous buffer, the distinct advantage of hybrid poplar buffers is that C and nutrient sequestration greatly increase with increasing site fertility, whereas they do so to a much lesser extent in herbaceous buffers.

1. Introduction

Worldwide, the intensification of agricultural practices has led to an increase of nutrient, chemical and sediment loads into receiving water bodies. Non-point inputs of nitrogen (N) and phosphorus (P) derived from fertilizer or manure application, soil erosion and high cattle densities are known as major causes of the degradation of aquatic ecosystems (Carpenter et al., 1998). Riparian vegetation has a critical role to play in non-point source pollution abatement and water quality protection within watersheds in agricultural areas (Schlosser and Karr, 1981; Lowrance et al., 1984, 1997; Gregory et al., 1991; Osborne and Kovacic, 1993). Therefore, restoration of riparian vegetation has the potential to improve water quality and provide other ecological functions within agroecosystems (habitats, micro-climate, soil stability, etc.) (Naiman et al., 2005).

The presence of riparian vegetated buffers tends to decrease nutrient loads to streams by reducing stream bank and soil erosion, by enhancing sediment deposition, water infiltration, bacterial denitrification, and nutrient accumulation by plant biomass (Lowrance et al., 1997). However, appropriate management of riparian vegetation is essential to maintain some of these functional attributes (Bentrup, 2008), particularly the nutrient accumulation potential (Lowrance et al., 1997; Schultz et al., 2004). Because plant communities will eventually reach a steady-state, a management approach that does not include the harvest of biomass will eventually become less effective in trapping nutrients such as P (Kelly et al.,

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2007). As described by Vitousek and Reiners (1975), nutrients are retained within an ecosystem as storage pools of nutrients increase in both biomass and soil. However, as biomass increment reaches zero, storage pools of the system reach a steady-state were nutrient outputs equal inputs (Vitousek and Reiners, 1975). A riparian buffer system that reaches this steady-state may be less effective in preventing nutrient leaching to the streams. Moreover, if plants are not harvested, N and P accumulated in biomass will be released back to the soil as riparian vegetation dies and decays (Bedard-Haughn et al., 2005; Dorioz et al., 2006). Thus, periodic harvest of vegetation has been recommended in order to maintain an active nutrient sink (Dosskey, 2001).

In addition to their water quality function, riparian buffers also have the potential to sequester large amounts of carbon dioxide when they are managed as agroforestry systems (Montagnini and Nair, 2004). This is particularly interesting in a context where the agricultural sector accounts for an estimated emission of 10–12% of total global anthropogenic emissions of greenhouse gases (Smith et al., 2007). Thus, multifunctional buffers can be designed to meet both water quality and carbon (C) sequestration objectives on farms, while creating economic opportunities (bioenergy, pulp, solid wood products, carbon credits, etc.) (Rockwood et al., 2004; Licht and Isebrands, 2005).

In temperate ecosystems, hybrid poplars (*Populus* spp.) and other trees from the Salicaceae family were identified as potential species to enhance nutrient capture in the riparian zone (Licht, 1992; O'Neill and Gordon, 1994; Schultz et al., 1995). Because these flood-tolerant pioneer species become established rapidly and grow very fast, they can be an important nutrient sink within a few years (Kelly et al., 2007). In agroforestry systems, fast-growing poplars are also very effective carbon sinks and can be planted to offset agricultural sources of carbon dioxide (Kort and Turnock, 1998; Oelbermann et al., 2004; Peichl et al., 2006).

While a large body of literature exists on hybrid poplar cultivation (Dickmann et al., 2001), few studies have assessed the potential of these species as nutrient and C sinks in the riparian zone of diverse agroecosystems (Haycock and Pinay, 1993; O'Neill and Gordon, 1994; Tufekcioglu et al., 2003). Also, few studies have compared the nutrient and C sequestration potential of hybrid poplar buffer strips with herbaceous buffer systems, unmanaged or planted (Tufekcioglu et al., 2003). The general conclusions of these studies were the following: (1) compared to a grass buffer, a poplar buffer was slightly more efficient for nitrate (NO_3) retention during the winter months with an efficiency of 99%; (2) biomass and N concentration of hybrid poplar roots increased with increasing soil NO_3 concentration, and (3) after 7 years, C accumulation in plant and litter biomass in a poplar and a switchgrass (*Panicum virgatum* L.) buffer averaged 2960 and 820 kg C ha^{-1} year^{-1}, respectively, while N immobilization rates averaged 37 and 16 kg N ha^{-1} year^{-1}.

In addition, little is known about the nutrient accumulation and C sequestration potential of different hybrid poplar clones across a range of riparian soil fertility conditions. There is also a need to compare these poplar clones to more conventional buffer systems (natural herbaceous vegetation) in the context of Quebec (Canada) agroecosystems, since no study has addressed these issues until now.

In this article, we address three main research questions: (1) how effective can hybrid poplars be at sequestering both C and nutrients in the riparian zone of different agroecosystems? (2) Are some hybrid poplar clones or unmanaged herbaceous vegetation more appropriate to fulfill these ecological services? (3) Is site fertility an important factor in determining hybrid poplar effectiveness for C and nutrient sequestration? The C and nutrient sequestration of five unrelated hybrid poplar clones growing in the riparian zone of four southern Quebec (Canada) agroecosystems is measured after 6 years of growth and compared to free-growing (unmanaged) herbaceous buffer strips.

2. Materials and methods

2.1. Study sites

During May 2003 four hybrid poplar riparian buffer strips were planted along small headwater streams in the Eastern Townships region of southern Québec, Canada. The buffers had accumulated 6 years (seasons) of growth in the year of the study (2008). Three of the four buffers (Magog, Bromptonville, and St-Isidore-de-Clifton) are located in pastures with different cattle densities and different surrounding landscapes. The other buffer (Roxton Falls) is in the riparian zone of a hayfield. The natural vegetation of the region is dominated by hardwood species, mainly sugar maple (*Acer saccharum* Marsh.).

Three study sites (Bromptonville, Magog and Roxton Falls) are located in the hilly regional landscape unit of Sherbrooke, with gentle slopes and a continental subhumid moderate climate (Robitaille and Saucier, 1998). This landscape unit has 71% of its area in natural and managed forest (mostly privately owned), 28% in agricultural land use and in 1% urban areas. The St-Isidore-de-Clifton site is located in the Mont Mégantic landscape unit, with subhumid–subpolar climate, higher elevation, steeper hillside slopes and a lower area in agricultural use (9% of land use) (Robitaille and Saucier, 1998). Both landscape units share a similar annual precipitation regime (1000–1100 mm).

Cattle densities at the three pasture sites are 0.6 cow ha^{-1} at Bromptonville, 0.2 cow ha^{-1} at Magog, and 0.5 cow ha^{-1} at St-Isidore-de-Clifton. Bromptonville and St-Isidore-de-Clifton sites are fertilized each year with cow manure, while Magog and Roxton Falls sites are not. Every 5 years, 0.8 t ha^{-1} of lime is also applied at the St-Isidore-de-Clifton site. A summary of site characteristics is presented in Table 1.

At each study site, riparian buffers were planted on both sides of the streams for a total length of 90 m and a width of 5.5 m on each stream bank. A row of silver maple (*A. saccharinum* L.) was planted directly on the stream bank, as recommended by Schultz et al. (1995). One meter away from the silver maple row, three hybrid poplar rows were planted, with a spacing of 1.5 m between rows and 3 m between trees within a row (4.5 m^2 per hybrid poplar or ~2222 hybrid poplars per ha). Bare root cuttings (2 m-high) were planted manually at 30–40 cm depth. Rooted cuttings were chosen in order to improve initial survival (Zsuffa et al., 1977). Planting stock was provided by the Berthierville nursery of the Ministère des Ressources Naturelles et de la Faune (MRNF) of Québec.

Table 1
Site characteristics of the four riparian buffer strip sites.

Sites	Land use	Yearly fertilization	Cattle density (cow ha^{-1})	Elevation (m)	Precipitation (mm year^{-1})	Growing season (d)	Topography
Bromptonville	Pasture	Cow manure	0.6	140	1000–1100	180–190	Hilly—gentle slopes
Magog	Pasture	None	0.2	208	1000–1100	180–190	Hilly—gentle slopes
Roxton Falls	Hayfield	None	–	147	1000–1100	180–190	Hilly—gentle slopes
St-Isidore-de-Clifton	Pasture	Cow manure	0.5	360	1000–1100	170	Hilly—moderate slopes