économies de coûts de 20% étaient projetés pour les arbres. Les frais d'arrosage et délagage s'estimaient à environ 95% de tous les coûts projetés des arbres. Ces concusions suggèrent que les arbres peuvent être un substitut de coût positif face aux abris aux arrêts d'autobus dans les villes de latitude moyenne où l'ombrage est utile.

Zusammenfassung: Baumschatten an den Bushaltestellen können den thermalen Komfort wartender Busfahrgäste steigern und sogar neue Fahrgäste anlocken um dadurch Luftverschmützung und Verkehrsstauungen zu reduzieren. Diese Studie wurde mit der Hilfe einer Computer-Vorspiegelung ausgeführt um bei 64 Bushaltestellen in Tucson, Arizona die Kostenwirksamkeit zwischen Schatten von metallen Schutzdächern und Baumschatten zu vergleichen. Der vierzigjährige Entwurf für die Gesamtkosten war 50% höher für Schutzdächer als für Bäume. Als Unterschiede für die Gesamtschattenflecken mithineinbezogen waren, wurde bei den Bäumen die Kosten 20% weniger. Die Bewässerungs- und Auslaubungskosten erledigen 95% aller entworfenen Baumkosten. Diese Ergebnisse deuten an, dass Bäume eine kosten-wirksame Ersetzung für metalle Schutzdächer bei Bushaltestellen in Städten mittlerer Breite sind.

EFFECTS OF A DEEP LAYER OF MULCH ON THE SOIL ENVIRONMENT AND TREE ROOT GROWTH[1]

by Gary W. Watson and Gary Kupkowski

Abstract. After two years, no detrimental effects were found from application of 0.45 m (18 in) of wood chip mulch over soil in which the roots of trees were growing. Soil temperature, moisture and oxygen diffusion rate (ODR) were similar to soil without mulch. Root density in mulched soil was not different from unmulched soil; additional roots had proliferated into the mulch.

Wood chip mulch is commonly used as a 'soft surface' to prevent personal injury in playgrounds. Many of these playgrounds are built near established shade trees. There is concern that roots could be damaged, because often, more than 45 cm (18 in) of wood chips are placed over the surface of soil containing roots. Most tree roots are very near the soil surface. The oxygen required by roots must enter through the soil surface, and any material covering the soil surface can interfere with the supply of oxygen.

The benefits of applying mulch approximately 10 cm (4 in) deep, for normal landscape uses are well documented (4). Under mulch, soil moisture is conserved, and temperature extremes are moderated. Root development is increased in the improved soil, and in the mulch itself (12).

The negative effects of mulch are not as well understood (4). Excessively deep mulch could potentially damage roots by reducing soil aeration. Rapid decomposition of the wood chips could produce excessive heat, or create a nitrogen deficiency from increased microbial activity.

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Materials and Methods

Ten Chicago Park District playgrounds in which 0.45 m (18 in) of coarse, uniform, fresh wood chips had been placed over soil containing portions of the root systems of established trees were identified. The mulch had settled to 0.35-0.40 cm (14-16 in) at most locations. Trees were 15-58 cm (6-23 in) in diameter. From 20-50 percent of the root system of each tree was covered by mulch. This arrangement allowed sampling soil around each tree with and without mulch. The chips were the type produced by large "whole tree chippers". The playgrounds were all constructed in 1988, two years prior to sampling. All trees were sampled July 25-30, 1990. Based on previous experiences with root responses to mulch (unpublished data), two years was judged to be the appropriate length of time to observe and measure the effect that the mulch would have on roots. The wood chip layer was still easily distinguishable from the soil.

Soil oxygen diffusion rate (ODR), temperature, pH, moisture and nitrate levels were measured at 23 locations within the root spread of individual trees (1-5 m from the trunk depending on the size of the tree and the playground construction). For each tree sampled, data were compared from the soil underneath the mulch layer, and from an area the same distance from the tree trunk, but without mulch over the soil.

Because the upper 30 cm (12 in) of soil is where the majority of the roots are located (8), sampling was limited to this area. Soil core samples were collected to a depth of 30 cm. Soil from the entire length of core was mixed, subdivided for individual tests, and refrigerated until analyzed. Soil pH measurements were performed according to the methods of McLean (7). Nitrate testing was performed using the ion-selective electrode method (6). Soil moisture was determined gravimetrically (2). Soil ODR and temperature were measured in the field. ODR was measured 15 cm (6 in) below the surface using the platinum electrode method (9).Soil temperature was measured 10 cm (4 in) deep with a digital thermometer. Root densities were determined by core sampling (11).

Data were analyzed using Analysis of Variance (ANOVA). Separation of means was accomplished with the Newman-Keul's Test with significance at 5 percent (0.05).

Results and Discussion

Measurements of soil ODR showed that there was no significant reduction in oxygen content of the soil under the mulch, compared to adjacent unmulched soil (Table 1). Both values are well above the 0.20 g/cm^2/min threshold level at which root growth is inhibited (10). The slightly lower value under the mulch could be associated with the higher moisture content of that soil. The additional water in the pore space displaces the air, and results in a lower ODR value. The coarse wood chips used in the playlots apparently allows sufficient oxygen to diffuse into the soil below it.

Average soil temperatures were nearly identical under the mulch and in adjacent unmulched soil (Table 1). Heat produced by decomposition of the mulch apparently dissipated adequately, though it is not possible to tell directly from these data if mulch or soil temperatures were elevated earlier in the two year period between mulch application and sampling. Under the mulch, temperatures fluctuated only half as much between cool and hot sampling days, only 4 days apart, demonstrating the ability of mulch to buffer soil temperature fluctuations.

Soil moisture, expressed as a percent of dry weight, was measured at 22.9 percent under the mulch and only 20.8 percent without mulch (Table 1). Rainfall was above average during the summer of the study, and even the unmulched soil was moist. The difference in soil moisture between mulched and unmulched soils was not significant. The difference may have been greater if the summer had been one of normal or below-normal rainfall. The coarse wood chips apparently allow

Table 1. The effect of 0.45 m (18 in) of wood chip mulch on properties of the soil beneath it.

Soil property	*Mulched soil*	*Unmulched soil*
Soil ODR (ug/cc/min)	0.38	0.46
Average soil temperature (_C)	22.3	22.7
Soil temperature range (_C)	19.4-25.2	18.3-30.2
Soil moisture (% dry weight)	22.9	20.8
Soil pH	7.6	7.6
Soil nitrates (ppm)	2.8*	4.2

* Significant difference at the .05 level.

ample water to percolate through to the soil, while helping to conserve soil moisture during dry periods. When soils are poorly drained, high evaporation rates may be desirable and mulching may be inappropriate. Some fine textured mulches can prevent water from reaching the soil beneath it, either by absorbing it all, or causing it to run off.

Soil pH was unaffected by the mulch (Table 1). The mean pH for both mulched and unmulched soil in the upper 30 cm was 7.6. The pH of the very shallow soils just under the mulch may have been affected by the mulch, but it was not detected by the sampling method used. Mulch can contribute to reducing soil pH in the upper 15 cm (6 in) over a longer period (5).

Soil samples were analyzed for nitrates, the form of nitrogen most available to plants. Nitrates were lower in the soil under the mulch, but both values are considered very low (A&L Great Lakes Labs, personal communication). Though the difference between the two values was statistically significant, it is difficult to consider the difference between the mulched and unmulched soils important when they are both so far below the acceptable 30-39 ppm range.

Decomposition of mulch requires an increased number and activity of microorganisms. The fungal rhizomorphs commonly observed in the mulch were evidence that decay organisms were very active in the mulch. This microbial activity can cause a temporary nitrogen deficiency, particularly in fine-textured mulches that are high in cellulose (4). Decomposition of hardwood species requires more nitrogen than softwood species (1). Gilman et al. (3) found that virtually all nitrogen applied to decomposing cypress wood chip mulch leached through within 25 days, indicating no requirement for supplemental nitrogen by the microbes. Park district arborists noted no deficiency symptoms at any time despite the generally low soil nitrate levels. In the long run, nutrients released as the mulch decomposes will be available for the tree.

Root density of 4 tree species from 14 of the study locations was measured (Table 2). There were no significant differences in root density between the mulched and unmulched soils. The lack of a significant difference in silver maple root density, even though the mulched soil root density appears to be twice as large, is attributed to large sample variation. This is not uncommon for root density data (10,11).

Since root densities were unaffected by the mulch treatment, it is likely that no detrimental changes in the root environment occurred between application of the the mulch and sampling time. If substantial root damage had occurred earlier, redevelopment of roots would probably take at least a full season after soil conditions returned to normal. Also, the crowns showed no signs of dieback usually associated with root loss. Root development should increase in the mulched soil over time, as it has in other studies (1,5).

There were many tree roots in the mulch, sometimes in higher density than observed in the soil itself. It was not possible to accurately quantify the large number of additional roots found growing in the coarse mulch layer. These additional roots are not reflected in the soil root density measurements. Though some roots of every species were found in the mulch, roots of silver maple and crabapple were by far the most numerous. Thus, these two species would benefit most rapidly from the mulch application, and would suffer most severely if the mulch were to be removed for any reason.

Conclusions

It is common to hear warnings of too much mulch, and sometimes these warnings may be justified. Though the half-meter (18 in.) thick layer of mulch applied in playground design in this study is unusually thick, it appears that these specific circumstances have created a very favorable environment for root growth in the coarse wood chip mulch, and in the soil beneath it. None of the

Table 2. The effect of 0.45 m (18 in) of wood chip mulch on the root density of the four tree species.

Tree	Number of trees	Root density (mm^2 surface area/cm^2 soil) Mulched soil	Unmulched soil
Silver maple, *Acer saccarinum*	3	12.6	5.2
Green ash, *Fraxinus pennsylvanica*	3	6.0	5.5
Honeylocust, *Gleditsia triacanthos*	4	11.1	12.0
Crabapple, *Malus*	4	4.7	4.9

harmful effects associated with rapid organic matter decomposition wasobserved. Only the favorable effects normally associated with mulch in the landscape were present. Other mulch materials may have different properties and roots may react differently to them, but general recommendations for, or against, applying thick mulch to established trees should be avoided. Mulch material should be selected carefully to assure adequate air and water penetration if mulch is to be used more than 10 cm (4 in) deep. Mulch should not be in contact with the bark because decay or rodent damage could result. The results of this study indicate that further research is needed to establish proper use of mulch under a wide variety of circumstances.

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Résumé. Après deux ans, aucun effet préjudiciable était observé par l'application de 0.45 m (18 po) d'un paillis de copeaux de bois sur le sol où les racines d'arbres étaient en croissance. La température du sol, l'humidité et le taux de diffusion d'oxygène (ODR) étaient similaires au sol sans paillis. La densité racinaire sur un sol paillé n'était pas différente de celle d'un sol non paillé; des racines supplémentaires avaient proliféré dans le paillis.

Zusammenfassung: Nach zwei Jahren sind keine schädliche Wirkungen von der Anwendung 45 cm Holzsplitterbedeckung über Erdboden, in dem Baumwürzeln wachsen, bemerkt. Bodentemperatur, Feuchtigkeit, und Sauerstoffausbreitungsrate (ODR) waren dem Erdboden ohne Bedeckung ähnlich. Die Würzeldichte in bedecktem Boden war nicht vom unbedeckten unterschiedlich; zusätzliche Würzel sind in die Bedeckung eingedrungen.

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