THE EFFECTS OF COLD STORAGE AND DORMANT PRUNING ON GROWTH OF RADIANT CRABAPPLE

by Michael A. Schnelle and James E. Klett[1]

Abstract. The effects of different durations of cold storage and bare root pruning treatments on two-year-old Radiant crabapple (*Malus* 'Radiant') were examined for one to three growing seasons after planting. Six pruning treatments, applied by length, were as follow: 1) 50% top (shoot) removal, 2) 30% root removal, 3) 60% root removal, 4) 50% top and 30% root removal, 5) 50% top and 60% root removal and 6) control (no pruning). Planting dates of March 15 and May 1, 1987 were selected to allow a six week difference in cold storage and planting dates. Leaf area, shoot regrowth, new root dry weights, total plant dry weights, leaf:new root ratios and total shoot:root ratios were determined. Virtually no statistically significant differences between treatments were noted until the third year. Shoot regrowth was then significantly greater for the 50% shoot pruning treatment than for all other treatments. Overall, this research indicated that the various pruning treatments applied to the roots or shoots of Radiant crabapple did not have major effects on their short or long term growth response.

The most appropriate post-harvest, pre-transplanting cold storage techniques for nursery stock are still being debated. Also, the necessity for routine bare-root pruning, prior to transplanting or containerization, is still unclear. These two practices require a great deal of time and expense for the grower.

Late planting depressed growth of Scotch pine (Pinus sylvestris) (12) for both outdoor and cold-stored seedlings but not for Mugo pine (*Pinus mugo*)(13), Douglas-fir (*Pseudotsuga menziesii*) or Noble fir (*Abies procera*) (23). Cold storage, however, may affect frost hardiness and drought resistance because carbohydrate reserves are depleted (18).

The majority of roots are lost from bare-root stock during the harvest of trees from a nursery field. Often only 5% of the original root system is recovered; therefore, growers often remove a significant portion (up to 30%) of the shoot system to compensate for the root loss (25, 26, 27).

Conflicting research results have been reported concerning the positive and detrimental effects of a high shoot:root ratio resulting from pruning at planting time. Loblolly pine (*Pinus taeda*) seedlings had lower overall survivability due to high shoot:root ratios (2). Proebsting (16) demonstrated that drought survival may be enhanced by increasing the root:shoot ratio. Evans and Klett (5, 6) found that pruning shoots of Newport plum (*Prunus cerasifera* 'Newportii') and Sargent crabapple (*Malus sargentii*) (7), resulted in temporary additional shoot regrowth. However, pruned trees were comparable to controls by the end of the first growing season. Pratt (15) found few long term effects on regrowth of Norway maple (*Acer platanoides*) and Sargent crabapple (*Malus sargentii*) from various bare-root:shoot and/or root pruning treatments prior to transplant. Results similar to Pratt (15) and Evans and Klett (5, 6) were found for Delicious apple (*Malus domestica*) after dormant heading treatments (30). Shoup and Whitcomb (20) conducted top pruning treatments of eleven species of bare-root deciduous trees. Top pruning resulted in no advantages over controls. Top pruning treatments exceeding 15% wood removal actually proved detrimental to the structural density of the trees. Southwick et al. (22) found heading back shoots to 51 cm above ground produced narrow angled branching in Bing sweet cherry (*Prunus avium*). Forshey and Marmo (9) observed that winter thinning of McIntosh apple (*Malus domestica* 'McIntosh') significantly increased shoot length. Barden et al. (1) found that dormant or summer pruning at three different severities decreased shoot numbers and mean shoot lengths.

Some researchers have reported advantages to root pruning field grown trees to enhance root density within the root ball (10, 28). Various re-

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searchers (11, 14, 19) offer reviews on root and shoot systems and physiological consequences for trees in relation to dormant shoot and root pruning.

The major objectives of this study were two-fold. The first was to use root and/or shoot pruning treatments prior to transplant of bare-root Radiant crabapple to investigate the short and long term effects on regrowth and survivability of the cultivar. The pruning treatments were designed to determine whether factors affecting growth were predominantly in the shoot and/or the root. The second was to better understand the consequences, if any, of long term cold storage of nursery stock prior to bare-root pruning and planting. This was accomplished by staggering planting dates.

Materials and Methods

One hundred fifty, two-year-old, bare-root, branched (1.7-2.0 m) Radiant Crabapple (*Malus* 'Radiant') were received from a wholesale nursery on February 19, 1987. The trees were placed in cold storage (3.5 °C) with a relative humidity of approximately 98% prior to potting on March 15 and May 1 of 1987. To avoid any additional desiccation injury, trees were covered with straw and misted as needed to maintain high humidity.

Early in the storage period (February 19 - March 15, 1987), the trees were visually graded, and culls discarded. The trees were then measured and graded utilizing height as the primary criterion. Shoot number and length, root number and length, and overall fibrousness of the root system prior to any applied treatments were recorded (data not shown).

Trees were randomly selected from all treatment groups and the root systems pruned by length to achieve a 30% or 60% reduction along with 50% of total length of each shoot (Figure 1). All pruning treatments were performed just prior to planting on the same day on trees already pruned by normal field harvest operations. Excised roots were washed and oven dried. A 19 and 39% weight reduction in the root systems resulted from 30% and 60% root pruning treatments, respectively. The 50% top or shoot pruning treatments of each scaffold/tree by length resulted in a 37% weight reduction of the canopy. A total of 120 trees were utilized for the ten replications of each bare-root pruning treatment and the two 1987 planting dates.

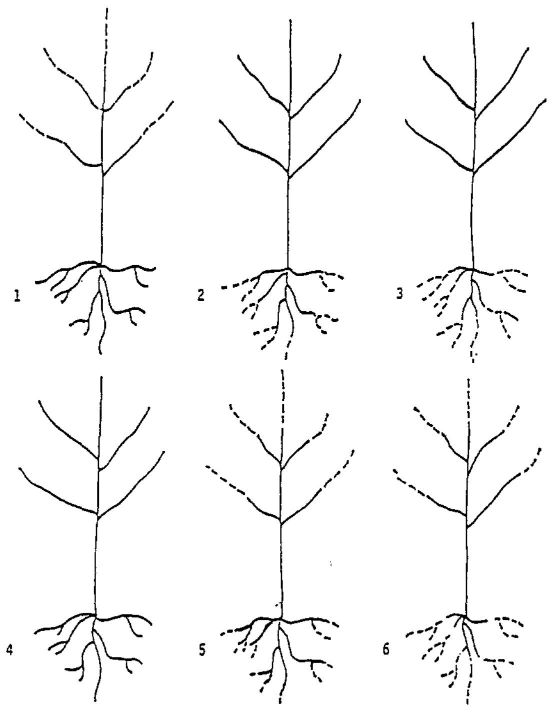

Figure 1. Pruning treatments used on two-year-old bare root branched *Malus* 'Radiant'. 1) 50% top pruned, 2) 30% root pruned, 3) 60% root pruned, 4) control, 5) 30% root pruned + 50% top pruned and 6) 60% root pruned + 50% top pruned. All pruning treatments were performed by length. Broken lines represent shoot and/or root removal.

Fifty percent of the trees from each treatment group were randomly chosen and used for the first planting date of March 15, 1987. The remaining sixty trees were kept in cold storage until planting on May 1, 1987. This allowed for a six week difference in cold storage and planting dates for the two sets of trees.

Trees were planted in 40 liter (10 gallon) pressed paper fiber containers and grown on an asphalt pad area. A steam pasteurized medium of Colorado sandy clay loam, washed plaster sand (0.1-1.0 mm particle size) and native sedge peat (1:1:1 v:v:v) was utilized. The medium had a pH of 7.3 and a soil test indicated adequate levels of all essential elements. Twenty five days after each planting, all trees were fertilized with Sierrablend Nursery Mix

19-7-10 (+1% iron) at a rate of 60 g per container. A randomized complete block design was utilized with all trees spaced on 1.5 meter centers. A 2 x 2 x 3 factorial was utilized to account for two planting dates and the six different root and/or shoot pruning treatments. Analysis of variance was performed and followed by a Newman-Keuls test for mean separations of treatment main effects (21).

A western exposure necessitated the use of a 47% mesh saran screen placed on a fence (1.5 meters tall) west of the growing area for wind and desiccation protection. Plants were watered every 2 to 4 days by hand throughout the duration of the experiment to maintain soil moisture levels near field capacity.

The trees were container grown thirteen weeks after applying the pruning treatments until August 20, 1987. At that time, half of the trees from each planting date (5 replications per treatment) were harvested to determine effects from the bare-root pruning treatments and/or cold storage duration. These five replications were randomly selected and were first defoliated to examine differences in leaf area of shoot or spur (defined as shoots less than 2.5 cm in length) growth during the first growing season. Leaf area was determined with a LiCor Model 3100 leaf area meter. In addition, new shoot and root regrowth as well as total plant biomass dry weights were determined for 15 randomly selected shoots. New root growth was lighter in color than mature roots since suberization had not yet occurred. This enabled an accurate excision of new root growth for dry weight measurement. The remaining five replicates were left undisturbed and overwintered during 1987-88 with straw around the containers to help minimize temperature fluctuations. Plants were irrigated as necessary during this winter period.

On May 12, 1988 the remaining trees were field planted on 2.0 meter spacings in a randomized complete block design. Two weeks after planting, all trees were fertilized by broadcasting 20-10-5 fertilizer around the dripline of each plant. During the 1988 growing season, trees were furrow irrigated as necessary and left undisturbed at the planting site. Mechanical weed control was performed as necessary in conjunction with several summer applications of glyphosate around the trees.

On September 4, 1988, trees were measured for new shoot growth on 15 randomly selected shoots per tree to determine if differences occurred due to earlier bare-root pruning treatments and/or the cold storage duration prior to planting. Since this study was designed to be conducted over a three-year-period, no other measurements were taken in 1988. Vinyl tree guards were used around each tree trunk to prevent rodent damage during the winter months.

In 1989, the Radiant crabapples received fertilizer and irrigation as described for the 1988 season and were allowed to grow until buds fully developed. On August 21, 1989, all trees were defoliated by hand and leaf area measured as described for the 1987 growing season. Fifteen randomly selected shoots per tree were measured as described in the 1987 harvest, as well as shoot and root dry weights recorded.

Lastly, trees were machine lifted with a Rokor 30 tree spade on August 25, 1989. Root systems were lifted with approximately 90 percent of roots recovered attributable to the shallow root system normally found in trees (19). Individual soil balls recovered were approximately 1.0 cubic meter in volume. Root systems were washed and oven dried at 80°C for 72 hours. Root dry weights were then taken along with the entire biomass dry weight of the trees. The 1989 data were statistically analyzed as described for the 1987 and 1988 growing seasons.

Results and Discussion

1987. No significant differences in shoot growth were found after the first growing season among the root pruning treatments or between the two planting dates (Table 1). Total leaf area was not affected by any of the pruning treatments or planting dates (Table 2). Also, when shoot leaf area and spur leaf area were examined separately, no significant differences were observed. Even with the most radical pruning treatment of 50% top and 60% root pruning, leaf area was not significantly different from that of the controls.

No significant differences in leaf weight, new root growth, leaf weight:new root weight ratios occurred between any of the pruning treatments or among the planting dates (Table 3).

No statistically significant differences occurred among total shoot: root ratios for trees harvested the first season (Table 4), based upon the total growth above and below the bud union. Since no differences were found after the first growing season, it is apparent that trees can quickly restore their shoot to root balance (leaf:new root ratio and shoot:root ratio). This conclusion was further shown by the lack of a significant reduction in leaf area, total dry weights or leaf or new root dry weights for trees with a large percentage of the roots or shoots removed. However, these plants were grown under near ideal conditions, which may have greatly influenced the non-significant results after one growing season.

1988 Field Planting. At the end of the second growing season, trees were measured for shoot regrowth which occurred in 1988 (Table 1). There were no significant differences among the pruning or planting date treatments. However, shoot regrowth was nominal in 1988 which can be attributed to transplant shock from field planting that season. Measuring shoot regrowth was nondestructive and this was the only growth parameter measured in 1988 since this study was to be continued into the 1989 growing season.

1989. After the 1989 growing season, a significant difference occurred from the 50% top pruning treatment for the May 1, 1987 planting date (Table 1). However, no significant differences in shoot growth resulted from the March 15 planting date. Leaf area measured for 1989 was not significantly different among any of the pruning treatments or between planting dates (Table 2).

Cumulative dry weights for the entire shoot system, root system, total shoot:root weight ratios, and total biomass resulted in no significant differences among any of the pruning treatments or planting dates (Table 4).

Field planting for this study was conducted to closely simulate growers' conditions; however, entire recovery of all of the trees' roots was not possible.

Table 1. Effects of dormant root and/or shoot pruning treatments on shoot regrowth for *Malus* 'Radiant' in September of the first, second and third growing seasons, 1987-1989.[z]

Growing season	Planting date	Control	50T[y]	30R	60R	50T 30R	50T 60R	S.D.
				Shoot regrowth (cm)				
1987								
Container grown	March 15	16.1a	15.8a	15.5a	14.9a	15.4a	16.2a	3.9 NS
	May 1	15.7a	15.0a	14.8a	14.6a	13.9a	14.7a	4.4 NS
1988								
Transplanted to field in May 1988	March 15	12.3a	11.2a	13.1a	10.8a	11.9a	9.9a	4.9 NS
	May 1	11.8a	12.3a	11.8a	12.0a	13.0a	11.5a	5.3 NS
1989								
	March 15	29.8a	34.6a	31.3a	28.8a	28.0a	27.8a	7.6
	May 1	31.4a	40.3b	25.9a	28.1a	29.1a	26.5a	5.1

[z]Mean separations by Newman-Keuls at p=0.05. Means followed by the same letter are not significantly different. No interactions occurred between pruning treatments and planting dates. Mean values based on 15 randomly measured new shoots/tree for the 1987-1989 growing seasons.
[y]50T represents 50% top (shoot) pruning by length.
30R represents 30% root pruning by length.
60R represents 60% root pruning by length.
50T/30R represents 50% top pruning and 30% pruning by length.
50T/60R represents 50% top pruning and 60% root pruning by length.

From visual observation, nearly 90% of the roots were recovered among all treatments (Table 4). Therefore, a consistent measurement for root dry weights was obtained.

In this study, trees were initially containerized to insure survival. This differs from other research studies where environmental conditions did not warrant this step prior to field establishment. Despite these differences, our results generally confirm prior research conclusions that root and/or shoot pruning treatments on bare root trees do not affect overall growth and survivability of *Malus* spp. or other deciduous species (6, 7, 15). However, results of this study are in conflict with Elfving and Forshey (4) who reported that increasing the severity of dormant heading cuts resulted in more shoots and greater shoot length. This study and that of Elfving and Forshey (4) demonstrate that 50% shoot removal stimulates additional shoot growth. This could explain why leaf area from this pruning treatment was unaffected. Our research resulted in shoot length that was also slightly increased but only for the third growing season and for one planting date.

Tree survival at the end of the third growing season was the same as at the end of the first growing season. The fact that no significant differences occurred from either root and/or shoot pruning treatments, except for the May 1 planting date in 1989 of the 50% top pruning treatment, is in agreement with research of Woessner and Van Hicks, Jr.(29) for green ash (*Fraxinus pennsylvanica*). Ferree (8) reported that root pruning apple caused shoot growth depressions on the trees but only for the first three weeks after treatment. Shoot growth was restored after week four. This study coincides with our results in that long term effects from root pruning or different

Table 2. Effects of dormant root and/or shoot pruning treatments on leaf area for *Malus* 'Radiant' at the end of the first and third growing seasons, in September 1987 and 1989.[z]

Growing Season	Planting date	Control	50T[y]	30R	60R	50T 30R	50T 60R	S.D.	
				Leaf area (cm)²					
1987									
Container grown	March 15								
	Shoot	6112	5123	4987	4567	4613	5211	481	NS
	Spur	398	692	483	557	611	578	184	NS
	TOTAL	6510	5816	5471	5124	5225	5789	515	NS
	May 1								
	Shoot	5129	6120	5211	5634	4967	4234	505	NS
	Spur	557	442	467	549	712	465	122	NS
	TOTAL	5687	6563	5678	6183	5680	4699	603	NS
1989									
Field	March 15	10006	9881	10113	10206	9599	10144	408	NS
Grown	May 1	9661	10130	9864	9542	9704	10038	375	NS

[z] Mean separations by Newman-Keuls at p=0.05. No significant differences occurred between pruning treatments. No interactions occurred between pruning treatments and planting dates.
[y] 50T represents 50% top (shoot) pruning by length.
30R represents 30% root pruning by length.
60R represents 60% root pruning by length.
50T/30R represents 50% top pruning and 30% root pruning by length.
50T/60R represents 50% top pruning and 60% root pruning by length.

planting dates were negligible. In contrast, Ramney et al. (17) found dormant shoot pruning to be quite detrimental to regrowth for Colt cherry (*Prunus avium x pseudocerasus* 'Colt') even under irrigated conditions.

Despite differences in results of pruning research, some agreement is evident. Routine bare-root pruning prior to transplanting may be unnecessary and in most cases results in no growth or survival advantages over unpruned trees. This research did show that even the most severe root pruning (60% root removal) did not stunt growth. Therefore, plants may be severely root pruned when necessary to fit into smaller containers. Gilman and Yeager (10) found root pruning of several deciduous species to be stimulative for new root growth. Our research also indicated that there was no harm in shoot pruning when necessary to form a better canopy. Pruning at transplanting should be considered on an individual plant basis and may not be necessary for most bare-root nursery stock.

Even though cold storage and subsequent differences in planting dates did not affect growth of the crabapples in this study, other researchers have reached different conclusions. Buckley and Lovell (3) reported growth depressions in overall vigor and dry weights for Sitka spruce (*Picea sitchensis*) when plants were held an additional 15 weeks in cold storage. Similar results were found for Scotch pine (*Pinus sylvestris*) (12). A significant effect may be more likely for coniferous stock than for deciduous plants (24). Planting dates in our study were staggered only six weeks. Other researchers found detrimental results after much longer periods of cold storage and delayed planting dates. This suggests that a great deal of latitude exists in removing nursery stock from cold storage. Convenience of removal and the time when the grower is ready to plant may dictate when plants should be removed. Our test plants could not be held longer without deleterious effects since shoot growth was beginning to occur by the May 1 planting date.

Our work indicates that the planting dates of March 15 and May 1, 1987, did not affect future growth and survival of the test trees. These results suggest that prolonged cold storage (six additional weeks) was not deleterious to future regrowth at least for this cultivar. Further work needs to be conducted, however, to examine just how long crabapple seedlings and many other untested species and cultivars can be safely refrigerated. A

Table 3. Effects of dormant root and/or shoot pruning treatments on leaf:new root ratios for *Malus* 'Radiant' at the end of the first growing season, September, 1987[z]

Planting date	Control	50T[y]	30R	60R	50T 30R	50T 60R	S.D.
March 15							
Leaf dry wt.(g)	69.3	58.7	55.4	61.0	63.8	59.4	12.9 NS
New root dry wt. (g)	31.6	29.8	30.4	27.5	28.4	30.3	14.1 NS
Leaf:new root ratio	2.2	1.9	1.8	2.3	2.2	1.9	.5 NS
May 1							
Leaf wt. (g)	61.5	59.8	60.7	61.1	60.9	63.2	11.8 NS
New root wt. (g)	34.3	29.8	32.0	32.5	28.7	31.3	13.3 NS
Leaf:new root ratio	1.8	2.1	1.9	1.8	2.2	2.0	.2 NS

[z] Mean separation by Newman-Keuls at p=0.05. No significant differences occurred between pruning treatments. No interactions occurred between pruning treatments and planting dates. Ratios based on means of leaf and root weights from five replicates/ pruning treatment/planting date.

[y] 50T represents 50% top (shoot) pruning by length.
30R represents 30% root pruning by length.
60R represents 60% root pruning by length.
50T/30R represents 50% top pruning and 30% root pruning by length.
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better understanding of cold storage limits could be advantageous to the grower for management and cultural decisions.

Additionally, this research indicated that the six bare-root pruning treatments applied, did not significantly affect overall short term or long term growth or survivability of Radiant crabapple.

Although considerable research has been conducted to date for both ornamental and orchard trees, many species/cultivars have not been tested for responses to various pruning techniques. Therefore, caution is still advisable in making a general statement that in all cases, root pruning is not warranted. Likewise, length of cold storage suitable for plants is still in question. Further work involving the evaluation of many species/cultivars

Table 4. Effect of dormant root and/or shoot pruning treatments on shoot and root dry weights for *Malus* 'Radiant' at the end of the first and third growing seasons in September of 1987 and 1989.[z]

Growing Season	Planting date	Control	50T[y]	30R	60R	50T 30R	50T 60R	S.D.
1987					Dry weights (g)			
	March 15							
	Shoots	614	564	589	536	604	661	135 NS
	Roots	443	491	401	388	477	379	195 NS
	Total biomass	1057	1056	991	925	1081	1040	241 NS
	Shoot:root ratio	1.4	1.2	1.5	1.4	1.3	1.7	.3 NS
	May 1							
	Shoots	588	535	544	486	499	451	195 NS
	Roots	475	435	381	392	370	366	223 NS
	Total biomass	1063	970	925	878	870	818	207 NS
	Shoot:root ratio	1.2	1.2	1.4	1.2	1.3	1.2	.2 NS
1989								
	March 15							
	Shoots	1057	988	896	955	843	855	299 NS
	Roots	801	796	734	742	832	720	220 NS
	Total biomass	1858	1785	1631	1697	1675	1575	386 NS
	Shoot:root ratio	1.3	1.2	1.2	1.3	1.0	1.1	.4 NS
	May 1							
	Shoots	1132	1061	1100	1080	989	1004	195 NS
	Roots	834	849	913	836	900	893	212 NS
	Total biomass	1967	1910	2013	1916	1890	1898	367 NS
	Shoot:root ratio	1.4	1.2	1.2	1.3	1.1	1.1	.3 NS

[z]Mean separation by Newman-Keuls at p=0.05. No significant differences occurred between pruning treatments. No interactions occurred between pruning treatments and planting dates. Dry weights were based upon total above-ground growth and entire root systems. Trees were separated at the bud union for determination of shoot and root weights.

[y]50T represents 50% top (shoot) pruning by length.

30R represents 30% root pruning by length.

60R represents 60% root pruning by length.

50T/30R represents 50% top pruning and 30% root pruning by length.

50T/60R represents 50% top pruning and 60% root pruning by length.

and diverse environmental backgrounds is necessary to fully understand the ramifications of root pruning and cold storage on nursery stock.

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Graduate student, and
Associate Professor
Department of Horticulture
Shepardson Building
Colorado State University
Fort Collins, CO 80523

Résumé. Les effets de différents traitements de durées d'entreposage à froid et de tailles sur des pommetiers Radient (*Malus* 'Radiant') à racines nues de deux ans étaient étudiés de une à trois saisons de croissance après la plantation. Les six traitements de taille, appliqués en fonction de la longueur, étaient les suivants: 1) enlèvement de 50% de la cime (pousses), 2) enlèvement de 30% des racines, 3) enlèvement de 60% des racines, 4) enlèvement de 50% de la cime et 30% des racines, 5) enlèvement de 50% de la cime et de 60% des racines, et 6) aucune taille (groupe contrôle). Les dates du mars et du 1er mai 1987 étaient choisies afin d'obtenir une différence de six semaines entre les dates d'entreposage à froid et de plantation. Étaient évalués la surface foliaire, la reprise de croissance des pousses, la masse sèche en nouvelles racines, la masse totale sèche de la plante, le rapport feuilles:nouvelles racines et le rapport pousses:racines. Virtuellement, aucune différence statistique significative entre les traitements était notée jusqu'à la troisième année. La reprise de croissance des pousses était significativement supérieure pour le traitement où il y avait enlèvement de 50% des pousses que pour tous les autres traitements. Globalement, cette étude nous indiquait que les différents traitements de taille appliqués aux racines ou aux pousses du pommetier Radiant avaient aucun effet majeur sur leurs réponses de croissance à court ou à long terme.

Zusammenfassung. Der Effekt verschiedener Kaltlagerungszeiten und Schnittmaßnahmen an Ästen und Wurzeln wurde an zweijährigen Holzapfelbäumen (*Malus* "Radiant") untersucht über einen Zeitraum von ein bis drei Vegetationsperioden nach der Pflanzung. Sechs Schnittvarianten wurden durchgeführt (Rückschnitt jeweils in Prozent der Länge): 1) 50% vom Trieb, 2) 30% der Wurzeln, 3) 60% der Wurzeln, 4) 50% vom Trieb und 30% von den Wurzeln, 5) 50% vom Trieb und 60% von den Wurzeln, 6) unbehandelte Kontrolle. Gepflanzt wurde am 15. März 1987 und am 1. Mai 1987, um unterschiedlich lange Kaltlagerungs- und Pflanzzeiten zu erzielen. Auswertungsparameter waren Blattfläche, Trieblänge, Trockengewicht der neugebildeten Wurzeln, Trockengewicht der ganzen Pflanze, Verhältnisse Blätter: neugebildeten Wurzeln und Trieb: Wurzeln. Bis zum dritten Jahr zeigten sich insgesamt keine statistisch abgesicherten Unterschiede. Lediglich die Triebneubildung war bei der Variante mit 50% Triebrückschnitt signifikant größer als bei allen anderen Varianten. Insgesamt zeigte sich, daß die verschiedenen Behandlungen keinen entscheidenden Einfluß auf das kurz- und langfristige Wachstumsverhalten haben.