TERMINAL BUD CLUSTER PRUNING PROMOTES APICAL CONTROL IN TRANSPLANTED SHADE TREE WHIPS

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Abstract. Transplant-induced loss of apical control, as measured by the central leader to total lateral branch caliper ratio, was documented for 'Patmore' green ash (*Fraxinus pennsylvanica*) and 'Autumn Purple' white ash (*F. americana*) by measuring trees one, two, five and 10 years after transplanting. For both species, the central leader to total lateral branch caliper ratio ranged from 0.3 to 0.5, regardless of the age from transplanting, indicating that large lower limb development (loss of apical control) was initiated at transplanting and persists for up to 10 years. Transplanted nursery grown 'Patmore green ash and 'Autumn Purple' white ash trees bud pruned to maintain a strong central leader had central leader to total lateral branch caliper ratios of 0.7 and 0.8, respectively. A pruning treatment, removing the lateral buds from the terminal bud cluster, reduced large lower limb development, maintained apical control and resulted in better lateral branch distribution in transplanted red oak (*Quercus rubra*) and 'Patmore' and 'Autumn Purple' ash whips than leaving the terminal bud cluster intact.

Introduction

Tree crown form results from the interaction of genetic and environmental factors (13). A tree's form is determined by the differential elongation of its shoots (6). In green ash (*Fraxinis pennsylvanica*) terminal buds in the upper crown positions are the first to elongate in spring, elongate faster and have a longer elongation period than lateral buds in the terminal bud clusters, or buds in lower crown positions (6).

Inherent crown form can be modified by environmental stress, especially water stress (13). Water stressed trees typically have multiple leaders, with a flat topped crown, indicating that water stress causes loss of apical dominance or control. Apical dominance is defined as the complete inhibition of lateral buds on the current year's shoot (central leader) (13). Loss of apical control refers to the release and rapid growth of two or more of the uppermost lateral buds in the spring which tend to suppress the terminal leader. Transplanting is a stress (9) and thus transplanted trees would have reduced apical control (10). An expression of reduced apical control is large diameter lower limb development (10) and an "intermediate" crown form type with more than one main stem (6).

Transplanting induced loss of apical control is easily corrected by timely pruning, especially during the first one-to-three years after transplanting (2). Corrective pruning focuses on maintaining a central leader by removing or severely pruning competing lateral branches. Intensive pruning as practiced in production nurseries is not widely practiced by municipal foresters (1 and 5). However, if competing lateral branches are not corrected, large diameter limbs develop in the lower crown. An inexpensive, fast, pre-transplanting pruning technique is needed so that apical control and natural crown form are maintained.

This study was conducted: 1) to describe loss of apical control by measuring lower limb caliper in transplanted whips of two ash cultivars, 2) to study the effects of lateral bud removal from the terminal bud cluster on apical control in transplanted red oak (*Quercus rubra*), and in green ash (*Fraxinus pennsylvanica* 'Patmore') and white ash (F. *americana* 'Autumn Purple') whips.

Material and Methods

Two series of experiments were conducted. In the first series, loss of apical control following transplanting was described. Because untransplanted control trees were not available, the growth of transplanted nursery-grown trees pruned to maintain apical control was used for comparison with trees transplanted to curb lawn sites. In the second series a novel method of maintaining apical control in transplanted red oak and ash whips was explored.

Loss of Apical Control Following Transplanting. The measure of apical control used in this study was the ratio between the central leader caliper to total limb caliper of the lowest branches. A low ratio indicates large lateral limb

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caliper relative to the central leader caliper and loss of apical control. The effect of transplanting on apical control was determined by measuring 'Patmore' green ash and 'Autumn Purple' white ash trees transplanted five (in 1990) or 10 years (in 1985) before measurements were taken in spring 1996. Ten unpruned trees of each species and age class were randomly selected from the City of Columbus street tree inventory. All trees were planted in curb lawn sites and had received no pruning before measuring. The caliper of the central leader 2.5 cm (1 in) above the lowest whorl of branches was measured, as were the calipers of the individual limbs in the lowest whorl of branches (Fig. 1). Limb calipers of individual trees were totaled, and the central leader to total lateral limb caliper ratio calculated. Central leader to lateral limb caliper ratios for trees one and two years after transplanting were obtained from control trees in the terminal bud cluster pruning experiment described below.

Similar measurements were made on 7 to 10 cm (2.5 to 4 in) caliper nursery grown (Scarff's Nursery, New Carlisle, OH) 'Patmore' green ash and 'Autumn Purple' white ash to estimate the central leader to lateral limb diameter ratio of "untransplanted" trees. These trees were transplanted four years prior to measurement and were pruned to enhance their natural form: maintaining a strong central leader and reducing large caliper limb development in the lower crown according to Flemer (2).

Terminal Bud Cluster Pruning. Two bud pruning experiments were conducted with red oak and one with 'Patmore' green ash and 'Autumn Purple' white ash. In a preliminary experiment, the dormant lateral buds in the terminal bud cluster of 200 red oak whips were removed by thumb nail in March 1993 (Treatment "B" in Fig. 2). If co-dominate terminal buds were present, one was removed. The whips were lined out in rows 3.1 m (10 ft) apart and spaced 1.2 m (4 ft) apart within the rows. The block was clean cultivated during 1993. In September 1993, terminal shoot length and the distance from the 1993 terminal bud scale scar to the lowest lateral branch formed during 1993 were measured and the number of intercluster buds forming lateral branches counted.

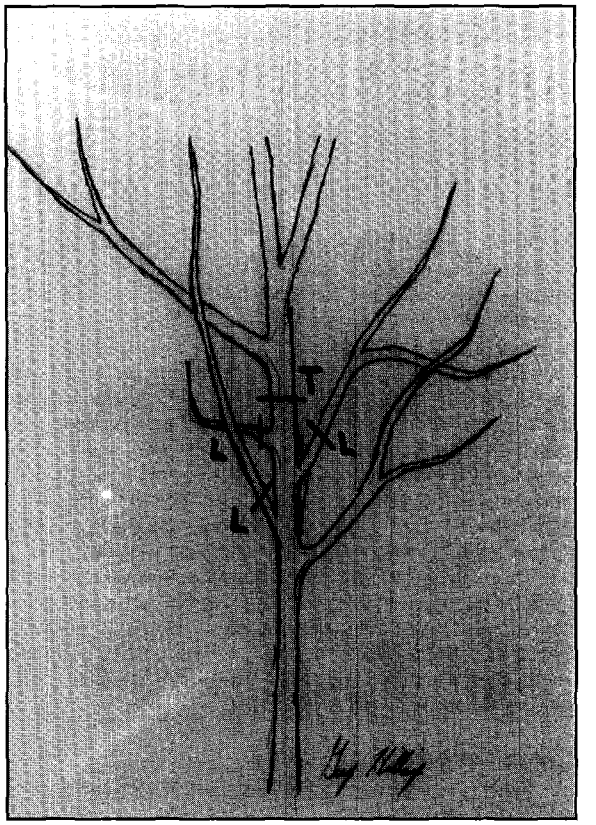

Figure 1. Drawing indicating the site of terminal shoot caliper measurement (T) and the sites of lower limb caliper measurements (L) of a tree transplanted 10 years before measurements were taken.

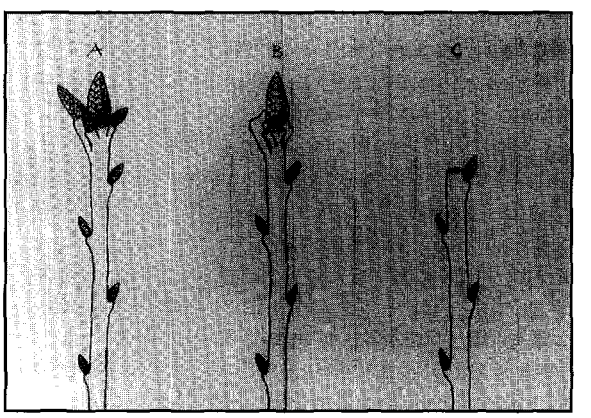

Figure 2. Drawings illustrating the terminal bud pruning cluster pruning treatments for red oak seedlings: Intact (A), Lateral Bud Removal where the lateral buds in the terminal bud cluster were removed (B), and Terminal Bud luster Removal where the terminal bud cluster was pruned and the upper most lateral bud taped to reestablish a single central leader (C).

A second red oak bud pruning experiment was conducted in spring 1995. On April 12, 60 container-grown whips, 1 to 1.2 m (3-4 ft) tall were selected. Three terminal bud pruning treatments were applied to 20 plants each: 1) intact—terminal bud left untouched; 2) lateral buds in the terminal bud cluster removed— lateral buds in the terminal cluster removed as described previously; and 3) terminal bud cluster removal—the terminal bud cluster was pruned, leaving only intercluster buds (Fig. 2). The "apical-most" intercluster bud on each plant was taped to train it into a central leader, a standard nursery practice used to restore a central leader when the terminal bud is damaged (Keith Warren, personal communication, J. Frank Schmidt and Son Co., Boring, OR). In September 1995, the terminal shoot, the longest lateral shoot and the distance from the base of the 1995 bud scale scar to the lowest lateral branch were measured, and the number of intercluster buds forming lateral branches during 1995 were counted.

A third terminal bud cluster pruning experiment was conducted with 'Patmore' green ash and 'Autumn Purple' white ash whips. Bare root 2 m (6 ft) tall whips (J. Frank Schmidt and Son Co., Boring, OR) were transplanted on April 8, 1994 into a sandy loam soil at the City of Columbus municipal nursery. Prior to planting, each whip received one of the three terminal bud pruning treatments described earlier: intact, lateral buds removed from the terminal bud cluster and terminal bud cluster removal (Fig. 3). The whips were planted on 3.1 m (10 ft) apart and spaced 1.2 m (4 ft) within the row using a completely random design with 10, one plant replications. The field was clean cultivated in 1994 and 1995.

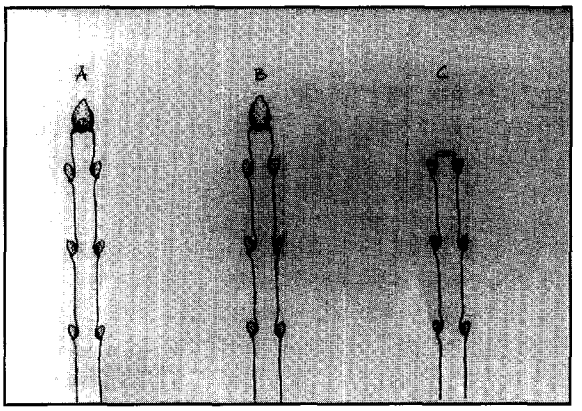

Figure 3. Drawings illustrating the terminal bud *pruning cluster pruning treatments for 'Patmore'* green ash and 'Autumn Purple' white ash whips: Intact (A), Lateral Bud Removal where the lateral buds in the terminal bud cluster were removed (B), and Terminal Bud Cluster Removal where the terminal bud cluster was pruned, one of the lateral buds was removed and the other lateral bud taped to reestablish a single central leader (C).

Table 1. Central leader caliper to total lateral shoot caliper ratio in transplanted 'Patmore' green ash and 'Autumn Purple' white ash trees at four ages from transplanting.

	Years After Transplanting			
Cultivar	1	2	5	10
'Patmore'	0.4	0.5	0.4	0.4
'Autumn Purple'	0.4	0.3	0.5	0.4

In October 1994, terminal shoot length and caliper were measured. Central leader caliper was measured 2.5 cm (1 in) above the 1994 terminal bud scale scar. For plants given the terminal bud removal treatment, the longest shoot was considered the "terminal" shoot and measured. Shoot length and caliper of all lateral shoots formed within 10 cm (4 in) of the 1994 terminal bud scale scar were measured. Total and average lateral shoot lengths and calipers were calculated. Ratios between the terminal and lateral shoot lengths and calipers were calculated as before. Terminal and lateral shoot calipers were measured in the same location in 1995 as in 1994. Also, the 1995 terminal shoot length and the length of the shoots developed from the terminal bud on the lateral branches formed in 1994 were measured.

Results and Discussion

Loss of Apical Control Following Transplanting. The central leader to total lateral shoot caliper ratio in transplanted 'Patmore' green ash and 'Autumn Purple' white ash was low (0.3 to 0.5) and remained relatively constant up to 10 years after transplanting. (Table 1) The low ratio

Table 2. Red oak terminal and lateral shoot growth following terminal bud cluster pruning treatments.

Bud pruning treatment[z]	Terminal shoot length (cm)	Lateral shoot No. elongating	Lateral shoot length of longest (cm)	Distance from the base terminal shoot to the lowest elongating lateral bud (cm)
Intact	48a[y]	4.7a	32b	5.3b
Lateral bud pruning	54a	4.3a	33b	10.0a
Terminal bud cluster removal	51a	3.5b	43a	7.4ab

[z] Bud pruning treatments: intact, no treatment; lateral bud pruning, lateral buds in terminal bud cluster were removed leaving the terminal bud intact; terminal bud cluster removal, the terminal 2.5 cm of the terminal bud cluster was removed and the upper most intercluster bud was taped to re-establish a central leader.
[y] Means within a column followed by different letters are significantly different from each other at the alpha=0.10 level using the Student-Newman-Kuels test.

indicates loss of apical control. The central leader to total lateral shoot caliper ratio of transplanted ash can be increased by cultural practices; the ratio in nursery-grown 'Patmore' green ash and 'Autumn Purple' white ash was 0.7 and 0.8, respectively. However, in the absence of cultural practices, large limb development is initiated the first season after transplanting and can persist for 10 years. Delaying corrective pruning would result in large pruning wounds.

Terminal Bud Cluster Pruning. Field transplanted red oak whips that had the lateral buds in the terminal cluster removed all maintained a strong central leader; whips averaged 45 cm (18 in) of terminal shoot growth in 1993. Unexpected was the elongation of 4 to 13 (average of 9) intercluster buds per whip. The lowest elongating intercluster buds were 30 cm (12 in) from the 1993 terminal bud scale scar. Typically oak intercluster buds do not elongate unless the terminal bud cluster is damaged (4, 11, and 12).

In untransplanted container-grown red oaks, terminal shoot growth was similar, regardless of the pruning treatment; terminal shoot growth ranged between 48 and 54 cm (19-21 in) (Table 2). Plants where the terminal bud cluster was removed had the fewest number of elongating buds. These plants also had long lateral shoots; the longest averaged 84% of the length of the terminal shoot. The lowest lateral to terminal shoot length ratio, 61%, occurred in plants where the lateral buds in the terminal bud cluster were removed. Elongating buds in control plants were almost exclusively cluster buds, thus the short distance from the terminal bud to the lowest elongating lateral bud. Removing the lateral buds in the terminal bud cluster allowed intercluster buds to elongate; the distance from the terminal bud to the lowest elongating lateral bud was almost double that of the control plants. Terminal bud cluster removal did increase the number of elongating intercluster buds, but the distribution of elongating buds was undesirable; they tended to be grouped around the residual shoot apex. Similar results were found by Ward (11).

In summary, the red oak results showed that lateral bud removal from the terminal bud cluster results in a more desirable crown shape than leaving the terminal bud cluster intact or removing the terminal bud cluster: the terminal shoot is more vigorous relative to the longest lateral shoot and normally dormant intercluster buds elongate resulting in better branch distribution. Additionally, Ward (11) found that when the terminal bud was damaged elongating intercluster buds had larger branch angles (undesirable "dog legs") and Harmer (4) found that the branches resulting from intercluster bud elongation tended to be shorter than branches resulting from lateral buds in the terminal bud cluster. Finally, the red oak data suggest that intercluster bud dormancy is

Table 3. Two year terminal and lateral shoot growth of 'Patmore' greenash and 'Autumn Purple' white ash whips after three terminal bud pruning treatments.

Year	Bud pruning treatment[z]	Terminal shoot length (cm)	Terminal shoot cal. (mm)	Lateral shoot No.	Avg. lateral shoot length (cm)	Avg. lateral shoot caliper (mm)
'Patmore' Green Ash						
1994	Intact	42.2a[y]	8.3a	2.9a	39.1ab	6.9a
	Lateral bud removal	44.0a	8.4a	2.3a	30.6b	4.9b
	Terminal bud cluster removal	46.6a	8.5a	2.7a	45.4a	6.4a
1995	Intact	76.8a	14.2a	--	78.7a	14.8a
	Lateral bud removal	94.7a	17.9a	--	78.0a	12.1a
	Terminal bud cluster removal	89.0a	17.3a	--	73.0a	14.5a
'Autumn Purple' White Ash						
1994	Intact	37.1a	7.2b	2.8a	32.8a	6.9a
	Lateral bud removal	44.4a	8.8a	2.2a	25.9a	5.1b
	Terminal bud cluster removal	36.9a	6.8b	1.9a	32.6a	7.0a
1995	Intact	29.8a	13.0a	--	18.2b	9.9ba
	Lateral bud removal	32.1a	15.1a	--	28.2ab	9.1b
	Terminal bud cluster removal	43.5a	15.5a	--	37.9a	12.8a

[z] Bud pruning treatments: intact, no treatment; lateral bud pruning, lateral buds in terminal bud cluster were removed leaving the terminal bud intact; terminal bud cluster removal, the terminal 2.5 cm of the terminal bud cluster was removed and the upper most intercluster bud was taped to re-establish a central leader.

[y] Means within a column and species followed by different letters are significantly different from each other at the alpha=0.10 level using the Student-Newman-Kuels test.

controlled by the lateral buds in the terminal bud cluster and not by the terminal bud.

The terminal bud cluster treatments applied to the two ash cultivars did not affect terminal shoot length of either species in either year (Table 3). 'Patmore' green ash terminal shoot caliper was

unaffected by terminal bud cluster treatments, but in 'Autumn Purple' white ash it was significantly greater in whips where the lateral buds in the terminal bud cluster were removed (Table 3).

In 1994, there were no differences in the number of lateral buds elongating in 'Patmore' green ash whips. However, average lateral shoot length and average lateral shoot caliper were greater in whips where the terminal bud cluster was left intact or where it had been removed, than in whips where the lateral buds in the terminal bud cluster were removed (Table 3). The patterns in total lateral shoot length and total lateral shoot caliper were similar to average lateral shoot length and average lateral shoot caliper (data not presented).

There were no differences among the treatments in the number or average length of 'Autumn Purple' white ash lateral shoots elongating during 1994 (Table 3). Average lateral shoot caliper was significantly less in whips where the lateral buds in the terminal bud cluster were removed than in the other treatments (Table 3). In 1995, average lateral shoot length and caliper were significantly greater when the terminal bud cluster was removed than when it was left intact (Table 3). The pattern in total lateral shoot length and caliper was similar to average lateral shoot length and caliper (data not presented).

Table 4. Two year terminal shoot to lateral shoot growth of 'Patmore' green ash and 'Autumn Purple' white ash after three terminal bud pruning treatments.

Year	Bud pruning treatment[z]	Terminal shoot to lateral shoot ratio Total caliper	Avg. caliper
'Patmore' Green Ash			
1994	Intact	0.4a[y]	1.0b
	Lateral bud removal	0.8a	1.7a
	Terminal bud cluster removal	0.5a	1.0b
1995	Intact	0.5a	1.3b
	Lateral bud removal	0.6a	1.7a
	Terminal bud cluster removal	0.6a	1.2b
'Autumn Purple' White Ash			
1994	Intact	0.4a	1.2b
	Lateral bud removal	0.8a	1.7a
	Terminal bud cluster removal	0.5a	1.3b
1995	Intact	0.3a	1.0b
	Lateral bud removal	0.7a	1.5a
	Terminal bud cluster removal	0.4a	1.2b

[z] Bud pruning treatments: control, no treatment; lateral bud pruning, lateral buds in terminal bud cluster were removed leaving the terminal bud intact; terminal bud cluster removal, the terminal 2.5 cm of the terminal bud cluster was removed and the upper most intercluster bud was taped to re-establish a central leader.
[y] Means within a species, year and column followed by different letters are significantly different from each other at the alpha=0.05 level using the Student-Newman-Kuels test.

In 1994, the terminal shoot of 'Patmore' green ash and 'Autumn Purple' white ash trees was relatively longer than the average lateral shoot in trees where the lateral buds in the terminal bud cluster were removed; there was a larger terminal shoot to lateral shoot ratio (Table 4). There were no treatment differences for either cultivar in 1995 (Table 4). Similarly in 1994, the terminal shoot caliper to average lateral branch caliper for both cultivars was greater when the lateral buds in the

terminal bud cluster were removed than in the other treatments (Table 4). These differences were maintained in 1995 (Table 4).

Lateral bud removal from the terminal bud cluster maintained greater apical control in transplanted 'Patmore' and 'Autumn Purple' ash than terminal bud cluster removal or leaving an intact terminal bud. Lateral bud removal maintained apical control because it removed the largest buds; Gill (3) found that the largest white ash buds occurred at the shoot tip and that bud size was positively correlated with the number of leaf primordia in the over wintering bud. Thus pruning the lateral buds from the terminal bud cluster removed those buds with the greatest potential leaf area and the greatest likelihood to form persistent lateral branches (7). Apical control was maintained by removing the buds that represent the greatest potential competition to the terminal bud.

Terminal shoot length to average lateral shoot length has been used as a measure of apical control in established green ash trees (8). A similar ratio can be calculated from the data in Table 3. In 1994, 'Patmore' green ash terminal shoot length to average lateral shoot length ratio was 1.1, 1.7 and 1.1 for the intact, lateral bud removal and terminal bud cluster removal treatments, respectively. Similar ratios for 'Autumn Purple' white ash were 1.1, 1.4 and 1.0. The treatment differences for 'Autumn Purple' were significant at the 0.05 level, but insignificant for 'Patmore' green ash. In both cultivars, the lateral bud removal from the terminal bud cluster treatment best maintained apical control. The 1.7 ratio for the lateral bud removal from the terminal cluster treatment was close to the 1.8 ratio found in established green ash (8).

Lateral bud removal from the terminal bud cluster is an effective, rapid method to maintain apical control and natural crown form in transplanted 'Patmore' and 'Autumn Purple' ash and in red oak whips. When applied at transplanting, future tree maintenance to correct large diameter lower limb development would be decreased.

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Résumé. La proportion de diamètres entre la branche centrale et les branches latérales a été utilisé comme méthode d'estimation de la perte en dominance apicale pour le frêne de Pennsylvanie 'Patmore' (*Fraxinus pennsylvanica*) et le frêne d'Amérique 'Autumn Purple' (*Fraxinus americana*) à un, deux, cinq et 10 ans après leur transplantation. Le développement de branches basses et grosses a débuté avec la transplantation et a persisté jusque 10 ans par après. La coupe des bourgeons latéraux sur la grappe terminale des frênes et du chêne rouge (*Quercus rubra*) lors de la transplantation a permis de maintenir la dominance apicale et d'obtenir une meilleure distribution des branches latérales.

Zussammenfassung. Das Verhältnis zwischen dem Umfang des zentralen Haupttriebes und aller Seitenäste wird als eine Methode benutzt, um den Verlust der apikalen Dominanz bei der 'Patmore'-Esche (*Frax. pennsylvanica*) und der Esche 'Autumn Purple' (*Frax. americana*) mit eins, zwei fünf und zehn Jahren nach der Verpflanzung zu schätzen. Die Entwicklung von großen, niedrigen Ästen wird durch das Verpflanzen angeregt und hält für bis zu 10 Jahren an. Das Entfernen von lateralen Knospen in der terminalen Triebspitze der beiden Eschenarten und der Roteiche während des Verpflanzens erhält die apikale Dominanz und führt zu besserer Seitenastentwicklung.