THE EFFECT OF WOOD MULCH TYPE AND DEPTH ON WEED AND TREE GROWTH AND CERTAIN SOIL PARAMETERS

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Abstract. The use of wood byproducts as horticultural mulch has increased in the last decade as the horticulture industries and landscape architects have raised the public's awareness of the aesthetic and maintenance benefits to be gained from mulch use. The objectives of this experiment were to evaluate the effect that two types (chipped pine and shredded hardwood chips) and three depths (7.5 cm, 15 cm, and 25 cm) of mulch and an unmulched control would have upon: 1) oxygen percent, moisture percent and soil temperatures; 2) growth of two thin barked trees (*Pinus strobus* and *Quercus palustris*); 3) establishment of weed populations; and 4) potential change in certain soil parameters (pH, nitrates, and soluble salts). After two years, no differences were found between mulch types, but soil oxygen levels declined (non-significantly), temperatures declined, and moisture levels increased with increasing depth of mulch. Weed density and diversity also declined significantly with increasing mulch depth. For both species, stem growth was greater with the 7.5 cm. depth of mulch than with other mulch depths or the control. Soil pH, nitrates, and salt levels were unaffected.

Enthusiasm for a mulched landscape has led at times to over zealousness in wood and bark mulch application. Depth of mulch applications have been as great as 50 cm or more from either single or multiple applications (16). Objection to excessive application has led to much supposition and some research on the potentially negative effects this practice may have on tree and shrub health.

The main functions that mulches provide include: weed suppression, soil water conservation, moderation of soil temperature fluctuations (daily and seasonal), increased infiltration of water droplets from precipitation or irrigation, soil protection from traffic compaction, improved soil structure and, for organic mulches, the slow release of nutrients over time (1,3).

Normal soil oxygen levels are approximately 19%, while reduced or low O_2 states are classified as anything less than 15% (6). Under reduced oxygen states, soil microbes, roots, insects, and worms deplete available oxygen so that anaerobic respiration accelerates. Roots cease to elongate and become unable to absorb water and nutrients as anaerobic activities progress. [(Undisturbed forest soils typically have an oxygen percent of 18% or more at 1 m below the surface (21).]

In one experiment, shallow rooted ericacious plants growing in a heavy mulch layer experienced root rot below the mulch (8). Mulch depths greater than 10 cm have been reported to be inhibitory to plant growth because of reduced soil aeration (2). But a study using 25 and 45 cm of mulch does not support this claim (20). The soil oxygen under the mulched areas in this study was similar to that of the unmulched controls and any reduction was not great enough to affect plant health.

A great deal of research has been done to date on the effect that mulching has on improving and maintaining a steady reservoir of soil moisture. A mulch layer disrupts the impact of rain drops on the soil surface (11,17): slows runoff, thereby increasing infiltration (9,20); reduces transpiration and competition by inhibiting weed growth; and acts as a mechanical barrier to diffusive processes (3,11,18). At the end of a growing season, organically mulched plots may have available water reserves to a depth of 1 m compared to unmulched plots at half that depth (10). Moisture levels beneath bark and wood mulches of similar chip size may be twice that of unmulched plots (18).

The temperature of the mulch and soil certainly contributes to these substantial differences. The temperature of an unmulched soil frequently reaches 10 degrees higher than a mulched site during the growing season (4). Organic mulches, if applied in layers 6 to 8 cm thick, keep soil temperatures elevated further into the winter, al-

lowing root growth to continue longer. This effect is beneficial for establishment of fall planted trees, but it has been implicated in twig dieback due to late hardening off (3,9). Mulching has proven to be effective in controlling the amount and type of weed growth for several reasons: 1) applying mulch directly on top of mature weeds may slow or damage them by removing light, interfering with stem elongation, encouraging fungal growth with the increased moisture contact, and by acting as a physical barrier (2); 2) mulches interfere with weed seed germination by blocking light (11); and 3) weeds which germinate in organic mulch are easier to pull either because the ground is softer due to higher moisture levels, larger pores, and greater aggregation, or frequently because of shallower rooting (9).

In addition to the increase in availability of soil water from mulching, there are other related benefits. Because the fertile upper layer of soil has extra thermal protection, the tree roots can optimally colonize that area. Organic mulch will release nutrients over a long period of decay (9). In one study potassium and phosphorus availability under mulch increased almost two times over the unmulched, clean cultivated plots (19). The only danger is with fine textured wood and bark mulches (11). These may expose too much surface area to the soil microbe population at once. Nitrification may be slower under mulched soils due to overall moisture increase and temperature decrease through the growing season (10).

Materials and Methods

Beginning in April, 1991, approximately 9 m^3 of both chipped pine mulch and shredded hardwood mulch were stored for 6 weeks in 1.2 m high piles before application. This was to allow normal precipitation and aeration to diffuse any alcohol that may have resulted from improper storage.

Thirty bare root, 3.8 - 5.0 cm caliper *Quercus palustris* trees, and thirty balled and burlapped, unsheared, 1.2 - 1.5 m tall *Pinus strobus* trees were chosen for their sensitivity to high pH soil and for their thin juvenile bark. The test site (7.5 m wide and 45 m long running north and south) was a heavy Collamer silt loam that had been under cultivation for various agronomic crops for at least

10 years. The plow layer was 20 to 35 cm deep, becoming increasingly dense, fractured, and heavily mottled with depth. Prior to planting, 2005 kg/ha of pelletized hydrated lime was applied to the site to raise the soil pH.

The trees were planted May 6 in holes dug with an auger and the diameter of each hole was widened with a shovel (to reduce the effects of glazed sides) to 0.75 m for pines and 1 m for the oaks. The pines had a standard root ball of roughly 0.5 m, and the bare-roots of the oaks were standardized. The weather in the summer of 1991 was extremely dry and hot. Although the balled and burlapped pines established quickly, the bareroot oaks suffered from the transition from a very cool storage warehouse to a very hot (>30°C) final site. Many oaks barely broke bud the first year and five died, preventing a complete statistical analyses of oak growth data.

The experiment was set up as a complete randomized block design with four blocks set end to end along the north/south axis. Each block included an equal number of *Pinus* and *Quercus* with 7.5 cm, 15 cm, and 25 cm depth application of each type of mulch in a 1.5 m square around each tree. In each block there was one unmulched square for pine and one for oak to be used as control. The mulch was maintained at the designated height to the edges of the square by a border "fence" of 1.25 cm cubed poly deer netting that was 7.5 cm taller than each mulch depth and was stapled to stakes at each corner. Unmulched trees were also surrounded by a 7.5 cm netting applied to the perimeter to trap organic debris from the trees and weeds.

An oxygen sampling chamber (Figure 1) made of a 15 cm length piece of 3.8 cm S/40 PVC pipe capped at the bottom with a piece of aluminum window mesh (7.2 by 6.5 strand per cm^2) so that as the chamber was inserted into the hole, loose soil would not reduce its capacity. The top of the oxygen chamber was sealed with a PVC cap glued tightly with PVC pipe cement. Volume of the chamber was 200 ml. A 0.32 cm hole was drilled in the center of the PVC cap and lengths of 0.5 cm Nalgene tubing were fitted tightly within the holes. The outside end of the tube was capped with a 5 by 9 mm serum stopper which was protected from
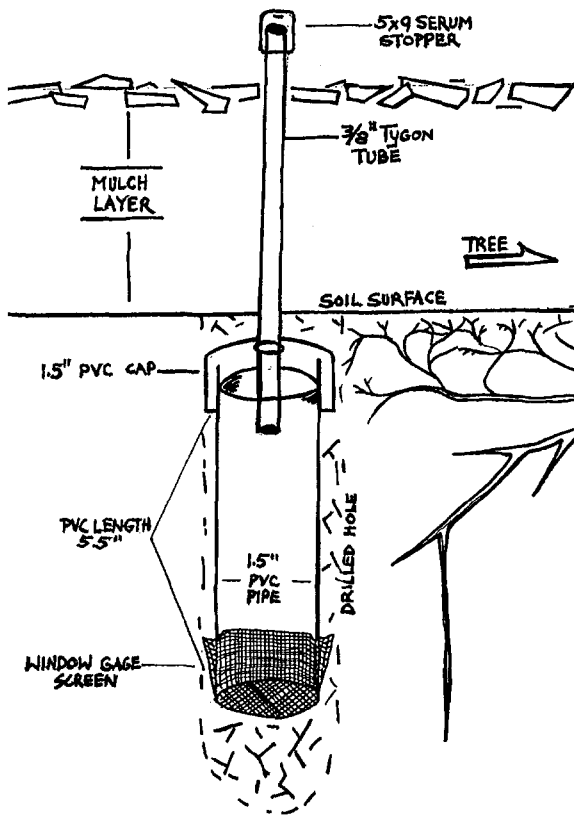
Figure 1. The PVC oxygen chamber that was constructed for the mulch experiment.

light degradation by aluminum foil wrapped around it. The caps were replaced periodically to assure an airtight seal. This capped end was placed so that when mulched it was accessible at the surface for sampling. The chamber was inserted into a 5 cm diameter hole at a 20 cm depth.

The soil surrounding each tree was allowed to settle for 18 days. Caliper measurements were taken just above the root flare of the trees. At this time height and branch spread measurements were taken per tree. All tree plots were mulched by the last week in May. Mulch was applied regularly until the settled depth was achieved. It was observed that a 25 cm depth of mulch required more than was originally calculated due to settling. The heavier the chip, the more it packed down upon application and the more total mulch was needed to reach the settled depth.

The entire test area was watered weekly through the rest of the growing season and fertilizer (20-20-15) was applied using a 1:100 GEWA setting #3 (45.5 g N/liter) at the end of June, July and August to facilitate establishment. A glyphosate herbicide (Roundup) was used monthly for weed control between the tree treatment squares and the blocks. From June 25 through Sept. 9, soil oxygen percent data were taken every two weeks using a Servomex (R) 574 Portable Oxygen Analyzer (Servomex Co., Norwood, MA). To introduce the soil atmosphere into the analyzer, a syringe needle was inserted into the serum stopper at the end of the tube leading to an oxygen chamber in the ground. A vacuum was drawn with a hand pump (Servomex 2387-0615) attached to the outflow of the instrument. Because of the sensitivity of the machine to moisture, we fabricated a dehydrating mini-chamber with silicon crystals that the air had to pass through on its way into the machine. The instrument was recalibrated for each date's measurements and the gas used to set the span was oxygen-free nitrogen (99.9%).

On September 15, 1991, the first season's weed population data were taken. Each plot was divided into smaller squares of 0.3 m. The percent of weed cover was visually estimated for each of these smaller squares and then summed for the total weed percent cover per tree plot. The species of weeds present in each square was individually determined. On September 17, 1992, weed data were taken again to show population change over two seasons with the measured variables being time of establishment, mulch type and mulch depth.

The entire study was not irrigated at all in the 1992 season in an attempt to determine the effect of the mulch alone on water conservation. Coincidentally, 1992 was a year of above average precipitation, so it is unlikely that the mulch had its maximum effect. Moisture percent in the top 5 cm of soil was determined gravimetrically on samples from each tree taken within 30 cm of the trunk. The samples were collected in the third week in June 1992 after a week without precipitation.

Beginning on the 23 of June 1992, soil temperature measurements were taken daily for a week to establish the degree of temperature fluctuation between mulch depths. Thermocouple

wires (Omega H20 TF-T-20-50 Teflon covered) attached to sub-miniature copper constantan plugs (SMP-T-M) were inserted through the mulch into the top 3 cm of soil in each plot and measurements were taken between 16:30 and 17:00 hours with a microprocessor thermometer (Omega HH20 series digital). Following these measurements, the soil temperature for each tree was measured weekly through September 6. Thermocouples were coated with an acrylic seal and monitored to insure that there were no misreading due to metal corrosion.

Tree growth measurements were taken in September, 1992 for shoot growth, and caliper, height and width change over the two-year period. Soil samples were taken for each tree and a full nutrient analysis was conducted by the Cornell Nutrient Analysis Laboratories. Statistical analysis was conducted on pH, nitrates, and soluble salt concentrations (mS/cm).

The data (weekly and seasonal soil temperature, 1991 and 1992 oxygen percent, soil moisture, weed percent and species numbers, and tree growth data) were analyzed through factorial analysis using the PROC-GLM procedure and a general linear model procedure, the Duncan's New Multiple Range test of SAS (SAS Inst. Inc. 1985, Carey, NC). Correlations were run on soil temperature, soil moisture and overall tree growth, soil H_2O, pH, nitrate, /salts, and weed growth.

Results

Percent oxygen data indicated a non-significant decline with each additional mulch increment (<1% overall). Seasonal means for mulch depths were: 0.0 cm - 19.8%, 7.5 cm - 19.5%, 15.0 cm - 19.4%, 25.5 cm - 18.9%. The lowest soil oxygen measurements obtained were two tree plots at 10 percent for one day, directly related to localized drainage problems. Type of mulch was not a factor and tree effect was insignificant.

The moisture data obtained were for a one time comparison based upon one soil core retrieved from each tree plot with four replications of each treatment. Moisture levels varied significantly with depth of mulch ($Pr > f = 0.0001$). After one week without precipitation, the unmulched control plots had a mean moisture of 9.8%. From the unmulched

control plots to the 7.5 cm mulch depth there was a steep increase of 58%. There were insignificant additional gains with increased mulch levels. Standard error for the mulched plots was quite variable (Table 1).

A highly significant relationship between mulch depth and soil temperature ($Pr > f = 0.0001$) was revealed through an ANOVA procedure. Soil temperature and soil moisture levels were positively correlated at $P = 0.05$. The seasonal mean temperatures for June through September, 1992 were 21.4°C for unmulched plots compared with 21.1°C at 7.5 cm, 19.3°C at 15 cm, and 18.5°C at 25 cm. The decrease in temperatures from 0.0 cm to 25 cm diminished as the season progressed (Table 2).

There were no relationships between either pH and mulch depth, or nitrates and mulch depth. Variation in soil pH was not consistent with any mulch depth. Mean soil nitrate concentrations ranged from 9.8 to 10.3 ppm and varied greatly within each mulch depth. These changes in soluble nitrate from control to the mulched plots were not consistent, nor were they large enough to have any appreciable effect on tree growth (data not shown). There were some significant trends in soluble salts concentrations data, although the amounts found were not large enough to negatively affect tree growth or health. In this study, tree species had an effect on soil salts concentration. The mean soluble salts concentration under oaks was 6.8 mS/cm compared to 9.8 mS/cm under pines (p = 0.05). The reason for this effect was not discernible.

Mulch depth had a dramatic effect on both weed number and weed species diversity, with

Table 1. Comparing mean percent soil moisture between three depths of mulch and and unmulched control after a precipitation free period of one week (4 cm depth core of surface soil).

Mulch depth	Moisture mean %	Moisture range %	pr>f
0 cm	9.8	4.9-10.8	0.0001
7.5cm	15.5	10.0-19.4	
15 cm	16.8	12.7-20.0	
25 cm	17.4	14.8-20.1	

Table 2. 1992 Season soil temperatures (°C) under 0 cm, 7.5 cm, 15 cm, and 25 cm depths of wood mulch.

Mulch depth	June 19	June 28	July 7	July 14	July 23	July 30
0	21.54 A+	22.52 A	21.58 A	23.29 A	19.56 A	20.60 A
7.5	19.76 B	20.24 B	20.85 A	22.08 B	19.41 A	20.20 A
15	18.79 C	17.78 C	19.08 B	19.97 C	18.68 B	18.67 B
25	17.93 D	16.07 D	17.47 C	19.00 D	18.42 B	18.27 B
	Aug. 6	Aug. 14	Aug. 20	Aug. 27	Sept. 6	Seasonal mean
0	21.57 A	21.74 A	19.66 A	24.11 A	20.98 A	21.4
7.5	20.69 A	22.63 A	20.23 A	23.98 A	20.40 A	20.1
15	18.21 B	19.28 B	18.86 B	22.68 B	18.46 B	19.3
25	17.55	17.85 C	18.66 B	21.69 C	17.89 B	18.5

Means followed by the same letter wihin a column are not significantly different at the alpha 0.05 level (according to Duncan's Multiple Range Test.).

the greatest effect being shown from 0 to 7.5 cm (Figure 2). Total percent weed cover in 25 cm mulched plots was only 3.5% at the end of the second season. Total weed species decreased sharply from 0 cm to 7.5 cm both in 1991 and in 1992. Most of the weed species in the 25 cm plots were perennial thick stemmed weeds (Cirsium lanceolatum and Asclepias syriaca) that penetrated the mulch after application. There were also several invading annuals and perennials that seeded directly on top to the mulch (Table 3). At the 7.5 cm mulch depth, grasses eventually either

penetrated the mulch with rhizomes in the first season or seeded into the mulch in the second season. Cyperus esculentus (yellow nutsedge) was able to penetrate the 7.5 cm of mulch, which was probably due to the stiff structure of the emerging new leaf blades. Other weeds that spread via underground runners (such as Solidago spp.) were able to spread rapidly in the 7.5 cm plots and became strongly established.

By utilizing an overall growth estimate (width x height x caliper) in an ANOVA procedure, an effect ($p = 0.10$) of mulch depth on growth was shown. Although there was a large standard error in the oaks due to failed establishment of certain individual trees, they proved more consistent than the pines in their overall growth response to the various mulch depths. Trees with all depths of mulch displayed some increase in mean caliper compared with those that were unmulched. Overall shoot growth (20 shoots per tree) was not affected by mulch type; however, mulch depth had a significant effect (Figure 3). Both pines and oak had greater shoot growth at 7.5 cm than at 15, 25, or 0 cm.

Bark on portions of tree trunks that had been in contact with mulch down to the soil surface was inspected. Fifty percent of the pine and twenty-five percent of the oaks were inspected for indica-
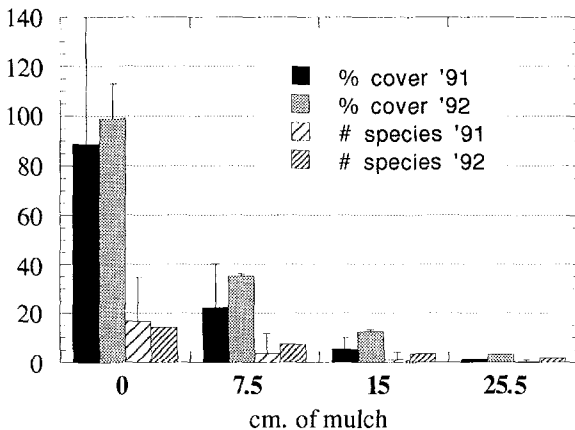

Figure 2. Percent weed cover and number of weed species from September 1991 to September1992.

Table 3. Most common weeds found in the treatments.

	1991	1992
1.	Senecio vulgaris	Senecio vulgaris
2.	Taraxicum officinale	Taraxicum officianale
3.	Panicum dichotomiflorum	Lonicera spp.
4.	Digitaria sanguinalis	Solidago spp.*
5.	Cyperus esculentus*	Vitus spp.
6.	Setaria glauca*	Oxalis stricta*
7.	Cirsium lanceoltum	Quercus spp.
8.	Solidago spp.*	Cyperus esculentus*
9.	Ambrosia artemesiafolia	Plantago rugelii
10.	Medicago lupulina	Agropyron repens
11.	Oxalis stricta*	Setaria glauca*
12.	Trifolia reptans	Erigeron canadensis

* Weed species that maintained their top twelve status but changed position in the hierarchy.
Total number of weed species in study
1991. 21 weed species   1992. 43 weed species

Figure 3. Effect of mulch depth on shoot growth of Pinus strobus and Quercus palustris from May 1991 to September 1992.

tion of discoloration and/or canker development that might have been stimulated by mulch piled up on the trunks. There was no discoloration or colonization of the bark by pathogenic fungi or canker causing agents. In addition, wounds that had been cut prior to planting exhibited normal preventative callus, so there was no attempt to culture bark samples.

There was abundant colonization of the mulch by an extensive network of white-gray fungal mycelia that were saprophytic in nature. This fungus had also grown onto the bark surface of the trees planted in mulch. The bark appeared to be involved simply as a supporting structure in contact with the decaying mulch. The natural sway of the 25 cm mulched oaks compressed the mulch horizontally, so there was an air passage 0.7 to 1.2 cm from the bark and tapering to contact from 5 to 10 cm down. The lenticels on the trunks of the oaks in contact with the bark were slightly enlarged and spongy at their perimeter. Only bark that was visibly wet had this effect.

Discussion

The results show that lack of sufficient oxygen is probably not a limiting or damaging factor in situations where trees are mulched heavily. Oxygen percent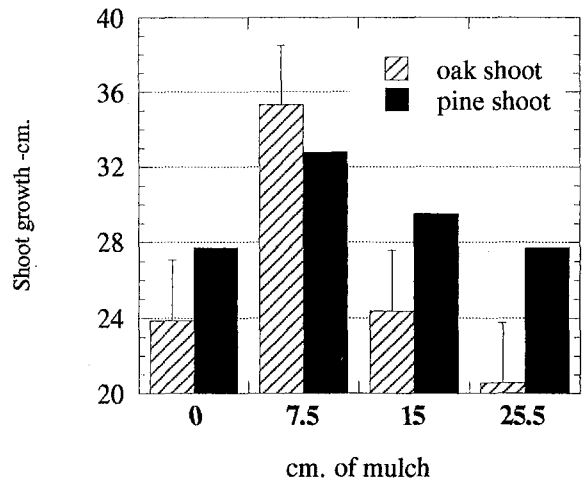s of 19% are considered normal in undisturbed forested sites and they must fall below 15% for any period of time to be considered poorly aerated (6,15). In this study, oxygen percent rarely reached below that level, even for individual trees. These results support work done by Watson, et al. (20) and undermine suppositions of others as to the 'suffocating' effect that deep layers of mulch create (7,8). Moisture samples taken during periods of extended precipitation indicated that there was very little difference between mulched and unmulched plots once the mulch becomes moist.

Soil temperature data reconfirm pervious studies in which mulched plots had lower soil temperature through the season (3,9). Soil under mulch was slower to warm into the middle of the summer, but the significant differences between soil temperature at all depths of mulch were reduced as the season progressed and the soil eventually warmed up at all depths. There was a difference in mean soil temperature of 5.9°C from the 0 to 25 cm mulch treatments on June 28 compared to a difference of 2.4°C for the same depths two months later on August 27.

In the spring the great variation between soil temperature without mulch and that under mulch can potentially affect root physiology. At that time of the year the soil is cool and any depth of mulch

has a buffering effect on the soil's rate of warming. The 7.5 cm mulch depth appears optimum, because it maintains a significantly increased soil moisture level and does not significantly reduce the soil temperature over the season, which could cause a possible setback in root growth for the 15 cm and 25 cm mulched plots. In studies (13,14,19) on other species of Pinus and Quercus, it was found that 18 to 24°C was usually optimum for root growth.

The fact that the data indicated no change in pH supports previous research conducted by Watson and Kupkowski (20) in which mean pH of the top 30 cm soil under 45 cm of mulch remained unchanged after two years. In this experiment the samples were taken from the surface 6 cm of soil to address the question of whether, over the same period of time, the surface layer of soil would acidify; it did not.

Research concerning wood mulch's effect upon soil nitrate levels (2,3,5,9,11,17) indicates that in most circumstances the increase in soil microorganisms due to a moist organic environment aids the slow decay of the mulch. Relative to nursery production standards, nitrate levels overall on the site were low (9 - 14 ppm) over all treatments, and there were no apparent trends between the treatments. Apparently, there is no immediate nutrient binding danger from surface wood mulches of the particle size that was used in this experiment.

It is apparent that mulch depths of 7.5 cm or greater make a large contribution to the control of weeds in the landscape (Figure 2). The thicker the mulch, the greater this benefit (at least up to 25 cm). There was a great deal of variation in rate of weed establishment at the thicker mulch depths because a herbicide was not applied previous to mulching, and some of the plots had perennial weeds that grew thorough and thrived in the thick layers of mulch. An application of a broad-spectrum herbicide before mulch application to kill strong stemmed plants and insidious underground rhizomes would be a sensible first step in prolonging the usefulness of a few inches of mulch. After application, loose cultivation with a rake to dislodge weed seedlings before they establish extensive root systems, a periodic herbicide application, or hand-weeding would increase the percent of weed reduction.

Summary
This study reaffirms that the current recommendation for mulch depth of 7.5 cm is appropriate. Soil oxygen levels, temperatures, and moisture levels are all within acceptable ranges under a mulch of this depth.

The 15 cm and 25 cm mulch depths were still quite viable both aesthetically and functionally after two seasons. The slowed warming of the soil under the 15 cm and the 25 cm depths of mulch may have reduced lateral root growth enough to have affected tree growth. Studies have shown that the slowed warming of the soil in spring under mulch has a restrictive effect upon plant root growth.

The fact that the trunk wounds on the pines had callused normally, despite deep mulching of 15 and 25 cm, was encouraging. Horizontal compression of the mulch by the natural trunk sway was unanticipated, but obviously facilitated air movement and drying of the bark into the mulch. The existence of the saprophytic fungi in the decomposing mulch indicates that it is a good substrate for fungal development. The lack of visible activity of parasitic or pathogenic fungi may only indicate that they were not present in the mulch in sufficient concentrations to invade the bark, that the trees' natural external bark barrier and internal defenses were thus far sufficient to prevent invasion, and/or they were out competed or suppressed by the presence of other fungi and soil microbes. The tissue swelling along the border of the lenticels was presumably a reaction to the moistness of the mulch. It may be that these soft gaps in the waxy cuticle could eventually become a sight of pathogen entry.

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