PERFORMANCE OF BLACK WALNUT-WHITE PINE PLANTATIONS IN SOUTHWESTERN ONTARIO

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ABSTRACT

The performance of black walnut *(Juglans nigra* L.) planted in mixture with white pine *(Pinus strobus* L.) on former agricultural land in southwestern Ontario was assessed in 130 plantations ranging in age from 6 to 18 years. Survival and mean annual height increment since planting were the parameters used to evaluate overall performance as well as the effects of species mixtures, soil texture and drainage, initial spacing, site preparation, post-planting competition control, refills, pruning and rodent control. Survival of black walnut and white pine ranged from 0 to 100%, with a mean survival for all plantations of 68% for black walnut and 65% for white pine. Mean annual height increment of black walnut in the best walnut-pine plantations was as high as that of the best previously surveyed pure walnut plantations in Ontario or the predicted values for walnut plantations (Site Index 50) in the United States. However, the majority of plantations did not perform as well as had been expected. Although several factors contributed to the poor survival and growth in many plantations, lack of adequate competition control was the single most important factor. Recommendations are made for improving plantation establishment and tending.

RÉSUMÉ

La performance du noyer noir *(Juglans nigra* L.) planté en association avec le pin blanc *(Pinus strobus* L.) sur d'anciennes terres agricoles du sud-ouest de l'Ontario a été évaluée dans 130 plantations dont l'âge variait de 6 à 18 ans. Pour évaluer la performance globale ainsi que les effets du mélange d'espèces, de la texture et du drainage du sol, de l'espacement lors du plantage, de la préparation du terrain, de la suppression de la compétition après le plantage, des regarnissages, de l'élagage et de la lutte contre les rongeurs, on a utilisé comme paramètres la survie et l'accroissement annuel moyen de la hauteur depuis le plantage. Les taux de survie des deux espèces variaient de 0 à 100 %; le taux moyen pour toutes les plantations étant de 68 % pour le noyer noir et de 65 % pour le pin blanc. Dans les meilleures plantations mixtes de noyers et de pins, l'accroissement annuel moyen de la hauteur du noyer noir était aussi élevé que dans les meilleures plantations pures de noyers ayant déjà été étudiées en Ontario ou que les valeurs prévues pour les plantations de noyers (indice de station: 50) aux États-Unis. Toutefois, la performance de la plupart des plantations n'a pas été aussi bonne que prévu. De nombreux facteurs expliquent la survie et la croissance moins bonnes observées dans de nombreuses plantations, la plus important étant l'absence de mesures adéquates de suppression de la compétition. Les auteurs formulent des recommendations pour l'amélioration de l'implantation des plantations et des soins culturaux.

ACKNOWLEDGMENTS

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FOREWORD

The field work for this study was funded by the Canada-Ontario Forest Resource Development Agreement (COFRDA). Two graduate foresters were hired to survey the plantations under the general supervision of J.D. Nolan of the Ontario Ministry of Natural Resources (OMNR). F.W. von Althen carried out the analysis of data and acted as scientific authority for the project. The final report was written jointly by F.W. von Althen and J.D. Nolan.

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INTRODUCTION

Black walnut *(Juglans nigra* L.) is the most valuable timber species in Ontario. In natural hardwood stands it occurs only as scattered individuals. Because the species is very intolerant of shade and competition, natural regeneration has been sparse. Early attempts to establish plantations on former farmland often resulted in failure because too little attention was paid to the growth requirements of the species (von Althen 1965a,b). These include a moist but well drained soil of high fertility, competition control, and protection from rodents and damaging winds during the early years. Recently, some excellent walnut plantations have been established by application of intensive agricultural methods such as plowing and disking of the entire plantation area followed by several years of competition control. These methods are expensive, however, and require considerable involvement on the part of the owner. Furthermore, they are not always feasible because often the land available for afforestation has been withdrawn from agriculture as a result of its inaccessibility during part of the year, its unsuitability for efficient use of agricultural machinery, or the danger of soil erosion.

Faced with a greatly increased demand for walnut planting, but aware of the reluctance or inability of many landowners to carry out intensive competition control, Johnston (1979) searched for an afforestation method that would reduce reliance on artificial control of competition. After close examination of the growth and form development of black walnut interplanted with white pine *(Pinus strobus* L.) in a 41-year-old plantation near Mount Salem, Ontario (Fleming 1979) (Fig. 1), Johnston developed a prescription for the establishment of mixed plantations of black walnut and white pine (Johnston 1979).

This prescription calls for the first row in a plantation to be planted entirely to white pine at a spacing of 2.1 m (7 ft). The second row alternates black walnut and white pine planted at a spacing of 2.1 m (7 ft) within the row and the same distance between rows. The third row is again entirely white pine and the fourth row is alternating walnut and pine. The net result is the establishment of black walnut at a spacing of 4.3 m (14 ft) surrounded by white pine (Fig. 2). Immediately after planting, the herbaceous vegetation is controlled by the spraying of simazine around individual trees at a dosage of 6.7 kg a.i./ha[1]. This herbicide treatment is repeated in spring of the third growing season and every two years thereafter until the canopy has closed, approximately 8 to 10 years after planting.

This prescription has four objectives: (1) to enable the pine component to shade out the herbaceous vegetation and thereby increase available soil moisture and nutrients; (2) by thus eliminating the herbaceous vegetation, to deprive meadow voles *(Microtus pennsylvanicus)* of

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[1] a.i./ha = active ingredient of herbicide applied per hectare treated

Figure 1. Black walnut in a 41-year-old walnut-pine mixture near Mount Salem, Ontario. Note white pine trees killed by juglone.

Figure 2. Black walnut-white pine plantations established according to the Johnston (1979) prescription.

cover and food and to prevent buildup of populations of voles, which are known to girdle young walnut trees (Radvanyi 1974, 1975); (3) to provide, by means of the white pine, protection from damaging wind, and to shade out the lower branches of the walnut, thereby improving the tree's stem form; (4) to enhance thinning by means of juglone, a strongly alkaline substance produced by walnut and toxic to white pine, which kills some of the white pine between 25 and 30 years after planting, when the walnut trees have produced 7.5-11 m (23 to 36 ft) of relatively branch-free bole (Camp 1986).

Since 1968 over 200 mixed plantations of black walnut and white pine have been established in southern Ontario but little is known of their growth performance. To determine survival and growth in these plantations and to identify the relative importance of factors contributing to plantation performance, a survey was carried out in the summer of 1986, with funds for the fieldwork provided under the Canada-Ontario Forest Resource Development Agreement (COFRDA). This report presents the results of the survey and makes recommendations for improvement in plantation establishment as well as management in the early years.

METHOD

To identify black walnut-white pine plantations that might be suitable for sampling, planting records for the Aylmer, Chatham, Simcoe and Wingham districts of the Ontario Ministry of Natural Resources (OMNR) were searched. Lists were compiled of all plantations established before 1982 in which at least 1000 black walnut seedlings had been planted on at least 2 ha of land. The number of plantations selected for the survey was based on the time available under the contract. Each OMNR district was asked to stratify its plantations on the basis of survival and growth. From this list an equal number of representative plantations with the best, worst and intermediate performances was selected. Planting records generally contained fairly detailed information on location, ownership, previous land use, soil type, site preparation, planting method, spacing and competition control. Plantations with incomplete records were rejected. The location of all plantations was verified by field staff.

One to three plots, depending on plantation size and variability of site conditions, were established in each plantation surveyed. Each plot contained 80 trees of each species planted. In a typical black walnut-white pine plantation 40 black walnut trees were tallied in each of two rows in which black walnut and white pine trees alternated. White pine was tallied in two rows made up of that species alone. Where trees appeared to be missing an attempt was made to locate the remains of a dead tree. Where no remains were found it was assumed that a tree had been planted to maintain an even spacing and that obvious gaps in spacing were the result of tree mortality. In plantations in which rows had been refilled at later dates an attempt was made to distinguish between trees planted in the original and in later plantings.

In plantations in which tree heights were less than 4 m (13 ft) or in open plantations in which heights could be readily measured, the height of all sample trees was measured with a rod to the nearest 10 cm and the diameter at breast height (DBH) of every tenth tree was taken with a diameter tape to the nearest centimetre. If a tree designated to be measured for DBH was dead or missing, the next living tree in the row was measured. In plantations with tall, densely spaced trees, in which it was very difficult to ascertain tree heights accurately, the DBH of all trees was measured to the nearest centimetre. The heights of at least two trees in each 1-cm diameter class found within the plot were measured for later diameter-height conversion. A linear regression was run on these data and the resulting equation was used to calculate the height of all trees. The mean height of trees in all plots was divided by the years since planting to obtain mean annual height increment (MAI) (mean height divided by years since planting).

In each plot at least one soil pit was dug with an auger and the soils were described according to the Field Manual for Describing Soils (Anon. 1985) (Fig. 3). In addition, notes were taken on tree condition and form, composition and density of the competing vegetation, and other factors, such as animal damage, that might have influenced plantation performance.

Figure 3. Survey crew (S. Cunningham and R. Eaton) collecting soil information in sample plot.

All pertinent information on the plantation history was obtained from the files and an attempt was made to interview plantation owners to obtain additional information that might help to explain plantation performance.

Survival and MAI were the two parameters used to evaluate the effects of individual factors, such as soil texture, site preparation and competition control, on plantation performance. An analysis of covariance was carried out to separate significant differences. However, during the analysis it was found that the influence of a single factor on plantation performance could not be determined with certainty. Because of the limited number of plantations with identical factors, it was generally necessary to combine the growth data of plantations varying in factors other than the one analyzed. For example, to test the effect of site preparation treatments on the survival and MAI of both species, data from plantations of different ages and growing on different soils had to be included in the analysis. This resulted in such a data spread that statistical analysis became meaningless.

RESULTS

Because the data were collected from plantations that varied widely in location, soil type and drainage conditions, site preparation methods, years since planting, planting stock quality, planting method and intensity of tending, the mean survival and height increment data presented must be regarded as indicators of trends rather than as absolute values that can be compared with values from other reports. Despite these limitations the results obtained provide a fair indication of the effects of different factors on the survival and MAI of both species.

Number, Age and Location of Plantations

In all, 178 plots were established in 141 plantations. Table 1 shows the distribution of plantations sampled by age and OMNR administrative district. The much larger number of plantations sampled in the Aylmer District reflects the greater number of plantations established in that district. It is also apparent that planting began much earlier in the Aylmer District and increased greatly in the other three districts starting in 1977.

Overall Performance

Survival of black walnut and white pine ranged from 0 to 100%, with a mean survival of 68% for black walnut and 65% for white pine for all plantations (Fig. 4 and 5). These survival data include an unknown number of seedlings planted as refills. Since few dead or dying trees were found during the survey it was assumed that most of the mortality occurred during the early years after planting. Even in the oldest

Table 1. Number of plantations sampled in four OMNR administrative districts, by number of years since planting

Age from planting (years)	Districts				Total
	Aylmer	Chatham	Simcoe	Wingham	
	(Number of plantations)				
6	3	-	1	3	7
7	7	6	3	2	18
8	11	3	4	3	21
9	5	1	2	2	10
10	5	2	1	2	10
11	7	4	-	-	11
12	3	1	-	1	5
13	12	1	1	-	14
14	5	1	1	-	7
15	11	1	1	-	13
16	10	-	-	-	10
17	8	1	1	-	10
18	5	-	-	-	5
Total	92	21	15	13	141

plantations surveyed, no mortality that might have been caused by juglone poisoning was found in the pine component.

Figures 6 and 7 show the respective mean heights of black walnut and white pine trees plotted by time since planting. In plantations with zero survival, mean height is shown as zero. Mean height of black walnut was much higher in the older plantations than in those established during the last 13 years because of more intensive competition control in the older plantations. The same is true for white pine, except that in the more recently established plantations mean height of white pine was generally greater than that of black walnut (Fig. 6).

Table 2 shows the survival, total height and DBH of black walnut and white pine in 19 mixed plantations 14 years and older in which the diameter of all trees was recorded. The mean values from these 19 plantations show that, in plantations 14 years and older, white pine had a higher survival and greater total height and DBH than black walnut.

Effect of Species Mixtures

Of the 141 plantations sampled, 130 were walnut-pine mixtures, 10 were pure walnut, and one was walnut interplanted with cottonwood

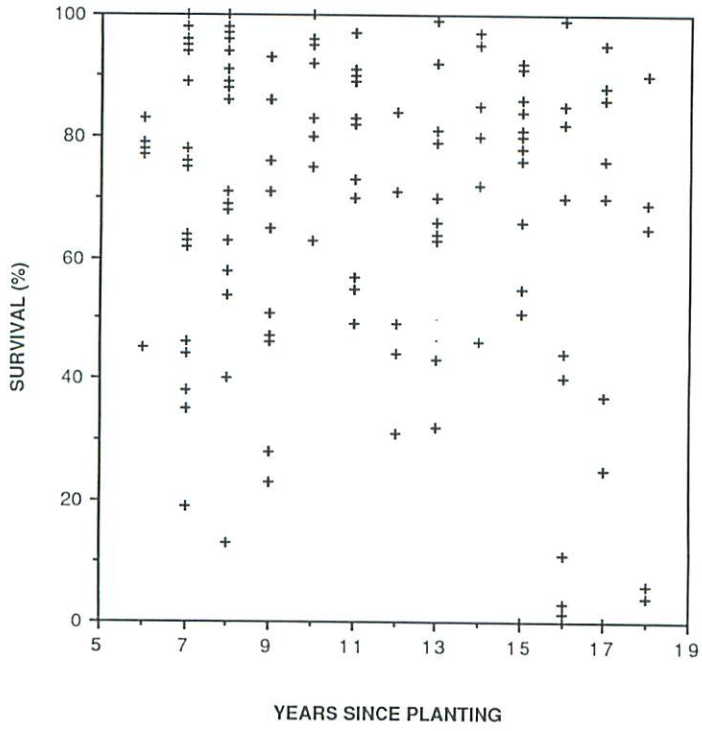

Figure 4. Survival of black walnut, by years since planting.

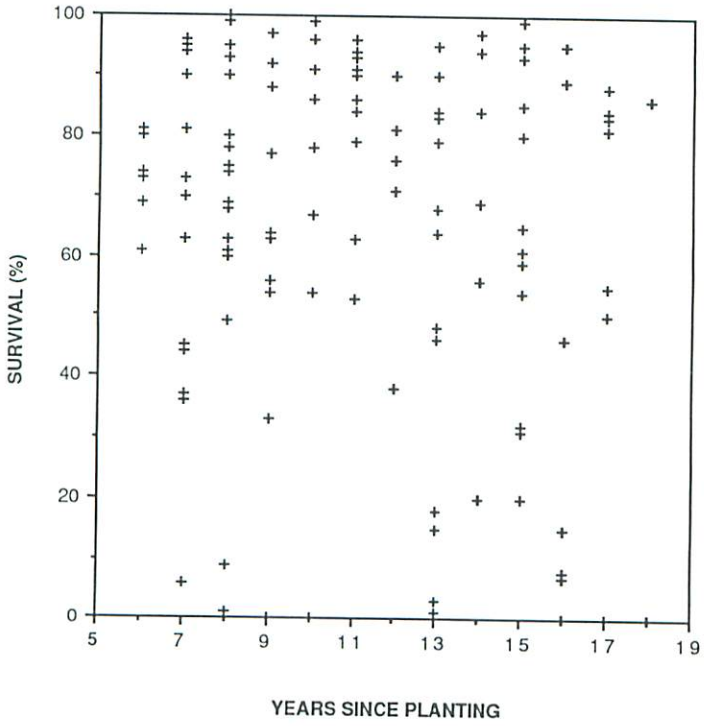

Figure 5. Survival of white pine, by years since planting.

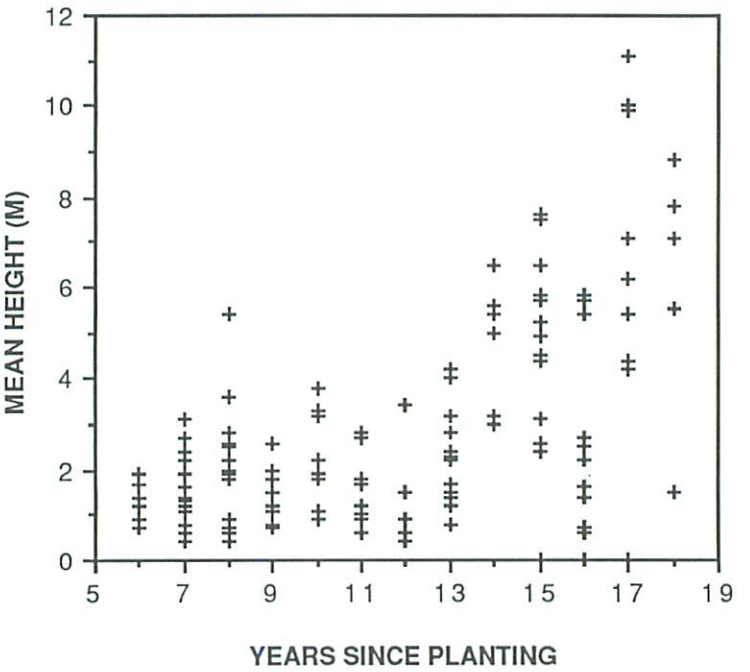

Figure 6. Mean height of black walnut, by years since planting.

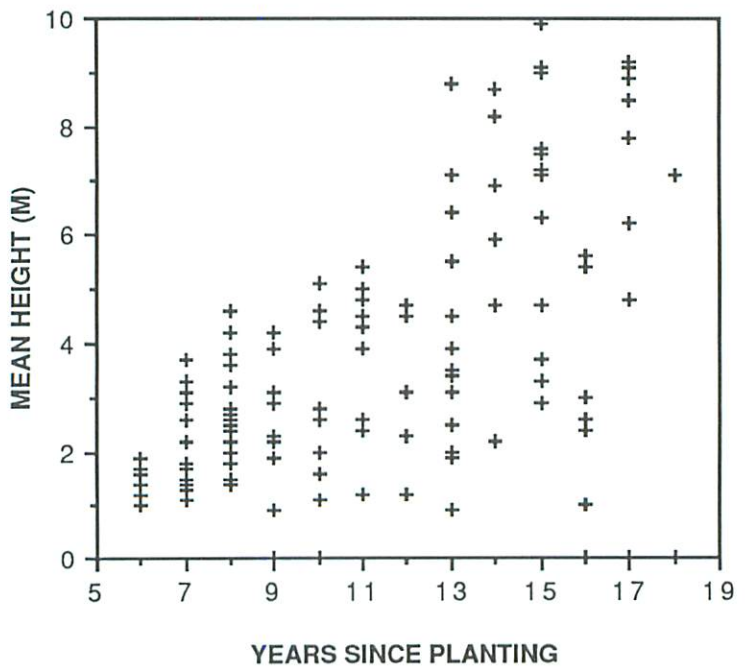

Figure 7. Mean height of white pine, by years since planting.

Table 2. Survival, total height and DBH of black walnut and white pine planted in mixture

Plantation no.	Age from planting (years)	Survival		Total height		DBH	
		Black walnut (%)	White pine (%)	Black walnut (m)	White pine (m)	Black walnut (cm)	White pine (cm)
2	17	86	83	11.1	8.5	11.8	12.2
3	18	90	86	8.8	7.1	9.5	9.7
4	15	92	99	6.5	7.6	7.3	11.9
5	14	72	94	5.6	8.8	3.6	16.3
10	14	85	56	6.5	6.9	9.5	10.5
20	14	46	20	5.4	5.9	8.3	9.3
25	15	66	95	5.2	7.6	4.3	12.5
26	15	51	93	4.9	7.5	4.0	12.2
30	14	80	84	5.0	8.2	8.7	11.3
41	17	76	88	10.0	8.6	8.7	11.3
44	17	37	81	6.2	7.8	4.5	12.2
69	15	80	31	7.5	3.3	8.9	4.0
84	16	24	83	4.1	7.0	3.2	7.3
89	15	81	59	4.5	7.2	2.7	6.5
90	15	84	65	5.8	9.9	4.7	10.4
91	15	91	85	4.4	7.1	3.7	12.0
145	17	88	81	5.4	6.2	5.8	10.1
146	15	78	93	7.6	9.1	5.1	13.8
183	17	63	85	11.0	9.9	5.8	12.1
Mean	15.5	72	77	6.6	7.6	6.3	10.8

(*Populus deltoides* Bartr.) (Table 3). Mean survival and MAI of black walnut were similar in the walnut-pine and the pure walnut plantations. This is most likely a reflection of site conditions and cultural treatments rather than the effect of species mixture. The same holds true for the walnut-cottonwood mixture, in which low survival and low MAI are believed to be reflections of poor drainage of the bottomland site rather than effects of the species mixture.

Table 3. Mean survival and mean annual height increment (MAI) of black walnut in pure and mixed plantations

Plantation species	No. of plantations	Survival of walnut (%)	MAI of walnut (cm)
Walnut-pine	130	69	27
Pure walnut	10	62	29
Walnut-cottonwood	1	6	8

Effect of Soil Texture and Drainage

For all plantations surveyed (regardless of age, competition control or other factors) soil texture of the planting site had little effect on the survival of black walnut and white pine (Table 4). Survival of both species was highest in plantations growing on medium sand. Whereas the survival of white pine was equally low in soils with a loam or silt texture, black walnut survival was lowest in silty soils.

MAI of black walnut was largest in plantations growing on fine sand and smallest in plantations growing on structureless silty clay or clay. MAI of white pine was equally large in plantations growing on fine sand or sandy loam and smallest in plantations growing on structureless silty clay or clay.

Tables 5 and 6, respectively, list the soil textures of the 10 black walnut and white pine plantations with the largest MAI per species. The results show a fairly even distribution of MAIs of both species over several texture classes. MAI of black walnut was largest in soils with loamy or clay textures, while MAI of white pine was largest in textures ranging from fine sand to clay loam. In only two of the 10 best plantations per species (numbers 146 and 183) did both species have excellent growth within the same plantation.

For all plantations, regardless of soil texture, age, competition control or other factors, drainage had little effect on the survival and height increment of either species. Only on bottomland that floods for

Table 4. Survival and mean annual height increment (MAI) of black walnut and white pine, by soil texture of the planting site

Soil texture	Black walnut			White pine		
	No. of plots	Survival (%)	MAI (cm)	No. of plots	Survival (%)	MAI (cm)
Medium sand; loamy medium sand	5	74	21	5	89	30
Fine sand; loamy fine sand; silty fine sand	8	65	35	8	64	42
Sandy loam; very fine sand; loamy very fine sand; silty very fine sand	17	66	24	17	78	42
Loam, silt loam; sandy clay loam; structured silty clay and clay (aggregate size <10 mm)	94	66	20	83	61	31
Silt; silty clay loam; clay loam; sandy clay; structured silty clay and clay (aggregate size >10 mm)	49	53	24	48	61	32
Structureless silty clay and clay	5	71	17	4	66	29

short periods during the year was survival of white pine much lower than that of black walnut (25% for white pine versus 53% for black walnut). On the same sites mean annual height increments of black walnut and white pine were 25 and 22 cm, respectively.

Effect of Spacing

The majority of plantations sampled were planted at spacings of 1.8 x 1.8 m (6 x 6 ft), 1.8 x 2.4 m (6 x 8 ft), or 2.1 x 2.1 m (7 x 7 ft) (Table 7). Three pure walnut plantations were planted at a spacing of 3.7 x 3.7 m (12 x 12 ft). In the walnut-pine mixtures, survival of

Table 5. Soil texture of the 10 black walnut plantations with the largest mean annual height increment (MAI)

Plantation no.	Plantation age (years)	Soil texture	MAI (cm)	Survival (%)
68	8	loam	68.0	40
2	17	loam	65.3	86
183	17	sandy loam	64.5	63
150	8	clay	55.1	95
146	15	fine sand	50.5	78
69	15	clay loam	49.9	80
128	7	clay	49.7	99
3	18	loam	49.0	90
125	14	loam	46.3	46
10	14	loam	46.1	85

Table 6. Soil texture of the 10 white pine plantations with the largest mean annual height increment (MAI)

Plantation no.	Plantation age (years)	Soil texture	MAI (cm)	Survival (%)
173	13	clay loam	67.9	84
41	17	clay loam	66.4	88
90	15	fine sand	65.9	65
48	11	loam	65.1	91
5	14	sandy loam	62.5	94
146	15	fine sand	60.6	93
59	15	fine sand	60.2	61
30	14	clay loam	58.5	84
183	17	sandy loam	57.9	85
61	8	loam	57.4	100

Table 7. Mean survival and mean annual height increment (MAI) of planted black walnut and white pine, by initial spacing

Initial Spacing	Black walnut			White pine		
	No. of plantations	Survival (%)	MAI (cm)	No. of plantations	Survival (%)	MAI (cm)
1.8 x 1.8 m (6 x 6 ft)	26	52	27	22	41	31
1.8 x 2.4 m (6 x 8 ft)	51	75	24	49	68	36
2.1 x 2.1 m (7 x 7 ft)	49	68	21	47	68	34
2.4 x 2.4 m (8 x 8 ft)	12	77	15	12	78	31
3.7 x 3.7 m (12 x 12 ft)	3	35	27	-	-	-

both species was substantially lower at the narrowest spacing. In the pure walnut plantations spaced at 3.7 x 3.7 m (12 x 12 ft) survival was only 35%.

MAI of black walnut planted in mixture with white pine was largest at the narrowest spacing and smallest at the widest spacing. MAI of white pine was largest at the intermediate spacing of 1.8 x 2.4 m (6 x 8 ft) and smallest at the narrowest and widest spacings.

Effect of Site Preparation

According to planting records of the 141 plantations sampled, 34 received some form of site preparation (Table 8). In 22 plantations, either the entire area had been plowed and disked or the seedlings were planted where an agricultural crop had been harvested in autumn before spring planting. On these latter areas, some cultivation was carried out after harvesting and before tree planting. In eight plantations, trees were planted on scalps approximately 40 cm^2 in size, made with a shovel or spade at time of planting. In four plantations, hawthorns (*Crataegus* spp.) and brush were cut to facilitate planting.

Although the intensity and effectiveness of site preparation treatments could not be verified and other factors such as soil texture

Table 8. Mean survival and mean annual height increment (MAI) of planted black walnut and white pine, by site preparation treatment

Treatment	Black walnut			White pine		
	No. of plantations	Survival (%)	MAI (cm)	No. of plantations	Survival (%)	MAI (cm)
No site preparation	107	57	20	102	60	36
Plowed and disked	22	87	26	19	81	33
Scalped	8	45	24	7	31	28
Thorns and brush removed	4	51	26	2	57	26

and drainage, previous land use, and post-planting competition control no doubt greatly influenced the results, the much higher survival of black walnut and white pine in plantations in which the entire site was plowed and disked attests to the benefits of intensive site preparation in plantation establishment. Survival of both species was lowest in plantations in which planting spots had been scalped.

MAI of black walnut was smallest in plantations with no site preparation. The three site preparation techniques appeared to have had little effect on the MAI of black walnut. MAI of white pine was largest in plantations with no site preparation and smallest in plantations from which thorns and brush had been removed.

Effects of Post-planting Competition Control

All plantations surveyed received one application of simazine immediately after planting and some plantations received up to five additional competition control treatments (Table 9). The most common treatment was the application of simazine (Princep). It could seldom be verified from the planting records, however, if the simazine was broadcast over the entire plantation area or applied in strips or around individual trees. A number of plantations received further applications of simazine, paraquat (Gramoxone) or glyphosate (Roundup). Dosages ranged from 4 to 8 kg a.i./ha for simazine and from 1 to 2 kg a.i./ha for paraquat or glyphosate. In six plantations competition was controlled by hoeing at least once and always in combination with simazine applications. In another six plantations the area between trees was mowed several times per year for a number of years.

Since all competition control treatments were applied several years prior to sampling, the effectiveness of the treatments could seldom be ascertained. The evaluation of treatment effects in plantations that had received similar competition control treatments was further confounded by differences in site, site preparation, age and other factors.

Table 9 shows the mean survival and MAI of plantations with similar competition control treatments. No analysis of variance was carried out because results would be meaningless as a result of the great diversity of site conditions and the lack of verification of the effec-

Table 9. Mean survival and mean annual height increment (MAI) of planted black walnut and white pine, by competition control treatments

Treatment	Black walnut			White pine		
	No. of plantations	Survival (%)	MAI (cm)	No. of plantations	Survival (%)	MAI (cm)
Simazine applied at time of planting	56	57	19	53	55	30
Simazine applied at time of planting and in one other year	45	68	24	41	70	33
Simazine applied at time of planting, plus two or more additional applications	16	88	33	16	83	41
Simazine applied at least twice, plus one or more applications of paraquat or glyphosate	12	78	24	12	65	20
Simazine applied at time of planting, plus hoeing	6	81	25	6	80	46
Simazine applied at time of planting, plus mowing between trees	6	88	21	5	76	42

tiveness of competition control in plantations that had received similar treatments.

Despite the confounding influence of other factors, survival and, to a lesser extent, MAI of black walnut show a definite positive response to increasing intensity of competition control. In plantations with simazine applied only at the time of planting, survival and mean annual height increment were 57% and 19 cm, respectively (Table 9). In plantations that received at least three applications of simazine, walnut survival and mean annual height increment were 88% and 33 cm, respectively--the best response to competition control.

Survival and MAI of white pine also improved with increasing intensity of competition control. However, white pine survival was lower and MAI was smaller in plantations treated with either paraquat or glyphosate than in plantations treated with simazine. While it could not be determined if white pine was damaged by the application of the contact herbicides, it is possible that some white pine mortality was caused by paraquat or glyphosate. It is also possible that paraquat or glyphosate were applied because the trees suffered from severe competition, and that either this competition or stem girdling by mice, rather than injury from the herbicides, caused the mortality.

Hoeing in combination with one simazine application immediately after planting improved the survival and height increment of both species over those that received only the simazine treatment. For white pine this treatment produced the greatest height (Table 9).

One application of simazine immediately after planting, followed by mowing between the trees for several years, improved the survival of both species and the height increment of white pine. Height increment of black walnut was only slightly larger in this treatment than in the treatment consisting of one simazine application immediately after planting, and smaller than in all other competition control treatments.

Combining the application of simazine with plowing and disking of the entire plantation area improved the survival and height increment of both species (Table 10). Though applied in only three plantations, plowing and disking of the total plantation area, followed by two or more applications of simazine, improved the survival and height increment of black walnut by 5% each and those of white pine by 9% and 8%, respectively. Scalping of individual planting spots, followed by one application of simazine at time of planting, failed to improve the survival and height increment of either species.

Refills, Pruning and Rodent Control

In plantations with unsatisfactory early survival, black walnut and white pine were replanted. Of the 141 plantations sampled, 39 were refilled once, 12 twice, 4 three times and 3 four times. Although an

attempt was made to distinguish between original and refill trees, this was seldom possible because of the time that had elapsed between the

Table 10. Mean survival and mean annual height increment (MAI) of planted black walnut and white pine, by combinations of site preparation and competition control treatments

Treatment	Black walnut			White pine		
	No. of plantations	Survival (%)	MAI (cm)	No. of plantations	Survival (%)	MAI (cm)
No site preparation, simazine applied at time of planting	42	55	18	41	53	29
Plowing and disking, simazine applied at time of planting	7	78	21	7	69	35
Scalping of planting spot, simazine applied at time of planting	7	52	19	5	43	23
No site preparation, simazine applied at time of planting and in one other year	36	62	22	33	65	33
Plowing and disking, simazine applied at time of planting and in one other year	9	88	30	8	89	35
No site preparation, simazine applied at time of planting, plus two or more applications	13	87	32	13	81	40
Plowing and disking, simazine applied at time of planting, plus two or more applications	3	92	37	3	90	48

planting and this survey. The survival data, therefore, most likely contain trees from the original as well as from early refill plantings.

In 32 of the 141 plantations surveyed, forks and large side branches had been pruned during the early years. This greatly improved stem form. In some older plantations, black walnut had been pruned to a height of up to 4 m (13 ft). In a few plantations the branches of white pine trees had been cut to provide additional growing space for the walnut crowns. All pruning treatments had a positive effect on tree form. However, numerous plantations were encountered in which the black walnut trees were in great need of pruning to develop high-quality stems suitable for the production of sawlogs or veneer bolts. These were generally plantations with low pine survival. Without shading from the side the walnut developed large crowns, often with multiple leaders, and branches covered up to nine-tenths of the height of the tree.

Mouse poison was applied in 10 plantations for one year and in 39 plantations for two years. Without controls it was impossible to assess the effectiveness of these treatments.

DISCUSSION

The objectives of this plantation survey were: (1) to determine growth performance of mixed plantations of black walnut and white pine, and (2) to determine the relative importance of factors affecting the survival and growth of both species. The first objective was fully realized by intensive sampling of 141 plantations ranging in age from 6 to 18 years since planting. Much greater difficulty was encountered in trying to achieve the second objective. Because this was a survey of operational plantations, established over a period of 12 years on many different sites, with different planting stock, planting methods, site preparation and competition control treatments, growth performance varied greatly and no two plantations were truly comparable.

Plantation performance is the combined result of the influence of many highly interdependent factors. But the influence of different factors on tree survival and growth is also highly variable and depends on the combination of factors as well as on the relative weight of each factor in a particular plantation setting. It is therefore not surprising that plantation performances, as assessed by this survey, varied widely in plantations that apparently grew on similar sites or had received similar treatments.

As shown in Table 11, the best walnut-pine plantations surveyed had a MAI comparable to that of Site Index 50 in the United States (Brinkman 1966) and to that of the best previously surveyed plantations in southern Ontario (von Althen 1965b). The excellent mean annual height increment of the two Ontario research plantations is the result of favorable site conditions and intensive management. The MAI of these plantations is therefore not truly comparable with that of the walnut-pine

Table 11. Comparison of mean annual height increment (MAI) of black walnut-white pine mixtures with walnut trees grown in plantations in Ontario and the United States

Plantation location	Age from planting (years)	MAI (cm)	Remarks
Walnut-pine plantation 10	14	46.1	10th best plantation surveyed
Walnut-pine plantation 125	14	49.0	9th best plantation surveyed
Walnut-pine plantation 69	15	49.9	6th best plantation surveyed
Walnut-pine plantation 146	15	50.5	5th best plantation surveyed
von Althen research plantation	15	69.0	good site, intensive management
von Althen research plantation	15	82.0	good site, intensive management
U.S. plantations SI 40	15	41.0	Brinkman 1966
U.S. plantations SI 50	15	53.0	Brinkman 1966
U.S. plantations SI 60	15	63.0	Brinkman 1966
Southern Ontario plantations	23	52.0	von Althen 1965b
Southern Ontario plantations	23	45.0	von Althen 1965b
Southern Ontario plantations	25	60.0	von Althen 1965b
Southern Ontario plantations	25	33.0	von Althen 1965b

plantations. Nonetheless, the data are included to show the potential of walnut plantations under intensive management.

While the performance of the best walnut-pine plantations was impressive, the majority of plantations surveyed did not perform as well as had been expected. Although a combination of several factors was probably responsible for the slow growth in many plantations, the factors discussed in the following paragraphs are believed to have played a major role in plantation performance.

One of the difficulties of establishing successful plantation mixtures of black walnut and white pine is the difference in the rate of juvenile height increment between the two species. In the year of planting, height increment of black walnut generally does not exceed a few centimetres. Beginning in year two, black walnut is capable of growing 1 m or more per year. The prerequisites to attaining such increment are planting site quality and effective competition control (von Althen 1974). In contrast, white pine has a much slower rate of juvenile height increment and generally requires four or five years to attain a height of 1.5 m (Horton and Bedell 1960). After the initial period of slow growth, white pine annual height increment increases rapidly and may average 1 m or more per year for a decade or more. For adequate growth white pine does not require the same intensive competition control as black walnut and therefore does not respond to weed control to the same degree as black walnut. This does not mean that white pine will not benefit from competition control, but the growth

response of white pine to competition control will seldom be as dramatic as that of black walnut.

In plantations with no site preparation and only spot treatment of simazine applied immediately after planting, the growth potential of black walnut is greatly underutilized for several years as a result of inadequate weed control (Fig. 8). Under the prescription for the establishment of walnut-pine plantations, the pine component is expected to provide natural weed control by shading out herbaceous competition. In plantations with high survival this does happen, but effective competition control is generally not achieved until 8 to 10 years after planting. In the meantime walnut trees suffer from inadequate competition control. The results are slow growth and poor stem form. During the slow-growth years the walnut trees are also exposed to the danger of stem girdling by meadow voles, which thrive in areas with dense herbaceous vegetation.

Approximately five years after white pine is planted, its height increment starts to accelerate greatly. At approximately 8 to 10 years after planting, the fast-growing white pine start to provide the competition control necessary for accelerated black walnut growth. However, because the white pine are growing at an annual rate of 1 m or more while the black walnut are just coming out of a period of semi-stagnation, there is a danger that the white pine will outgrow the black walnut, and that severe suppression of the walnut will result (Fig. 9). This situation could probably be avoided by simazine applications at time of planting and at years 3, 5 and 7 as recommended by Johnston (1979). However, it was very apparent that most of the plantations surveyed had not yet achieved crown closure and were in great need of competition control.

The importance of site quality for adequate walnut growth is well known (Carmean 1966), but factual information for the identification of soil series suitable for good walnut growth is still inadequate (Losche 1973a,b; Taylor and Jones 1986). For all 141 plantations sampled in this survey, MAI of black walnut was highest in the texture class consisting of fine sand, loamy fine sand or silty fine sand (Table 4). However, the 10 plantations with the greatest MAIs of black walnut had soil textures of loam or sandy loam (Table 5). Although Carmean (1966) states that "best growth [of black walnut] occurred on deep, medium-textured soils that had loose, well drained subsoils", it is most probable that the results obtained in our plantation survey were greatly influenced by other factors such as site preparation and competition control. For example, a soil of fertile loam or clay loam will support much denser herbaceous vegetation than a sandy soil. Without adequate competition control walnut growth may therefore be poorer on the more fertile soil because of intense competition.

The inconclusive results of this survey with respect to the effects of soil texture and drainage on the growth of black walnut and white pine were probably greatly influenced by the young age of most

Figure 8. Stagnating black walnut as a result inadequate weed control.

Figure 9. Black walnut overtopped by white pine.

sample plantations (Taylor and Jones 1986). Because all plantations were established on former agricultural land with relatively fertile A and B horizons, tree growth during the early years after planting was probably greater than one would expect on soils that were unsuitable for good walnut growth because of shallow A and B horizons, very light or very heavy soil textures or poor drainage.

It is also interesting to note that in only two of 20 plantations did both species grow sufficiently well to be included in the list of plantations with the largest MAI. This indicates that the two species have different site requirements, with black walnut favoring loam and clay loam textures and white pine favoring sandy and loam textures.

On upland sites drainage had little effect on the survival and height increment of both species. However, these results were probably influenced by the confounding effect of other factors because many previous studies have clearly shown that neither black walnut nor white pine will grow well in poorly drained soil (Auten 1945, Hansen and McComb 1958, Losche 1973b, Taylor and Jones 1986).

On bottomland soils, which flood for short periods, drainage greatly affected the survival of white pine and, to a lesser extent, the survival of black walnut and the height increment of both species. The results of this survey indicate that white pine is unsuitable for afforestation of bottomland sites that are subject to periodic flooding. Mortality of white pine and, to a lesser extent, black walnut is high on these sites and the form of surviving black walnut trees is generally poor. Interplanting black walnut with silver maple *(Acer saccharinum* L.), white ash *(Fraxinus americana* L.) or green ash *(Fraxinus pennsylvanica)* appears to have possibilities on these sites because these species grow well in bottomland soils. Because of their high growth rate they are able to provide competition control and to force up walnut growth, thereby improving walnut stem form and natural pruning (Johnson 1977, von Althen unpubl.).

The minor effect of initial spacing on survival and height increment of both species was probably due to natural mortality and the age of the plantations at time of sampling. With a mean survival rate of 68% for black walnut and 65% for white pine, the effects of initial spacing had largely disappeared by time of sampling. However, several of the more successful plantations clearly demonstrated the benefits of close initial spacing.

For optimum growth black walnut requires control of competing herbaceous vegetation (Byrnes 1966). During the early years after planting this control must be provided by mechanical or chemical treatments. As the trees grow, they start to provide their own competition control through shading. Unfortunately, black walnut has a rather open crown that provides relatively little shade. White pine, on the other hand, has a dense foliage that is capable of providing excellent competition control. The time required for canopy closure and provision of natural

competition control depends on initial spacing, survival and rate of growth. Planted at a spacing of 2.1 x 2.1 m (7 x 7 ft) with high survival, a black walnut-white pine plantation is capable of achieving crown closure within 10 years after planting. However, if the initial spacing of the plantation is 3.6 x 3.6 m (12 x 12 ft), crown closure will probably not occur until 15-20 years after planting. Provision of the competition control necessary for adequate walnut growth at the wider spacing may therefore require the application of mechanical or chemical competition control treatments for many years.

Another purpose of close initial spacing is to provide side shade from the surrounding trees to force walnut growth upward and thereby produce a long, straight bole with no lower side branches. If planted at a wide spacing, black walnut will produce a short bole with a large crown. Diameter growth will be greater but much artificial pruning will be required to produce a bole of acceptable length and quality.

One disadvantage of close initial spacing is the necessity of thinning. In many of the surveyed plantations with high survival, the crowns of black walnut were very short and narrow and the stem diameter of these trees was small because crown expansion was severely restricted by crowding from the fast-growing pines (Fig. 10 and 11). To provide the space necessary for expansion of the walnut crowns, both laterally and vertically, it will be necessary either to remove some white pine trees or to lop tops or prune branches. However, proper consideration must be given to the degree of release to avoid breakage or stem distortion of the small-diameter walnut trees.

Site preparation is the first step in effective competition control. By themselves, most site preparation treatments have little effect on long-term tree survival and growth (von Althen 1987). However, in combination with post-planting competition control, the method and intensity of site preparation can greatly improve the success of plantation establishment. The main purpose of site preparation is the elimination of established vegetation, especially that of deep-rooted perennials, which are difficult to control through applications of simazine.

The results of the plantation survey indicate that plowing and disking of the entire plantation area was the most effective method of obtaining high survival and increased height increment of both species (Table 10). This was particularly evident in plantations in which simazine was applied only at the time of planting. In these plantations plowing and disking of the entire plantation area improved survival of black walnut and white pine by 23% and 16%, respectively. However, in plantations with two or more applications of simazine the improvement in survival was only 5% for black walnut and 9% for white pine. This indicate that repeated applications of simazine, as prescribed by Johnston (1979), may, to some degree, compensate for lack of intensive site preparation. Also, relatively few sites are suitable for plowing and disking of the entire area and high costs make these treatments unattractive.

Figure 10. Eleven-year-old black walnut with good stem diameter and excellent stem form.

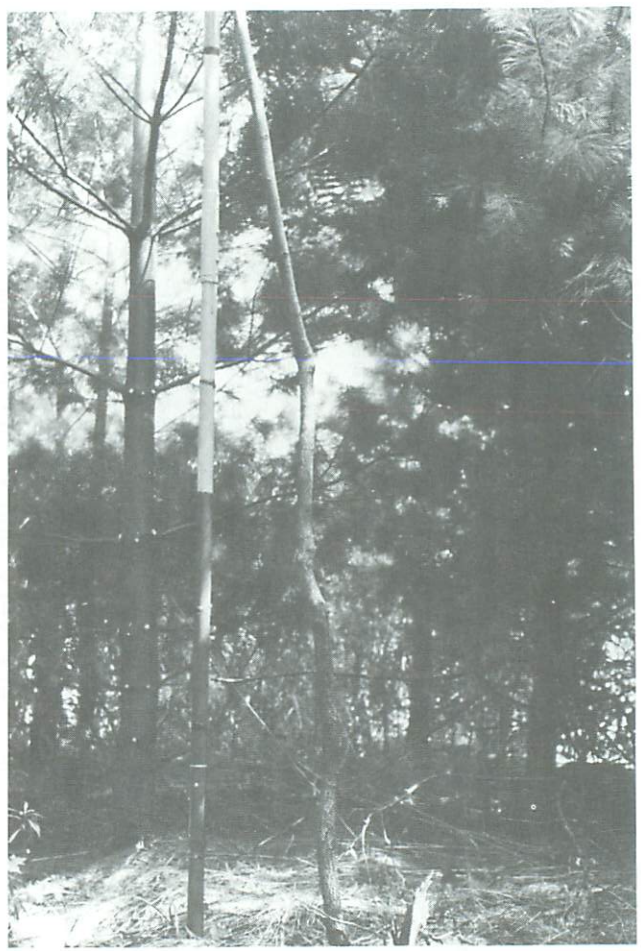

Figure 11. Black walnut in the same plantation. Poor stem diameter and form are the result of suppression by the faster-growing white pine.

Scalping of individual planting spots resulted in the lowest survival of both species. This result cannot be fully explained because scalping is an acceptable method of site preparation in soils that support a light-to-medium density of ground cover. However, it is possible that incorrect scalping or improper planting contributed to the results obtained. Proper scalping is very difficult in heavy-textured soils that support a heavy sod or other dense ground vegetation. Scalping too lightly removes only the aboveground parts of the vegetation without reducing the belowground competition and without greatly impairing the ability of the plants to regrow quickly. Scalping too deeply removes a thick layer of the most fertile topsoil and creates a depression. Seedlings planted in these depressions lose their height advantage over the surrounding vegetation, their roots may be placed in less fertile soil and water may collect in the depressions for extended periods, thereby restricting soil aeration.

Post-planting competition control was the single most important factor in the successful establishment and early growth of all sample plantations (Table 9). It was found that the greater the degree of competition control, the greater the survival and height increment of black walnut and white pine. The relatively greater establishment success and greater height increment of black walnut in the older plantations could also be traced directly to the greater intensity of competition control in these plantations. In contrast, the majority of more recently established plantations suffered from lack of competition control, which manifested itself in small height increments and poor walnut stem form. This was particularly noticeable in plantations with high white pine mortality. Where white pine was unable to close the canopy and thereby shade out the competition, a dense cover of grasses *(Agropyron repens, Bromus* spp.), sedges, *(Carex* spp.), goldenrod *(Solidago* spp.), wild aster *(Aster* spp.) and milkweed *(Asclepias syriaca)* persisted between the trees and continued to compete vigorously with the black walnut trees (Fig. 8).

The most common method of competition control was the application of simazine. Simazine is an excellent herbicide for use in walnut plantations because black walnut and, to a lesser extent, white pine are resistant to injury from simazine. Simazine is a selective pregermination herbicide that controls many broadleaved weeds and grasses. It enters the plants through the roots, and uptake through the aboveground parts of plants is minimal. It may therefore be applied in plantations without the necessity of shielding the trees. It is most active in the uppermost 5 cm of the soil and kills by disrupting photosynthesis of newly germinated plants. It has little effect on deep-rooted weeds or grasses. For greatest effectiveness simazine should therefore be applied on site-prepared ground to control the regrowth of weed species. The results of the survey clearly indicate that if simazine was applied only at time of planting, plowing and disking were prerequisite to high walnut and pine survival and growth (Table 10). If, however, simazine was applied more than once, mechanical site preparation improved survival and growth only marginally. Scalping of individual planting spots, followed

by one application of simazine shortly after planting, failed to improve the survival and height increment of either species. Scalping plus simazine resulted in much lower survival and much less height increment than did plowing and disking plus simazine.

Mowing between the trees improved survival of black walnut as well as survival and height increment of white pine, but failed to improve the height increment of black walnut. This result closely corresponds with research that proved that mowing is no substitute for mechanical or chemical competition control (von Althen 1984). There were also strong indications that mowing may be more detrimental to good walnut growth than the absence of weed control because mowing intensifies the belowground competition for water and nutrients between the roots of the herbaceous vegetation and the walnut trees. Since white pine is much less susceptible to competition from broadleaved weeds and grasses, mowing appears to have had some beneficial effect on the height increment of this species.

Refill planting is an acceptable method of assuring even spacing in plantations with high initial mortality. This mortality may occur in years with unfavorable weather conditions. However, experience has shown that replanted trees seldom catch up. It is therefore of the utmost importance to assure adequate survival at the first planting. Of the 141 plantations surveyed, 58 plantations, or 41%, required refill planting, and 19 plantations required two or more refills. This appears to be an unacceptably high number of failures and was probably related to the vagaries of weather, rodent damage, and a lack of adequate site preparation or followup competition control. Improper planting or substandard stock quality or storage are other possible reasons for plantation failures. Although topography or other conditions of the planting site may prevent the application of mechanical site preparation methods, chemical methods are available that can greatly improve survival when they are used in combination with post-planting competition control.

Young walnut trees were pruned in 15% of the plantations surveyed. This greatly improved stem form. However, the majority of plantations had received no corrective pruning, although a pruning treatment was recommended in the management plans of most plantations.

Girdling of stems of young hardwood trees by meadow voles is a serious problem in hardwood plantations. However, vole population densities are cyclical, with peak populations occurring about every 5 to 7 years. Although damage may be heavy during peak population densities, it is generally tolerable in the intervening years. Meadow voles prefer the bark of some tree species to that of others and like that of black walnut the least.

Mouse poison was applied in 49 of the 141 plantations sampled but the effectiveness of the treatment could not be ascertained because of the absence of controls and the application of poison during several years prior to sampling.

SUMMARY

In all, 141 black walnut plantations ranging in age from 6 to 18 years were surveyed in southwestern Ontario. Of these, 130 were mixtures of black walnut and white pine established more or less according to the prescription developed by Johnston (1979). In 10 plantations, only black walnut was planted, and one plantation was a mixture of black walnut and eastern cottonwood. The low number of pure walnut plantations prevented a meaningful comparison of mixed and pure plantations.

MAI of black walnut in the best walnut-pine plantations was as great as that of the best previously surveyed pure walnut plantations in Ontario or as the predicted values for walnut plantations Site Index 50 in the United States. However, the majority of plantations, both mixed and pure, did not perform as well as was expected. The main reason for the slow growth appeared to be lack of competition control. Mean survival in all plantations was 68% for black walnut and 65% for white pine. Many plantations were understocked and the white pine component was unable to provide the required competition control. The management plans of most plantations called for repeated applications of herbicides but these recommendations were often not followed, apparently because of funding restraints.

Plowing and disking of the plantation area prior to planting greatly improved tree survival and height increment, but scalping of individual planting spots failed to improve survival or height increment.

The effects of soil texture and drainage on tree survival and height increment could not be clearly determined because of the relatively young age of the plantations and the confounding influence of other factors such as site preparation and competition control. Only on bottomland soils, which flood during parts of the year, did poor drainage greatly reduce the survival and height increment of white pine and, to a lesser extent, those of black walnut.

Although more research is required to determine the relative importance of factors affecting the performance of walnut plantations, this plantation survey has shown that the black walnut-white pine mixture can produce excellent plantations. It has also shown that planting black walnut in mixture with white pine is no substitute for intensive tending. The control of competing vegetation during the early years following planting is necessary until the pine trees are large enough to shade out the competition. It is also necessary to prune the walnut trees repeatedly to produce stems suitable for the production of veneer bolts or high-grade sawlogs.

Depending on initial spacing and tree survival it is also necessary either to thin the pine component of the plantation, to prune the pines severely, or to lop tops of some pine trees to provide adequate space for the development of full walnut crowns.

Every tree planter should also remember that black walnut is a very demanding species that responds exceptionally well to intensive management. For optimum growth, black walnut requires "tender loving care" that includes intensive weed control, frequent light prunings and protection from animal damage.

RECOMMENDATIONS

To assure the success of black walnut afforestation in south-western Ontario, the following recommendations are made:

1. Plant black walnut only in fertile but well drained sandy loams, silt loams or clay loam with A and B horizons at least 50 cm deep.

2. On sites with high owner involvement and a topography suitable for mechanical cultivation and weed control, plant black walnut alone and maintain intensive mechanical and/or chemical competition control to obtain maximum growth.

3. On sites with limitations in accessibility or owner involvement, plant black walnut in mixture with white pine according to the Johnston (1979) prescription.

4. On bottomland that is subject to periodic flooding, plant either black walnut alone or in mixture with other hardwood species such as silver maple, white ash, or green ash.

5. To eliminate the established vegetation, either plow and disk the entire plantation area or apply 1800 g a.i./ha of glyphosate (5 L/ha of commercial product) in late August over the entire plantation area or, as a minimum, in strips or spots with a diameter of at least 1.5 m. (Application of glyphosate in August facilitates translocation of the herbicide to the roots, thereby killing the weeds and providing a weedfree soil in spring for planting and the application of simazine, which will prevent the reinvasion of the weed cover.)

6. Plant walnut, walnut-pine, or walnut-hardwood mixtures at spacings of 2.1 x 2.1 m (7 x 7 ft) as recommended by Johnston (1979), or at 3 x 1.5 m (10 x 5 ft) to allow cultivation and herbicide applications with a medium-sized tractor. This will facilitate early canopy closure, and will promote natural weed control through shading.

7. Immediately after planting apply 6.7 kg a.i./ha of simazine (7.5 kg/ha of Princep Nine-T) over the entire plantation area, or, as a minimum, in strips at least 1.5 m wide, or around individual trees (with a treated area of at least 1.5 m in diameter). Repeat applications in early spring of the third growing season and every two years thereafter until the canopy has closed.

8. If possible, inspect plantations annually and prune forks and large side branches of walnut trees, where necessary, to improve stem form. Ideally, prune in summer, autumn or early winter of the third and sixth growing season. Continue as required until the trees have attained between 7.5 and 11 m (25 to 36 ft) of branch-free bole.

9. When crowns are touching on all sides or when the interplanted trees overtop the walnut, prune side branches, lop tops or remove some interplanted trees to provide space for the expansion of walnut crowns.

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