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Field performance and biomass production of 12 willow and poplar clones in short-rotation coppice in southern Quebec (Canada)

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Abstract

Twelve clones of fast growing trees (willow and poplar) were planted in 1999 under short-rotation intensive culture (SRIC) on an abandoned farmland in southern Quebec. The plantation was established at a density of 18,000 trees per hectare from stem cuttings and no fertilizer and irrigation were applied. Trees performances were measured at regular interval during four growing seasons. The aims of the experiment were to compare the growth, insect and disease resistance of these clones in order to select those that have good potential for use as commercial biomass energy crops in northern regions of North America. The follow up of the growing performance has shown statistically significant differences between the clones. Poplar clones registered the highest aboveground biomass yield after 4 growing seasons (from 66.48 to 72.20 tDM ha^{-1}). The best willow biomass productivity was obtained from clones SX64 (67.58 tDM ha^{-1}) and clone SX61 (62.34 tDM ha^{-1}). Only one willow clone S301 (*Salix interior* × *S. eriocephala*) was sensitive to leaf rust (*Melampsora* spp.) and clones SVQ (*S. viminalis*) and SV1 (*S. dasyclados*) were more prone to insect attacks. The results proved that some clones of *S. miyabeana* and *S. sachalinensis* were more productive and more resistant to insect and disease damage than *S. viminalis* which has been widely planted in SRIC in southern Quebec since many years.

Keywords: Willow; Poplar; Short-rotation intensive culture; Biomass yield; Insect and disease resistance

1. Introduction

The use of woody crop biomass is considered an economic and ecological option to produce electricity with regional benefits [1]. Locally, plantations can contribute to the reduction of soil erosion, provide a means to recycle organic residue

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such as sludge or manure, and further demands on existing natural forests [2]. A woody crop plantation can also contribute in reducing the rate of CO_2 build-up by sequestering carbon and by displacing fossil fuels [3]. In addition to being a source to generate electricity and providing environmental benefits, willow biomass is becoming a product of interest for different industries. Pulp and paper and wood panel companies have recently shown an interest towards willow fiber produced from willow plantation [4,5].

In Quebec (Canada) the abundance of marginal agricultural lands or abandoned farmlands offers great opportunities and these territories could possibly be reconverted and allow the production of fast growing woody species such as willows and poplar for different purposes (energy, wood product, etc.) [6].

Studies on willows in short-rotation and intensive culture (SRIC) have been conducted in southern Quebec for more than 10 years and it was demonstrated that the climatic conditions of the region could be conducive to the development of this activity [6–10]. The best growth rate and yield were recorded by *Salix viminalis* L., a European species imported from Sweden and massively planted in many of the plantations established in Quebec. However, this species has shown sensitivity to insect attacks year after year and the risk of epidemic disease is becoming more and more important as new areas are planted each year with the same clone. Therefore, the use of a diversity of clones and species in the production of biomass are desirable in order to decrease the risks incurred by diseases and insects.

The aims of the experiment were to compare the growth and pest resistance (insect and disease) of two clones of poplar and 10 clones of willow in order to identify new clones which could be appropriate for propagation in SRIC in Quebec and eastern regions of Canada.

2. Methods

2.1. Study area

The experiment was conducted on an abandoned farmland located in the area of the Upper St. Lawrence region (45°08′ N, 74°08′ W) 90 km southwest of Montreal. The climate of the area is continental type, characterized by an annual average temperature of 6.4 °C and an annual average of precipitation of 954 mm [11]. The period without freezing is 182 days and the total number of degrees above 5 °C is 2106. The mean total precipitation during the growth season (from May to September) calculated over a period of 21 years (1961–1990) for the Upper St-Laurent region was 427 mm.

2.2. Site characteristics and soil preparation

Experiments were conducted on a 1 ha marginal site which was formerly used for agriculture. Samples of soil collected (0–20 and 20–40 cm) at two depths showed that the soil had a clay-silt texture (Table 1). The organic matter content was good on the first level (0–20), but decreased with increasing depth. The soil was low in available P but rich in K and Ca. The analysis of the exchange capacity (CEC) showed an average fertility on the first layer (0–20 cm), which decreased with depth.

Table 1
Soil characteristics of the experimental site

Component	Units	Depth (cm)	
		0–20	20–40
Sand	wt%	2	9
Silt	wt%	48	43
Clay	wt%	50	48
Texture		Clay-silt	Clay-silt
Organic matter	wt%	9.1	5.8
pH		5.7	6.8
Available P	kg/ha	30.2	18.4
Available K	kg/ha	256	259
Available Ca	Kg/ha	7650	7840
Available Mg	kg/ha	2118	2410
CEC	meq/100 g	32.4	29.5
Al	mg/kg	914	989
B	mg/kg	1.0	0.68
Cd	mg/kg	9.2	10.6
Cr	mg/kg	57.9	68
Cu	mg/kg	2.63	2.35
Fe	mg/kg	177	151
Mn	mg/kg	50.1	72.2
Na	mg/kg	55.13	61.22
Zn	mg/kg	3.42	2.38

The pH was slightly acid at the surface but became neutral in the second level of soil analyzed.

In the fall preceding the plantation (1998), weed vegetation was killed by an application of $2.5\,l\,ha^{-1}$ of glyphosate (Roundup), followed by plowing and disking. In the spring of 1999, the soil was plowed again before plantation, then a mixture of herbicides (7.5 kg of Devrinol and 1.5 kg of Simazine ha^{-1}) was band-spraying immediately after planting.

2.3. Species and experimental design

The majority of willow and poplar cuttings used in the study were supplied by the State University of New York College of Environmental Science and Forestry (SUNY-ESF) of Syracuse. Details of the clones and their origin are presented in Table 2.

Willow and poplar clones were planted on four blocks, each divided into 12 plots corresponding to the 12 studied clones. The surface of each plot was $124.8\,m^2$ and the density of plantation was of 18,000 cuttings per hectare obtained by spacing the cuttings at 0.33 m on the row and leaving 1.67 m between the rows.

During the course of the study, the plantation was neither fertilized nor irrigated and no pest control against disease or insects was done. Observations were regularly done to check for insects or possible diseases developing on the branches and leaves of the studied clones.

2.4. Measurement and sampling

At the end of each growing season, 384 plants were randomly selected for measurement (8 for each plot (12) and each bloc (4)). The height (from its origin to its apex), diameter at the base of the main stem, the number of stems produced by each plant as well as the dry matter biomass was evaluated. In November, each measurement plant was harvested and weighed in the field using a spring scale. To evaluate the dry matter of willow aboveground biomass, the whole green stem samples collected from the field were oven-dried at 70 °C (to constant mass) before being weighed again. Productivity (in $t\,DM\,ha^{-1}$) was calculated by taking into account a plantation density of 18,000 plants ha^{-1} for all clones and the dry matter of biomass for each clone.

Chemical analyses of soil were conducted by Agri-Direct Laboratory using methods recommended by the Conseil de production végétale du Québec [12]. Soil texture was determined by granulometric analysis [13]. Total nitrogen was measured using the Kjeldhal method. P, K, Ca, and Mg were extracted by Mehlich-3 digestion and determined using ICP (Inductively Coupled Plasma Spectrophotometry) [14].

Table 2
List of willow and poplar clones used in the study

Clone number	Taxon	Origin
SV1	*Salix dasyclados*	Ontario Ministry of Natural Resources
S301	*S. interior* × *S. eriocephala*	University of Toronto, ON
S25	*S. eriocephala*	University of Toronto, ON
S365	*S. discolor*	University of Toronto, ON
SX61	*S. sachalinensis*	University of Toronto, ON
SX64	*S. miyabeana*	University of Toronto, ON
SX67	*S. miyabeana*	University of Toronto, ON
S546	*S. eriocephala*	University of Toronto, ON
S625	*S. eriocephala* × *S. interior*	University of Toronto, ON
SVQ	*S. viminalis*	Forest Ministry of Quebec (5027)
NM5	*Populus maximowiczii* × *P. nigra*	Ontario Ministry of Natural Resources
NM6	*P. maximowiczii* × *P. nigra*	Ontario Ministry of Natural Resources

Analyses of variance (three-way ANOVA) followed by multiple comparisons of means according to Tukey's method were performed on growth and productivity [15]. The number of stems was analyzed using log-linear models.

3. Results

The variation in precipitation and temperature recorded over the 4-year study period are presented in Fig. 1.

During the first growing season (1999), the temperatures were higher than normal and the distribution of rain during the season was not uniform: a high percentage of precipitation (37%) was recorded in September. The second growing season (2000) began with low temperatures which remained below the normal until the end of September. The total precipitation (431 mm) during the season was slightly superior to the normal (400 mm). Moreover, the high precipitation recorded in spring (May) and the uniform distribution of rain during the season was very favorable for the growth of willows. The third season (2001) was characterized by precipitation lower than the average and was, therefore, generally less favorable for the growth of willows. Finally, during the last season (2002), the temperatures from May to July were lower than average, accompanied by abundant precipitation, which in turn stimulated growth. From July to September, an unusual and severe drought was recorded and only very few millimeters of rain were recorded.

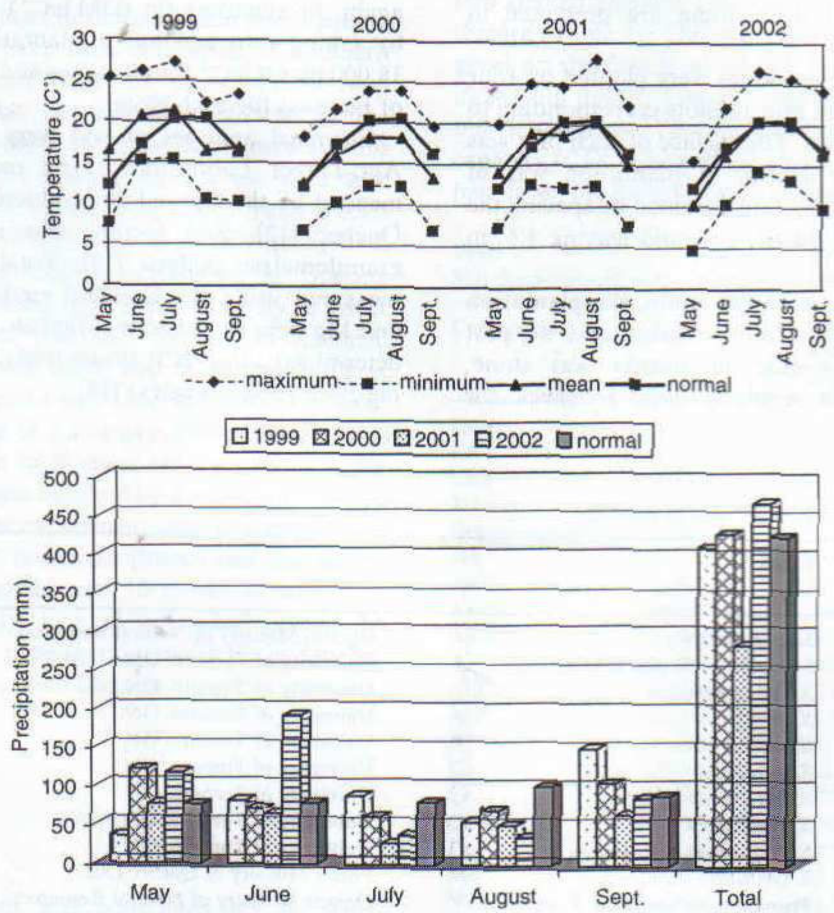

Fig. 1. Meteorological data recorded at the experimental site from 1999 to 2002.

3.1. Growth and productivity

3.1.1. First season

At the end of the first growing season, poplar clones NM5 and NM6 had significantly taller stems compared to willow clones (Fig. 2). Correspondingly, the poplar stems were less ramified. (Fig. 3). Among the willow clones, S25 and SX67 produced the tallest and thickest stems (Fig. 2). The number of stems varied depending on the clone. SX67 followed by SX61, SVQ, and S365 produced more branches than the others. The biomass yield of the two poplar clones was several times greater than that of any willow clones (Fig. 3). The best performance of willows (in a decreasing order) was recorded by: S365, S301, S25 and SX64.

3.1.2. Second season

Throughout their second season of growth, the poplar clone stems height and diameter, remained significantly larger than those of the willow clones (Fig. 2). In general, the willow plants produced a higher number of stems per plant than the poplar plants (Fig. 3).

The biomass yield of the two poplar clones, measured at the end of fall, was two to three times greater than that of any willow clones (Fig. 3). In terms of stem height, the willow clones can be divided in two categories: the best performing clones including S25, S301, SV1, SX61, SX64, SX67, and less performing clones like S365, S546, S625 and SVQ. The diameter of all willow clones were more or less similar. SVQ was the only clone which produced stems with a smaller diameter (Fig. 2). The yield of SVQ was therefore particularly low compared to the other willow clones.

3.1.3. Third season

At the end of the third season, the height and diameter of the two poplar clones (NM5 and NM6) was still largely superior to any of the willow clones (Fig. 2). In general, the biomass yield of the two poplar clones was two times higher than that of the willow clones. However, the

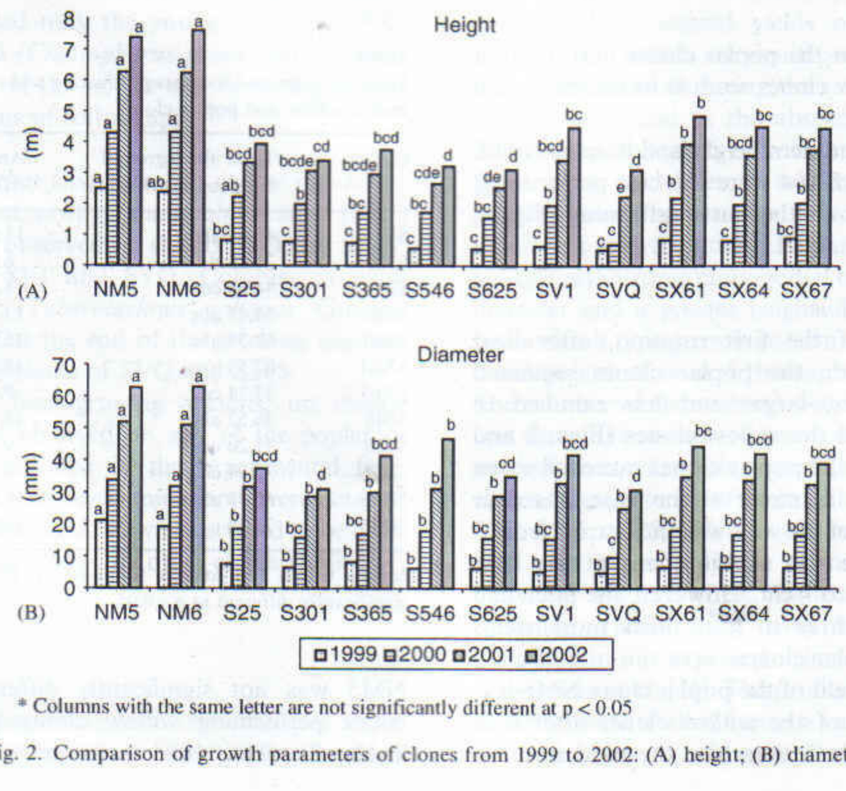

Fig. 2. Comparison of growth parameters of clones from 1999 to 2002: (A) height; (B) diameter.

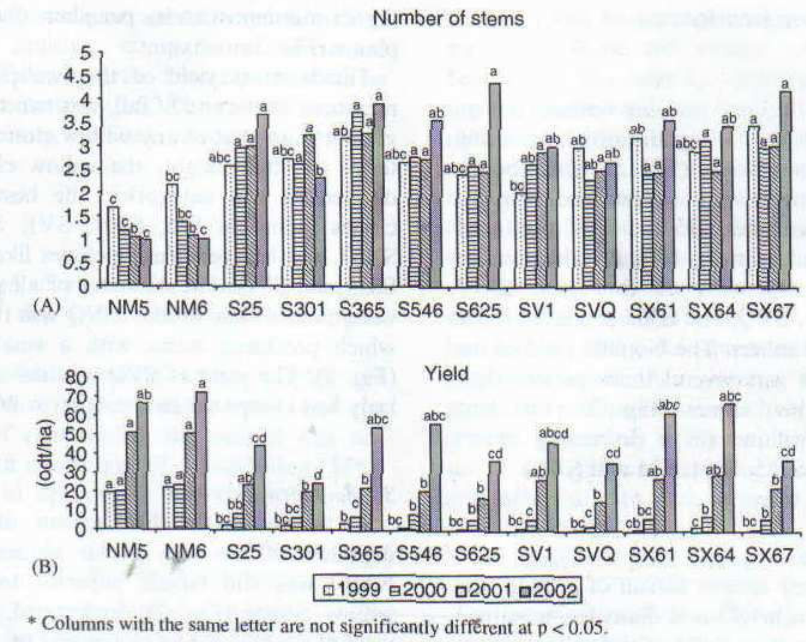

Fig. 3. Comparison of the performance of the clones from 1999 to 2002: (A) number of stems per plant; (B) aboveground biomass yield.

difference between the poplar clones and the best performing willow clones seemed to decrease each year.

According to the stem height and biomass yield, clones SX61 and SX64 were the best performing, while clone SVQ was the least performing (Figs. 2 and 3).

3.1.4. Fourth season

At the end of the first rotation, after four seasons of growth, the poplar clones remained significantly taller, larger and less ramified in comparison to all the willow clones (Figs. 2 and 3). The height of the poplar clones exceeded seven meters and their diameter at the base was over 6 cm. The height of the willow clones varied from 3 to 4.5 m and the size of the stems at the base ranged from 2.3 to 4 cm. However, the later had produced from three to four times more stems than the two poplar clones.

The biomass yield of the poplar clone NM6 was higher than any of the willow clones after four seasons of growth. Meanwhile, the yield of clone NM5 was not significantly different from the better performing willow clones (Fig. 3B and Table 3). The yield recorded was 66.5 and

Table 3
Total aboveground biomass production and annual yield of the twelve willow and poplar clones

Clones	Total aboveground biomass ($tDM\,ha^{-1}$)	Annual yield ($tDM\,yr^{-1}$)
SV1	46.64 abcd	11.66
S301	24.84 d	6.21
S25	44.38 cd	11.10
S365	54.48 abc	13.62
SX61	62.34 abc	15.59
SX64	67.58 abc	16.90
SX67	37.74 cd	9.44
S546	56.52 abc	14.13
S625	37.20 cd	9.30
SVQ	35.84 cd	8.96
NM5	66.48 ab	16.62
NM6	72.20 a	18.05

Means within the column followed by different letters are significantly different at $p<0.05$.

72 tDM ha^{-1}, respectively for poplars clones NM5 and NM6. In comparison, the highest yield for willow clones were recorded from clones SX64 and SX61 (67.5 and 62.3 tDM ha^{-1}, respectively). The total aboveground biomass and annual production (yield divided by the number of year) are shown in Table 3. The estimated annual yield of poplar clones was 16.62 and 18.05 tDM ha^{-1} for clones NM5 and NM6, respectively. In comparison, the annual yield for willow clones varied between 6.21 and 16.90 tDM ha^{-1}.

3.2. Insect attack and disease

3.2.1. Insects observed on the foliage

Willow leaf beetles (*Plagiodera versicolora* Laicharteg. and *Disonycha alternata* Illiger) were frequently observed on leaves of clones SV1 and SVQ. Occasionally these two beetles were also observed on the leaves of both poplar clones.

Another chrysomelid beetle species, *Calligrapha multipunctata bigsbyana* Kirby, was often seen especially on the *S. eriocephala* taxa (S25, S546, S625). The potato leafhopper (*Empoasca fabae* Harris) attacked only the young leaves of SVQ. The leaf aphid (*Chaitophorus populicola* Thomas) was observed on the poplar clones during two of the four seasons of follow up.

3.2.2. Insects that feed on young willow shoots

Willow shoot sawfly (*Janus abbreviatus* (Say)) was especially observed on shoots of clones SX61, SX64, SX67, SV1 and SVQ. Colonies of giant willow aphid (*Tuberolachnus salignus* Gmelin) were observed at the end of the growing seasons, particularly on stems of SVQ and S365.

During the four growing seasons, no disease infestation was observed on any of the poplar or willow taxa cultivated in the experimental field. However, each year *Melampsora* spp. were detected on the leaves of clone S301 which seemed to be more vulnerable to rust than any other clones studied.

4. Discussion

Several studies conducted on willow in short-rotation intensive culture (SRIC) in Southern Quebec demonstrated that climatic conditions of the region are favorable for biomass production and that high yield can be achieved. However, these interesting field performances were obtained by willow taxa of *S. discolor* and *S. viminalis* which were the only two taxa studied over these years [6–8]. The identification of new clones well adapted to northern climatic conditions is important since the interest for regional development for willow as woody crop is increasing in Quebec (Canada).

The follow up over four growing seasons of a plantation mixing a diversity of clones revealed that many of them performed very well in spite of the fact that summer, and particularly those of 2001 and 2002, were characterized by severe drought. The best performing clones in this study were the two taxa of poplar, NM6 and NM5 (*Populus maximowiczii* × *P. nigra*). Their aboveground biomass at the end of their first 4-year growing cycle was 72 and 66 tDM ha^{-1}, respectively. Two clones of willow, *S. miyabeana* (SX64) and *S. sachalinensis* (SX61) have also shown great potential and produced high biomass yield (68 and 62 tDM ha^{-1}, respectively). These values correspond to annual yields of about 16 and 17 tDM ha^{-1}, which are significant considering that they were obtained during the establishment phase of the plants and in the absence of fertilization. Statistically, the yield of willow clones SX64 and SX61 were not different to the one of the two poplar clones. Poplar and willow clones studied had a different growth pattern. Poplar clones developed a single orthotropic monopodial trunk with a larger diameter and a greater height. The willow clones had a shrub type growth pattern which implied the development of several thinner stems at the base. The number of stems developed from each cutting was three to four times greater explaining why the yield of some willow clones compared to the poplar clones. The tendency of some willow clones notably S25, S546, S625, SV1, to become more ramified each year is probably due to measurement variability and not to intrinsic characteristics.

Similar studies using many of the clones also used here in our experiment have been conducted by Kiernan et al. [16]. The production and survival of clones were studied across a variety of sites from northern New York and Vermont to central

Delaware. Clone SX64 and SX67 were found to be the most plastic according to their survival percentage and field performance. In three of the eight sites used in the study, SX64 was the most productive clone. The field performance of this clone was also demonstrated and confirmed in our study. However, the highest aboveground biomass production reported for this clone was only 34.7 tDM ha^{-1} after a 3-year rotation which means about 12 tDM ha^{-1} yr^{-1}. This value is inferior to what we obtained (16.9 tDM ha^{-1} yr^{-1}). The difference could be due to many circumstances such as soil quality, drainage conditions or weed control treatment applied.

Clone SVQ (*S. viminalis*) was one of the worst performers among the clones tested in our study. Curiously, this clone was used abundantly in many plantations established in Quebec and many studies have highlighted its great growth potential and reported high yield achieved by this taxa [6,17]. The poor performance of this clone could be explained by the higher susceptibility of this taxon to insects (notably by potato leafhopper) in comparison to other clones. It is likely that SVQ was more intensively attacked in plantations grouped with more resistant clones. Bell et al. [18] also reported that beetles are selective and target preferred varieties.

No disease infestation was observed on foliage or stems on the cultivated trees. Vujanovic and Labrecque [19] reported that it takes a certain period of time before fungal communities develop on willow plants which have been recently established. In an older plantation, they reported to have identified no less than 30 potential pathogenic species on clone SVQ of *S. viminalis* [19]. The majority of these fungi were found for the first time on willow plants in North America and several of these fungi were regarded as being particularly pathogenic for these plants [20]. Another study showed that the susceptibility of willow towards rust infection (*Melampsora allii-fragilis*) was increased by herbivore feeding [21]. Simon and Hilker [21] reported that a higher number of rust sori were observed on leaves adjacent to feeding-damaged leaves. Clones, which are more susceptible to herbivore feeding, such as clone SVQ, could also become vulnerable to rust fungi.

5. Conclusions

In this study it was demonstrated that many clones of willow and poplars could be cultivated in SRIC with great success under the climatic conditions of southern Quebec. At the end of a first coppice rotation, the best performances were obtained by the poplar clones NM6 and NM5 (*P. maximowiczii* × *P. nigra*) followed by willow clones SX64 (*S. miyabeana*) and SX61 (*S. sachalinensis*). These results corroborate with similar studies carried on with the same clones in southern regions such as New York, Vermont and Delaware. Clone SVQ (*S. viminalis*), frequently used in several plantations in Quebec, has demonstrated very poor performance and biomass yield. It also showed a higher susceptibility to insect attack which probably explained its lower productivity. Its cultivation in a mixture with more resistant clones, could make it more vulnerable and hence a better target for herbivores.

The identification of new clones well adapted to northern climatic conditions is important to increase the numbers of taxa that could be used by farmers and land owners interested by woody crop biomass production. Another three to 4-year rotation would probably be necessary notably to evaluate the growth and productivity following coppicing and pest resistance in the long term.

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