All lime treatments were similar, even the surface applied, and resulted in greater shoot dry weight compared to the unlimed treatment.

It appears that fine grades of limestone are effective in adjusting the container media pH throughout a normal production period thus satisfying the liming needs of plants such as boxwood. The idea is unfounded that fine grades of limestone are leached from the container and are not effective in adjusting container media pH over time. In fact, the finer limestone grades in this study were more effective in raising pH than the coarser grades, even after two years. The faster rate of dissolution by the finer particles grades (1, 2, 3) is more important in terms of pH adjustment than the leaching potential of the finer grades.

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Soil Moisture Uptake by Green Ash Trees After Transplanting[1]

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Abstract

Forty-five Summit green ash trees (*Fraxinus pennsylvanica* Marsh. 'Summit') were planted on a compacted clay soil site. Unamended soil, amended soil, and friable topsoil were used as backfill, in combination with holes slightly larger than the root ball, twice, and 3 times the diameter of the root ball. Soil moisture tension (SMT) was monitored in the root ball, in the backfill, and outside of the planting hole. Soil moisture tension reached at least −50 KPa within the root ball in as little as two days. Improved backfill soil and large planting holes resulted in earlier significant uptake of soil moisture outside of the root ball compared to nearby soil where roots were excluded. SMT inside the root ball were significantly more negative than the surrounding soil for all treatments until twenty weeks after transplanting. At 68 weeks after transplanting, differences in SMT between the root ball, the backfill, and the soil outside the planting hole became insignificant for all treatments. Soil moisture tensions levels reported to inhibit root growth were frequently measured in the root zone throughout the first two growing seasons after transplanting.

Index words: Soil moisture tension, backfill amendments, *Fraxinus pennsylvanica*

Significance to the Nursery Industry

Little information is available on the soil moisture supply of transplanted trees, or how moisture supply is affected by planting hole design, backfill type, and root regeneration. This information is important in determining optimum planting specifications. The results of this study indicate that watering newly planted trees is required more frequently, and for a longer period of time than is commonly practiced.

Introduction

Plant growth is reduced more often by water deficits than by any other factor (5). When available soil water is adequate, water movement through the plant is controlled by transpiration. When soil water is limited, water movement through the plant is regulated primarily by soil water supply and conductivity of the roots (9). When soil moisture tension (SMT) reaches −50 KPa, root growth is checked and capacity to absorb water is reduced because of suberization (2).

Water outside of the root zone is largely unavailable to the plant (6). Water uptake within the root ball exceeds water diffusion into the root ball (1), even if movement is not inhibited by a soil textural difference. Thus, the root ball soil is the only source of moisture available to newly planted trees until the roots grow out into the surrounding soil.

Root growth results in exploitation of an ever-increasing soil volume and the greater volume of water associated with it. Barnett (1) reported that soil water available to transplanted privet increased from a 2 to 23 day supply, over a 17 week period after transplanting. As water supply increases, incidence of stress is likely to decrease.

Planting hole preparation is an extremely important factor in the transplanting success (7). Root incursion decreases in compacted and hard to penetrate soils (8). Well aerated soils around the root ball assist in rapid root development (11). Large planting holes can result in greater development of new roots (4). The purpose of this study is to examine the role of planting hole design and backfill soil type in soil

[1]Received for publication May 20, 1991; in revised form August 26, 1991. Supported, in part, by grants from the Illinois Nurserymen's Association, the Horticultural Research Institute, 1250 I Street, N.W., Suite 500, Washington, D.C. 20005, and the International Society of Aboriculture Research Trust.

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moisture uptake following transplanting on a compacted, high clay content soil, typical of many urban areas.

Methods and Materials

Forty-five B&B Summit green ash (*Fraxinus pennsylvanica* 'Summit') were planted in a compacted (1.5 g/cm^2 bulk density), clay loam soil on the grounds of the Morton Arboretum, Lisle, Illinois. The soil was typical of disturbed soils often encountered in the suburban landscape. The trees were 5–7 cm (2 to 2½ in) caliper with 50–55 cm (20–22 in) diameter root balls when planted in April of 1988. Three hole shapes and three backfill materials were used as treatments. The hole shapes were 1) slightly larger than the root ball (1.2x where x = root ball diameter) with vertical sides, 2) twice the root ball diameter with sloped sides (2x) and, 3) 3 times the root ball diameter with sloped sides (3x). The three backfill soil types were 1) unamended clayey soil removed from the holes, 2) site-soil amended with 2 mm sand and composted organic matter (50%, 40%, 10% by volume, respectively), and 3) friable loam topsoil. All possible combinations of hole shapes and backfill soils were used in nine treatment combinations. Each of the treatments was replicated five times. Trees were placed on 4.25 m (14 ft) centers in a completely random design. The soil around each tree was mulched with a 15 cm (6 in) deep, 3 m (10 ft) square area of wood chips to minimize evaporational water loss from the soil.

In the first year, each tree was watered with 48–60 liters (12–15 gallons) of water from a hand-held hose, up to three times per week, as needed to insure survival. No supplemental water was applied to the trees for the 1989 season, as tree loss was no longer feared. The mulch squares were kept weed-free with both glyphosate herbicide and hand-weeding. No supplemental fertilization was applied.

In 1988, two tensiometers were placed 15 cm (6 in) deep in the soil inside the root ball (15 cm [6 in] from the trunk), and in the backfill soil (3 cm [1 in] from the edge of the root ball). In 1989, a third tensiometer was placed outside of the planting hole, 60 cm (24 in) from the edge of the root ball. Additional tensiometers located at the same depth in nearby mulched site-soil with no plant roots to absorb water, were used as a comparison. Soil moisture tension (SMT) was measured with a digital tensimeter from Soil Measurement Systems, Las Cruces, NM.

The data were analyzed using One-way Analysis of Variance. Newman-Keuls test was used for analysis of mean separation.

Results and Discussion

Over 95 percent of the root system of nursery grown trees can be lost in the transplanting process (10). Only the water held in soil permeated by roots is available for absorption by the roots (6). In the nursery, the intact root system is in contact with a large soil volume, and thus a large quantity of soil moisture is available for absorption. After transplanting, only the soil held in the root ball soil is available to the tree.

The small soil volume of the root ball can hold only a limited amount of water (12 liters or less, based on a 50 cm [20 in] diameter root ball and 15 percent available water by volume). Growth is closely correlated with the availability of water (5). Rapid root development into the soil surrounding the root ball is vital so that additional soil moisture is available to the tree. If the site soil is not conducive to rapid root growth, then the planting hole itself must provide enough soil of adequate quality for rapid initial root establishment.

In this study, evaporation was minimized by mulch on the soil surface, and increases in SMT were assumed to be closely related to absorption by roots. The higher the root density, the greater the rate of water absorption (1). Transpirational water loss caused root ball SMT to change by over −40 KPa in as little as two days (Fig. 1). SMT frequently surpassed −50 KPa in the root ball while the backfill SMT remained between −6.8 and −16.6 KPa (Table 1). Root growth is inhibited at −50 KPa (2). During periods of high transpiration, newly transplanted trees may require watering every second or third day to avoid drought induced inhibition of root growth.

Eleven weeks after planting, the SMT of the backfill soil was significantly less negative than the SMT of the soil in the root ball, for all treatments (Table 1), indicating there was still little or no moisture uptake by roots outside the root ball.

The first indication of moisture uptake outside of the root ball occurred twelve weeks after planting. For the improved backfill soils (with the exception of the topsoil-3x treatment) and the unamended-3x treatment, SMT of the backfill soil was significantly more negative than the soil with roots excluded (Table 2), though still not as negative as in root ball. Increased early access to backfill soil moisture by the root system may be very important to the survival of transplanted trees, particularly when supplemental watering is minimal. Increased early uptake from unamended-3x treatment supports previous reports that larger planting holes result in increased root growth even without modification of the backfill soil (3, 4, 11). The low SMT associated with the topsoil-3x treatment backfill is difficult to explain since field inspections of roots in the backfill indicated that root development was similar to other 3x and topsoil treatments.

By the end of the first summer (week 20), SMT had become more negative in the backfill and less negative inside the root ball relative to week 12. There was no longer a significant difference between SMT measurements in the root ball and backfill soils for any treatment. Increased

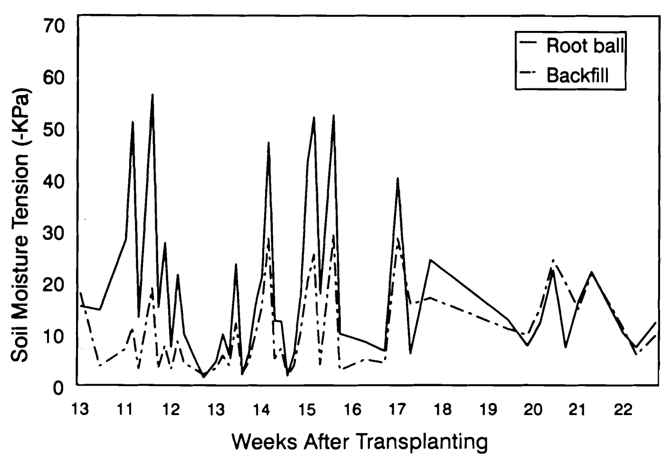

Fig. 1. Soil moisture tension of recently transplanted trees, measured in the root ball and backfill soil during the first summer after planting. These data from the topsoil-2x treatment are typical of all treatments.

Table 1. Soil moisture tension in and around the root ball of transplanted trees.

Weeks after planting (Date)		Soil moisture tension (−KPa)									
		11 (July 7)		20 (Sept. 9)		60 (June 19)			68 (Aug. 11)		
Hole type	Backfill type	RB[u]	BF	RB	BF	RB	BF	OH	RB	BF	OH
1.2x	Unamended	44.2	9.1[x]	17.1	25.9	64.4	42.1	3.7[v]	31.1	28.3	37.7
1.2x	Amended	54.1	14.7[x]	35.5	21.8	59.7	45.7	5.5[v]	28.9	47.6	19.0
1.2x	Topsoil	49.0	16.6[w]	35.0	21.2	51.7	70.1	21.8[v]	33.9	52.1	39.6
2X	Unamended	49.6	6.8[x]	24.7	24.2	57.6	24.3[w]	3.6[y]	28.1	30.9	17.5
2X	Amended	46.2	15.7[w]	18.2	22.0	59.9	31.8[w]	12.0[y]	23.9	31.4	34.6
2X	Topsoil	50.9	11.3[x]	27.6	24.3	63.4	52.2	11.5[z]	26.2	35.9	21.2
3X	Unamended	67.4	7.6[x]	24.0	21.7	66.5	37.5[w]	3.5[y]	30.0	50.9	29.8
3X	Amended	52.0	7.5[x]	28.0	25.3	68.2	27.1[x]	3.4[z]	21.5	19.7	34.6
3X	Topsoil	43.1	12.7[x]	14.9	10.2	59.6	18.7	8.6[z]	38.1	31.2	16.6

[z]significantly different from RB and BF measurements on the same date at the .01 level.
[y]significantly different from RB and BF measurements on the same date at the .05 level.
[x]significantly different from RB measurement on the same date at the .01 level.
[w]significantly different from RB measurement on the same date at the .05 level.
[v]insufficient data for statistical analysis.
[u]RB = Root ball soil, BF = Backfill soil, OH = soil outside planting hole.

Table 2. Soil moisture tension (SMT) in backfill soil around the root balls of transplanted trees 12 weeks after planting.

Treatment combination		
Hole	Backfill	SMT (−KPa)
1.2x	Unamended	10.0 b[z]
1.2x	Amended	19.1 a
1.2x	Topsoil	22.2 a
2X	Unamended	7.1 b
2X	Amended	16.3 a
2X	Topsoil	18.9 a
3X	Unamended	10.1 a
3X	Amended	11.6 a
3X	Topsoil	6.1 b
Soil outside planting hole		5.7 b

[z]Data bearing the same letter were not significantly different at the 5% level.

uptake in the backfill was attributed to the root development observed. Cooler temperatures may have contributed to lower SMT inside the root ball. (Average daily maximum temperature June 1–August 18 = 33°C [92°F], August 19–September 20 = 28°C [83°F]. Source of all weather data is the US National Weather Service Station-Wheaton 3SE, located on the grounds of the Morton Arboretum.)

At the beginning of the second summer, 60 weeks after planting, SMT of the backfill soil was consistently more negative than in week 20. Root ball SMTs were also more negative than in week 20, and once again, significantly more negative than the backfill soil for some treatments. The reoccurrence of more negative root ball SMTs may have been related to the lack of irrigation and below normal rainfall (January–June rainfall deficit of 17 cm [6.8 in]). Differences in SMT between root ball and backfill soils appear to be most pronounced under drought conditions, and point out the need to water the root ball during dry weather.

At week 60, little uptake was occurring outside of the planting holes. The SMT remained between −3 and −12 KPa, while SMT in the root balls was −51 to −68 KPa. SMT was significantly lower outside the planting holes compared to the backfill and root ball soils for all treatments for which sufficient data were available. Between week 61 and 65, soils became so dry that valid tensiometer readings could not be recorded. Near the end of the second season (week 68) SMT was more negative outside of the planing hole, and there was no longer a significant difference between SMT at any of the 3 measured locations for any treatment. This again was a period of cool weather as well as above normal rainfall. (Average daily maximum temperature July 12–August 12 = 28°C [83°F], July rainfall was 5.4 cm [2.12 in] above 20 year average), and may account, in part, for the lack of significant difference.

These SMT data imply that it takes nearly two full growing seasons for roots of green ash to develop in sufficient density to absorb substantial amounts of soil moisture outside the planting hole, two feet from the root ball. At this time, approximately 9 times as much soil is exploited by the root system, and therefore, up to 9 times as much moisture would be available for absorption by the root system. This water supply should be adequate for approximately two weeks without rainfall, compared to the two day supply of water during the first weeks after transplanting. This estimate is supported by the data from Fig. 2. There was no rainfall between weeks 74 and 76 (September 14–30) and the most negative SMT recorded was −47 KPa.

The data from this study indicate that hole size and backfill type are important in early stages of root regeneration after transplanting, but appear to have little influence on longer-term root development and soil moisture uptake after transplanting. The growing root tips furthest from the root ball would be in low density, causing minimal drying of the mulched soil as they advanced. If these growing tips are not subjected to water stress, root extension could continue at a rapid rate, irrespective of planting treatment and how dry the soils nearer the root ball became. This could account for the similar pattern of soil moisture uptake for all treatments.

Top growth, as measured by twig elongation, was reduced by approximately 95 percent for both 1988 and 1989 as a

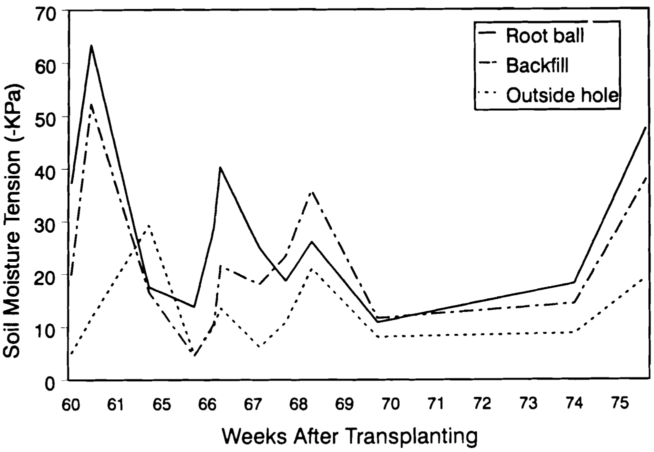

Fig. 2. Soil moisture tension of recently transplanted trees, measured in the root ball, backfill soil and soil outside the planting hole during the second summer after planting (topsoil-2x treatment). Soils were too dry for accurate SMT measurements between weeks 61 and 64.

result of transplanting (data not shown). There were no significant differences between treatments. Lack of growth differences reflected the similar overall patterns of soil moisture uptake among treatments.

The results of this study, including the survival of all 45 transplanted trees, indicate the importance of careful monitoring of soil moisture and frequent irrigation. Periods with daily high temperatures exceeding 32°C (90°F) seem to be the most likely to cause rapid drying of soil in the root zone, especially in the root ball.

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