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Establishment success of trees planted in riparian buffer zones along an agricultural intensification gradient

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ABSTRACT

Although riparian zones provide numerous ecological services, they have been widely degraded by agricultural intensification. To recover water quality and restore other critical services, tree planting has been implemented in agricultural riparian buffer zones worldwide. However, intensive agricultural practices adjacent to tree plantations are likely to impede their establishment. In this study, we assessed the survival and size of trees planted in riparian buffer zones along a gradient of agriculture intensification. We studied 68 riparian buffer zones in two agricultural watersheds of southeastern Québec (Canada) where trees had been planted 3–17 years prior to sampling. Tree survival and size (height, diameter and crown width) were measured and related to agricultural intensification, quantified as the frequency of annual crops in the agricultural field adjacent to riparian zones during the seven years prior to sampling. Tree survival decreased by 25% with increasing frequency of annual crops ($P < 0.0001$; $R^2 = 35\%$), independently of the planting year. Aside from the influence of tree age, tree size varied with the frequency of annual crops but only for three of the six most frequently planted tree species ($P = 0.0007$; $R^2 = 46\%$). These three species (*Fraxinus pennsylvanica* Marsh., *Quercus macrocarpa* Michx. and *Picea glauca* (Moench) Voss) showed reduced size with higher cultivation frequency of annual crops, whereas the other three species (*Acer saccharum* Marsh., *Larix laricina* (Du Roi) K. Koch and *Quercus rubra* L.) were more tolerant to agricultural intensification. While tree planting is carried out in riparian buffer zones to mitigate the environmental impacts of agricultural practices, agricultural intensification in turns impedes the establishment success of trees. To increase the environmental benefits provided by agroforestry projects, tree planting in riparian buffer zones should focus on species that tolerate agricultural intensive practices. Additionally, more frequent inclusion of hay meadows in the crop rotation of fields adjacent to riparian buffer zones may be beneficial to the establishment success of planted trees.

1. Introduction

Riparian zones which correspond to the ecotones between upland and aquatic ecosystems under the influence of flooding or shallow groundwater, provide numerous ecological services (Neary et al., 2010). Besides their high biodiversity, riparian zones reduce soil erosion, increase water quality and regulate hydrological regimes, especially when they include forested plant communities (Lowrance et al., 1984; Marshall and Moonen, 2002; Boutin et al., 2003; Lovell and Sullivan, 2006). Trees improve soil cohesion, increase infiltration of runoff water and trap sediments, nitrogen and phosphorus more effectively than herbaceous species (Osborne and Kovacic, 1993; Schultz et al., 1995; Lee et al., 2000, 2003). Despite these environmental benefits, riparian zones have been degraded worldwide. Some authors have, for example, estimated that up to 80% of pristine riparian zones have been lost over the last 200 years in Europe and North America (Naiman et al., 1993). These losses are mainly attributed to agricultural intensification, which has destroyed some riparian zone functions directly

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through clearing or grazing, and indirectly disturbed others through fertilizer inputs, pesticide use or soil tillage (Allan, 2004; Tscharntke et al., 2005). Intensive cereal production has doubled globally since 1960s (Tilman et al., 2002), and an 18% increase in agricultural land is predicted by 2050, implying the conversion of 10^9 ha of natural ecosystems to agriculture (Tilman et al., 2001). The maintenance of natural riparian zones and their associated ecosystem services is thus increasingly critical worldwide.

Important governmental measures, including legal protection and restoration, have been implemented worldwide to recover the ecological services provided by riparian zones among agricultural landscapes. In the USA, guidelines for multispecies riparian buffer installation have, for example, been developed by the USDA Natural Resources Conservation Service to promote the reduction of nonpoint source pollution (USDA, 1997). The Common Agriculture Policy also fosters the establishment of environment-friendly practices in agricultural landscapes throughout Europe (Kleijn et al., 2006). In Québec (eastern Canada), agricultural practices such as soil tillage, fertilization and pesticide applications have been banned in a riparian zone of at least 3 m wide along streams adjacent to agricultural fields since 1987, and financial incentives encourage farmers to plant trees in riparian buffer zones (Gouvernement du Québec, 1987). When planted with trees, riparian buffer zones indeed offer multiple agronomic advantages that result in increased crop productivity (e.g. through windbreak effect and improved pollination and pest control; Brandle et al., 2009) and stock safety and exclusion from rivers (when fenced). Forested riparian zones also provide several external benefits to society, like increased landscape aesthetics, beyond their positive impact on terrestrial and aquatic biodiversity and ecosystem services (Jose, 2009; Kulshreshtha and Kort, 2009). Furthermore, tree harvest can generate direct income for farmers (Lockaby et al., 1997; Correll, 2005) without affecting water quality when best management practices are used for forestry operations (such as keeping machinery out of waterways, minimizing stream crossing and establishing sediment control treatment; Neary et al., 2010; Smethurst et al., 2012). Agricultural intensification has, however, been shown to impact spontaneous plant communities on field margins, reducing their species diversity and influencing their composition in favour of nitrophilous and ruderal herbaceous species (Boutin and Jobin, 1998; Mensing et al., 1998; Marshall and Moonen, 2002). Similarly, trees planted in agricultural riparian zones may also be negatively impacted by agricultural intensification. Yet, to our knowledge, no previous study has investigated the success of tree planting in riparian buffer zones relative to agricultural practices on adjacent lands.

Intensive agricultural systems such as the cultivation of annual crops require high chemical inputs of fertilizers and pesticides (e.g. herbicides, fungicides, insecticides, plant growth regulators; Tscharntke et al., 2005) to sustain productivity. In turn, drifts from agricultural inputs represent strong environmental disturbances that can lead to biotic homogenization and biodiversity losses of spontaneous plant communities in adjacent riparian zones (Tscharntke et al., 2005). Similarly, for trees planted at field margins, intensive agricultural practices have the potential to decrease establishment success. While drifts of non-selective herbicides (such as glyphosate) can reduce the survival of both planted trees and spontaneous herbaceous plants, trees might be more sensitive and regenerate slower especially when they are small. Moreover, the leaching of fertilizers from intensive fields is more likely to favour fast-growing herbaceous plants, and thereby to decrease the growth of planted trees through competition. Since hay meadows corresponds to low-intensity agricultural practices with less chemical inputs than annual crops, they may attenuate the detrimental environmental impact of annual crops when included in crop rotation (Bignal and McCracken, 1996; Sutherland, 2002). Understanding the response of planted trees to agricultural intensification is needed to improve decision-making and implement economically and environmentally productive tree planted riparian buffer zones or other agroforestry systems in agricultural landscapes (Jose et al., 2004; Smith et al., 2012).

The goal of this study was to assess the effect of agricultural intensification on the survival and size of different trees species planted in agricultural riparian zones. Agricultural intensification was quantified as the cultivation frequency of annual crops in adjacent fields over the seven years preceding sampling. We hypothesized that agricultural intensification decreases the survival and size of planted trees. As growth rate is species-specific (Cogliastro et al., 1990; Burton and Bazzaz, 1995), we also hypothesized that tree species respond differently to agricultural intensification. Our study fills a knowledge gap that has recently been identified by different agricultural stakeholders in Canada (Tartera et al., 2012; Masse et al., 2014).

2. Materials and methods

2.1. Study area and sampling design

Riparian buffer zones planted with trees along relatively uniform rivers (in terms of river width and flow) of two agricultural watersheds in southeastern Québec, Canada were sampled during the summer of 2012. These watersheds are characterized by gleysolic and brunisolic soils. The region has a mean annual temperature of 4 °C (19 °C in July and −12 °C in January) and mean annual precipitation of 1300 mm, of which 24% falls as snow (Environment Canada, 2015). In the Boyer watershed (216 km^2 area; 46°41′N, 70°55′W), 66% of the land is used for agriculture, of which 26% is farmed with annual crops (principally wheat, corn and soybean). From 1984 to 1992, channelization of waterways was implemented to improve soil drainage for crop cultivation along 73% of the 215 km of rivers (OBV Côte-du-Sud/GIRB, 2011). In the Bélair watershed (43 km^2 area; 46°26′N, 70°56′W), agriculture covers 33% of the land, of which annual crops account for about half, i.e. 56% (MAPAQ, unpublished data).

In the study area, crop rotation of dairy farms generally consists in four to five years of hay meadows (harvested each year; 2–3 cuts/year), followed by one or two years of genetically-modified silage corn roundup ready (RR), one year of genetically-modified soybean RR and one year of wheat. For cash crop farms, crop rotation generally corresponds to two to three years of genetically-modified grain corn RR, one year of genetically-modified soybean RR and one year of wheat. Nitrogen fertilization is applied at about 150 kg N/ha in corn, 100 kg N/ha in wheat and 20–160 kg N/ha in hay meadows according to year of production and cover of grasses (CRAAQ, 2010). In corn and hay meadows, N fertilization is fractioned in two or three applications (combination of liquid manure and mineral fertilizers). In corn and soybean, herbicide is sprayed in one or two applications of roundup (glyphosate, a non-selective herbicide). In wheat, an herbicide against broaded-leaf weeds is applied at stage 3–5 leaves of cereals. In hay-meadow, no herbicide is applied, or sometimes a broaded-leave herbicide in the first year. Minimum tillage is often used in cash crop (corn, soybean, wheat) while conventional tillage (with plowing) is generally conducted after hay meadows. Across the study area, pastures were rare as livestock was generally kept indoor farming facilities, and fenced when present to prevent livestock access to riparian zones and rivers.

Between 1995 and 2009, after the provincial government banned agricultural practices in buffer zones at least 3 m wide along streams (Gouvernement du Québec, 1987), trees were planted extensively on the flat edge of agricultural fields in the