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Assessing the Extent of Soil Loss from Nursery Tree Root Ball Excavation

A soil quality management issue unique to tree nurseries is the removal of soil off site when ornamental trees and shrubs are harvested and sold with a balled and burlapped (B & B) root ball. The amount of soil removed with B & B harvest and sale has been estimated as much as 5 cm per year (Luce, 2007a). The amount removed may vary widely among growers and fields depending on plant spacing, harvest cycle, and root ball size. Soil replacement is also sometimes practiced by importing excavated soil and wood chips from off site to fill tree holes (Black, 2009).

Soil loss during B&B tree harvest is estimated using the volume of the holes left behind. However, the soil balls wrapped for B & B removal are generally densely permeated with tree roots, leading some to assume that much or most of the ball removed consist of roots rather than soil.

There is a dearth of published data on soil removal and published methods that will allow for reliable calculation of soil being removed from individual enterprises. Improved information and methods, potentially as an online calculator, would allow individual nursery growers to estimate the amount of soil removed off site, and to take steps to reduce the loss or replace the soil. Tree nurseries documenting sufficiently low net soil loss might be eligible for state incentives for a range of best management practices under the Water Quality Improvement Act and others, as well as for state agricultural lands protection under the Federal Range and Farmland Protection Act.

UMD Researchers Conducted Study of Roots and Soil Material Removed

To obtain objective data on the relative amounts of roots and soil material removed in B & B root balls, we conducted a study using two tree species and two types of spading machines.

The objectives of the study were to:

1. Determine the mass and volume of soil removed from field nurseries that use two methods of ball and burlap harvesting.
2. Determine the proportion of roots and soil mass and volume in B & B root balls.

Data on B & B and Turf Grass Soil Removal are not Well-documented

Intentional soil removal is an integral part of the production process for two agricultural commodities: field-grown nursery stock and turfgrass. The extent and impact of routine soil removal in these industries, however, are not well documented. Turfgrass sod is grown in field soil and harvested with 1 cm or more of soil and thatch around the root mat, which is removed every 15 months or so. Harvest of field-grown landscape trees and shrubs includes excavating a ball of soil kept intact around a portion of the plant's roots large enough to ensure a successful transplant into the landscape.

For U.S. agriculture in general, soil conserving practices, education, incentives, and regulations have reduced erosive soil loss from cropland by 40 percent since 1985 (USDA, 2010), with a trend toward long-term sustainability. In contrast, estimates from the literature suggest that B&B tree harvest is not sustainable for individual farm enterprises. One often-cited source estimates soil loss on B&B nursery fields at 67 to 100 tons per acre annually (Davidson, 2000).

An indirect measurement of soil removal compares *solum thickness* (the soil depth above unconsolidated parent material) on paired fields where one has been in field nursery production for an extended period, and the other has not. For example, an assessment of differences in solum thickness in soil profiles of adjacent Connecticut sites either farmed for up to 30 years or unfarmed (adjacent forest) showed soil removal from three Connecticut field nurseries at the rate of 0.5 to 2 inches per year. Two fields of a Connecticut turf farm removed 0.33 inch per year (Luce, 2007b); (Krall, 2006), (Krall, personal communication).

There are some possible drawbacks to such an assessment. It is nearly impossible to determine how much soil loss resulted from B&B harvesting versus erosion, given that best management practices to reduce erosion were not implemented until the 1980's. Even with grass aisles in place, erosion is not zero.

Adjacent control sites selected for comparison with field nursery sites may not have been identically managed prior to B&B harvesting. Field nurseries are often established on historically farmed land, and control sites in adjacent woods would not have experienced the same erosion as agricultural fields over the decades or even centuries of farming.

When control sites were in adjacent woods, which are frequently in less well-drained areas, soil transport processes that moved mineral soil from the fields to the woods may have occurred well before the study period. Accumulation of solum thickness in the woods due to organic matter additions differ from the organic matter dynamic in the agricultural fields.

High variance of solum thickness within a field may cause the difference between adjacent nursery and non-nursery solum depths to be expressed as a wide range that may include or be close to zero.

Researchers Developed a Different Way to Estimate Soil Loss

A more direct measure of soil removed from field nurseries is the estimate as the product of the number of tree holes per acre -year, the measured volume of tree holes in the field and the soil bulk density.

Annual soil loss = holes/acre x volume/hole x soil bulk density

The bulk density can be estimated from soil survey data and confirmed by field measurements, for the map unit and soil horizons in question. Units for bulk density data are usually in g/cm^3, so they should be converted to lbs/cu ft if the hole volumes are based on inches of diameter and depth.

On one Connecticut field nursery, this analysis resulted in estimated annual soil removal of 1.1 cm (approximately 0.5 inch or 60 tons/acre). Years of remaining productivity in several soil map units varied between 30 and 70 years (Conn. NRCS letter 2004). This estimated rate of soil loss overshoots the U.S. Natural Resources Conservation Service's recommendation that most soils in the Mid-Atlantic can tolerate (that is, retain productivity in spite of) soil loss of three to five tons of soil per acre-year (Duiker, 2006).

Measuring the volume of holes left by tree harvest may be the simplest and most valid method of estimating soil removal, but it leaves unanswered the question of whether the bulk density of the soil in the root ball volume is the same as that of undisturbed soil. In other words, is the mass of soil removed in the ball essentially the same as if there was no tree roots in the soil ball, or do the tree roots account for a large portion of the mass or volume such that the main material removed is roots, not soil?

The mid-Atlantic nursery industry has grown rapidly during the past several decades, so most tree farms have been recently converted from cropland. Tree growers tend to develop their nurseries on land where degradation is not apparent in the short term – nearly level to gently sloping, deep soils with relatively fertile subsoils and a high tolerance for soil removal – in other words, prime farmland.

The use of prime farmland for B & B operations has been controversial from a soil and land conservation viewpoint. For example, Connecticut does not allow nurseries to purchase or use state-preserved prime farmland. Opposing views of this practice were aired during testimony for and against a measure to allow field production nurseries on Connecticut agricultural preserves. The Connecticut office of the USDA/NRCS and the State Agriculture Commissioner argued against the measure, which would allow for "soil restoration and replacement" to counteract soil removal (Kolesinskas, 2009; Prelli, 2009).

Nursery growers, state representatives and farm credit banks came out for the measure (Fritz, 2009; Newman, 2009).

From the individual nursery perspective, growers may see no prospect of their land becoming unproductive in their own lifetimes. This perspective was reflected in the results of our 2008 survey of eight Maryland B&B nursery-stock growers: one had no concern about soil loss on the sustainability of fields, four had only low- to moderate- concern, two had a high level of concern, and one did not respond.

There have been limited scientific efforts to document the level of soil loss by B&B nurseries. In the 1980's, a Connecticut nursery grower, with extension support, measured the volume of soil in B&B root balls by separating roots from soil, packing soil into a box of known area and measuring the soil depth in the box (no native, excavated, or packed bulk densities were recorded). The study indicated that 6.4 mm (about ¼ inch) of soil would be potentially removed per year from this Connecticut farm if it were rented out for field nursery production. At that time, the land owner considered this soil removed by the lessee annually to be a trivial amount. When assessed in terms of tons of soil per acre-year, 6.4 mm soil removed translates to about 30 tons per acre-year, a figure many times the 3 to 5 tons per acre-year that is considered tolerable on agricultural lands of the region.

Farmer perceptions thus may not be in line with the reality of soil removal. The same informal Connecticut study reportedly observed that tree roots occupied about 2/3 of the root ball volume, and soil only 1/3 of the root ball volume. Such reported observations may have contributed to continuing doubts over the validity of the preceding formal soil removal estimates. Nurserymen and extension agents continue to harbor beliefs that the ball that is removed with harvested trees is "mostly roots."

Justification

To determine the extent of the soil removal problem in nurseries using B&B harvest, concrete figures on the amount of soil being removed are needed. Direct measurement of the weight of soil in a tree root ball, in combination with figures on land area under B&B production, and number and size of trees harvested would form the basis for considering whether soil loss from these practices is a serious problem, and whether conservation practices currently recommended, such as organic matter additions and replacing mineral soil (BCMAFF, 2010), can mitigate soil loss. In addition, if our calculation of soil removal made using bulk density taken in native soil near B&B harvest sites and tree spade or tree hole volume matches our direct measurement of root ball soil, then a soil-core method can be used at individual sites to calculate past and expected soil removal. This method, once proven, could enable growers, extension agents, and researchers to track on-farm changes in mineral soil removal rates under soil conservation regimes, raising awareness and increasing industry buy-in for soil conservation practices.

Objective: Determine the quantity of soil removed and the mass and volume proportion of tree roots in root balls of two tree species harvested using two different spade geometries.

Hypothesis: The amount of soil removed with B & B tree and shrub harvest is largely predictable from tree spade geometry (volume of hole) and soil bulk density with influence of tree root mass.

Materials and Methods

Field study

Site selection. A nursery grower was identified in northern Montgomery County MD to provide trees and equipment. The site is located on the Northern Piedmont, ie., Major Land Resource Area 148 of Land Resource Region (USDA/NRCS, 2006). Trees were harvested from areas of Duffield-Ryder silt loams (Soil Survey Staff, 2020; USDA/NRCS, 2020), which are mixed, active or semiactive, mesic Ultic Hapludalfs. These are moderately deep to deep well-drained soils formed in residuum weathered from thin bedded shaley or impure limestone. These soils have an ochric epipedon to plowed depth (Ap horizon), and an argillic horizon (Bt) from 25 cm to as deep as 58 to 130 cm (Soil Survey Staff, 2020) Quartz or quartzite gravel measuring 1.3 cm to 6.4 cm made up 3% to less than 0.5% of soils excavated. *Equipment*. Two 81-cm (32-inch) diameter tree spades were used to dig trees, including a conical spade (Caretree; Graettinger, IA, U.S.A.) and a hemispherical spade (Pazzaglia FZ; Pistoia, Italy).

Tree harvest. Six Norway maples (*Acer platanoides* L.) and six 'Emerald Green' arborvitae (*Thuja occidentalis* L. 'Emerald Green') of comparable age and three-inch caliper size were selected and irrigated for two days in preparation for digging. The trees were root-pruned as liner plants when entering the gather nursery but they were not root-pruned during subsequent years while growing in the field. Three trees of each species were dug using each of the two spades for a total of 12 tree root balls.

A soil ball from treeless soil was also excavated with each of the spades. All soil balls were dug by nursery staff using standard procedures. They were wrapped in burlap and some in wire baskets for stability. Trees were then cut away six to ten inches above the soil ball surface (Figure 1, *below*).

Figure 1. (top) Preparing tree balls for analysis at the nursery. (bottom) Taking bulk density core from tree ball prior to separation of roots and soil. (Photos by R. Weil).

Field measurements taken. After harvest, the volume of each tree hole was measured. The root balls with trunk stub attached and burlap wrap were weighed. Volumetric soil moisture was determined using a calibrated capacitance probe and handheld reader (Decagon EC-5, ECH2O Check; Pullman, WA, U.S.A.). Moisture readings were taken in the unwrapped root ball at three locations 5 to 15 cm below the soil surface, and at three locations 30 to 40 cm below the soil surface (Figure 1, *right*). Bulk density soil cores were taken from each root ball at two locations 5 to 15 cm below the soil surface, and at two locations 30 to 40 cm below the soil surface. Bulk density cores remained to be taken from the same depths in the native soil at the site of the root ball excavations. Steel bulk density rings measured 7.3 cm internal diameter and 6.0 cm length, and were driven into intact root ball soil using a section of 9-cm-by -9-cm lumber and a mallet. Bulk density core soil was stored on ice in sealed plastic bags and returned to the lab.

The remaining root ball soil was carefully removed with hand tools from the central root mass on site, sieved through 1.3-cm mesh hardware cloth, and weighed in approximately 45-kg batches (Figure 2). Gravel larger than 1.3 cm in diameter was collected, air dried, and weighed. Tree roots sieved from the root ball soil were collected and returned to the lab. Burlap wraps and wire baskets were weighed.

Figure 2. (top) Separating and sieving soil from roots at the nursery. (bottom) Example of main root mass after soil removal, including power washing. Fine roots were collected and analyzed at the lab, but were a negligible proportion of the total root mass. (Photos by R. Weil).

The main root mass with tree stub was washed free of soil residue with a high- pressure hose, surface dried, cut at the soil surface level, and the belowground root mass and aboveground stub weighed separately. Woody roots were collected from each root mass and returned fresh to the lab for density determination. Tree hole dimensions were measured for a sample of holes in the field for each tree spade geometry, and a set of 1.92 cm diameter bulk density cores taken to 40 cm depth in undisturbed field soil adjacent to each tree holes, for calculation of tree hole volume and field soil bulk density.

Lab measurements taken. Soil samples from bulk density rings were weighed moist, then air dried and crushed through a 2-mm mesh sieve. Gravel from each bulk density sample was weighed. Soil was further dried for one week at 60 °C and then weighed to obtain gravimetric soil moisture and bulk density. Soil from each bulk density sample was analyzed for total C, H and N (LECO CHN analyzer; St. Joseph, MI, U.S.A.). Fine roots sieved out of the root ball were washed in detergent solution and rinsed, allowed to surface dry, then weighed fresh. Roots were then dried at 60 °C for one week and weighed dry.

Fresh woody root samples from the field operation were washed in detergent solution, surface dried, and weighed. Sample volume was obtained by submersion in water in a 100-mL graduated cylinder. Samples were dried for one week at 60 °C and weighed to obtain root density.

Measured soil weight. The average amount of soil removed from the field with a 32-inch tree spade was 440 lbs (SE 11.3, n=12). When analyzed across both tree spade types, the amount of soil removed in harvesting each species was not significantly different. When each species was analyzed by tree spade type, there was a difference in the amount of soil removed by the different tree spades for Arborvitae, but not for Norway maple (Figure 3), showing an interaction between spade type and tree species.

Within each tree species, there was less variation in the amount of soil removed by the Pazzaglia hemispherical tree spade than by the Caretree conical tree spade (Figure 3), coinciding with practices particular to each. With the Caretree spade, the point of the conical root ball is knocked off, removing a varying amount of soil from the root ball, while the Pazzaglia spade cleanly removes a bowl-shaped root ball which is not normally altered before wrapping.

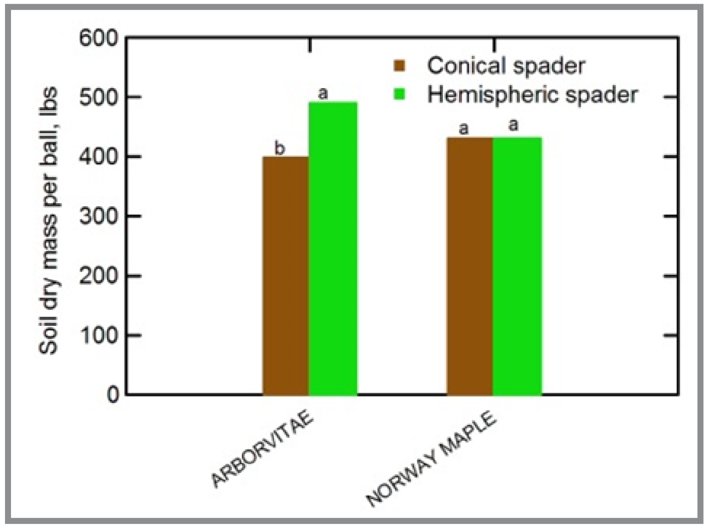

Figure 3. Amount of soil removed in 32 inch diameter tree root balls. For Arborvitae, tree harvester type affected the amount of soil removed. The point of the conical root ball (Caretree spade) is knocked off, removing a varying amount of soil from the root ball. The hemispherical root ball (produced by Pazzaglia spade) is bowl shaped and not normally altered before wrapping. N=12.

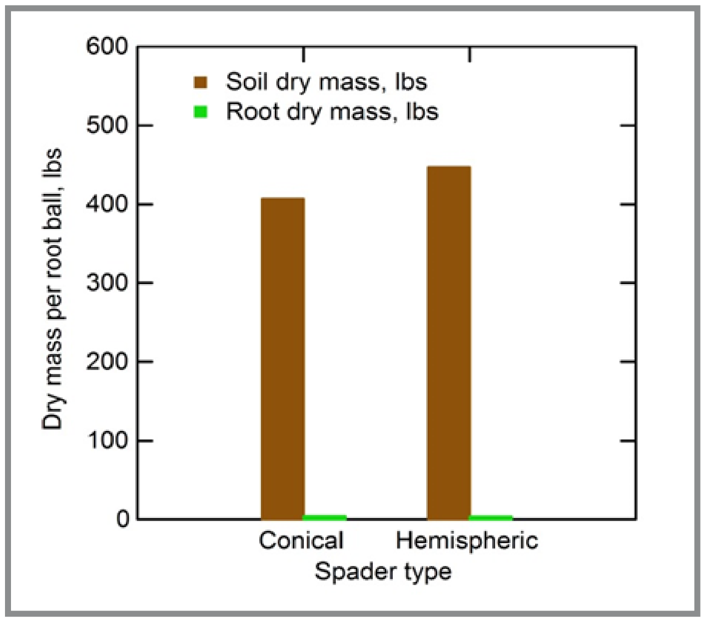

Figure 4. Dry weight of soil and root material in tree root balls made by two types of spade. The dry weight of the roots was negligible compared to that of the soil in each case. N=12

Root weight. Dry weight of tree roots averaged 4.54 lbs (SE 0.12, n=12) in each root ball, about one percent of total dry root ball weight. The Arborvitae root balls averaged 6.6 lbs of dry root matter, while the Norway maple root balls averaged 2.48 lbs (SE 0.33, n=6). Even though total root weight differed between the two tree species, the magnitude of root weight for either species was trivial compared to soil weight in the root ball (Figure 4). Roots comprised only about 1.5% of the root ball dry weight for Arborvitae and about 0.5% for Norway Maple, although this percentage was slightly altered by spade type in the Arborvitae root balls (Figure 5). Root volume per root ball was not affected by spade type.

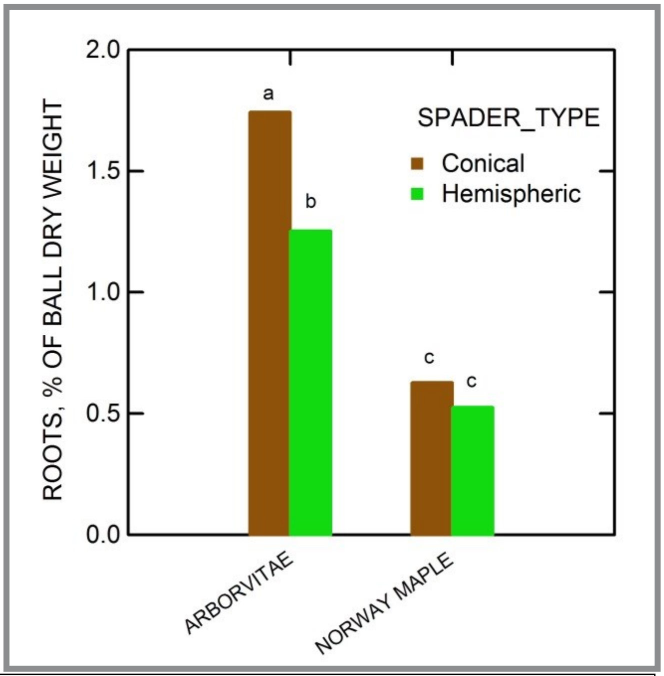

Figure 5. Roots comprised about 1.5% of the root ball dry weight for Arborvitae and about 0.5% for Norway Maple. n=12.

Averaged across both spade types, root volume per ball was 0.0978 cu ft (2.77 L, SE = 0.33) for Arborvitae and 0.215 cu ft (6.09L, SE=0.33) for Norway maple. The hemispherical root ball volume can be calculated as ½ of a sphere of 32 inches (81 cm) diameter or 4.96 cu.ft. (139 L). Therefore, the roots occupied between 2 and 4% of the root ball volume (2.77/139 to 6.09/139).

Bulk density. Average A horizon depth measured was 10.5 inches (SE 0.027, n=11). The average bulk density in the root balls measured at 2 to 6 inches deep (A horizon) was 1.35 g/cm^3 (SE 0.019, n=24). At 12 to 15 inches deep (B horizon) average bulk density was 1.50 g/cm^3 (SE 0.026, n=24). The bulk density was slightly higher in the A horizon and significantly higher in the B horizon for the root balls made with the conical spade than the hemispherical spade (Figure 6). This result suggests that the action of the conical spade caused more compaction of the root ball soil.

Soil organic matter: As a percent of total soil dry weight, carbon and was higher in the A horizons (1.04%) than in the B

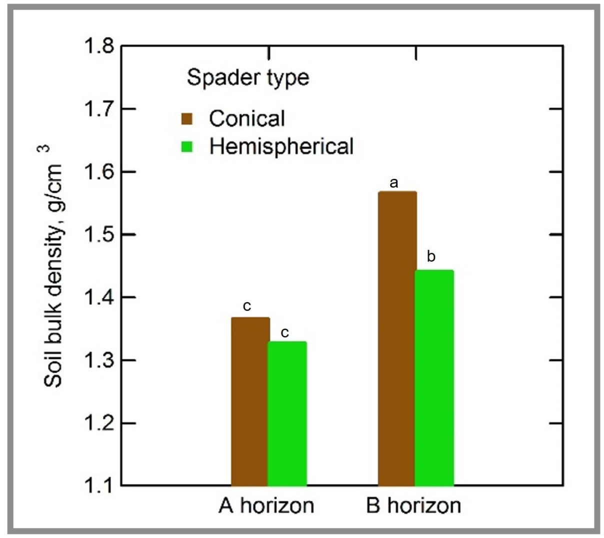

Figure 6. Soil bulk density in A and B horizons (topsoil and subsoil) of root balls for two spade types. Means of two tree species. n=12.

horizons (0.45%). The ratio of carbon to nitrogen (C/N) in the soil was 13.2 in the A horizons, compared to 16.3 in the B horizons, and was significantly higher in the root ball soil from Norway maple than from Arborvitae trees (16.0 compared to 13.4, Figure 7).). Since it is unlikely that deciduous leaf litter from the Norway Maple would influence the C/N in the B horizon, these data suggest that the fine roots of Norway maple contain less N or decay more slowly than those of the Arborvitae. The soil bulk density was negatively correlated with soil carbon content overall (r = -0.82), but less so in both the A horizon (r = -0.55) than in the B horizons (r = -0.84). It is generally thought that soil organic matter helps reduce bulk density through its influence on soil structure and because organic matter has a much lower particle density than mineral soil material.

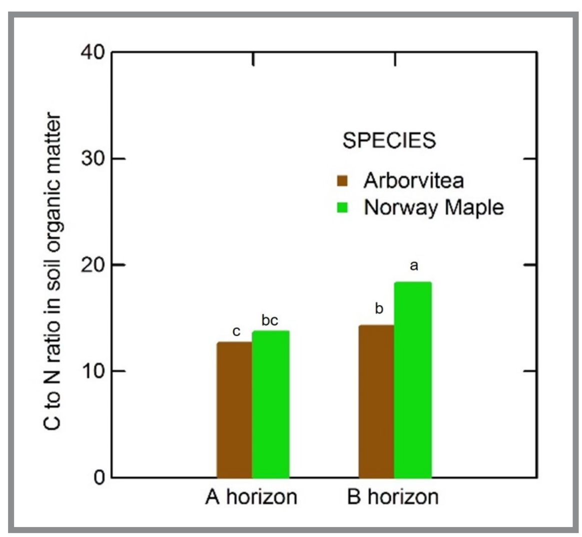

Figure 7. The C/N ratio of the soil organic matter was influenced by both the soil horizon and the tree species. n=12.

Estimating annual rates of soil removal

To extrapolate these measurements to estimate annual mass soil removal per acre, we began with the assumption of 6 x 10 ft tree spacing, theoretically giving 726 trees per acre. We further assumed that on a 5-year cycle, and all trees are harvested with an 32 inch tree spade producing a 440 lbs root ball, as was the case in this study. Then

440 lbs /tree x 726 trees/A x 1 harvest//5 years = 63,888 lbs or 32 tons soil removal per acre-year.

In the root balls studied, about half of the mass (generally more than half the volume) was topsoil, suggesting that about 16 tons of topsoil are lost per acre-year. To put this amount of soil loss in perspective, it is greater than 5 times as much as the USDA/NRCS T-value or tolerable loss by soil erosion. Substantially fewer than the number of trees planted may actually be dug; on the other hand, fifth-year shade trees may require a larger root ball than 32 inches. Estimates of soil removal for any particular nursery field will ultimately will depend on nursery records of numbers of trees exported from the nursery and sizes of root balls on those trees.

Conclusions

The main conclusion from this study is that a balled and burlapped (B & B) root ball consists almost entirely (99%) of soil and that the tree roots take up only a negligible portion of the mass and volume. These results contradict the perception by many producers that the root balls contain mainly tree roots and relatively little soil so that the soil loss is much smaller than the volume of the hole left behind. Our results show that in fact, the volume of the hole left behind is a reasonable estimate of the volume of soil removed.

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