Vegetative Propagation of Butternut (*Juglans cinerea*) Field Results

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ABSTRACT—*Juglans cinerea* L. is a hardwood species valued for its wood and edible nuts. Butternut canker disease (*Sirococcus clavigignenti-juglandacearum*) threatens its survival. Vegetative propagation will be required to produce clones of genotypes selected for resistance to butternut canker disease. In 2000, 10 trees were randomly selected from a 6-year-old butternut plantation located in Rosemount, MN. Hardwood stem cuttings were collected in March, April, and May. Softwood cuttings were collected in June and July. Indole-3-butyric acid-potassium salt (K-IBA) at 0, 29, or 62 mM in water and indole-3-butyric acid (IBA) at 0, 34, or 74 mM in 70% ethanol were tested for root induction on cuttings. The basal end of cuttings were dipped in a treatment solution for 10 to 15 s, potted in a peat:perlite mixture and placed in a mist bed for 5 to 8 weeks. Rooted cuttings were gradually hardened off from the mist bed, allowed to initiate new growth, over-wintered in a controlled cold-storage environment, and then outplanted to the field. Rooting was greatest for hardwood cuttings taken in mid-May (branches flushed out), 22% with 62 mM K-IBA and 28% with 74 mM IBA. Softwood cuttings rooted best when taken in June (current season's first flush of new growth or softwood growth 40 cm or greater) and treated with 62 mM K-IBA (77%) or 74 mM IBA (88%). One-hundred and seventy three (173) out of 186 rooted softwood cuttings (93%) survived over-wintering and acclimatization to the field. Average heights and stem diameters were after 1 year (28.6 cm, 12.4 mm) or 2 years (92.8 cm, 18.6 mm). When plants were protected from deer browse, rodent damage, and weed controlled, 91% survived in the field.

INTRODUCTION

Butternut (*Juglans cinerea* L.), also known as white walnut or oilnut, is a relatively slow-growing hardwood species found in bottomlands, moist uplands, and old fields (Leopold and others 1998). Moist, rich loamy soils of hillsides and streambanks are the preferred growing sites, although butternut can grow quite well on dry, rocky soils. *Juglans cinerea* is considered to be one of the most winter hardy (USDA Hardiness Zone range of 3 to 7) of the *Juglans* species (Cathey 2003, Dirr 1998). Butternut is seldom found growing in pure stands, but rather in association with several other tree species such as black cherry, American basswood, white and northern red oak, black walnut, white ash, red and sugar maple, and American elm. It is native to the northeastern United States and adjacent Canada, ranging from New Brunswick to Georgia, and west to Minnesota and Arkansas (Rink 1990). Butternut is valued ecologically and economically for its edible nuts and wood (Ostry and Pijut 2000). The nuts are oily and sweet, and are an important food source for wildlife. Seed production begins on trees around 20 years of age, with good seed crops occurring every 2 to 3 years, based on seedling stands not grafted trees. Because of the limited availability of quality butternut wood, it commands a high market price for many uses including furniture, cabinets, paneling, veneer, and fine woodworking. Its light tan heartwood is very workable with hand and power tools (for specialty carving products) and can be stained to resemble black walnut.

Butternut canker disease, caused by the fungus *Sirococcus clavigignenti-juglandacearum* N.B. Nair, Kostichka and Kuntz (Nair and others 1979) has

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caused widespread mortality and is threatening native tree survival (Orchard and others 1982; Tisserat and Kuntz 1984; Cummings 1993; Ostry 1997, 1998; Nair 1999). The fungus, believed to be introduced (Furnier and others 1999), causes perennial cankers on all above ground parts of the tree, even the buttress roots (Sinclair and others 1987). The spores of the fungus are disseminated by rain splash and can travel in aerosols to adjacent trees where infection occurs on young branches in the upper crowns. Several insect species have been found associated with fungus spores on infected trees (Katovich and Ostry 1998). The fungus has also been found on the fruit of butternut and black walnut, causing lesions on the husks of both species (Innes 1998). The cankers cause the wood to turn dark brown to black in an elliptical pattern (Ostry and others 1996) that reduces the quality and marketability of the wood. The girdling effect of multiple coalescing cankers eventually kills the trees.

Butternut is propagated easily from seed (Brinkman 1974), but the canker fungus is also seed-borne (Orchard and others 1981, Orchard 1984). Vegetative propagation will be required to produce clones of genotypes selected for resistance to butternut canker disease. Grafting of butternut to black walnut rootstock (Ostry and Pijut 2000) can be successful, but grafting is a time consuming process with variable success. There are few reports of vegetative propagation of butternut through cuttings (Pijut and Barker 1999, Pijut and Moore 2002). Rooting is reported for other *Juglans* species: *J. hindsii* (Lee and others 1977), *J. microcarpa* (Shreve 1990), *J. nigra* (Farmer 1971, Shreve 1972, Shreve and Miles 1972, Farmer and Hall 1973, Carpenter 1975), *J. regia* (Gautam and Chauhan 1990), *J. sinensis* (Kwon and others 1990), and hybrids (Serr 1964, Reil and others 1998). This paper describes the experimental conditions and results for successful cutting propagation of butternut, and growth and survival data of some of the rooted cuttings after 1- or 2-years in the field.

MATERIALS AND METHODS

Hardwood Cuttings

In 2000, 10 trees were selected from a 6-year-old butternut field plot located in Rosemount, MN. Hardwood cuttings were collected at specific growth stages: dormant (Mar. 29, 2000); budbreak (May 2, 2000); and branches flushed out (May 19, 2000). Six to twelve cuttings (25 cm in length) were taken from each tree at each collection date. Two years of growth were pruned from the remaining branches (after last hardwood collection date) to encourage sprouting. Cuttings were placed in polyethylene bags, held on ice, and transported to the greenhouse, where the cuttings were processed the same day. Stems were recut to between 20 and 23 cm in length. The basal 3 cm of cuttings were treated by dipping for 10 to 15 s in either 0, 29, or 62 mM indole-3-butyric acid-potassium salt (K-IBA) dissolved in deionized water or 0, 34, or 74 mM indole-3-butyric acid (IBA) dissolved in 70% ethanol. Cuttings were inserted vertically to a depth of 5 to 7 cm in Deepots™ (D40) (Stuewe and Sons, Corvallis, OR) containing a moist medium of 1 perlite : 1 peat (v/v). Cuttings in Deepots™ were placed under intermittent mist (15 s every 18 min) on a greenhouse bench with bottom heat maintained at 27° C. Twelve hours of supplementary irradiance (from 0600 to 1800 HR) were provided by high-pressure sodium lamps (60 µmol·m-2·s-1 at bench top), and greenhouse temperature was maintained at 22 $\pm$ 2° C. After 6 to 8 weeks, cuttings were harvested and number of cuttings rooted, number of roots per cutting, and individual root lengths were recorded. Data were analyzed using statistical programs for categorical data (Rugg, unpublished data), log linear modeling (SPSS 1998), and logistic regression (Mehta and Patel 1996). The number of roots per cutting were square root transformed and the data analyzed using linear regression. The data for root lengths were log transformed and the data analyzed using linear regression.

Rooted cuttings were transplanted in Treepots™ (Tall One) (Stuewe and Sons) containing a moist medium of Sunshine SB-40 bark mix (Sun Gro Horticulture, Bellevue, WA), with 14N–14P–14K Nutricote® timed-release fertilizer (Chisso-Asahi Fertilizer Co., Tokyo, Japan) and returned to intermittent mist for 1 week. Rooted cuttings were then acclimatized to greenhouse benches and allowed to initiate new shoot growth. In late October or early November, rooted cuttings were placed in a cooler environment (15° C or less) and lower light to induce dormancy. After a month, containerized cuttings were placed in polyethylene bags and moved to a controlled cold-storage environment (3 to 4° C in darkness) for 4 to 5 months. After overwintering, the pots were returned to the greenhouse (March/April, the following year), and allowed to acclimatize to this environment. Pots were hand-watered as needed until budbreak, after which the pots were placed on an automatic drip irrigation system until they were field-planted in July.

Softwood Cuttings

In 2000, the same 10 trees as used for hardwood cuttings were used for softwood cuttings. Softwood cuttings were collected at specific growth stages: current season's first flush of new growth (June 12, 2000); softwood growth 40 cm or greater (June 23, 2000); shoots beginning to become lignified (July 7, 2000); and shoots starting to set bud (July 19, 2000). Six to twelve cuttings (40 to 45 cm in length) were taken from each tree at each collection date. All but two leaves were removed. Softwood cuttings were handled and processed as described for hardwood cuttings, except no bottom heat was used in the mist bed. After 5 to 6 weeks, cuttings were harvested and rooting data recorded. Data collection and statistical analyses were the same as described for hardwood cuttings. Rooted cuttings were maintained, allowed to initiate new growth, overwintered, and planted in the field as described for hardwood cuttings.

Field Plantings

Rooted cuttings were planted in the field at the Southeast Purdue Agricultural Center (SEPAC) (July 2001; 56 plants) located near North Vernon, IN, and at the Vallonia Nursery (July 2002; 81 plants) located in Vallonia, IN. The butternut plants transported to the Vallonia nursery were kept in the Treepots™ outdoors for one additional year until the site was available for planting in July 2002. Therefore, data on these plants are considered as 1-year-old field results. When feasible rooted cuttings were protected with mesh cages to prevent deer browse and rodent damage, and sprayed with herbicides to control weeds. Percent survival, stem heights (cm), and stem diameter (mm) at ground level (root collar) were recorded in 2003.

RESULTS

Hardwood Cuttings

Rooting success did not vary by growth stage (collection date) ($P > 0.85$). K-IBA or IBA were equally effective in promoting rooting ($P = 0.38$). There was a significant effect of the auxin concentration ($P = 0.007$). The controls [deionized water or 70% ethanol] were not different ($P = 0.11$) from the low concentration [29 mM K-IBA or 34 mM IBA], but did significantly differ ($P = 0.005$) from the high concentration [62 mM K-IBA or 74 mM IBA] (Table 1). The low and high concentrations did not differ ($P = 0.24$) from each other in rooting success, but a logistic regression on these data showed that a linear response to concentration accounts for nearly all of the variability in the data. The greatest rooting success was with 62 mM K-IBA (22.2%) and 74 mM IBA (27.8%) when hardwood cuttings were collected when the branches had flushed out (mid-May). There was no difference in the number of roots regenerated per hardwood cutting ($P > 0.1$). No differences ($P = 0.02$) were observed for root lengths. Six out of six rooted cuttings (100%) survived over-wintering in cold storage and acclimatization to the field.

Table 1.—Effects of time of collection and rooting treatment concentration on rooting percentage, root count, and root len gth of Juglans cinerea hardwood cuttings.[1]

Rooting Treatment (mM)	Date of Collection[2] 2000		
	29 March	2 May	19 May
	Rooting (percent)		
0 K-IBA	0 a[3]	0 a	11.1 a
29 K-IBA	9.1 a	6.3 ab	16.7 ab
62 K-IBA	0 a	12.5 b	22.2 b
0 IBA	0 a	0 a	11.1 a
34 IBA	0 a	6.3 ab	11.1 ab
74 IBA	0 a	6.3 b	27.8 b
	Mean number of roots[4]		
0 K-IBA	- -	- -	1.0 a
29 K-IBA	1.0	4.0 a	7.0 a
62 K-IBA	- -	1.5 a	4.8 a
0 IBA	- -	- -	2.0 a
34 IBA	- -	7.0 a	1.0 a
74 IBA	- -	2.0 a	3.1 a
	Mean root length (mm)w		
0 K-IBA	- -	- -	8.0 a
29 K-IBA	22	21.5 a	23.4 a
62 K-IBA	- -	7.3 a	9.4 a
0 IBA	- -	- -	13.7 a
34 IBA	- -	17.9 a	8.0 a
74 IBA	- -	5.0 a	11.2 a

[1]*Average sample size for each collection date and rooting treatment concentration, n =14.*

[2]*Hardwood cutting growth stages: dormant (2000 March 29); bud break (2000 May 2); and branches flushed out (2000 May 19).*

[3]*Mean separation within a column by LSD, P < 0.05. Letters indicate significant differences among means within a column for a given variable. "- -" indicates that no mean was calculated because no observations were available.*

[4]*Means are per rooted cutting.*

Softwood Cuttings

Sample development stages showed no change in rooting success (P > 0.40). Auxin type did not effect rooting success (P = 0.79). However, there was a significant additive effect on rooting success with the auxin concentration of rooting treatment used (P < 0.0001). Using K-IBA (29 or 62 mM) or IBA (34 or 74 mM) improved rooting success over the control, but there was no difference (P = 0.39) between the treatment levels (Table 2). The greatest rooting success of 76.9% (62 mM K-IBA) and 87.5% (74 mM IBA) was achieved when softwood cuttings were taken in June (Fig. 1A). Using K-IBA or IBA produced more roots than controls (P < 0.0001), but the auxin concentrations did not differ in number of roots produced (P = 0.43). There were no differences between the controls (water versus 70% ethanol) in number of roots produced (P = 0.69). In addition, the high concentrations of both K-IBA and IBA produced a similar number of roots (P = 0.11). However, the 34 mM IBA treatment resulted in significantly greater root numbers (P = 0.0001) than in the similar concentration of K-IBA. For K-IBA, the low concentration (29 mM) was not statistically different from either the control (P = 0.14) or the high concentration (P = 0.08). However, the high concentration produced more roots than the control (P = 0.006). Using K-IBA produced a linear dose-response relationship for number of roots produced. Softwood cuttings have a uniformly higher number of roots produced than do hardwood cuttings. Cuttings, from the current season's first flush of new growth (20.8 cm) and shoots beginning to become lignified (24.7 cm) development stages, had shorter roots than the softwood growth 40 cm or greater development stage (34.9 cm). There was no difference in root length from cuttings from the first, third, and fourth sample development stages. Mean root length was similar for all treatments and controls. One hundred and seventy three out of 186 rooted softwood cuttings (93%) survived over-wintering and acclimatization to the field (Fig. 1B).

Table 2.—Effects of time of collection and rooting treatment concentration on rooting percentage, root count, and root length of Juglans cinerea softwood cuttings.[1]

Rooting treatment (mM)	Date of Collection[2] 2000			
	12 June	23 June	7 July	19 July
	Rooting (percent)			
0 K-IBA	37.5 a[3]	17.9 a	10.7 a	23.1 a
29 K-IBA	37.5 b	73.1 b	42.9 b	50.0 b
62 K-IBA	44.4 b	76.9 b	42.9 b	57.7 b
0 IBA	37.5 a	25.0 a	10.7 a	19.2 a
34 IBA	37.5 b	67.9 b	39.3 b	50.0 b
74 IBA	87.5 b	75.0 b	46.4 b	46.2 b
	Mean number of roots[4]			
0 K-IBA	3.0 a	3.5 a	1.7 a	3.8 a
29 K-IBA	7.0 b	9.7 b	3.9 b	8.0 b
62 K-IBA	13.8 c	7.3 c	13.3 c	11.2 c
0 IBA	3.0 a	3.1 a	1.7 a	3.0 a
34 IBA	9.7 c	20.6 c	10.7 c	12.2 c
74 IBA	18.7 c	21.0 c	7.4 c	6.0 c
	Mean root length (mm)[w]			
0 K-IBA	29.0 a	42.0 a	35.3 a	24.2 a
29 K-IBA	13.8 a	40.2 a	22.2 a	38.7 a
62 K-IBA	26.5 a	32.5 a	24.2 a	30.9 a
0 IBA	12.7 a	17.5 a	18.0 a	58.7 a
34 IBA	26.2 a	41.0 a	24.1 a	22.1 a
74 IBA	16.7 a	36.1 a	24.5 a	20.9 a

[1]Average sample size for each collection date and rooting treatment concentration, n = 21.

[2]Softwood cutting growth stages: current season's first flush of new growth (2000 June 12); softwood growth 40 cm or greater (2000 June 23); shoots beginning to become lignified (2000 July 7); shoots starting to set bud (2000 July 19).

[3]Mean separation within a column by LSD, P < 0.05. Letters indicate significant differences among means within a column for a given variable. "- -" indicates that no mean was calculated because no observations were available.

[4]Means are per rooted cutting.

Field Plantings

In the SEPAC planting, 51 out of 56 plants (91%) survived in the field after 2 years. These plants were protected with mesh cages to prevent deer browse and rodent damage, and routinely sprayed with herbicides to control weeds (Fig. 2). Average stem heights in centimeters (mean number ± SE) ranged from 66.4 ± 8.0 to 123.7 ± 25.6, with a total average of 92.8 ± 5.9 after 2 years (Table 3). Average stem diameters in millimeters (mean number ± SE) ranged from 14.1 ± 0.9 to 21.3 ± 3.1, with a total average of 18.6 ± 0.7 after 2 years.

In the Vallonia planting, 54 out of 81 plants (67%) survived in the field after 1 year. These plants were not protected with mesh cages to prevent deer browse. Herbicides were used at this site (prior to planting and once after planting), but several factors (remote site, unavailability of spray equipment, and wet weather) combined to render control of weeds ineffective. Deer browse, drought in the summer, and weed competition in this planting had the greatest overall effect on survival of the butternut plants. Average stem heights in centimeters ranged from 15.7 ± 6.4 to 46.3 ± 10.3

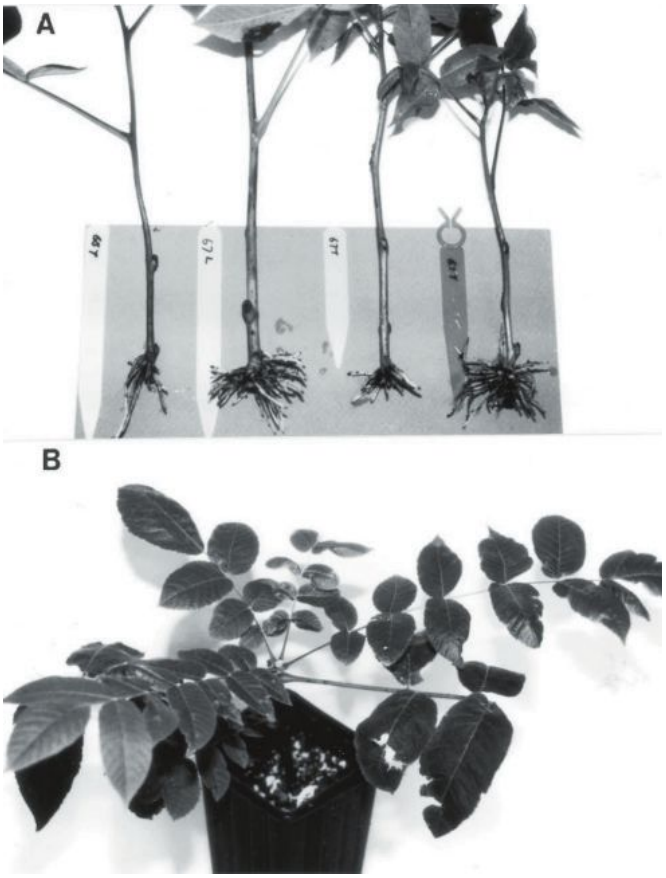

Figure 1.—(A) Rooted softwood cuttings of Juglans cinerea after 4 wk under mist (from left to right: 34, 74 mM IBA, and 29, 62 mM K-IBA). (B) Butternut plant (softwood cutting, June collection, 62 mM K-IBA) ready for transplanting to the field. [Reprinted with permission from HortScience 37(4): 697-700. 2002]

Figure 2.—Butternut plant (rooted cutting) after 2 years in the Southeast Purdue Agricultural Center field. For comparison, the woman in the photo is 160 cm tall.

with a total average of 28.6 ± 1.9 after 1 year (Table 4). Average stem diameters in millimeters ranged from 8.0 ± 1.0 to 14.0 ± 0.8, with a total average of 12.4 ± 0.5 after 1 year.

DISCUSSION

Propagation of 6-year-old *J. cinerea* from hardwood cuttings collected in mid-May (branches flushed out in the spring) was successful (11.1 to 27.8%), although at a low percentage. The greatest rooting success of 22.2% and 27.8% was achieved when hardwood cuttings were treated with 62 mM K-IBA or 74 mM IBA. Rooted hardwood cuttings were successfully over-wintered in cold storage and planted to the field. Propagation of other *Juglans* species by hardwood cuttings has also been investigated. Hardwood cuttings of 'Paradox' walnut (*J. hindsii* x *J. regia*) root with variable success (30 to 80%) after a quick dip in 20 mM to 39 mM IBA or a 24-hr soak in 1mM to 1.5 mM IBA (Serr 1964, Reil and others 1998). Dormant cuttings taken from 4- to 5-year-old hedges of *J. regia* rooted (14.5%) when treated with 74 mM IBA (Gautam and Chauhan 1990). Carpenter (1975) reported 60 to 70% rooting of hardwood cuttings taken from mature black walnut trees (*J. nigra*), when soaked in ethephon for 6 hr, but shoots did not elongate following this treatment and no survival was reported.

Softwood cuttings of butternut rooted better than hardwood cuttings. Softwood cuttings rooted (10.7 to 87.5%) at all collection dates and rooting treatment concentrations tested. Rooting success ranged from 17.9 to 87.5% when June cuttings (current season's first flush of new growth or softwood growth 40 cm or greater) were treated with 0 K-IBA or 74 mM IBA. The greatest rooting success (76.9% and 87.5%) was achieved when softwood cuttings collected in mid- to late-June 2000 were treated with 62 mM K-IBA or 74 mM IBA. Rooted softwood cuttings were successfully over-wintered and transplanted to the field. Propagation of other *Juglans* species by softwood cuttings is also successful. Cuttings taken from adventitious shoots of eastern black walnut, *J. nigra*, (from one to 135-year-old material) rooted 80 to 100% when

Table 3.—Growth parameters of butternut plants (rooted softwood cuttings) after 2 years in the Southeast Purdue Agricultural Center field.

Tree No.	Height (cm)	Stem Diameter (mm)
103	126.0	24.3
103	142.0	28.5
103	158.0	23.8
103	105.0	18.6
103	39.0	11.7
103	93.0	18.3
103	98.0	21.5
Mean number + SE	108.7 + 14.7	21.0 + 2.0
104	51.0	12.4
104	95.0	19.3
104	96.0	20.5
104	89.0	22.1
104	167.0	29.5
104	55.0	14.1
Mean number + SE	92.2 + 17.0	19.7 + 2.5
105	45.0	10.2
105	79.0	16.0
105	70.0	21.2
105	51.0	10.8
105	87.0	14.1
Mean number + SE	66.4 + 8.0	14.5 + 2.0
108	102.0	15.1
108	94.0	15.9
108	31.0	12.1
108	56.0	13.1
Mean number + SE	70.8 + 16.6	14.1 + 0.9
110	47.0	13.0
110	132.0	27.6
110	100.0	16.3
110	153.0	28.6
110	145.0	21.0
Mean number + SE	115.4 + 19.3	21.3 + 3.1
112	80.0	18.9
112	96.0	21.9
112	50.0	14.9
112	90.0	24.9
112	19.0	9.9
Mean number + SE	67.0 + 14.4	18.1 + 2.6
113	69.0	16.2
113	148.0	24.0
113	102.0	20.1
113	32.0	12.5
113	124.0	21.4
113	99.0	14.1
Mean number + SE	95.7 + 16.7	18.1 + 1.8
114	153.0	19.9
114	42.0	11.0
114	148.0	21.4
114	166.0	24.3
114	47.0	23.1
114	186.0	23.9
Mean number + SE	123.7 + 25.6	20.6 + 2.0
115	96.0	17.9
115	70.0	17.3
115	46.0	13.8
115	149.0	26.4
Mean number + SE	90.3 + 22.1	18.9 + 2.7
117	87.0	20.3
117	57.0	14.8
117	72.0	16.3
Mean number + SE	72.0 + 8.7	17.1 + 1.6
TOTAL		
Mean number + SE	92.8 + 5.9	18.6 + 0.7

Table 4.—Growth parameters of butternut plants (rooted softwood and hardwood cuttings) after 1 year in the Vallonia field.

Tree No.	Height (cm)	Stem Diameter (mm)
103	25.0	13.0
103	18.0	16.0
103	34.5	9.0
103	32.0	16.0
Mean number + SE	27.4 + 3.7	13.5 + 1.7
104	27.5	9.0
104	14.0	9.0
104	5.5	6.0
Mean number + SE	15.7 + 6.4	8.0 + 1.0
108	36.0	9.0
108	56.5	13.0
Mean number + SE	46.3 + 10.3	11.0 + 2.0
110	43.0	16.0
110	56.5	19.0
110	43.5	9.0
110 Hardwood	48.5	13.0
110	16.0	13.0
110	26.0	13.0
110	15.0	6.0
110	53.0	16.0
Mean number + SE	37.7 + 5.8	13.1 + 1.5
113	21.0	16.0
113	18.0	16.0
113	4.0	9.0
113	8.0	6.0
113	15.0	13.0
113	11.0	16.0
113	12.0	16.0
113	8.0	6.0
113	15.0	13.0
113	29.0	13.0
113	41.0	16.0
113	42.0	16.0
113	48.0	19.0
113	42.5	16.0
113	38.0	16.0
113	19.0	13.0
113	41.0	13.0
113	42.5	16.0
113	39.0	9.0
113 Hardwood	50.0	16.0
113 Hardwood	39.5	22.0
113	34.5	13.0
113	55.0	13.0
Mean number + SE	29.3 + 3.3	14.0 + 0.8
114	17.0	13.0
114	32.0	9.0
Mean number + SE	24.5 + 7.5	11.0 + 2.0
115 Hardwood	23.0	9.0
115	31.0	3.0
115	28.0	16.0
115	25.0	13.0
115	10.0	13.0
115	23.5	13.0
115	19.0	6.0
115	20.0	6.0
115	26.0	13.0
115	28.0	9.0
115	14.5	9.0
115	22.5	13.0
Mean number + SE	22.5 + 1.7	10.3 + 1.1
TOTAL		
Mean number + SE	28.6 + 1.9	12.4 + 0.5

treated with 25 to 49 mM IBA (Shreve 1972, Shreve and Miles 1972). Rooting (0 to 100%) of juvenile black walnut (2-year-old seedlings) occurs after extensive etiolation and auxin treatments (Farmer 1971, Farmer and Hall 1973). Lee and others (1977) reported that cuttings taken from adventitious shoots of a 5-year-old *J. hindsii* tree had a significantly greater number of roots produced as a result of pretreatment with 2N sulfuric acid prior to a 10 sec dip in 15 mM IBA. Shreve (1990) reported rooting (percentage not stated) *J. microcarpa* (river walnut) softwood cuttings by treatment with 34 mM IBA and without the use of a mist bed.

This is the first report of field survival of *Juglans cinerea* (butternut) plants vegetatively propagated from cuttings of 6-year-old trees.

CONCLUSIONS

Juglans species are, for all practical purposes, recalcitrant to routine, commercial-scale, vegetative propagation. However, successful propagation of *J. cinerea* on a commercial scale can be achieved if the type of cutting (softwood), date of collection (early season), auxin concentration (62 mM K-IBA or 74 mM IBA), and greenhouse parameters (mist bed, supplemental lighting, etc.) are carefully considered. High field survival and good growth parameters can be achieved if plants are protected from deer browse and weeds are controlled.

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