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Biomass carbon, nitrogen and phosphorus stocks in hybrid poplar buffers, herbaceous buffers and natural woodlots in the riparian zone on agricultural land

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In many temperate agricultural areas, riparian forests have been converted to cultivated land, and only narrow strips of herbaceous vegetation now buffer many farm streams. The afforestation of these riparian zones has the potential to increase carbon (C) storage in agricultural landscapes by creating a new biomass sink for atmospheric CO_2. Occurring at the same time, the storage of nitrogen (N) and phosphorus (P) in plant biomass, is an important water quality function that may greatly vary with types of riparian vegetation. The objectives of this study were (1) to compare C, N and P storage in aboveground, belowground and detrital biomass for three types of riparian vegetation cover (9-year-old hybrid poplar buffers, herbaceous buffers and natural woodlots) across four agricultural sites and (2) to determine potential vegetation cover effects on soil nutrient supply rate in the riparian zone. Site level comparisons suggest that 9-year-old poplar buffers have stored 9–31 times more biomass C, 4–10 times more biomass N, and 3–7 times more biomass P than adjacent non managed herbaceous buffers, with the largest differences observed on the more fertile sites. The conversion of these herbaceous buffers to poplar buffers could respectively increase C, N and P storage in biomass by 3.2–11.9 t/ha/yr, 32–124 kg/ha/yr and 3.2–15.6 kg/ha/yr, over 9 years. Soil NO_3 and P supply rates during the summer were respectively 57% and 66% lower in poplar buffers than in adjacent herbaceous buffers, potentially reflecting differences in nutrient storage and cycling between the two buffer types. Biomass C ranged 49–160 t/ha in woodlots, 33–110 t/ha in poplar buffers and 3–4 t/ha in herbaceous buffers. Similar biomass C stocks were found in the most productive poplar buffer and three of the four woodlots studied. Given their large and varied biomass C stocks, conservation of older riparian woodlots is equally important for C balance management in farmland. In addition, the establishment of poplar buffers, in replacement of non managed herbaceous buffers, could rapidly increase biomass C, N and P storage along farm streams, which would be beneficial for water quality protection and global change mitigation.

1. Introduction

Worldwide, food systems contribute to 19–29% of anthropogenic greenhouse gas emissions, with agricultural production being responsible of 80–86% of emissions related to food systems (Vermeulen et al., 2012). These emissions contribute to global change, which in turns threatens food security because of its potential adverse effects on agricultural yields (Lal et al., 2011; Vermeulen et al., 2012). Consequently, management strategies that reduce the carbon (C) footprint of agricultural production systems are essential for climate change mitigation and the sustainability of farming systems (Lal et al., 2011). Such strategies include afforestation and agroforestry to promote atmospheric CO_2 storage in plant biomass on degraded farmland, but also the production and use of renewable energy derived from woody biomass (Keith et al., 2009; Montagnini and Nair, 2004; Righelato and Spracklen, 2007). However, afforestation projects should not

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cause excessive agricultural activity displacement, which could lead to deforestation elsewhere and negate C benefits, but also reduce food production and security (Campbell et al., 2008; Melillo et al., 2009).

In several temperate agricultural landscapes, riparian forests along farm streams have been cleared to increase cultivated areas and narrow strips of naturally regenerated herbaceous vegetation now line many of the once forested banks (Rheinhardt et al., 2012; Sweeney et al., 2004). These changes in vegetation cover have contributed to a marked decline of C stocks, but also a decline in other ecosystem services, including habitat for biodiversity and non-point source pollution abatement (Boutin et al., 2003; Jobin et al., 2004; Lowrance et al., 1997; Rheinhardt et al., 2012; Sweeney et al., 2004). Allowing forest to regrow in herbaceous-dominated riparian zones could be a promising strategy to increase C storage since C stocks along farm streams generally increase along the successional gradient. In the Coastal Plain of North Carolina (United States), mature riparian forests (>50 years-old) can store around 240 t/ha, which is 7–13 times higher than riparian zones dominated by perennial herbs, shrubby vegetation or row crops (Rheinhardt et al., 2012). In the Northeastern United States, white pine forests regenerated on abandoned farmland sites showed a linear increase in biomass C and N stocks in relation to time since abandonment (Hooker and Compton, 2003). These stock increases were mainly caused by the large gain in aboveground plant biomass that occurred along the chronosequence, with 9 t/ha observed 10 years after abandonment and 250–300 t/ha after a century (Hooker and Compton, 2003).

Promoting forest regrowth in agricultural riparian zones would contribute to water quality protection. Because they are interfaces between terrestrial and aquatic ecosystems, riparian zones control the movement and fate of different pollutants of farm streams, including nitrogen (N) and phosphorus (P), which are both responsible for eutrophication and water quality decline (Carpenter et al., 1998; McClain et al., 2003; Vidon et al., 2010). As reviewed by Di and Cameron (2002), nitrate leaching losses reaching more than 100 kg N/ha/yr have been found in both grazed pastures and arable cropping systems of the temperate zone. In Denmark, median losses of total N and total P in agricultural catchments reached 23.4 kg N/ha/yr and 0.29 kg P/ha/yr, while these losses were only 1.7 kg N/ha/yr and 0.07 kg P/ha/yr in undisturbed catchments, highlighting the contribution of agricultural activities to the non-point source pollution of streams (Kronvang et al., 1995). In this context, trees growing in riparian zones can uptake nutrients escaping from adjacent cultivated fields and contribute to long-term storage of those nutrients in biomass, thereby reducing the N and P loads that reach farm streams (Dosskey et al., 2010; Kelly et al., 2007).

However, in the absence of human intervention, forest regrowth in areas dominated by herbaceous vegetation may take several decades, sometimes a century, even if the surrounding vegetation is composed of woody species (Inouye et al., 1987; Maycock and Guzikowa, 1984). As an alternative to natural succession, tree plantations and agroforestry systems can be established, as buffers, in degraded riparian zones to increase C and nutrient storage, but also to improve local forest biodiversity (Brockerhoff et al., 2008; Chazdon, 2008; Fortier et al., 2012). For example, fast-growing hybrid poplars (*Populus* × spp.) have the potential to restore some forest attributes within a decade (Boothroyd-Roberts et al., 2013a), but also to promote rapid C stocks accumulation in plant biomass, compared to other farm land uses (Arevalo et al., 2009). There is growing evidence that over a few years after establishment, hybrid poplar buffers can become larger C and nutrient sinks in their biomass compared to non harvested herbaceous buffers of various compositions (Kelly et al., 2007; Tufekcioglu et al., 2003). However, site fertility can have a significant effect on biomass growth, but also on C and nutrient storage of planted poplars (Fortier et al., 2010a,b; Truax et al., 2012).

While C storage in growing tree biomass is a sink for atmospheric CO_2, C storage in biomass can provide additional benefits in riparian zones. Organic C derived from decaying root biomass and leaf litter can fuel denitrification in waterlogged soils and streams, and contribute to water quality protection (Hill, 1996; Lowrance, 1992; Newcomer et al., 2012). In addition, litter may also have an important contribution to stream N and P budgets, a contribution that varies depending on types of riparian vegetation cover (Molinero and Pozo, 2006).

Presently, there is a lack of empirical data on the C and nutrient storage potential of different types of riparian vegetation cover in agricultural landscapes, with very little information regarding the distribution of C and nutrients in different biomass compartments, including decaying biomass (Rheinhardt et al., 2012; Tufekcioglu et al., 2003). There are also indications that for a particular riparian vegetation cover type, wide variations in C and nutrient stocks are observed between sites, at least for the different aboveground biomass compartments (Fortier et al., 2010b). In this context, evaluating the size and the variability of C and nutrient stocks in different biomass compartments, across different farmland settings, is important to understand the potential contribution of riparian agroforestry systems for C and nutrient management in agricultural landscapes. While tree buffers generally provide higher long-term nutrient storage capacity than herbaceous buffers, there is still little evidence that tree buffers are more effective than herbaceous buffers at reducing soil nutrient movement or availability across riparian zones (Dosskey et al., 2010; Mayer et al., 2007; Sabater et al., 2003). Additional studies are therefore needed to document the complex relationship between nutrient uptake, storage and release by biomass, and soil nutrient status in agricultural riparian buffers.

The present study aims at comparing C, N and P stocks in the different aboveground, belowground and detrital biomass compartments, of three types of riparian vegetation cover (9-year-old hybrid poplar buffers, herbaceous buffers and natural riparian woodlots) across four agricultural sites. Also, we evaluate the potential effects of these different vegetation cover types on soil nutrient availability (supply rate) in the riparian zone, with a specific emphasis on the comparison between poplar buffers and adjacent herbaceous buffers. We hypothesized that 9 year-old poplar buffers will store greater amounts of C, N and P in their biomass than adjacent herbaceous buffers, independent of the agricultural site studied. We also hypothesized that the greater nutrient storage in poplar buffers will result in a lower NO_3 and P availability in riparian soils during the growing season, when compared to adjacent herbaceous buffers.

2. Materials and methods

2.1. Study sites and experimental design

This study took place in the southern region of the province of Québec, Canada. At the four study sites (Bromptonville, Magog, Roxton Falls, St-Isidore-de-Clifton) three types of riparian vegetation cover were studied: (1) hybrid poplar riparian buffer, (2) herbaceous riparian buffer and (3) natural riparian woodlot. At each site, hybrid poplar riparian buffers where planted in spring 2003 at a density of 2222 stems per hectare on both sides of the streams for a total length of 90 m and a width of 4.5 m on each stream bank. These buffers are composed of 3 poplar rows, parallel to the stream, with a 1.5 m spacing between rows and a 3 m spacing between trees within a row. Bare-root hybrid poplar plants were 1 year-old