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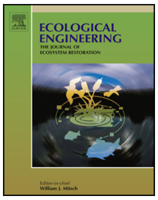

Riparian buffer growth and soil nitrate supply are affected by tree species selection and black plastic mulching

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

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ABSTRACT

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

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* 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).

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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.

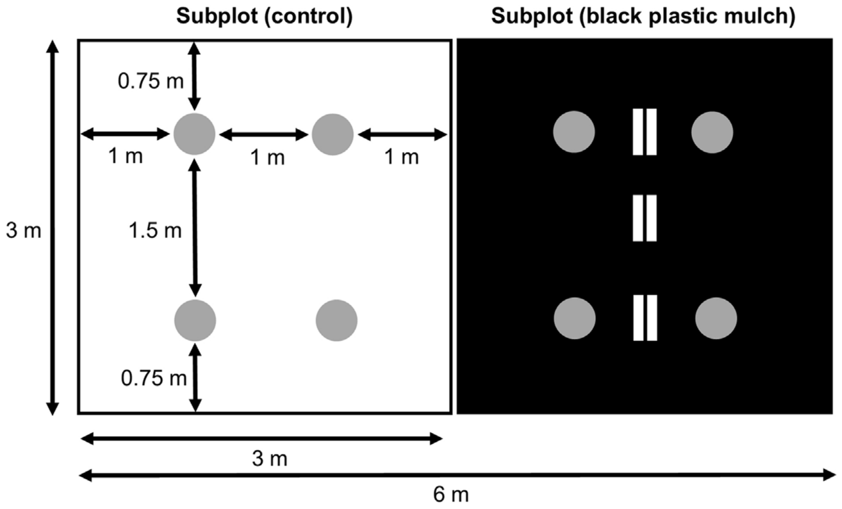

Fig. 1. Schematic representation of a main plot for a single tree species (6 m long parallel to the stream × 3 m wide). The main plot is subdivided into two subplots (3 × 3 m each), one with no vegetation management (control) and one with a vegetation management treatment (black plastic mulch). Each subplot contains 4 trees represented by grey circles. The size of the black plastic mulch is identical to the size of the subplot (3 × 3 m). PRS-probes placement for nutrient supply rate measurements within a subplot is indicated (white rectangles; position identical in both subplots).

This farm-scale study took place along a 1 km section of a headwater stream bordering a low fertility pasture site in southern Québec (southeastern Canada). Different tree species with contrasted ecological characteristics (hybrid poplar, red (green) ash, bur oak, red oak, white pine) were planted in a recently fenced riparian zone dominated by herbaceous species. The first objective of this study was to evaluate the effects of tree species selection and the use of wide strips of black plastic mulch on tree growth and survival. The second objective was to measure the combined effect of the tree species and vegetation management treatment (plastic mulch vs. no treatment) on soil nutrient supply in the buffer zone during the growing season. Considering that N is often the most growth limiting nutrient in temperate ecosystems (Vitousek and Howarth, 1991) and that tree species have different juvenile growth patterns, N-requirements and N-source preferences (Walters et al., 2014), we hypothesized that the prolonged use of plastic mulch in a riparian buffer would produce species-specific growth responses and feedbacks on soil NO_3 supply.

2. Materials and methods

2.1. Study site description

The study took place at the Lamontagne farm (45°14′31.75″ N; 72°08′02.44″ W) located in the municipality of Magog in the Estrie administrative region of southern Québec (southeastern Canada). The study area is located just north of the Vermont (USA) border. It belongs to the sugar maple – basswood ecoregion, which is part of the broader northern hardwoods forest ecosystem (Robitaille and Saucier, 1998; Westveld, 1956). The studied riparian buffer was established in spring 2010 along Boily creek, draining into the Magog River, and further down into the St. François River. During summer, Boily creek has a mean width of 2.1–2.4 m and a mean depth of 0.20 m (Simavi, 2012). Although this creek has been subjected to channel reconfiguration and streambank deforestation at the study site (J. Lamontagne, personal comm.), water quality is very good and many clean and cold water fish species (including brown, rainbow and brook trout) are found in this headwater stream habitat (Simavi, 2012). At the study site, the agricultural land use that borders Boily creek is a relatively poor and non-fertilized pasture supporting a low cattle density of 0.2 cow/ha (J. Lamontagne, personal comm.). Gentle slopes characterize site topography, which is representative of most pasture or hayfield sites located in the hilly landscape unit of Sherbrooke (Robitaille and Saucier, 1998). The regional climate is a continental subhumid moderate climate, with a mean annual precipitation of 1000–1100 mm and a growing season of 180–190 days (Robitaille and Saucier, 1998). Mean annual temperature at nearby Magog is 5.3 °C.

2.2. Experimental design

In May 2010, a tree riparian buffer was established along a 1 km reach of Boily stream. The riparian zone had been fenced during summer 2009 prior to buffer establishment in order to prevent livestock browsing. This riparian zone was dominated by herbaceous vegetation, mostly pasture grasses and other ruderal species, both introduced (exotic) and native, including many agricultural weeds (Fortier et al., 2011). Two vegetation management treatments (black plastic mulch and no vegetation management (control)) and five tree species were used in the experimental design. The tree species were selected for their contrasted growth traits and ecological characteristics: (1) a hybrid poplar (*P. × canadensis* Moench clone D × N-3570), resulting from the cross between two riparian poplar species, *Populus deltoides* (native) and *P. nigra* (Eurasian-African); (2) red ash (*Fraxinus pennsylvanica* Marsh.), also named green ash, a native bottomland species; (3) bur oak (*Quercus macrocarpa* Michx.), a native bottomland species; (4) red oak (*Quercus rubra* L.), a native upland species and (5) white pine (*Pinus strobus* L.), an ubiquitous native species. Characteristics of planted species are presented in Table 1.

A split-plot factorial design integrated into a randomized block design was established. A total of 8 blocks, each containing 5 main plots (one main plot for each tree species) was established along the farm stream, for a total of 40 main plots. Each main plot was subdivided into 2 subplots, one for each of the two vegetation management treatments, for a total of 80 subplots. The two vegetation management treatments tested were black plastic mulch and no vegetation management (control). Main plot factors (tree species) were assigned randomly within each block, as was also the case of each subplot factors (vegetation management treatments) within each main plot.

Each block is 30 m long (parallel to the stream) by 3 m wide (perpendicular to the streambank). Each main plot is 6 m long (parallel

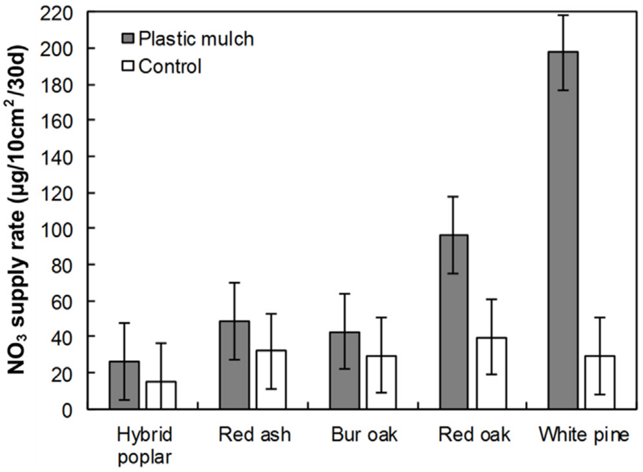

Fig. 2. Species x Weed treatment interaction for soil NO_3 supply rate ($p < 0.01$) measured during 30 days (June 25 to July 25, 2013) during the 4th growing season in an agricultural riparian buffer. Vertical bars represent standard errors (SE).

to the streambank) by 3 m wide (18 m^2/main plot). Each main plot is subdivided into two 3 m × 3 m (9 m^2) subplots (one per vegetation management treatment). In the black plastic mulch treatment, the area covered by the black plastic mulch is identical to the size of the subplot (3 m × 3 m = 9 m^2). In each main plot, 8 trees from a single species were planted (4 trees in the plastic mulch treatment subplot and 4 trees in the control treatment subplot). In the black plastic mulch treatment subplots, each tree benefits from 2.25 m^2 of mulch area (or 4 trees/9 m^2 of mulch area). A schematic representation of a main plot (for a single tree species) is provided in Fig. 1, as well as the spacing used between planted trees. The whole experimental design contained 80 subplots × 4 trees/subplot for a total of 320 trees (64 trees per species). In all, the studied riparian buffer consists of two rows of trees on each streambank, with a 1.5 m spacing between the two rows planted parallel to the streambank.

The 8 blocks of the experimental design were not spatially contiguous across the 1 km length of the stream. However, in between blocks, buffer zones were planted in order to create a continuous linear tree structure along the streambanks, thereby reducing edge effects on trees in plots located at the ends of blocks. These buffer zones contained the same tree species that were positioned in the first and last main plots in a block. Long strips of black plastic mulch (1.5 m wide) were used to increase tree survival and growth in the buffer zones planted between blocks. Topographically, all blocks were placed on the more homogeneous soil sections of the fenced riparian zone, and poorly drained areas were avoided. All trees planted within the experimental design were located outside of the bankfull stage (above the top of the streambank, on the talus), but inside the floodplain zone. On the streamside along all blocks, one row of hybrid willows (*Salix* × spp.) was planted outside the experimental design, directly adjacent to the stream, between the top and the toe of the streambank (in the active stream channel zone). These willows were planted to provide additional streambank stabilization, but also to create an overhanging canopy structure above the stream channel, which enhances stream shading, and provides allochthonous inputs of organic matter and terrestrial insect preys (Baxter et al., 2005; Lyons et al., 2000; Wallace et al., 1997).

In late summer of the year prior to tree planting (2009), the black plastic mulch squares (0.06 mm thick) were installed manually directly on top of the flattened herbaceous vegetation (no weed removal or soil cultivation prior to mulch installation). Two 1.5 m wide × 3 m long mulch strips were juxtaposed in order to cover the whole area of the subplot (3 m × 3 m). Plastic mulch was pinned down with large wooden pegs, and rocks found in the stream zone were also used to maintain the mulch close to soil surface when necessary. The plastic mulch rolls were purchased from Dubois Agrinovation Inc. (Napierville, QC). In May 2010, all trees were planted manually with a shovel, through a slit in the plastic (reclosed and pinned by wooden pegs). The following type of seedlings were used for each tree species: (1) one-year-old bare root stock for hybrid poplar (1-0), two-year-old bare root seedlings for red ash and bur oak (2-0), one year-old container seedlings for red oak (1-0) and two-year-old container seedlings for white pine (2-0). All tree seedlings were provided by the Berthier nursery (Sainte-Geneviève-de-Berthier, QC) of the Ministère des Forêts, de la Faune et des Parcs (MFFP) of Québec.

2.3. Soil characteristics

The soil at the study site has developed on a thick glacial till deposit and it belongs to the «Magog stony loam» soil series, which is characterized by a relatively high stone content and an imperfect drainage (Cann and Lajoie, 1943). Soil characteristics (0–20 cm) were determined at the main plot level (n = 40) during summer 2009, one year prior to tree planting. In each main plot, a composite soil sample was collected to a 20 cm depth. Soil samples were air dried and sieved (2 mm). Soil pH, organic matter content, available P, K, Ca and Mg content, cation exchange capacity (CEC) and base saturation were determined by the Agridirect Inc. soil analysis lab in Longueuil (Québec). Methods used are those recommended by the Conseil des productions végétales du Québec (1988). The determination of soil pH was made using a 1:1 ratio of distilled water to soil. Percent organic matter was determined by weight loss after ignition at 550 °C for 4 h. Available P, K, Ca and Mg concentrations were determined following extraction with the Mehlich III method (Tran and Simard, 1993) and by using ICP emission spectroscopy (AOAC, 1999). Cation exchange capacity and base saturation were calculated following the recommendations of the Centre de référence en agriculture et agroalimentaire du Québec (CRAAQ, 2003). At the study site, riparian soil characteristics were the following (± standard deviation): pH = 5.6 (±0.3); percent organic matter = 4.4 (±1.2); P = 43.6 (±35.7) kg/ha; K = 95.1 (±47.1) kg/ha; Ca = 1521 (±429) kg/ha; Mg = 851 (±179) kg/ha; CEC = 14 (±2.0) meq/100 g; percent base saturation = 48.2 (±8.2) %. Soil temperature (0–10 cm) was measured in each subplot (n = 80) between 10h00 and 14h00 on June 11, 2012 (3rd growing season) and on July 26, 2013 (4th growing season). In each subplot, temperature measurements were taken at a single point at the center of the four planted trees.

2.4. Soil nutrient supply measurements

Nutrient (NO_3, NH_4, P, Ca, Mg) supply rates in the entire experimental design were determined using Plant Root Simulator (PRS^{TM}-Probes) technology from Western Ag Innovations Inc. (Saskatoon, Canada). The PRS-probes consist of ion exchange membranes encapsulated in thin plastic probes, which were inserted vertically in the surface soil (0–10 cm) with little disturbance of soil structure. The membrane surface exhibits surface and sorption characteristics similar to those of a plant root. Nutrient supply rates measured with this method are overall strongly correlated with conventional soil extraction methods over a wide range of soil types (Qian et al., 1992), including agricultural buffer soils of the study area (Fortier et al., 2013). On June 25, 2013 (4th growing season), three pairs of probes (an anion and a cation probe in each pair) were buried in the A horizon of each subplot (n = 80) for a 30-day period. Probe placement within a single subplot is indicated in Fig. 1. After probes were removed from the soil, they were washed in the field with distilled water, and returned to Western Ag Labs for analysis. Composite samples were made in each sub-

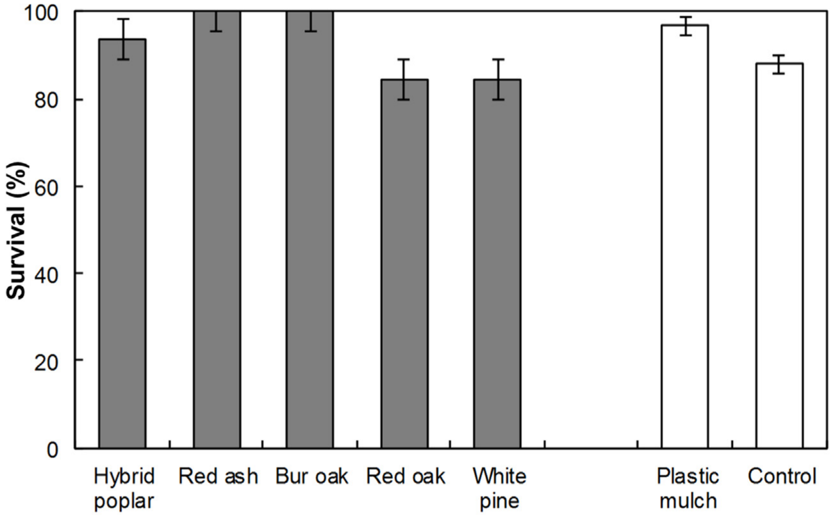

Fig. 3. Species ($p < 0.05$) and weed treatment ($p < 0.01$) effects on tree survival after 5 years in an agricultural riparian buffer. Vertical bars represent standard errors (SE).

Table 2
Nitrate supply rate ratios between the two different vegetation treatments and between the most productive tree species (hybrid poplar) and the other tree species for the two different vegetation treatments. Nitrate supply rates were measured during 30 days of the 4th growing season (June 25 to July 25, 2013).

Species	Soil NO_3 ratios between vegetation treatments (plastic mulch/control)	Soil NO_3 ratios between tree species (hybrid poplar/native trees)	Plastic mulch	Control
H. poplar	1.7	H. poplar/Red ash	0.54	0.47
Red ash	1.5	H. poplar/Bur oak	0.61	0.52
Bur oak	1.5	H. poplar/Red oak	0.27	0.38
Red oak	2.4	H. poplar/W. pine	0.13	0.52
W. pine	6.8			

plot by combining the three pairs of probes. Probe supply rates are reported as μg of nutrient per 10 cm^2 per 30 days.

2.5. Growth and survival measurements

At the end of the 4th and 5th growing seasons (in late October 2013 and 2014), survival, total height, basal diameter and, when possible, diameter at breast height (DBH at 1.3 m) were measured for each of 320 trees, with a digital caliper (mean of two diameter measurements taken perpendicularly). Stem volume outside the bark was then calculated for two tree categories, those having no DBH and those having a DBH value. For trees with no DBH, the simple cone volume formula was used (West, 2009):

$$V = \pi D_B{}^2 H/12 \tag{1}$$

where V is the stem volume (cm^3), D_B is the basal diameter (cm) and H is the tree height (cm). For trees with a DBH value, the stem volume was measured by summing the volume of two stem sections (1) from basal diameter to DBH and (2) from DBH to tree tip. For stem section 2, Eq. (1) was used, but D_B was replaced by a DBH value and H was replaced by the height of the stem section from DBH to the tree tip. For stem section 1, the following formula was used (Perron, 1996):

$$V = \pi/12(D_1{}^2 + D_2{}^2 + D_1 D_2)L \tag{2}$$

where, V is the volume (cm^3) of a stem section, D_1 is the base diameter (cm) of the stem section, D_2 is the diameter (cm) at the top of the stem section, and L is the length (or height) of the stem section. Thus, the volume of stem section 1 was measured by replacing D_1 by a basal diameter value, D_2 by a DBH value and L by 130 cm in Eq. (2).

At the plot level, a relative growth rate (RGR) value (Hunt, 1990) was calculated for stem volume for the 0–5 year time period:

$$RGR = (\ln V_2 - \ln V_1)/(t_2 - t_1) \tag{3}$$

where, V_1 was tree volume (cm^3) just after planting ($t_1 = 0$ years) and V_2 was tree volume (cm^3) at the end of 5th growing season ($t_2 = 5$ years). Although we did not measure tree volume (just after planting), we used average height and basal diameter data for each tree species provided by the planting stock producer (Berthier nursery) to calculate an initial stem volume using Eq. (1). Initial planting stock height (H), basal diameter (D) and volume (V) were the followings: hybrid poplar (H = 148 cm, D = 11.4 mm, V = 50.4 cm^3), red ash (H = 97.8 cm, D = 13.6 mm, V = 47.4 cm^3), bur oak (H = 43.7 cm, D = 9.5 mm, V = 10.3 cm^3), red oak (H = 46 cm, D = 5.6 mm, V = 3.8 cm^3) and white pine (H = 20.2 cm, D = 5.1 mm, V = 1.4 cm^3).

2.6. Statistical analyses

Main plot factor (Tree species) and subplot factor (Vegetation management treatments) effects on measured variables were analyzed using ANOVA in a fixed factorial design. ANOVA tables were constructed in accordance with Petersen (1985), where degrees of freedom, sum of squares, mean squares and F-values were computed. When a main effect (Species or Vegetation treatment) or an interaction effect (Species × Vegetation treatment) was declared statistically significant, the standard error of the mean (SE) was used to measure differences between means for three levels of significance ($^*p < 0.05$, $^{**}p < 0.01$ and $^{***}p < 0.001$). All of the ANOVAs were run with the complete set of data (5 species × 2 vegetation treatments × 8 blocks = 80 experimental subplots). Only growth and survival data measured after 5 years were analyzed with the

Table 3
Stem volume production ratios after 5 years between the two different vegetation treatments and between the most productive tree species (hybrid poplar) and the native tree species for the two different vegetation treatments. Stem volume ratio between species at planting is also indicated.

Species	Stem volume ratio between vegetation treatments after 5 yrs (plastic mulch/control)	Stem volume ratio between tree species (hybrid poplar/native trees)	At planting	Plastic mulch (after 5 yrs)	Control (after 5 yrs)
H. poplar	5.0	H. poplar/Red ash	1.1	5.2	4.4
Red ash	4.2	H. poplar/Bur oak	4.9	15.6	9.8
Bur oak	3.1	H. poplar/Red oak	13.3	40.4	155.9
Red oak	19.1	H. poplar/W. pine	36.6	19.9	8.6
W. pine	2.1				

ANOVA and are presented in the results. Being proportions, survival data were logit transformed prior to ANOVA (Warton and Hui, 2011), but survival rate results are reported in percent values. Pairwise correlations were used to identify potential correlations between soil nutrient supply rate (NO_3, NH_4, P, Ca, K and Mg) and stem volume growth. Thereafter, regressions were developed between key soil variables and volume growth. Given that soil nutrient supply rate data had been collected during the 4th growing season relationships between nutrient supply rates and stem volume were developed using volume calculated from diameter and height measurements after 4 years. All statistical analyses were done using JMP 11 from SAS Institute (Cary, NC).

3. Results

3.1. Species and vegetation treatment effects on soil temperature

A highly significant Vegetation treatment effect ($p < 0.001$) was obtained for soil temperature measurements made during the 3rd and 4th growing seasons. During the 3rd growing season, soil temperature reached 23.1 ± 0.2 °C in the plastic mulch treatment and 16 ± 0.2 °C in the control treatment, while a smaller difference in soil temperature was observed between mulched trees and trees from control plots during the 4th growing season (19.4 ± 0.1 °C vs 17.2 ± 0.1 °C).

3.2. Species × Vegetation treatment interaction on nitrate supply rate

Given that there was no significant Species or Vegetation treatment effects or interaction effect on the supply of NH_4, P, Ca and Mg, only NO_3 supply rate results are presented.

A significant Species × Vegetation treatment interaction ($p < 0.01$) was observed on soil NO_3 supply rate measured during 30 summer days of the 4th growing season (Fig. 2). Overall, the combination of white pine and plastic mulch resulted in the highest soil NO_3 supply rate, followed by the combination of red oak and plastic mulch. Among all the other species/vegetation treatment combinations, the soil NO_3 supply rate was not statistically different and was always lower than the NO_3 supply rate observed in white pine and red oak soil covered by plastic mulch. Across the five species, NO_3 supply rate was far less variable in the subplots with no vegetation removal treatment (control), compared to subplots were the mulch was used. In the control treatment, NO_3 supply rate ranged 15.2-39.6 $\mu g/10\,cm^2/30$ days across the five species, being the lowest for hybrid poplar and the highest for red oak. In the plastic mulch treatment, NO_3 supply rate ranged 26.2-197.6 $\mu g/10\,cm^2/30$ days, being the lowest for hybrid poplar and the highest for white pine. Across all species/vegetation treatment combinations, the largest soil NO_3 supply difference was observed between white pine in plastic mulch and hybrid poplar in the control treatment (a 13-fold increase in soil NO_3 supply rate) (Fig. 2). For each tree species studied, NO_3 supply rate was always higher in the soil under plastic mulch. At the species level, a very wide range in soil NO_3 supply rate differences between the mulch and the control treatment was observed across the experimental design, with the largest differences observed for white pine followed by red oak (Fig. 2). Nitrate supply rate ratios between plastic mulch and the control treatment were similar for hybrid poplar (1.7), red ash (1.5) and bur oak (1.5). However, a ratio of 2.4 and of up to 6.8 was observed for red oak and white pine, respectively (Table 2). In the control treatment, an especially large range of soil NO_3 ratios between pairs of species was also observed when hybrid poplar was compared to the native species (Table 2). In the plastic mulch treatment, soil NO_3 supply rate was found to be 87%, 73%, 39% and 46% lower under hybrid poplar than under white pine, red oak, bur oak and red ash, respectively. However, in the control treatment, NO_3 supply rate in hybrid poplar subplots was 48–62% lower than in subplots of native species.

3.3. Species and vegetation treatment effects on survival

Vegetation treatment had a significant effect on survival ($p < 0.01$), with trees growing with plastic mulch having a higher survival rate (96.9%) than trees growing in the control treatment (88.1%) (Fig. 3). A weaker, but significant, Species effect ($p < 0.05$) was observed on survival, with red oak and white pine having lower survival rates than the three other tree species (Fig. 3). For the five species, survival was relatively high after 5 years, averaging between 84.4% and 100% across both vegetation treatments.

3.4. Species × Vegetation treatment interaction on growth variables after 5 years

Highly significant Species × Vegetation treatment interactions ($p < 0.001$) were observed after 5 years for total height, basal diameter, stem volume and RGR (on a stem volume basis) (Figs. 4 and 5). All species responded positively to the plastic mulch treatment (Fig. 4). However, this positive response varied considerably in magnitude from species to species. Species-level volume production ratios between the plastic mulch treatment and the control treatment illustrate these variations (Table 3). Proportionally, red oak was the species that had the strongest positive response to the plastic mulch treatment, with a 19.1 times larger volume production than in the control treatment, while white pine showed the weakest response with a 2.1 times larger volume production in the mulch treatment compared to the control (Fig. 4 and Table 3). The positive height response of white pine to the plastic mulch treatment was especially weak, and not significant, with a mean tree height of 225 cm in the plastic mulch and of 194 cm in the control (SE ± 16 cm). This trend contrasted with white pine's diameter growth, which was far superior in the plastic mulch treatment (72.3 ± 3.4 mm) than in the control (48.7 ± 3.4 mm).

Across the whole experiment, the highest height, diameter and volume growth was observed for hybrid poplar in the plastic mulch treatment, while the lowest height and diameter growth was observed for red oak in the control treatment. Consequently, the use of hybrid poplar in combination with plastic mulch results

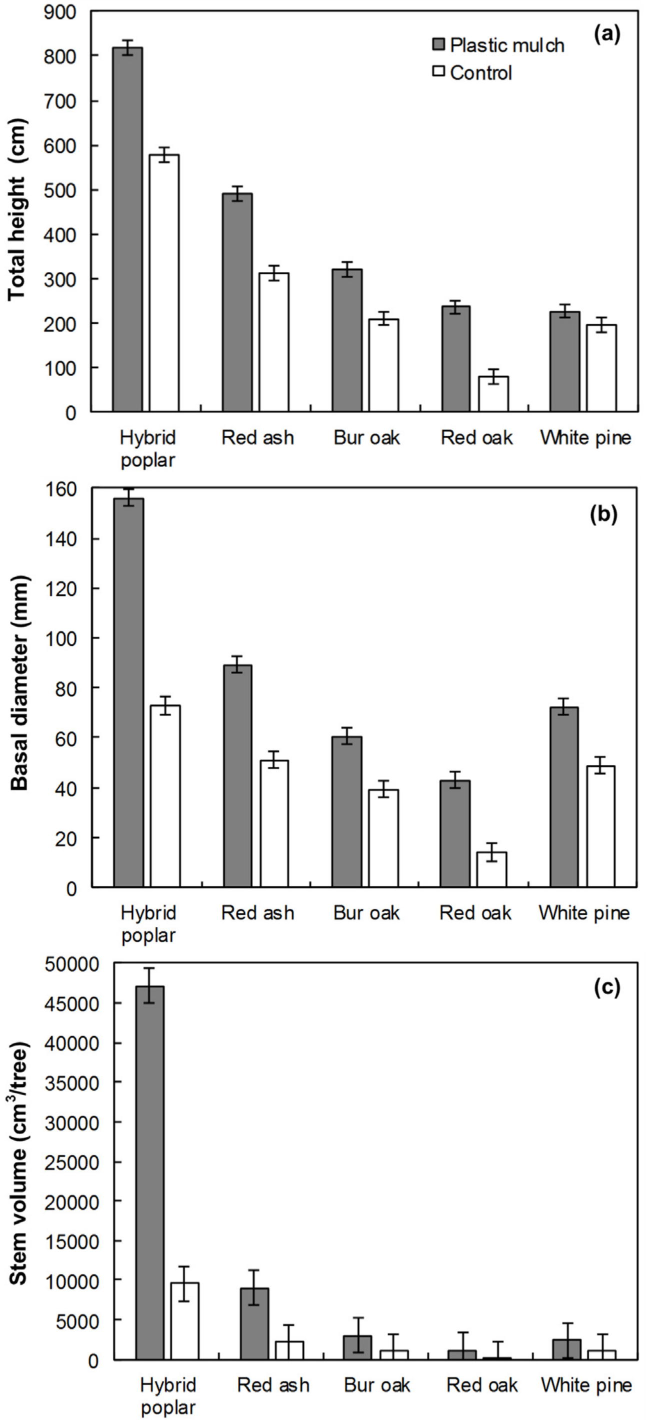

Fig. 4. Species × Weed treatment interactions for (a) total height ($p < 0.001$), (b) basal diameter ($p < 0.001$) and (c) mean stem volume ($p < 0.001$) after 5 years in an agricultural riparian buffer. Vertical bars represent standard errors (SE).

in a stem volume production that was 774 times higher than for red oak planted without the mulch (Fig. 4). The total height of hybrid poplar in the control treatment was also higher than for any other species in both control and plastic mulch treatments. Compared to the four native species, hybrid poplar produced between 5.2–40.4 times more stem volume in the plastic mulch treatment, and between 4.4–155.9 times more stem volume in the control treatment (Table 3). However, in terms of stem volume RGR, white pine growing in the plastic mulch treatment had the highest values across the experimental design, with 1.47 $cm^3/cm^3/yr$ (Fig. 5). Hybrid poplar in the mulch treatment and white pine in the control treatment ranked second for RGR, with 1.34 $cm^3/cm^3/yr$ and 1.31 $cm^3/cm^3/yr$ (SE ± 0.04 $cm^3/cm^3/yr$), respectively. Low RGR values where observed in the control treatment for red ash (0.71 $cm^3/cm^3/yr$) and red oak (0.46 $cm^3/cm^3/yr$).

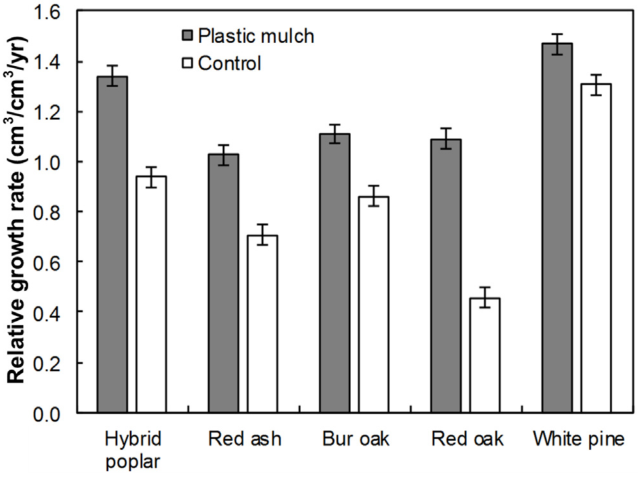

Fig. 5. Species × Weed treatment interaction ($p < 0.001$) for the relative growth rate (on a stem volume basis) observed after 5 growing seasons in an agricultural riparian buffer. Vertical bars represent standard errors (SE).

3.5. *Relationships between soil nitrate and tree volume growth*

At the species-level, a highly significant and strong positive logarithmic relationship was observed between NO_3 supply rate and hybrid poplar volume growth for trees growing without the plastic mulch treatment ($R^2 = 0.86$, $p < 0.001$) (Fig. 6). In the plastic mulch treatment, a negative relationship was observed between NO_3 supply rate and red oak volume growth ($R^2 = 0.57$, $p < 0.05$) (Fig. 6). Using mean values for each of the 5 species in the control treatment across the 8 blocks, a very strong negative relationship was observed between volume growth and soil NO_3 supply rate ($R^2 = 0.91$, $p < 0.05$) (Fig. 7). A weak negative relationship was equally observed between these two variables in the plastic mulch treatment ($R^2 = 0.63$, $p = 0.11$) (Fig. 7).

4. Discussion

4.1. *Black plastic mulch produces species-specific growth responses and feedbacks on soil NO_3*

In this study, all five species took advantage of the favorable nutritional environment (warmer soil and increased NO_3 availability) created by the large plastic mulch area (3 m × 3 m per 4 trees) (Figs. 2 and 4). However, as shown by the significant Species × Vegetation treatment interactions observed on growth variables and soil NO_3 supply, the magnitude of growth increase due to the plastic mulch treatment was very different from species to species (2.1–19.1-fold increase in volume after 5 years) (Table 3 and Fig. 4), as was the case for the magnitude of NO_3 supply rate increase (1.5–6.8-fold increase during the 4th growing season) (Table 2, Fig. 2). To illustrate these species-level changes in growth and soil NO_3 supply rate resulting from the plastic mulch treatment, a bivariate plot with vectors indicating the direction and magnitude of such changes is provided in Fig. 8. The contrasted ecological characteristics, growth traits and N-form preference between the studied species (Table 1) can partly explain the vectors shown in Fig. 8. Our hypothesis proposing that the prolonged use of plastic mulch to establish riparian buffers will produce species-specific

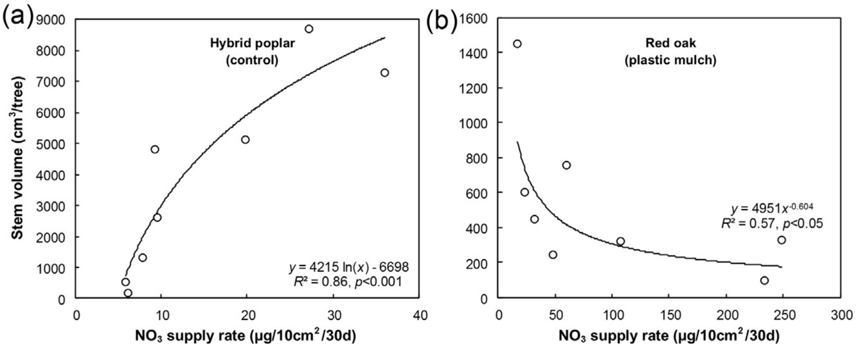

Fig. 6. Relationship between NO_3 supply rates measured during 30 days of the 4th growing season (June 25 to July 25) and stem volume measured at the end of the 4th growing season in an agricultural riparian buffer.

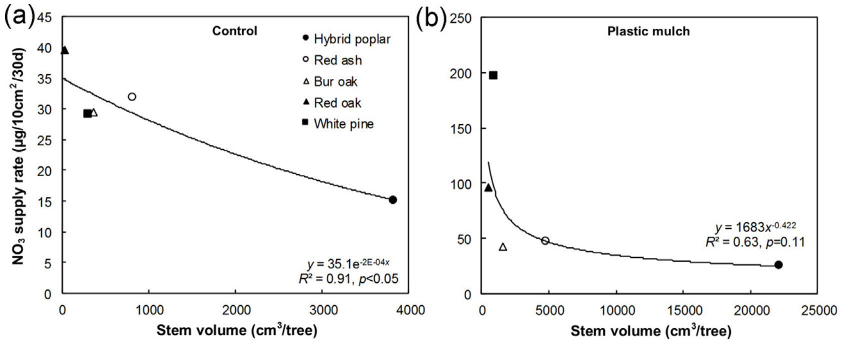

Fig. 7. Negative relationship between mean stem volume of the five tree species and mean NO_3 supply rates measured during 30 days (June 25–July 25) in an agricultural riparian buffer. NO_3 supply rate was measured during the 4th growing season and stem volume at the end of the 4th growing season. Each data point is the mean value of 8 subplots.

growth responses and feedbacks on soil N-status is also supported by Fig. 8. Such interactions between tree species, vegetation management treatment and soil NO_3 status should be fully considered when designing and establishing riparian buffers (see Section 4.2).

For *Pinus strobus*, the plastic mulch treatment resulted in the largest increase in soil NO_3 supply (from 29.2 to 197.6 μg/10 cm²/30 days, a 6.8-fold increase), but also the smallest volume growth gain (Figs. 2, 4 and 8). This highlights the limited capacity of white pine to take advantage of soil NO_3 enrichment during its establishment phase, reflecting its low nutritional requirements to achieve optimal growth (Wendel and Clay Smith, 1990), but also its much higher affinity for NH_4 uptake than for NO_3 uptake (Bauer and Berntson 2001; Walters et al., 2014). Thus, the observed accumulation of soil NO_3 in mulched white pines probably reflects the fact that N-requirements where largely exceeded for this species. High and repeated N fertilization doses (150 kg N/ha/yr) had been previously linked to high N leaching loss in mature *Pinus* stands, but not in nearby hardwood stands (Aber et al., 1993). Additionally, white pine was the only species to have a similar height growth in both vegetation management treatments (Fig. 4a), suggesting that the more favorable soil conditions created by the mulch did not translate into significantly higher juvenile height growth in an open habitat. Such a trend could explain why white pine is generally outcompeted by broadleaved species in nutrient rich environments (Wendel and Clay Smith, 1990), with the height growth of all broadleaved species studied strongly benefiting from the plastic mulch treatment (Fig. 4a). Still, white pine has a clear advantage over hardwoods for the invasion of N limited ecosystems, such as abandoned fields/grasslands, as it more efficiently retains assimilated N by increasing N residence time in its biomass, thereby minimizing plant N losses (Laungani and Knops, 2009). Such a N-use strategy could explain the especially high RGR of white pine under strong herbaceous competition in the control treatment (Fig. 5).

For *Quercus rubra*, the use of the plastic mulch resulted in a pattern that is similar to the one observed for white pine, with a small growth gain (in absolute growth) and a large increase in soil NO_3 (Figs. 2, 4 and 8). Indeed, white pine and red oak have similar ecological characteristics and often share the same forest habitats, with the exceptions that white pine tolerates poorly drained soils and herbaceous competition, and that red oak does not (Crow 1988; Gauthier and Gagnon 1990; Sander 1990; Truax et al., 2000; Walters et al., 2014; Wendel and Clay Smith 1990). The low tolerance of red oak to herbaceous competition was confirmed in this study as this species had the lowest growth (Figs. 4 and 5) and survival rate (72%, data not shown) in the control treatment after 5 years. This negative effect of competition from herbaceous vegetation could have been exacerbated by the lack of a diverse community of ectomycorrhizal fungi, which has been observed in red oak planted outside forest ecosystems (Karpati et al., 2011). Though red oak produced 19.1 times more stem volume in the mulch treatment than in the control (Table 3), red oak growth was still relatively poor in the mulch treatment (Fig. 4). This poor growth, combined with the higher capacity for NH_4 than for NO_3 uptake (Beckjord et al., 1980; Truax et al., 1994b), could explain the high NO_3 supply in the soil under the mulched red oak (Fig. 2). Relatively low nitrate reductase activity (NRA) in root and leaf tissues of red oak seedlings, compared to red ash (Truax et al., 1994a, 1994b), also suggest that red oak has physiological limitations to respond to high soil NO_3 availability. The negative relationship ($R^2 = 0.57$, $p < 0.05$) observed between soil NO_3 supply rate and volume growth of red oak in the mulch treatment supports this hypothesis (Fig. 6). Thus, it is not surprising that optimal growth conditions of planted red oaks were previously found on abandoned farmland soils with

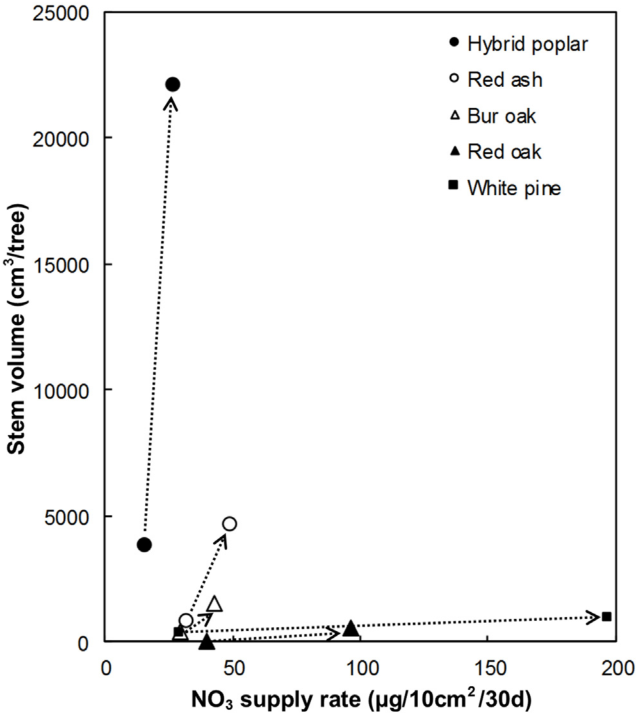

Fig. 8. Bivariate plot with vectors indicating, for each tree species, the direction and magnitude of change in soil NO_3 supply rate and stem volume caused by the plastic mulch weed treatment in a 4 year-old riparian buffer. Each data point is the mean value of 8 subplots. The origin of all vectors is the control treatment.

the lowest pH and NO_3 content (Cogliastro et al., 1997) and on forest soils with the highest NH_4 content (Walters et al., 2014).

For *Populus* × *canadensis*, the plastic mulch treatment resulted in the smallest increase in the soil NO_3 supply rate and the highest growth increase among all species (Fig. 8), suggesting that most of the soil NO_3 enrichment created by the plastic mulch treatment was assimilated to sustain high aboveground biomass growth. The large NO_3 uptake by fast-growing hybrid poplars is the most likely explanation for measuring the lowest NO_3 supply rates in soils under hybrid poplar in both vegetation management treatments (Fig. 2, Table 2). Greenhouse studies and field trials in riparian buffers involving hybrid poplars have shown that increasing soil N availability results in a high and rapid allocation of biomass and assimilated N to aboveground tissues in order to increase photosynthetic capacity (Cooke et al., 2005; Fortier et al., 2010a, 2010b). In the control treatment, we equally observed a strong positive relationship between soil NO_3 supply rate and volume growth ($R^2 = 0.86$, $p < 0.001$) (Fig. 6), suggesting that in a more competitive environment for resource uptake hybrid poplar takes great advantage of NO_3-rich soil patches. Such a response would be consistent with the fact that the studied hybrid poplar genotype (clone D × N-3570) has a particularly high capacity for NO_3 assimilation, as revealed by the positive correlation between soil NO_3 availability and leaf NRA previously observed across two riparian buffers near the study area (Fortier et al., 2012). Results from this study are also in agreement with a restoration study done in Missouri (USA) showing that riparian poplar species grow much faster than oaks and ashes, when planted in post-agricultural floodplain habitats (Steele et al., 2013).

Fraxinus pennsylvanica, alike the parental species of the hybrid poplar clone (*P. deltoides* and *P. nigra*), is an early-successional tree species typical of rich bottomlands and riparian areas (Table 1). For this species, the plastic mulch treatment resulted in the second highest stem volume gain and a small increase in soil NO_3 (Figs. 2, 4 and 8). The strong growth response of this species in the mulch treatment resulted in a 4.2-fold increase in stem volume after 5 years (Table 3, Fig. 4). This suggests that soil NO_3 enrichment created by the mulch resulted in high NO_3 uptake and high allocation to aboveground biomass, which is consistent with the fast-growth and high capacity for NO_3 uptake of this native species (Kennedy, 1990; Truax et al., 1994b). Previous plantation trials on abandoned farmland of the study area also showed that red ash growth strongly responds to weed management (Truax et al., 1994a), and to nutrient rich and moist soils (Cogliastro et al., 1997).

For *Quercus macrocarpa*, the use of the plastic mulch treatment resulted in a relatively small increase in soil NO_3 and an intermediate growth response, with a lower growth gain than fast-growing nitrophilous species (hybrid poplar and red ash), but a higher growth gain than species having a preference for NH_4 uptake (white pine and red oak) (Table 1, Figs. 2, 4 and 8). Such a result can be explained by the relatively conservative early growth pattern of bur oak, even in optimal habitats (Truax et al. 2000), but its relatively good capacity for NO_3 assimilation when this N-source becomes increasingly available in field plantations (Lambert et al., 1994). Bur oak's good growth and absence of mortality in the control treatment (Figs. 3 and 4) are also indications of the tolerance of this species to herbaceous competition (Lambert et al., 1994). Bur oak has also the ability to form symbiotic associations with ectomycorrhiza already present in perennial grass species (Dickie et al., 2004), thereby facilitating its establishment under strong herbaceous competition. In addition, at the seedling stage, bur oak rapidly forms a deep taproot and allocates a large proportion of its biomass belowground, which enhance its competitive ability against shallow rooted herbaceous vegetation (Danner and Knapp, 2001). However, bur oak's lower RGR than white pine in the control plot (Fig. 5) may indicate a less efficient N-use strategy (shorter N residence time in biomass) during its establishment phase in N-limited herbaceous-dominated ecosystems (Laungani and Knops, 2009).

Despite the contrasted ecological characteristics of the studied species, we observed that overall there was a strong negative relationship between stem volume growth and NO_3 supply rate in the presence of dense herbaceous competition ($R^2 = 0.91$, $p < 0.05$) (Fig. 7). This suggests that when planted in riparian environments dominated by herbaceous competitors, the tree species developing the largest aboveground structure will be responsible for the largest reduction in riparian soil NO_3 supply rate. However, the shape, the strength and significance of such a relationship is significantly altered in the plastic mulch treatment (Fig. 7), reflecting the contrasted species-level growth response and plant-soil feedback on the N cycle caused by the plastic mulch treatment.

4.2. Management considerations for agricultural riparian buffers

The evaluation of specific plant species or genotypes for optimizing particular functions or ecosystem services is a growing research field in riparian buffer design (Fortier et al., 2011; Kelly et al., 2007; Schultz et al., 2004). Yet, this farm-scale study, along a 1 km section of a headwater stream, is among the first to show that some tree species/vegetation treatment combinations can not only strongly affect early riparian buffer structural development (Fig. 4), but also soil NO_3 dynamics during the growing season (Fig. 2). Because NO_3 enrichment of stream ecosystems has negative consequences for water quality, instream habitats, stream C sequestration capacity and greenhouse gas emissions (Carpenter et al., 1998; Kaushal et al., 2014; Rosemond et al., 2015), results from this study suggest that some tree species (hybrid poplar, red ash and bur oak) may be more suitable than others (white pine and red oak) when the goal is to minimize NO_3 leaching during riparian buffer establishment, especially if a permanent vegetation management treatment (plastic mulch) is used. From that perspective, hybrid poplars (or native riparian poplars) are particularly interesting species because they have specific traits that may contribute to a high rate of soil NO_3 phytoremediation. These include their physiological capacity to respond to high periodic N inputs by increasing N storage in the form of proteins (Bradshaw et al., 2000; Cooke and Weih, 2005), their very strong growth response to increased NO_3 availability in agricultural riparian zones (Fortier et al., 2010a) (Fig. 6), but also their deep-rooting and facultative phreatophyte habits (Rood et al., 2011), which promote nutrient uptake in deeper soil layers and denitrification in groundwater, even during the dormant season (Ausland et al., 2015). Others studies have also clearly shown that among various land-uses of agricultural landscapes (annual crops, perennial crops and deciduous forests of different successional status), hybrid poplar plantations were by far the land-use with the lowest NO_3 leaching over an 11 year time frame (Syswerda et al., 2012).

Another important observation from this study was that NO_3 supply rate was not statistically different among tree species in the control treatment (Fig. 2). This suggests that despite the large growth differences between species (Fig. 4), and potential differences in biomass N accumulation and N-form preferences, the presence of herbaceous vegetation around trees may play a central role in soil NO_3 retention or uptake during the growing season. Because the prolonged use of plastic mulch can greatly increase soil NO_3 supply for some species (red oak and white pine), it may be important to remove the plastic mulch once those species are properly established to allow herbaceous colonization underneath trees.

We also observed extreme variations in volume growth after 5 years for the different tree species/vegetation treatment combinations, with hybrid poplar planted in the plastic mulch treatment producing 774 times more stem volume than red oak planted without vegetation management (Fig. 4c). In the plastic mulch treatment alone, hybrid poplar was found to be 5.2–40.4 times more productive than native species in terms of stem volume production (Table 3). This highlights the need for appropriate species/vegetation treatment combination selections, especially if the goal is to rapidly create a forest-like structure along farm streams. Red ash and the hybrid poplar, a tree and a hybrid of trees that are early-successional species of bottomlands and riparian corridors, respectively reached 4.9 and 8.2 m in height and 8.9 and 15.6 cm in basal diameter after 5 years in the mulch treatment (Fig. 4a, b). Catalyzing canopy development with these fast-growing species planted in a competition-free environment would greatly reduce the time needed to provide suitable microclimate and habitat for forest biodiversity, or to provide stream shading, allochthonous organic matter inputs to the aquatic food wed and flood impact attenuation. However, the recent arrival of the emerald ash borer (*Agrilus planipennis* Fairmaire) in southern Québec may compromise the use of red ash for riparian afforestation in many agricultural landscapes.

On the other hand, the inclusion of slower-growing species that produce nuts (acorns) such as oaks would be of particular interest to improve riparian buffer structural heterogeneity and to attract different bird and mammal species. However, red oak should not be planted in flood prone areas or in soils with impeded drainage (Sander, 1990; Truax et al., 2000). Rather, it could be included in well-drained sections of riparian buffers along extensive cropping systems or pastures, as long as herbaceous vegetation competition is repressed during its establishment phase (Fig. 4). Thus, in riparian areas where no vegetation management is possible and/or where soil has impeded drainage, bur oak should be preferred to red oak. However, bur oak's slow growth and shade intolerance are also indications that this species should not be combined with faster growing species at planting (Truax et al., 2015). Although bur oak grows well on imperfectly drained bottomland or riparian sites, its planting should also be avoided in buffers experiencing prolonged floods (several weeks), because unlike hybrid poplar or red ash, bur oak's seedlings may not remain healthy following such events, although surviving them (Kabrick et al. 2012; Kennedy, 1990). Finally, from a conservation perspective, the restoration of bur oak along farm streams of southern Québec should be seen as a regional priority, considering that this species was overexploited and its numbers considerably reduced following British colonization (Simard and Bouchard, 1996).

The integration of conifers, such as white pine, in riparian buffers would also provide additional riparian buffer functions, as this species provides year-round shelter and an important food source (bark, foliage and seeds) for wildlife (Wendel and Clay Smith, 1990). Still, the very high NO_3 supply rate observed in the white pine/plastic mulch combination should not be overlooked. Consequently, along small streams of more marginal and extensively managed farmland, white pine should be planted for its wildlife value, especially where no vegetation management is possible (Fig. 4).

Though not necessarily planted in their optimal habitat, all species achieved high survival rate, even without vegetation management (Fig. 3), which contrasts with results from many riparian forest restoration studies (Curtis et al., 2015; Keeton, 2008; Sweeney et al., 2002). Such high survival rates were potentially achieved because of the pasture fence that reduced predation by large herbivores, a major factor affecting woody regeneration and planted trees along recovering riparian corridors (Opperman and Merenlender, 2000; Sweeney et al., 2002). Equally, the large growth gains observed in the mulch treatment for several species may be related to the very large size of the plastic mulches used ($9\,m^2$ of mulch/4 trees or $2.25\,m^2$/tree) (Fig. 1). Much more conservative growth gains have been reported for smaller-sized mulches (Thomas et al., 2001).

As a final recommendation, it may be indicated to remove black plastic mulch from riparian buffers once trees are adequately established (after 3–5 years, depending on the species). Such a strategy would provide the short-term benefits of plastic mulching for tree establishment (reduction of herbaceous competition, lower loss of soil water by evaporation, increase in soil nutrient availability, and in temperatures of both soil and air), while minimizing its potential longer-term impacts. These impacts may include higher runoff in riparian zones due to the imperviousness of polyethylene mulches, the loss of soil organic carbon and N stocks resulting from the over-mineralization of organic matter, the gradual release of toxic compounds (including phthalates), the modification of water infiltration properties of riparian soils when mulch becomes buried underneath sediments deposited during flooding, the potential drift of mulch pieces during stormflow events and their effect on stream biodiversity, and the reduced aesthetic quality of farmland landscapes (Kasirajan and Ngouajio, 2012; Li et al., 2004; Rochman 2015; Steinmetz et al., 2016). However, the removal of plastic mulch requires a great expenditure of time and/or funds (Kasirajan and Ngouajio, 2012), especially in tree plantations, where mulches need to be cut off into pieces to be pulled off from tree bases. Once removed, plastic mulch is still an environmental problem as it cannot be recycled or burned in incinerators due to high contamination by soil particles (Kasirajan and Ngouajio, 2012). Thus, the final fate of removed plastic mulch is often on-site open burning, with its major consequences for air quality, or disposal in landfills (Kasirajan and Ngouajio, 2012). Given these considerations, there is clear a need to develop long-lasting (3–5 years) biodegradable mulches for specific tree applications or to develop reusable plastic mulches that could be used at the individual tree level.

5. Conclusion

Plant species selection in agricultural riparian buffer design is a determining factor to optimize one or more ecosystem functions or services. This farm-scale study provides evidence that particular tree species/vegetation management treatment combinations strongly influence buffer structure and soil NO_3 supply rate a few years after buffer establishment, along a headwater stream. The combination of non nitrophilous species (white pine and red oak) with plastic mulch has resulted in the greatest increase in soil NO_3 supply rate, while the use of early-successional nitrophilous species (hybrid poplar and red ash) in combination with the plastic mulch had the lowest effect on soil NO_3, but lead to large gains in tree growth, and therefore in buffer structural attributes. Overall, tree stem volume was found to be a strong negative predictor (across all species) of soil NO_3 supply, indicating that under strong herbaceous competition larger trees have a greater ability to reduce soil NO_3.

Finally, this study opens the door for testing new hypotheses related to interactions between tree species, soil, and vegetation management treatments in the context of agricultural riparian buffer design. Tree species with highest shade-tolerance often have a preference for NH_4 uptake, as NH_4 can be assimilated at a lower energetic cost than NO_3, and because soil NO_3 is not abundant in the soils of many undisturbed or weakly disturbed forests (Jerabkova et al., 2011; Walters et al., 2014). The capacity of such species for soil NO_3 phytoremediation under open-field conditions in agricultural riparian buffers receiving high NO_3 loads should be investigated more fully and compared with the NO_3 uptake capacity of early-successional species.

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