MANAGING PLANT GROWTH AND WATER RELATIONS DURING TRANSPLANTING

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ABSTRACT. -- The effects of reductive pruning, a film antitranspirant and soil-applied paclobutrazol were evaluated as transplanting treatments in newly transplanted 'Colt' cherry trees under well-watered and water-stressed conditions. Under well-watered conditions all three treatments were effective in reducing plant water use as compared to the control. However, all three treatments resulted in large reductions in mean growth rate, root dry weight and root surface area. The pruning treatment had no effect on the leaf area:root area ratio, whereas the antitranspirant treatment resulted in an increased leaf area:root area ratio; a response considered undesirable. Paclobutrazol decreased the leaf area:root area ratio but also induced abnormal radial enlargement of plant roots. Under water-stressed conditions, all three treatments were effective in reducing plant water use and were successful in delaying the onset of plant water stress.

Transplanting practices often result in a considerable reduction in a plant's root system. By one estimate (Watson and Himelick 1982), as much as 98% of a trees root system may be removed during transplanting. This disruption of the natural balance between root absorptive area and transpiring leaf area predisposes newly transplanted trees and shrubs to water stress (Kozlowski and Davies 1975) and can lead to poor performance or failed plantings in the landscape.

A variety of transplanting treatments have been utilized in order to reduce plant water use and thereby minimize water stress during transplanting and re-establishment:

1) Reductive pruning is often recommended during transplanting (Flemmer 1982) in order to reduce transpiring leaf area, conserve water and to help re-establish a more optimal balance between roots and leaves. Some research (Evans and Klett 1984, 1985) has indicated dormant pruning does little to reduce leaf growth and has little effect on the functional relationship between leaves and roots. Yet, field observations often suggest that "... trimming at transplanting time increase both survival and subsequent growth." (Flemmer 1982).

2) Use of antitranspirants is an alternative method for reducing transpiration (Davies and Kozlowski 1974; Lee and Kozlowski 1974), conserving water and improving plant water status during re-establishment (Davenport, Martin, and Hagan 1972).

3) In addition to these conventional practices, the use of plant growth regulators can also serve to regulate leaf expansion, improve root regeneration and stimulate increased partitioning of growth to the root system; common objectives of transplanting practices. Paclobutrazol [(2RS,3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1H-1,2,4 triazol-1-yl) pentan-3-ol], a gibberellic acid biosynthesis inhibitor, has been found to increase adventitious rooting (Davis *et al.* 1985; Wang and Faust 1986; Upadhyaya, Davis, and Sankhla 1986; Davis *et al.* 1986), to effectively control shoot and leaf expansion in a wide variety of woody plants (Arron 1985; Asamoah and Atkinson 1985; DeJong and Doyle 1984; Greene 1986; Hield 1983; Sterrett 1985; Sterrett and Tworkoski 1987), increase assimilate partitioning to the root system (Balamani and Poovaiah 1985; Wang, Byun, and Steffens 1985) and minimize plant water stress (Swietlik and Miller 1983; Wieland and Wample 1985).

The purpose of this study was to evaluate and compare the effects of three transplanting treatments: reductive pruning (PR), a film antitranspirant (AT), and soil applied paclobutrazol (PB) on plant growth, morphology, and water relations in 'Colt' cherry trees under both well-watered and water-stressed conditions.

MATERIALS AND METHODS

Bare-root, whips of *Prunus avium x pseudocerasus* 'Colt' were potted on 15 May, 1986 in 38 liter (10 gallon) plastic containers filled with a 1 peat moss : 1 vermiculite : 1 soil (by volume) mixture. Each plant received one of four treatments: 1) control; 2) 150 mg active ingredient paclobutrazol (50% WP, ICI Americas Inc., Wilmington, DE) per container applied as a soil drench in 1 liter of water (14.34 kg/ha or 12.79 lbs/acre) at planting; 3) pruning of dormant shoots to 20 cm (50% reduction) in length at planting; or 4) a foliar spray of 3% Folicote, a wax emulsion film antitranspirant, with 0.25% Triton B-1956 surfactant applied at 1300 hr EDT on 1 July, 1986. Each treatment was comprised of 20 plants.

Plants were grown outside in Ithaca, NY. Containers were spaced on 2 meter (6.6 foot) centers and were sunken in the ground such that the surface of the potting medium was even with the surrounding grade. Empty containers were used as sleeves to line the holes so that the plant-holding containers could be removed and replaced more easily. The top of the containers were covered with white polyethylene film to minimize evaporation and prevent infiltration of rainwater.

Plants were well-watered for 60 days after planting. At that time, 10 plants were harvested from each treatment. The remaining 10 plants in each treatment were then water-stressed by discontinuing watering for 24 days in order to observe how the treatments and their effects on plant morphology influenced plant water use and tolerance to water-stress.

Water use was measured gravimetrically. During well-watered conditions, plants were irrigated every evening. Daily water use was measured on seven occasions between 4 July and 11 July, 1986. Mean unit leaf transpiration rates for well-watered plants were calculated from mean plant transpiration rates divided by total leaf area which was measured with a leaf area meter (LI-COR model 3100, Lincoln, NE) when the plants were harvested on 15 July, 1986. Pre-dawn water potentials were measured with a pressure chamber (Plant Moisture Status Console, Soil Moisture Corp., Santa Barbara, CA) between 0300 and 0430 hr EDT. Vapor pressure deficit, defined as the difference between saturated vapor pressure at ambient temperature and actual vapor pressure, was measured with a Cambell 201 relative humidity probe in conjunction with a Cambell CR21 data logger (Cambell Scientific, Logan UT). Accumulated vapor pressure deficit (AVPD) was calculated as the sum of hourly averages of accumulated vapor pressure deficit and was used as a standardized measure of evaporative demand.

Once harvested, roots were washed free of soil and root surface areas were determined on roots less than 5 mm in diameter. Root length and surface area was measured using a video image analysis system as described by Barnett *et al.* (1987). The 2-dimensional area measured by the image analyzer was used to estimate root surface area, assuming roots were round in cross-section, by multiplying the measured area by π. Mean root diameter was calculated from length and surface area measurements. Plant dry weights were determined after drying at 70 C for 96 hours.

A sample of ten plants from each of the pruned and un-pruned treatments were harvested when treatments were applied to determine mean initial dry weights for use in growth analysis. Because the PR treatment reduced initial plant weight, and because absolute growth is typically relative to initial weight (Hunt 1982), mean relative growth rate was also used for comparing treatments. Mean relative growth rate was calculated according to Radford (1967):

$$\text{Mean relative growth rate} = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

where ln is the natural log and W_1 and W_2 are total dry weight at times (t) 1 and 2 respectively. The experiment was arranged as a completely randomized design and was analyzed by analysis of variance. Transpiration data was analyzed using a repeated measures (nested) protocol (Snedecor and Cochran, 1980).

RESULTS AND DISCUSSION

Well-watered conditions All three treatments (AT, PR, PB) were equally effective in reducing plant water use (mean plant transpiration rate) (Table 1). Such a reduction can occur due to reduced transpiration per unit leaf area or due to a reduction in plant leaf area. The AT treatment reduced plant water use primarily as a result of lower transpiration per unit leaf area as there was no significant decrease in total leaf area. Conversely, PR plants had lower plant water use as a result of lower plant leaf areas. The effect of dormant pruning on leaf area may be influenced by the method and severity of pruning and the species in question. Evans and Klett (1984) found that for *Malus sargentii*, thinning reduced total leaf weight, but heading shoots back did not. However, thinning shoots of dormant *Prunus cerasifera* 'Newportii' resulted in only a small decrease in leaf weight even when as much as 78% of the total branch length was removed (Evans and Klett 1985). The PB plants maintained lower mean plant transpiration rates as the result of a large (71%) reduction in plant leaf area. This reduction in leaf area offset a significant increase in mean leaf transpiration rate.

Although the AT, PR, and PB treatments were effective in reducing plant water use, the three treatments also reduced mean growth rate by 31%, 49% and 71% respectively (Table 3). Comparisons of mean shoot growth rate and mean caliper growth rate showed similar trends. The reduced mean relative growth rate of the PR plants demonstrates that pruning inhibited growth independent of its effect on initial plant weight.

Antitranspirants have been shown to reduce photosynthesis and growth in a variety of plants (Davies and Kozlowski 1974). This inhibition may result from blocked stomata, inhibited metabolic function, reflected light, poisoning due to toxic buildup of metabolic products (Olofinboba, Kozlowski and Marshall 1974), or due to reduced uptake of water-soluble nutrients (T.O. Perry, per. comm.). Reductions in growth in PR and PB treatments were most likely the result of reduced leaf area.

Pruning had no effect on the leaf area:root area ratio, a measure of transpirational area to root absorptive area, indicating that PR and CO plants had a similar balance between leaf area and root area, but that PR treated plants were simply reduced in size (Table 3). The reduced root weight of PR treated plants supports the findings of numerous other studies which have shown that shoot pruning generally inhibits or has no effect on root growth in most species (Table 4); with the noted exceptions of *Quercus coccinea* (Lee, Moser, and Hess 1974) and *Liriodendron tulipifera* (Kelly and Moser 1983). The general dependence of root growth on actively growing shoot and leaf growth might reflect a requirement for photosynthate or shoot produced growth regulators and suggests that reductive pruning at transplanting is counterproductive to plant growth and re-establishment under well-watered conditions.

The AT treatment resulted in an unfavorable increase in the leaf area:root area ratio, a result counter to desired objectives. This adverse effect resulted primarily due to an inhibition of root growth, both in dry weight and surface area (Table 3). This result suggests that after the antitranspirant looses effectiveness, the AT treated plants would be more predisposed to water-stress, due to an underdeveloped root system, than would untreated plants.

Paclobutrazol treated plants had reduced leaf area:root area ratios; however, not without peculiar abnormalities. The roots of PB treated plants were found to be unusually short with significantly greater mean root diameter as compared to other treatments (Table 3). Similar changes in roots have been found in paclobutrazol treated *Prunus persica*, *Tagetes erecta* (Williamson, Coston, and Grimes 1986), *Malus* (Steffens and Wang 1984), and *Citrus sinensis* (Bausher and Yelenosky 1987); and were observed by the authors in seedlings of *Nyssa sylvatica* (unpublished data). This unusual enlargement of PB treated roots has been found to be the result of radial, rather than longitudinal, expansion of the inner-most layer of cortical cells. (Williamson, Coston, and Grimes 1986).

<u>Water-stressed conditions</u> When water was withheld, the control plants continued to loose water at the greatest rate followed by the AT, PR and PB treated plants (Fig. 1). The reduction in the rate of water loss of treated plants resulted in the delay of plant water stress (Fig. 2). The control plants reached a mean pre-dawn water potential of -1.0 MPa (a stress sufficient to induce mid-day wilting) after 17 days (315 AVPD) and a mean pre-dawn water potential of -2.0 MPa (a stress sufficient to induce pre-dawn wilting) by 22 days (400 AVPD). In contrast, the AT and PR plants reached -1.0 MPa after approximately 20 days (350 AVPD) and 24 days (450 AVPD) respectively, never reaching a mean of -2.0 MPa pre-dawn water potential. The PB plants never dropped below a mean of -0.6 MPa even after 24 days without irrigation. These data demonstrate that AT, PR, and PB treatments can effectively reduce plant water use and minimize water stress under drought-like conditions.

Table 1. Transpiration rates and leaf area for plants measured during well-watered conditions.

Treatment	Mean plant transpiration rate ($g \cdot plant^{-1} \cdot hr^{-1}$)	Mean unit leaf transpiration rate ($mg \cdot cm^{-2} \cdot hr^{-1}$)	Leaf area (cm^2)
Control	62.1 a[z]	10.8 b	5807 a
Antitranspirant	35.3 b	6.8 c	5190 a
Pruned	38.9 b	11.6 b	3418 b
Paclobutrazol	28.0 b	16.9 a	1682 c

[z]Values are main effect means of treatment, for 10 plants, averaged over seven different days. Average vapor pressure deficit, over all measurement periods, was 1.663 KPa. Means followed by the same letter, within a column, are not significantly different using LSD comparisons, $P<.05$.

Table 2. Growth measurements after 60 days of well-watered treatment.

Treatment	Mean growth rate ($g \cdot day^{-1}$)	Mean relative growth rate ($mg \cdot g^{-1} \cdot day^{-1}$)	Mean caliper growth rate ($mm \cdot day^{-1}$)
Control	1.11 a[z]	21.6 a	0.08 a
Antitranspirant	0.77 b	18.6 b	0.07 b
Pruned	0.57 b	17.3 b	0.05 c
Paclobutrazol	0.32 c	9.5 c	0.01 d

[z]Values represent means of 10 plants. Means followed by the same letter, within a column, are not significantly different using LSD comparisons, $P<.05$.

Table 3. Morphological measurements after 60 days of well-watered treatment.

Treatment	Leaf area: root area ratio ($cm^2 \cdot cm^{-2}$)	Root dry weight (g)	Root surface area (cm^2)	Mean root diameter (mm)
Control	1.48 b[z]	7.14 a	3970 a	1.38 a
Antitranspirant	2.47 a	3.58 c	2166 b	1.26 a
Pruned	1.55 b	5.30 b	2653 b	1.24 a
Paclobutrazol	0.95 c	3.46 c	2111 b	1.94 b

[z]Values represent means of 5 plants. Means followed by the same letter, within a column, are not significantly different using LSD comparisons, $P<.05$.

Table 4. Reports on the effects of shoot pruning on subsequent root growth.

Author	Treatment	Species	Effect on root growth
Evans and Klett 1984	thinning and heading	*Malus sargentii*	no effect on root weight
Evans and Klett 1985	heading	*Prunus cerasifera*	no effect on root weight
Farmer 1979	heading	*Quercus spp.*	reduced root weight
Knight 1934	heading	*Malus spp.*	reduced root weight
Larson 1975	heading	*Quercus rubra*	reduced root number, no effect on root weight
Lee and Hackett 1976	heading and disbudding	*Pistacia chinensis*	reduced root number
Young and Werner 1982	heading	*Malus spp.*	reduced root weight
Randolph and Wiest 1981	heading	*Ilex crenata*	reduced root weight
Lee, Moser and Hess 1974	heading	*Quercus palustris*	reduced root number
		Quercus coccinea	increased root number
Struve and Moser 1984	bud removal	*Quercus palustris*	reduced root number
		Quercus coccinea	no effect on root number
Kelly and Moser 1983	heading (fall)	*Liriodendron tulipifera*	no effect on root weight
	heading (spring)	"	increase in root weight

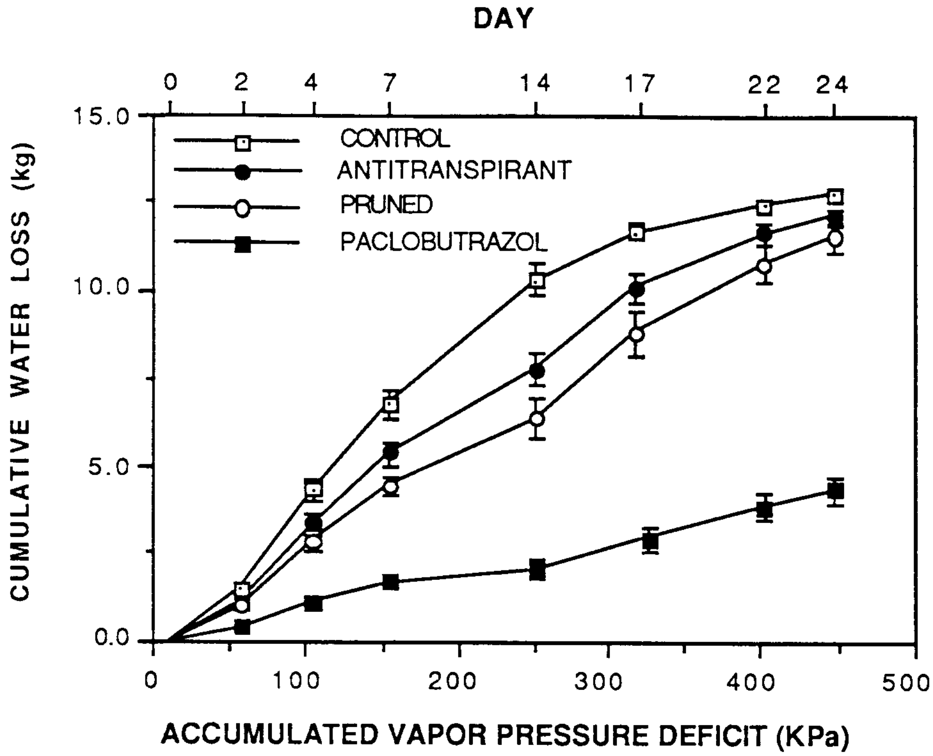

Figure 1. Water use of control (CO), antitranspirant (AT), pruned (PR) and paclobutrazol (PB) treated plants during a 24 day period with no irrigation. Symbols represent means of 10 plants ± SEM. Accumulated vapor pressure deficit is the sum of hourly means over the treatment period.

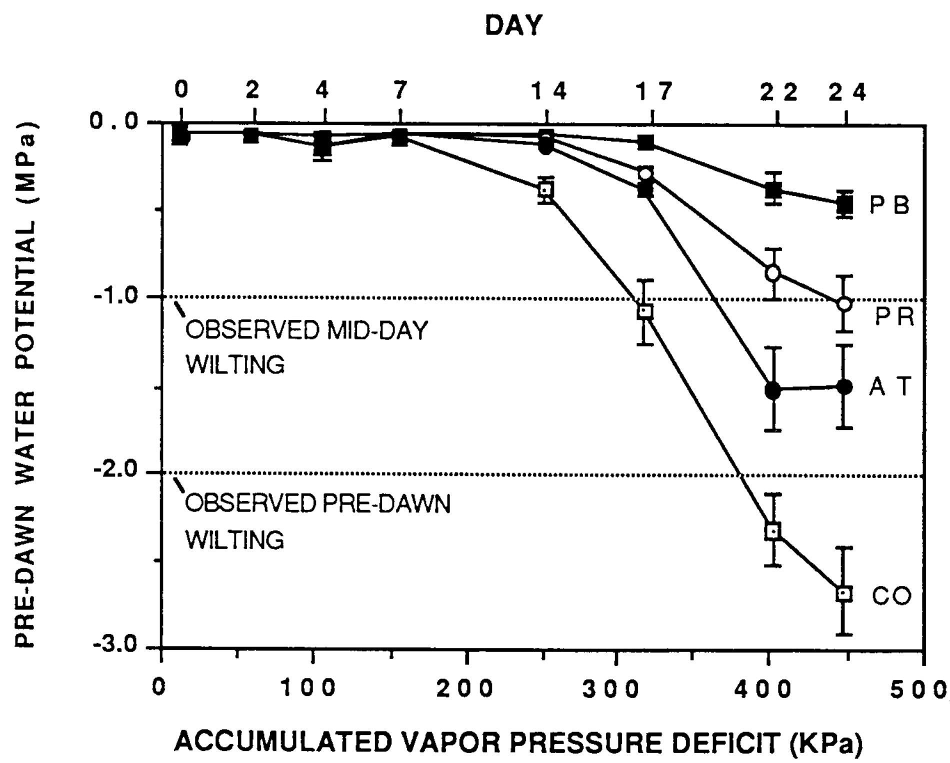

Figure 2. Pre-dawn water potential of control (CO), antitranspirant (AT), pruned (PR) and paclobutrazol (PB) treated plants during a 24 day period with no irrigation. Symbols represent means of 10 plants ± SEM. Accumulated vapor pressure deficit is the sum of hourly means over the treatment period.

RECOMMENDATIONS

These results indicate that there is little justification for reductive pruning, use of antitranspirants, or application of paclobutrazol as transplanting treatments, when transplanting dormant stock, if adequate irrigation can be provided. All three treatments severely reduced plant growth under well-water conditions. Furthermore, the application of an antitranspirant after a spring flush of leaves can limit growth and photosynthesis at a time when growth and regeneration of the root system is most critical. Pruning was successful in reducing leaf area and water use but also impaired root growth. Paclobutrazol also caused abnormal root development.

If adequate irrigation is not possible and plant survival is of primary concern, the consideration of these practices becomes more justified. All three treatments were effective in reducing plant water loss and minimizing water stress. The conservation of water during drought periods is particularly important in determining the short term survival of a newly transplanted tree as the regeneration of a proportionally sized root system may take a number of years, especially for larger trees (Watson 1985). The effectiveness of antitranspirants, pruning, and paclobutrazol would most likely depend on the species of plant being treated, and the rate or extent, the timing, and the method of treatment. The selection of any one of these options would have to be based on and compatible with management objectives.

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