Ecological Engineering 106 (2017) 82–93

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Riparian buffer growth and soil nitrate supply are affected by tree species selection and black plastic mulching

Benoit Truax[a,*], Daniel Gagnon[a,b], France Lambert[a], Julien Fortier[a]

[a] Fiducie de recherche sur la forêt des Cantons-de-l'Est/Eastern Townships Forest Research Trust, 1 rue Principale, Saint-Benoît-du-Lac (QC), J0B 2M0, Canada

[b] Department of Biology, University of Regina, 3737 Wascana Parkway, Regina (SK), S4S 0A2, Canada

A R T I C L E I N F O

Article history:
Received 7 February 2017
Received in revised form 18 May 2017
Accepted 22 May 2017
Available online 15 June 2017

Keyword:
Hybrid poplar
Red and bur oak
Red (green) ash
White pine
Riparian forest restoration
Agroforestry

A B S T R A C T

Tree species selection in the design of agricultural riparian buffers is important to optimize particular ecosystem services, while vegetation management (weed treatment) is often critical in obtaining first-rate tree growth and survival. This farm-scale study took place along a 1 km section of a headwater stream in southern Québec (southeastern Canada). Five tree species with contrasted ecological characteristics were planted (*Populus* × *canadensis*, *Fraxinus pennsylvanica, Quercus macrocarpa*, *Quercus rubra* and *Pinus strobus*), with black plastic (polyethylene) mulches as the vegetation management method, as well as a control with no vegetation management, all within a fenced herbaceous riparian buffer. Tree growth and survival were measured along with soil nutrient supply. Significant Species × Vegetation treatment interactions where observed for all growth variables ($p < 0.001$), but also for soil nitrate (NO_3) supply ($p < 0.01$). All species benefited from the plastic mulch treatment, but varied greatly in their responses. After 5 years, mulched hybrid poplar produced 774 times more stem volume than red oak without mulch. Across all species/vegetation treatment combinations, a 13-fold variation in soil NO_3 supply rate was observed during the 4th growing season. Compared to the other species, NO_3 supply rate in hybrid poplar plots was 39–87% lower in the plastic mulch treatment and 48–62% lower in the control treatment. Significantly higher soil NO_3 supply rates were observed beneath the mulches of non nitrophilous species (white pine and red oak). Red oak growth was negatively correlated with NO_3 supply ($R^2 = 0.57$, $p < 0.05$) in the mulch treatment. Early-successional nitrophilous species (hybrid poplar and red ash) planted with the plastic mulch led to the lowest increase in soil NO_3 and the greatest gains in buffer structural attributes (stem volume, diameter and height). Hybrid poplar growth was positively correlated with soil NO_3 supply ($R^2 = 0.86$, $p < 0.001$) in the control treatment. Natural abandoned field/grassland invaders (white pine and bur oak) grew well without black plastic mulch, while the growth of non-mulched red oaks was marginal. In the control treatment, stem volume was a strong negative predictor (across all species) of soil NO_3 supply ($R^2 = 0.91$, $p < 0.05$), indicating that under herbaceous vegetation competition larger trees have a greater ability to reduce soil NO_3. This study provides evidence that particular tree species/vegetation management treatment combinations strongly influence early riparian buffer structural development and soil NO_3 dynamics in agricultural riparian zones.

1. Introduction

Riparian forests are considered keystone landscape components because the value of their ecological and biogeochemical functions, and their biodiversity, are disproportionally high despite the very small area of land they occupy (Décamps et al., 2004; Gregory et al., 1991). However, in many regions of the world, agricultural development has led to major modifications of natural riparian ecotones. Streamside forests have often been cleared to maximize arable land area, which has substantially reduced ecosystem services provided by riparian zones and the streams they protect (Rheinhardt et al., 2012; Sweeney et al., 2004). The important role of riparian ecotones in the management of water quality and biodiversity in agricultural watersheds has led to the recognition of forested riparian buffers as a best management practice (BMP) (Lowrance et al., 1997). Forest vegetation growing in riparian buffers provides

* Corresponding author.
E-mail addresses: btruax@frfce.qc.ca (B. Truax), daniel.gagnon@uregina.ca (D. Gagnon), france.lambert@frfce.qc.ca (F. Lambert), fortier.ju@gmail.com (J. Fortier).

http://dx.doi.org/10.1016/j.ecoleng.2017.05.037

Table 1
Ecological caracteristics of studied tree species.

Common name	Habitat range[a]	Site fertility class	Growth	Shade tolerance	N-form preference	Successional status in optimal habitat	References
Hybrid poplar	Bottomlands, floodplains and riparian corridors	High	Very fast growth	Low	NO_3	Early	(Dickmann and Kuzovkina, 2008; Fortier et al., 2012; Woolfolk, 2000)
Red ash	Bottomlands, floodplains and riparian corridors	High	Fast growth	Low to intermediate	NO_3	Early	(Kennedy, 1990; Truax et al., 1994b)
Bur oak	Bottomlands, riparian corridors and dry calcareous sites	High	Slow growth	Low to intermediate	NO_3/NH_4	Early	(Johnson, 1990; Lambert et al., 1994)
Northern red oak	Various sites ranging from rocky hill top to well-drained valley floors	Low to moderate	Moderate to fast growth	Intermediate	NH_4	Mid	(Beckjord et al., 1980; Crow, 1988; Sander, 1990; Truax et al., 1994b; Walters et al., 2014)
Eastern white pine	All types of sites ranging from rocky hill top to sphagnum peatland	Low to moderate	Moderate to fast growth	Intermediate	NH_4	Mid	(Bauer and Berntson, 2001; Farrar, 2006; Walters et al., 2014; Wendel and Clay Smith, 1990)

[a] Habitat range of hybrid poplar is based on the habitat range of both of its parental species *P. nigra* and *P. deltoides*.

stream shading, structurally reinforces streambanks, removes and stores soil nutrients (particularly nitrogen (N) and phosphorus (P)), captures carbon (C), provides litter inputs that feed the instream food web, while improving farmland habitat and the quality of the ecological network for a variety of animal and plant species (Boutin et al., 2003; Fortier et al., 2015; Jobin et al., 2004; Mander et al., 2005; Meier et al., 2005; Sweeney and Newbold 2014).

To promote the reestablishment of trees along degraded pasture streams, fencing has been recommended as a passive restoration strategy (Opperman and Merenlender, 2000). Yet, the exclusion of herbivores or the removal of cropping activities, applied as a sole BMP, is usually not sufficient to provide favorable conditions for spontaneous tree reestablishment in many agricultural riparian zones. After studying the vegetation of 124 riparian buffers in various agricultural landscapes of southern Québec (Canada), D'Amour (2013) observed little evidence of riparian community development towards a forested ecosystem, even on sites where riparian communities had been protected from agricultural activities for over 50 years. In many cases, proactive restoration or rehabilitation strategies will be required to overcome obstacles that have interrupted the natural successional process (McIver and Starr, 2001). Among these strategies, the planting of native tree species has been widely used in post-agricultural floodplain areas (Keeton 2008; Smaill et al., 2011; Steele et al., 2013; Sweeney et al., 2002). Exotic and native tree planting in riparian buffers of various agricultural systems around the world have also been used to rehabilitate stream and riparian environments, while improving ecosystem service provision on farmland (Fortier et al., 2016; Kelly et al., 2007; Parkyn et al., 2003; Schultz et al., 2004).

According to several authors, the success of riparian afforestation or tree buffer establishment projects often lies in the selection of tree species that are well-adapted to the local environment (Keeton 2008; Smaill et al., 2011; Sweeney et al., 2002). These authors have also found that the use of one or a combination of silvicultural treatments is often critical in obtaining satisfactory levels of initial tree growth and survival. A variety of silvicultural treatments have been recommended to promote tree establishment and growth in riparian zones. These include micro-topography enhancement and soil cultivation (Curtis et al., 2015), the use of individual tree shelters/protectors to reduce cervid browsing and girdling by small mammals (Keeton 2008; Sweeney et al., 2002), stream fencing or exclosures to reduce livestock and cervid browsing (Opperman and Merenlender, 2000), and various treatments for herbaceous vegetation management (Smaill et al., 2011).

However, most riparian afforestation studies have only evaluated the effect of different vegetation management strategies on tree growth and survival, without further investigation of the effects of vegetation management treatments on the soil environment. Short-term studies done in upland hardwood plantations have shown that applying black plastic mulching improves the growth of several tree species by creating a favorable soil environment for resource acquisition (higher soil temperature, moisture content and nitrate (NO_3) availability) (Truax and Gagnon, 1993). However, there is a paucity of data in the literature regarding the longer-term effects of plastic mulch on soil environment and tree growth in the riparian areas of farmlands (Steinmetz et al., 2016).

Agricultural studies have shown that the prolonged use of plastic mulch can result in the over-mineralization of soil organic matter, which can lead to soil NO_3 accumulation if plant requirements are exceeded (Li et al., 2004). This matter requires further examination, as one of the main functions of riparian buffers is to reduce non-point source pollution from excess nutrients in agricultural watersheds. The accumulation of NO_3 in agricultural soils can lead to increased losses of NO_3 to groundwater and aquatic ecosystems (Di and Cameron, 2002), thereby contributing to stream eutrophication and water quality decline (Carpenter et al., 1998). Nitrogen (N) enrichment of streams also increases the rate of leaf litter decay and organic mineralization in streams, which in turn negatively affects the C storage capacity of streams (Rosemond et al., 2015). Thus, there is a need to assess how tree species with different nutritional requirements and growth patterns would take advantage of the microenvironment created by black plastic mulch, and how such species/vegetation management treatment combinations could affect nutrient availability in riparian soils bordering cultivated fields or pastures. Recent findings suggest that riparian vegetation cover type (fast-growing trees vs. herbaceous vegetation) influences NO_3 availability or supply rate in riparian buffer soils (Fortier et al., 2015). Different tree species have also been found to have contrasted effects on soil N-status following their establishment in abandoned field/grassland ecosystems (Laungani and Knops, 2009). However, there is little information available on tree/soil interactions for species with contrasted ecological characteristics, planted with and without a vegetation management treatment, in agricultural riparian buffers.