New Forests (2006) 32:197–210
DOI 10.1007/s11056-005-5960-8

Effects of full and partial clearing, with and without herbicide, on weed cover, light availability, and establishment success of white ash in shrub communities of abandoned pastureland in southwestern Quebec, Canada

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Received 11 November 2003; accepted in revised form 8 December 2005

Key words: Hardwood plantation, Light, Shrubland, Vegetation management, White ash

Abstract. Shrub communities established on former pasture land are currently under-used and their forestry potential is of interest to land owners wishing to increase valuable hardwood regeneration on their properties. The comparative effects of strip clearing and total clearing, both treatments applied with or without herbicide, on competing vegetation cover, light availability, and survival and growth of planted white ash (*Fraxinus americana* L.) were examined in two different shrub dominated sites for 3 years in southwestern Québec, Canada. Survival was high in all treatments. At the site with the richest soil and in comparison to total clearing, strip clearing produced the lowest light level in the third year, which induced lower total herbaceous weed cover. These combined effects produced the same growth results for white ash seedlings in all treatments. At the second site, with the highest woody vegetation regrowth, strip clearing has promoted seedling height growth and produced the highest height: diameter ratio for white ash. This ratio was also superior at this site in the absence of herbicide. Treatment effects were soil/site dependant. Because partial clearing in strips has never reduced tree growth in comparison to total clearing, it represents a promising method for the establishment of valuable hardwoods in shrubby vegetation, with lower management intensity and lower landscape impact than total clearing.

Introduction

During the last century, the modernization of agricultural methods has led to the abandonment of less productive lands (Houerou 1993; Orwig and Abrams 1994; Tatoni and Roche 1994). These abandoned agricultural lands have become re-vegetated with new plant communities, including shrub dominated vegetation (Meilleur et al. 1994b; Stover and Marks 1998). These environments are currently under-used and their forestry potential should be studied.

From 1971 to 1996, the total agricultural area in the province of Quebec has decreased by 21%, for an average of 36,600 ha/year; during the same period, pastures have lost 72% of their area, slightly less than 20,000 ha/year (Statistique Canada 1992a, b; 1997). In south-western Quebec, glacial deposits are usually left as pastures because stoniness limits the use of machinery and the growing of cereal crops. The analysis of an area of the province revealed that 35% of agricultural land on glacial deposits has been abandoned during the 20th century (Pan et al. 1999). These abandoned lands have been gradually recolonized by shrub species, often selected by cattle browsing during the last years of pasture use, creating a shrubby vegetation over soils of varying stoniness. These sites have very little potential for modern agriculture. In southwestern Quebec, on the rare occasion that afforestation is practiced in such shrub communities, full vegetation clearing is generally applied and conifer species are planted most often. In this Sugar maple – Hickory vegetation zone (Grandtner, 1966), only 4.7% of planted trees, from 1999 to 2002, were hardwoods (Ministère des Ressources naturelles, de la Faune et des Parcs du Québec 2003).

In a territory where the forest landscape needs to be reconstructed (Bouchard and Domon 1997), it is essential that the potential of sites occupied by shrubby vegetation be evaluated for valuable hardwood production. The surrounding shrubby vegetation can modify the quantity and the quality of the light reaching the young planted tree (Holbo and Childs 1987; Ballaré et al. 1990; Schmitt and Wulff 1993), as well as daytime climate conditions (Childs and Flint 1987; Barg and Edmonds 1999; Man and Lieffers 1999), soil water content (Childs et al. 1985) and various soil nutrients (Binkley 1984; Kim et al. 1995; Prescott 1997). Managing surrounding shrubby vegetation is a key factor to create successful conditions for artificial hardwood regeneration: full vegetation clearing should be compared to an approach that preserves a higher proportion of the initial shrubby vegetation.

Our study was undertaken to complement existing knowledge regarding artificial regeneration of valuable hardwood species by studying different management practices in shrub communities. Specific objectives were to analyze the effects of different intensities of mechanical control (total or strip clearing) of shrubby vegetation on (1) competing vegetation (2) light availability, and (3) early growth of white ash (*Fraxinus americana* L.) planted in shrub communities. We also sought to verify the need of herbicide applications for improving the growth of planted trees at this successional stage. Strip or total clearing treatments may allow the reduction of some of the constraints to tree regeneration survival in shrubby vegetation, which have already been underlined by Putz and Canham (1992).

Materials and methods

Description of study area and plantation sites

This study was carried out in the Regional County Municipality of Upper-St. Lawrence, located in south-western Quebec (Canada), north of the State of

New York (USA) and south of the St. Lawrence River. The region has 2136 degree-days (above 5 °C). Mean annual temperature was 6.5 °C at the St. Anicet station (45°08′ N; 74°21′ W), whereas mean monthly temperatures for January and July were −9.6 °C and 20.9 °C respectively (Ministère de l'Environnement du Québec 2000).

Two plantation sites (Clay site: 45°08′45″ N; 74°10′00″ W. Sandy loam site: 44°59′40″ N; 74°09′20″ W) were selected for their characteristics as shrub-dominated abandoned agricultural land (time since abandonment: 10–15 years), their low natural tree regeneration, as well as for providing two contrasting shrub communities and types of surficial deposits (based on existing data on the geomorphology of the study area; see Meilleur et al. 1994a). Soil characteristics, measured initially (first year) from 12 samples per site (composite sample of two per experimental unit, one by tree row) taken between 10 to 15 cm depth, are presented in Table 1 (Agridirect Inc. Laboratory, Longueuil, QC, Canada). Drainage class was determined by digging a soil profile and using a key to soil drainage class (Bates et al. 1985). Based on drainage, clay content, total nitrogen and cation exchange capacity (CEC), the clay site had the richest soil. The natural woody regeneration of the clay site was dominated by common domestic apple (*Malus pumila* Mill.) and wild raspberry (*Rubus idaeus* L.) with hawthorns (*Crataegus* spp.) as secondary species. Staghorn sumac (*Rhus typhina* L.) and wild raspberry were dominant on the loamy sand site with hawthorns as secondary species. The shrub communities averaged 3–4 m in height. Dominant herbaceous species were wild strawberry (*Fragaria virginiana* Duchesne), hooked agrimony (*Agrimonia gryposepala* Wallr.) and dandelion (*Taraxacum officinalis* Weber) at the clay site, and wild strawberry, Kentucky blue-grass (*Poa pratensis* L.) and field sorrel (*Rumex acetosella* L.) at the loamy sand site.

Experimental design

The experimental design used was a split plot design, where the main plot and subplot factors are respectively clearing intensity and herbicide application. The two plantation sites each had three blocks (36 m × 12 m per block). On

Table 1. Soil characteristics of the two experimental plantations sites.

Site	Drainage classes	Deposit	pH	Clay %	Sand %	Total N %	P (kg/ha)	CEC mEq/100 g
Clay site	Well to imperfect	Dolomitic moraine	6.57a[A]	48a	14a	0.52a	26a	31a
Loamy sand site	Rapidly	Late glacial till	6.23b	11b	82b	0.26b	51b	15b

[A]Means in each column followed by the same letter do not differ at $p < 0.05$ according to t-test.

half of each block (18 m × 12 m), the initial shrubby vegetation was totally cleared. On the other half, the shrubby vegetation was partially cleared in 2 m wide strips (for planting trees), alternating with 2 m wide uncleared strips. The clearings (strip and total) were made using a brushcutter. The cleared strips and plantation rows were oriented north–south.

Plots contained 8 rows of 10 white ash seedlings. The tree spacing was 4 m between rows and 1 m along the row. In addition to the vegetation clearing treatment (total or strip), done in April 1998, a second vegetation control treatment (subplot factor) was used. It consisted in applying or not (with or without) a glyphosate herbicide (Roundup, Monsanto Inc., Montreal, QC, Canada). Glyphosate is the only herbicide approved for forestry purposes in Québec. Two adjacent rows, selected at random among the four (rows 1 and 2, or rows 3 and 4), received the herbicide treatment. The two remaining rows served as controls (no herbicide). Glyphosate applications were made twice at both sites in the first year (May and July 1998) and repeated in the third year: once only at the loamy sand site (May 2000), and twice at the clay site (May and June 2000), the richest site, in order to maintain a comparable herbaceous cover on both sites. We decided to cancel herbicide application in the second year because of the relatively low herbaceous vegetation cover. Herbicide (1: 3 herbicide: water dilution, corresponding to 11% glyphosate active ingredient) was applied within a 50 cm radius at the base of the planted trees using a sponge (wick) applicator in order to avoid any drift. When leaves of plant competitors were close to the leaves of white ash seedlings, we cut these plants down to a lower height just before herbicide application to avoid contact with planted trees. Applications were made to touch the leaves of herbaceous or woody competing species, including sprouting stems (such as staghorn sumac). White ash seedlings were planted manually using a shovel between April 20 and 23, 1998. A plot contained 20 white ash seedlings planted in two adjacent rows and received the same treatments of vegetation clearing (total or strip) and herbicide application (herbicide or control). Spiral plastic protectors against rodents (TIMM enterprises Ltd, Milton, ON, Canada) were installed, and deer repellent applications (Skoot, Plant products company, Brampton, ON, Canada in May 1998; Deer-Away, IntAgra, Inc., Minneapolis, MN, USA all other years) were made each spring to protect the annual shoot, and each fall to prevent winter browse. No rodent damage was noticed, and only rare and isolated cases of deer damage were observed from year to year. The bare-root seedlings (1 + 0 age) were all measured for initial mean height (31.2 cm ± 9.4 cm) and diameter (0.69 cm ± 0.20 cm). They were produced at the Berthier nursery of the Québec Ministry of Natural Resources. Seedlings were extracted from the field at the government nursery during November and stored in a refrigerated warehouse for the winter. At the beginning of April, seedlings were transferred to the regional refrigerated warehouse near the plantations sites. Seedlings were left at room temperature (20 °C) 24 h before planting to facilitate root separation between seedlings stored in the same bag.

Light conditions

Measurements of the photosynthetic photon flux density (PPFD) were done in 1998 and 2000 (between July 30 and August 4 in both years), during days when the solar disk was not clearly visible because of cloud cover. This method provides a good estimate of microsite light availability (Parent and Messier 1996) and a single measurement obtained in cloud cover conditions provides an estimate of the mean growing season percent photosynthetic photon flux density under a canopy (Gendron et al. 1998). Measurements were done systematically on half of the living white ash trees located on the central row (to avoid edge effects). The probe was placed just above the terminal shoot of each plant to measure the effect on light interception of competing vegetation overtopping planted trees, and to integrate white ash seedling height position from year to year. In 1998, measurements were made with a Ceptometer (Model SF-80, Decagon Devices, Inc., Pullman, WA, USA), with a one metre-long probe, by averaging two measurements per plant (one taken along the north–south axis, the other along the east–west axis). During summer 2000, a sensor for photosynthetically active radiation (PAR) (Li-Cor®), connected to a datalogger (model Li-1400, Li-Cor Inc., Lincoln, NE, USA), replaced the Ceptometer. To obtain % PPFD, these data (1998 and 2000) were divided by the total available light taken, at the same time, by another PAR sensor installed nearby in an open field and connected to a datalogger (model Li-1000, Li-Cor®, USA). The data for 1998 (Ceptometer) were transformed to allow comparisons with data for 2000 (PAR sensor). A regression between data obtained simultaneously by the two instruments in different light conditions allowed for a good calibration ($r = 99.2$).

Competing vegetation

The initial vegetation of each plantation site was sampled in June 1998, assuming that the vegetation sampled in remaining strips was representative of the whole site. In each of the three blocks at each site, 12 sampling plots were laid out in the three central remaining vegetation strips (out of 5, after strip clearing), using nested permanent plots of 4 m^2 for all woody plants and of 1 m^2 for herbaceous plants.

Sampling plots for competing vegetation were located in each of the two central rows (rows 2 and 3) being respectively the herbicide treatment and the control treatment (no herbicide) on strip clearing or total clearing plots. For each row, the cover of competing vegetation surrounding four trees (randomly chosen) was measured in a 1 m^2 plot during the second week of August 2000 (third year).

Cover classes, visually estimated, were used to record the cover of each species (0–1, 1–5, 5–10, 10–15, 15–25, 25–50, 50–75 and 75–100%). To allow means to be calculated, the data were transformed from classes to class midpoint values (ex. class 15–25 = 20%). The mean cover of herbs and woody species was calculated for each sampling unit. Data were also transformed into an Importance Value (I.V.) for each species. This importance value is the mean, for each species, of the relative cover and the relative frequency in all of the sampling plots for each site.

$$\text{I.V. species } A = (\text{relative cover species } A + \text{relative frequency species } A)/2,$$

where relative cover species A = % cover species A/total % cover of all species, and where relative frequency species A = % frequency species A/total % frequency of all species.

Tree growth measurements and statistical analysis

Survival, diameter, height and length of annual shoot were measured at the end of each year (October), but only the third growing season results are presented here. All statistical analyses were performed on SAS (SAS Institute Inc. Cary, NC, USA). A frequency analysis of live trees, using a log-linear model (PROC CATMOD) was done to analyze survival. Analysis of variance (ANOVA) followed by Tukey's multiple means comparison test were applied to % PPFD, competing vegetation cover and white ash growth measurements. The statistical significance level was fixed at $p < 0.05$. The analyses of tree growth were done using measurements from trees located in the two central rows (rows 2 and 3) of strip and total clearing, in order to avoid edge effects. Statistical analyses were done separately for each site. The variance model for tree growth variable is represented by the following equation:

$$y_{ijkl} = \text{ì} + \text{B}_i + \text{C}_j + \text{BC}_{ij} + \text{T}_k + \text{BT}_{ik} + \text{CT}_{jk} + \text{BCT}_{ijk} + \text{ó}^2_{ijkl}$$

where B is the replication (i = 1,2,3) a random effect, C is the clearing (j = strip clearing or total clearing), a fixed effect and T is the treatment (k = herbicide or control), a fixed effect. BC, BT and BCT are experimental errors for C, T and CT respectively, and ó is the sampling error.

Correspondence analysis, using importance value for each plant species, was done to illustrate the effects of treatments on vegetation composition in the immediate vicinity of the planted trees (PROC CORRESP).

Results

Light conditions

Total clearing at the clay site produced 80% PPFD mean value during the third year compared to 45% in the strip clearing (p = 0.021). These third year values were 54% PPFD and 18% PPFD respectively for total and strip clearing at the loamy sand site, but without a statistically significant difference ($p = 0.068$). Herbicide application did not modify light availability at the clay site, but allowed for a significantly higher % PPFD to reach the planted white ash at the loamy sand site during the third year (57% compared to 46% without herbicide ($p = 0.028$)). At this last site, this effect was mostly achieved by restricting the growth of woody species (see high woody cover value on loamy sand site Figure 2). Between the first and third year, the mean reduction of light availability at the loamy sand site was of 49% and 21% in strip and total clearing respectively while light availability changes during the same period were negligible at the clay site.

Competing vegetation at the base of tree seedlings

As the direction and the length of vectors shown in Figure 1, plant species composition on the planted tree rows of the clay site was more strongly modified by the type of clearing than by the herbicide application when compared with initial vegetation composition. Total clearing has reduced *Malus pumila* (MPU) presence compared to strip clearing or to the initial community and, when combined with herbicide, has produced an increase in *Trifolium pratense* (TPR) importance value, whereas the absence of herbicide was associated with a greater importance value of *Poa pratensis* (PPR) (Figure 1).

On the tree rows of the loamy sand site, herbicide applications created the greatest change in vegetation composition compared to the type of clearing (Figure 1). At this site, the greatest importance value of *Populus tremuloides* Michx. (PTR; aspen) and of *Fraxinus* spp. (FSP; ash species) found in the herbicide plots was a major change in vegetation composition in comparison to the initial or strip clearing vegetation (Figure 1). The ash regeneration was however insufficient to insure the adequate hardwood regeneration of this site. The absence of herbicide application at the loamy sand site created distinct communities according to the type of clearing treatment; total clearing was associated with the presence of *Rhus typhina* L. (RTY), *Rubus alleghaniensis* Porter (RAL) (Alleghany blackberry) and *Solidago nemoralis* Ait. (SON) (wood goldenrod), whereas strip clearing was associated with the presence of *Rubus idaeus* (RID) and *Acer saccharum* Marsh (ASA) (sugar maple) (Figure 1).

Site comparisons of competing vegetation show that the herbaceous layer was more developed on the clay site, whereas woody plants were more abundant on the loamy sand site (Figure 2). The sprouting stems of the dominant shrub staghorn sumac explain the higher cover by woody plants on the tree rows of the loamy sand site.

The use of herbicide significantly reduced herbaceous cover at the clay site for each year: p-values for herbicide effect at year one, two and three were respectively 0.0023, 0.0009 and 0.008 (see Figure 2, clay site, for third year).

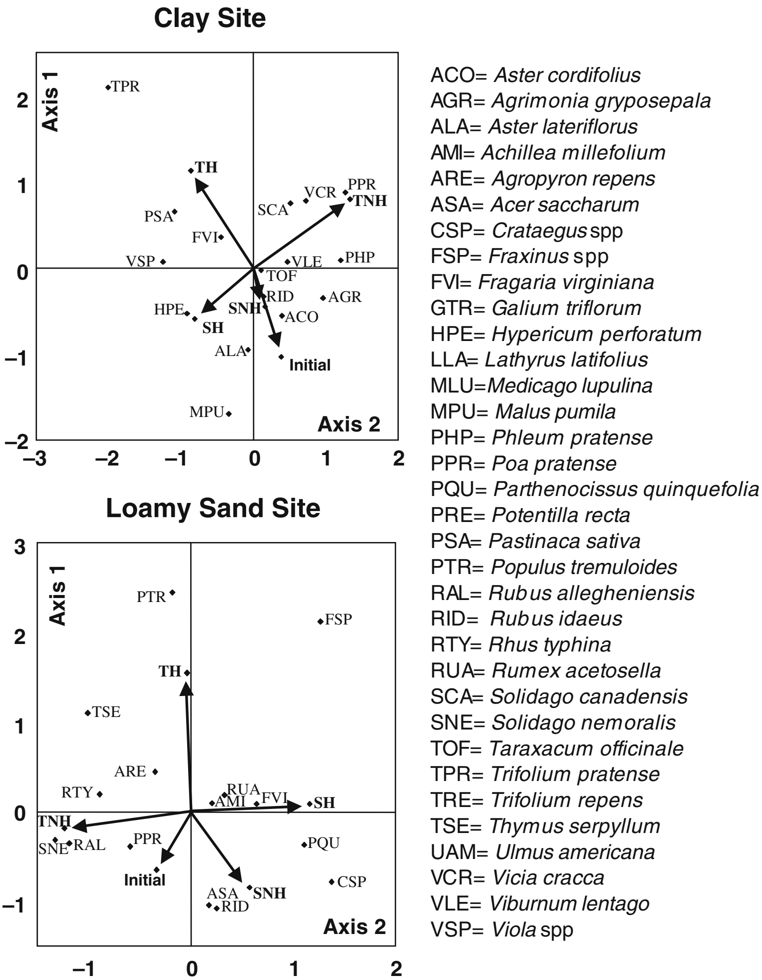

Figure 1. Correspondence analysis comparing initial vegetation to vegetation on tree rows in relation to treatments after 3 years. T = total clearing; S = strip clearing; H = herbicide; NH = no herbicide, Initial = initial vegetation.

During the third year at the clay site, strip clearing produced lower herbaceous cover than total clearing when no herbicide was applied (statistically significant interaction C*H in year three, p-value = 0.002, Figure 2). At the loamy sand site, no clearing type effect on herbaceous vegetation cover was detected, and herb cover was essentially reduced significantly by the herbicide treatment during year one ($p = 0.046$) and year 3 ($p = 0.010$) (see Figure 2 for third year). At this site, the herbicide reduction effect on woody species (mostly staghorn sumac) was detected starting from the second year ($p = 0.022$) and remained significant during the third year ($p = 0.038$) (Figure 2).

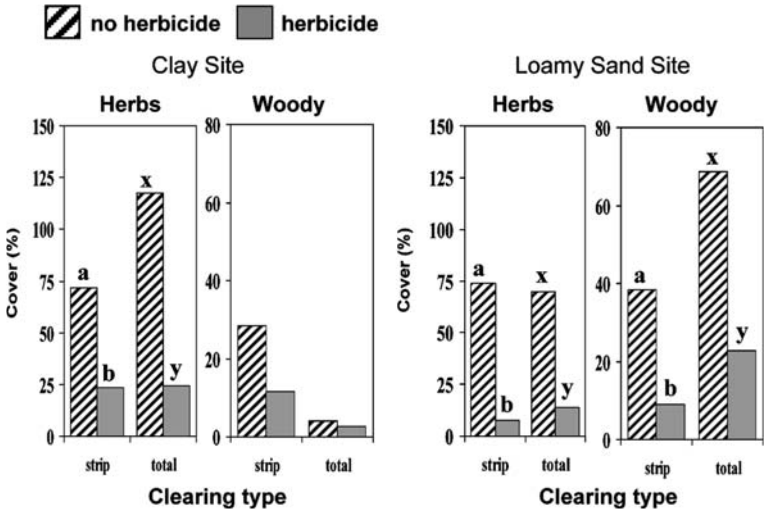

Figure 2. Third year total cover (%) of competing vegetation (herbaceous and woody) surrounding (1 m^2) planted trees in relation to treatments at each site.

Survival and growth of white ash

During the first two growing seasons of the study (1998 and 1999), the mean temperature of the month of May was warmer than normal by 3.7 °C in the first year and by 1.5 °C in the second. In May, lower total precipitations of 63% and 43% of the normal were recorded for the first and the second years respectively (Ministère de l'Environnement du Québec 2000). In spite of these difficult establishment conditions, the survival rate of planted trees at the end of the third growing season (2000) was higher than 90% and no significant differences were detected among treatments.

The average height for white ash planted on the loamy sand was significantly higher in the strip clearing treatment without herbicide (statistically significant interaction C*H in year three, p-value = 0.029, Table 2); strip clearing also promoted the growth of the annual shoot (Table 2). Also at the loamy sand site, the absence of herbicide, as well as the strip clearing, promoted a higher height/diameter ratio for white ash (Table 2), which was mostly due to height increment because no significant effect on diameter was detected. No significant white ash seedling growth differences were detected among treatments applied at the clay site, where means values were 92 cm for height, 27 cm for third year shoot length and 68 for height:diameter ratio.

Discussion

Despite warmer temperatures and lower spring precipitation during the establishment phase, the three year survival rate of white ash planted in

Table 2. White ash growth for each treatment at the loamy sand site (with Anova results for main factors); no significant effects were obtained at the clay site.

Treatment	Loamy sand site								
	Diameter (cm)		Height (cm)		Annual shoot in 3rd year (cm)		Height/Diameter ratio		
	Strip clearing	Total clearing	Strip clearing	Total clearing	Strip clearing	Total clearing	Strip clearing	Total clearing	Mean
No herbicide	1.13	0.89	95.1x[A]	59.8y	25.0	11.4	85	68	76a[B]
Herbicide	1.12	1.08	79.3	65.8	19.8	9.2	70	61	65b
Mean	1.13	0.98	87.3	62.8	22.4x	10.3y	77x	64y	

[A, B]Means in each row (clearing effect) followed by the same letter do not differ at $p < 0.05$; means in each column (herbicide effect) followed by the same letter do not differ at $p < 0.05$; (Tukey's multiple means comparison test).

shrubby vegetation was high in all treatment combinations. This reflects competition control that is adequate to ensure tree establishment. Survival results presented here are comparable to those of other studies in forests (Adams 1997; Buckley et al. 1998) and abandoned fields (Davies 1988; Cogliastro et al. 1990, 1993; Truax and Gagnon 1993), where efficient methods of competing vegetation control were used.

The loamy sand site was the site with the highest light reduction during the three growing seasons. At this site, the height growth of white ash (height, third annual shoot length increment, and height/diameter ratio) was promoted in the strip clearing treatment (accentuated by the absence of herbicide) and reflects plant elongation phenomena. This was induced by lower light intensity created by the growth of staghorn sumac at the edges of the strip, and by the growth of its woody suckers around the planted trees (without herbicide). This is a good indication of the sensitivity and the plasticity of white ash to light variation. Schlesinger (1990) reported the beneficial effects of wind protection and competition from other species in reducing branchiness in pioneer white ash. Many studies indicate morphological modifications in hardwood trees with light availability variation (Beaudet and Messier 1998; Goulet et al. 2000; Takahashi et al. 2001; Ponder 2003). This elongation effect in trees may contribute in maintaining an advantageous light interception position within shrub communities during the establishment phase, and may help in decreasing the period of vulnerability of planted seedlings to terminal leader removal by white-tailed deer (Groninger et al. 2004). To limit lateral branch development, and pruning requirements, it is suggested by some authors that woody companion species be provided on abandoned agricultural land by using shrubs planted near hardwood seedlings (Becquey 1997a, b). In old coppices being prepared for hardwood plantation, it is also proposed that the existing shrubby vegetation be managed in a manner so as to maintain peripheral woody vegetation in the proximity of planted trees (Allegrini 1995; Armand 1995; Boulet-Gercourt and

Lebleu 2000). Staghorn sumac communities under management (by strip clearing) or planted sumac in the surroundings of planted hardwood trees in open fields, may well achieve several functions of companion species.

The effect of treatments on the plant species composition was dependant on site characteristics. Important changes were associated to the type of clearing at the clay site, but not at the loamy sand site where they were mostly associated to herbicide use. At the clay site, total clearing without herbicide was associated to a community in which Kentucky Blue-grass (*Poa pratensis*) was dominating. Mercier et al. (2001) have shown that a community dominated by this species creates a vegetation layer that becomes progressively more resistant to tree invasion. At the loamy sand site, the absence of herbicide use could lead to the dominance of species known to have negative impacts on the growth of existing trees, such as *Rubus* spp. (Newton et al. 1987) and *Solidago* spp. (Groninger et al. 2004). However, the negative effect of these species could be less important at this site because of a lower biomass than in an open field, associated to a lower light intensity. In fact, the strip clearing plots without herbicide at this site had a regeneration of sugar maple.

With the use of herbicide at the loamy sand site, an aspen and ash regeneration was promoted. The seedlings of these species were probably not reached by the herbicide when applied using the wick applicator (May 2000), but they benefited from the reduced competition from the other species that were successfully controlled. In the future, a selection of ash stems and the elimination of aspen stems could be carried out at this site.

We observed that strip clearing led to a lower need of herbicides for controlling the herbaceous cover at the rich soil site. The successional stage of the study sites, with a well developed shrub layer that reduced the light reaching the herbaceous layer, would tend to produce a less severe level of weed competition for hardwood tree establishment than reported in several studies in old field plantations (von Althen 1987; Davies 1988; Cogliastro et al. 1993; Truax and Gagnon 1993; Adams 1997). Herbicide treatments are currently less acceptable to the public, and the results presented here attest to the successful establishment of planted trees in shrub communities without the use of herbicide. Nevertheless, use of herbicide has been proven to increase yields in hardwood plantation (von Althen 1987; Cogliastro et al. 1990; Truax et al. 2000). The growth results presented are probably not the best that can be obtained in shrub communities on sites with rich soils, such as the clay site. Annual herbicide applications may lead to a superior tree productivity on such rich sites, but the strip clearing treatment may require lower application rates. Our results for the clay site show a lower cover of herbaceous competitors at the base of planted trees in the strip clearing compared to total clearing when no herbicide was applied (see year three, clay site in Figure 2). Hardwood plantations done in shrub communities on abandoned pastureland using strip clearing only, is in perfect accord with an herbicide avoidance strategy.

Third year survival and growth of white ash in shrub communities of abandoned pasture are promising for owners wishing to implement hardwood enrichment. These environments can be considered opportunities for the production of timber and the reconstruction of forested environments without a total clearing. It will be important to continue monitoring studies in shrub communities to determine if the lower management intensity and landscape impact represented by the strip clearing treatment (as opposed to total clearing) are well reflected in the growth of different hardwood tree species as different shrub communities continue to develop and change in composition.

Acknowledgements

This research has received funding from the Québec Ministry of Natural Resources, the Natural Sciences and Engineering Research Council of Canada, and the Fonds pour la Formation de Chercheurs et l'Aide à la Recherche (FCAR). The Groupe de Recherche en Écologie Forestière Interuniversitaire (GREFI) provided a scholarship to K. Benjamin. We are grateful to research assistants, for their help in the laboratory and in the field, and to S. Daigle for his advice on statistical analyses. We thank the owners of the study sites, Mr. R. Guillon and Mr. G. Madison.

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