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Effect of *Eucalyptus cladocalyx* mulch on establishment of California sycamore (*Platanus racemosa*)

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Abstract

Mulches prepared from fresh and composted *Eucalyptus cladocalyx* prevented growth of annual weeds, increased soil moisture retention, reduced diffusive resistance of California sycamore (*Platanus racemosa*) and increased stem diameter compared to unmulched sycamores. Sycamore root lengths were greater in soil profiles under mulched trees than in soil under unmulched ones. Eucalyptus mulches reflected more photosynthetically active radiation and maintained lower surface temperatures than biosolids mulch or unmulched soils. Eucalyptus branches both freshly chopped and composted were effective in promoting growth of sycamore.

Key words: Biosolids, pine bark, composting, *Eucalyptus cladocalyx*, *Platanus racemosa,* mulch

Introduction

Eucalyptus trees are commonly planted as windbreaks and amenity plantings in orchards and landscapes throughout subtropical and mediterranean regions of the world. Suppression zones of sparse understory vegetation are often associated with eucalyptus trees and are sometimes caused by allelopathic mechanisms (del Moral and Muller, 1969 & 1970; del Moral *et al.*, 1978; Nishimura *et al.*, 1984; Lamont, 1985; Molina *et al.*, 1991). Reduction in growth of row-crops is also associated with eucalyptus allelochemicals (Rao and Reddy, 1984).

Shredded or chopped leaves of some eucalyptus species can be toxic to seedlings (Baker, 1966; Nishimura *et al.*,1984; Igboanugo, 1986; Molina *et al.*,1991; Kohli and Singh, 1991). Molina *et al.* (1991) found that leachates from decomposing eucalyptus litter reduced germination of herbaceous annuals. However, May and Ash (1990) suggested that decomposition of leaf litter destroys the toxic effects found in living eucalyptus trees. Yet, Duryea *et al.* (1999) found that *Eucalyptus grandis* mulches contained phytotoxic residues three months after application to soil.

Eucalyptus trees are common landscape trees that when trimmed or removed, become components of "green-waste" that is now frequently collected and recycled. Although eucalyptus allelopathy has been demonstrated, there is little information on the phytotoxic potential of eucalyptus mulches that might be used in landscapes. Because eucalyptus phytotoxins may harm desirable plants, there is concern that municipally collected "green-waste" could be contaminated with eucalyptus that will "poison" yardwaste compost products.

The purpose of this study is to determine the suitability of mulches made from *Eucalyptus cladocaylx* trimmings for the establishment of young sycamore trees and whether composting reduces any phytotoxicity symptoms that might be associated with fresh *Eucalyptus cladocalyx.*

Materials and methods

Platanus racemosa Nutt. seedlings were planted from #1 (3.7L) containers at a site in Ojai, Ca. The soil type was an Ojai stony fine sandy loam (fine-loamy, mixed, thermic Mollic Haploxeralfs). Forty-eight trees were planted at 6m distance and allowed to grow for 3 months before mulch was applied.

Branches of *Eucalyptus cladocalyx* F.J. Muell. (up to 8cm diameter) were pruned from mature landscape trees and chipped with a commercial brush chipper to produce 4-6 cm long chips. Approximately 4 m^3 of fresh chipped branches (including leaves, flowers, fruit and bark) were composted using the rapid composting method (Raabe, 1974). Ammonium sulfate was applied once to initiate breakdown of the compost (0.454kg $(NH_4)_2SO_4$). m^{-3} of fresh eucalyptus). The compost was turned at seven-day intervals for 90 days and moisture added as needed to maintain compost heat. After the compost was stable (no longer heating), branches were again harvested from the same trees, and chipped to 4-6 cm long chips (large chips) or 1 cm chips (small chips). The following mulches were then applied ten cm deep around each tree: 1. Unmulched; 2. pine bark (Xerimulch®, Kelloggs Supply Inc., Carson, CA); 3. composted biosolids and wood (Growmulch®, Kelloggs Supply Inc., Carson, CA); 4. composted *E. cladocalyx*; 5. fresh *E. cladocalyx* (large chips); and, 6. fresh *E . cladocalyx* (small chips). The mulched zone around each tree was 2.5 by 2.5m. All treatments were applied in randomized complete block design with 8 replications. No fertilizer was applied before planting or during the study. Irrigations were by micro-sprinkler and applied so that water percolated through the mulch materials. Trees were irrigatied when soil moisture tension (at 15cm depth) exceeded 60Kpa. During planned dry downs, soil moisture tensions exceeded 100 Kpa. Soil moisture was monitored with gypsum blocks (Irrometer Company, Riverside, CA). Soil moisture content (% by volume) was determined by time domain reflectometry with a Trace® TDR (Soil Moisture Equipment Corporation, Santa Barbara, CA), using 15cm waveguides.

Waveguides were inserted into soil only. On mulch treatments, the mulch was temporarily removed for TDR measurements. Reference evapotranspiration (Et_o) was estimated on site with a Livngston atmometer (C&M Meterological Supply, Colorado Springs, CO). Transpiration was measured with a LI-COR 1600 autoporometer (LI-COR, Inc.,Lincoln, NE). Transpiration measurements were made mid-day on the youngest mature leaves of each tree. Three readings per tree were made on separate leaves and averaged before further statistical analysis.

Mulch, soil, air and stem temperatures were measured with a Digi-Sense 8528-20, J probe, thermocouple thermometer (Cole-Parmer Instrument Company, Niles IL. Mulch surface temperatures were measured in full sunlight (no shading) 30 cm from the trunk. Photosynthetically active radiation (PAR) reflected from mulched and unmulched surfaces was measured by holding the PAR sensor of the LI-COR 1600 one meter above the mulch surface, pointed directly toward the ground, at mid-day, at four locations over each plot and averaging the values. PAR readings were taken during the first summer of the study.

Tree growth was monitored using trunk caliper measurements at 30cm above the mulch or soil surface. Early dormancy was rated using a dormancy rating scale: 0 = no leaf drop all leaves verdant, no dormancy; 1 = no leaf drop, 25% of leaves yellowing; 2 = no leaf drop, 50% of leaves yellowing; 3 = 25% leaf drop, 75% of retained, leaves yellowing 4 = 50% leaf drop, retained leaves all yellowing; and, 5 = leafless—dormant tree.

Weed cover (percent of plot covered) was visually estimated in each plot. Weed abundance was determined by counting all weeds in the plot. Before mulches were applied, weeds were removed by hoeing, so that all plots were clean when the experiment started. Weeds were not removed from any of the plots after the mulch treatments were applied.

Mulch was removed from four 30 x 30 cm areas on each tree/ mulch plot at compass points 1m distant from the trunk. Root intersections were counted *in situ* at the end of the second season of growth, at the interface of mulch and soil on a 2 cm grid covering the 900 cm^2 sampling area. Roots of unmulched trees were sampled at 7.5 cm depth to approximate and compare to the interface sample in mulched treatments. Roots were cut and removed under the same 30 x 30 cm sampling area below the interface to 15 cm depth (22.5cm depth in unmulched trees) then placed under the grids, their intersections counted, and root lengths calculated using the Newman (1966) method. There were six replicate samples from each mulch treatment. Four sub-samples from each tree were averaged and the means were used for statistical comparisons of treatments.

Significance of treatment differences was calculated with ANOVA and means were separated by Tukey's Honestly Significant Difference test (HSD) or Fisher's protected LSD. Where appropriate, single degree of freedom contrasts were used to make individual treatment or individual vs. group treatment comparisons. MSTATC (Michigan State University) was used to make statistical comparisons of treatments and to calculate factorial ANOVA for main effects, interaction means and multiple range tests.

Results and discussion

Ten months after initial mulching (432 days after planting), diameter of mulched trees were larger than those of unmulched trees (orthogonal contrasts of all mulched treatments vs unmulched treatments: significant, $P<0.01$). Stem growth of trees in the various mulch treatments was numerically but not significantly greater than that of unmulched trees on several measurement dates in the second growing season, (Non significant Tukey's $HSD_{0.05}$ on various dates, data not shown). Near the end of the study (Days 516 and 607), trees mulched with fresh eucalyptus (small chips) had significantly larger stems diameters than unmulched trees. (Fig. 1). Biosolids mulched trees had the smallest measured calipers of any mulched tree and were not significantly larger than unmulched trees (Tukey's $HSD_{0.05}$). Sycamores growing under fresh or composted ***Eucalyptus cladocalyx*** mulches never showed symptoms of stunting, yellowing, chlorosis, or any other indications of poor growth.

Mulches delayed the dormancy of sycamore. At the end of the first season, unmulched trees did not retain their leaves as long as biosolids and eucalyptus compost mulched trees (Table 1).

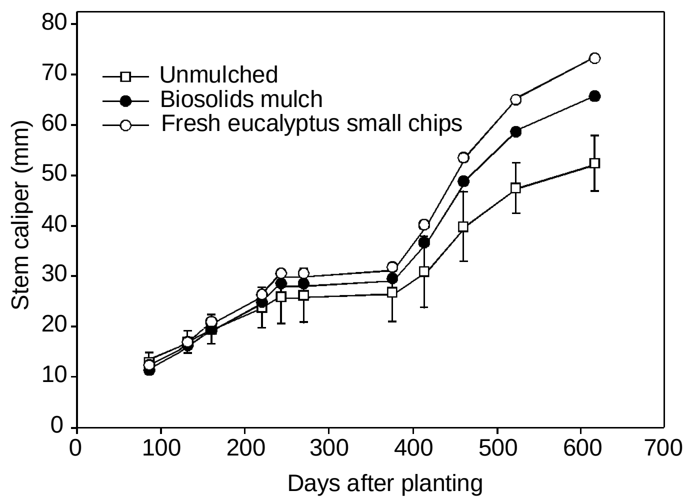

Fig. 1. Effects of biosolids and fresh eucalyptus mulch on growth of sycamore. Bars are Tukey's $HSD_{0.05}$ values for the separation of the three means.

However, in the second season, dormancy was significantly retarded only by pine bark mulches. .

Sycamore root lengths (total roots) were increased by all mulches compared to the unmulched trees (Table 2). Under biosolids, pine bark and fresh large eucalyptus chips root lengths increased over other treatments at the interface of mulch and soil. Fresh eucalyptus (large chips) produced the largest numerical root length in combined zones (total roots).

Mulches decreased canopy air and sycamore trunk temperatures (Table 3). Canopy air temperatures were slightly reduced by the mulches yet, there were less significant differences between mulch treatments (Table 3). Sycamore stem temperatures were significantly cooler in mulched plots than in unmulched plots. The highest surface temperatures were measured on biosolids composts followed by bare soil. Fresh eucalyptus (large chips) had the lowest surface temperature, while composted eucalyptus mulch, pine bark and fresh eucalyptus (small chips) surface temperatures were similar (Table 3). Biosolids compost reflected significantly less photosynthetically active radiation (PAR) than

Table 1. Effect of mulches on early dormancy of *Platanus racemosa*

Treatment	Dormancy rating^z	
	Season I	Season II
Unmulched	4.0a	2.1a
Pine bark	3.0ab	1.1b
Biosolids	2.5c	2.1a
Composted eucalyptus	2.7bc	1.6ab
Fresh eucalyptus large chips	2.9ab	1.8ab
Fresh eucalyptus small chips	3.4ab	1.8ab

^{z}Dormancy rating is: 0=no leaf drop all leaves verdant, no dormancy; 1=no leaf drop, 25% of leaves with some yellow; 2=no leaf drop, 50% of leaves with some yellow; 3=25% leaf drop, 75% of retained leaves with some yellow; 4=50% leaf drop, retained leaves all showing yellow color; 5= leafless—dormant tree. Means followed by the same letter not significantly different according to ANOVA and Tukey's $HSD_{0.05}$.

Table 2. Root length of mulched and unmulched sycamore trees

Treatment	Root length (cm)^z		
	Interface	15cm depth	Total roots
Unmulched	13.5b	114.8b	128.3c
Pine bark	80.0a	430.4a	510.4ab
Biosolids	116.7a	294.4ab	411.1b
Composted eucalyptus	48.1ab	338.4a	386.5b
Fresh eucalyptus large chips	89.5a	598.8a	688.3a
Fresh eucalyptus small chips	56.7ab	314.7a	371.4b

^{z}Interface is the root length measured at juncture between the soil and mulch, 15cm is root length of all roots harvested below the interface to 15cm depth and total roots is the sum of interface and 15cm values. Column means followed by the same letters are not significantly different according to ANOVA and Tukey's $HSD_{0.05}$. Data were square root transformed before analysis to homogenize variances (root length means shown). Root lengths measured at the end of the second season.

any other surface. Fresh eucalyptus (large and small chips) mulches reflected significantly more PAR than most other surfaces (Table 3). The PAR reflectance of pine bark and composted eucalyptus did not differ from unmulched soils.

Soil under mulches held more water than unmulched soil (Fig. 2. Significant ANOVA and Tukey's HSD, P<0.01 on day 16). There were no differences in soil moisture content between mulch treatments (data not shown). Mulched soils held more water than unmulched soils throughout the dry down period (significant orthogonal contrasts, P<0.05, unmulched vs all mulched plots after day 16, data not shown).

Trees growing under fresh eucalyptus (large chips) had lower diffusive resistance values (higher transpiration rates) during a

Table 3. Effects of mulch on temperatures and photosynthetically active radiation

Mulch treatment	Temperature (^{o}C)^z			PAR^y
	Canopy air	Trunk	Mulch surface	($\mu E{\cdot}m^{-2}{\cdot}s^{-1}$)
Unmulched	31.4a	29.3a	45.3b	135.9c
Pine bark	29.5b	26.7b	40.6c	132.4c
Biosolids	29.5b	27.2b	50.7a	87.1d
Composted eucalyptus	29.8b	26.3b	40.8c	147.8bc
Fresh eucalyptus large chips	30.2ab	26.2b	38.2d	166.5a
Fresh eucalyptus small chips	29.8b	26.4b	41.8c	153.6ab

^{z}Treatments followed by the same letter not significantly different according to ANOVA and Tukey's $HSD_{0.05}$.
^{y}PAR is photosynthetically active radiation measured in micro Einsteins per square meter per second. PAR and temperatures measured.

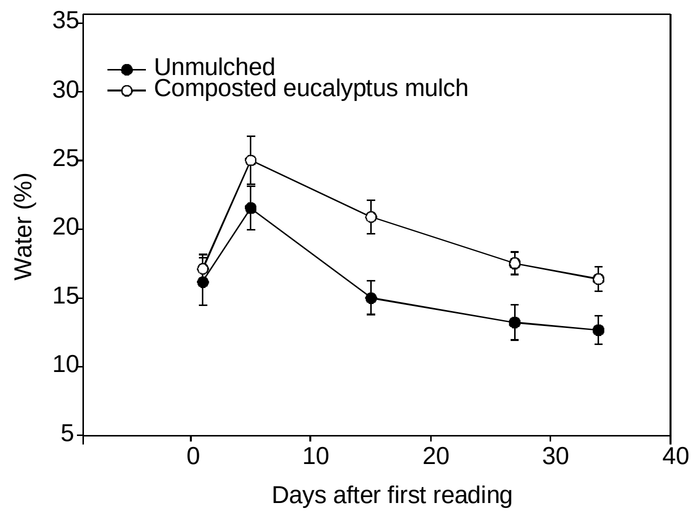

Fig. 2. Moisture depletion of mulched and unmulched soils. Bars represent standard deviation of the mean of 8 replicates.

dry down period between irrigations (Table 4). Unmulched and biosolids mulched trees had the numerically highest diffusive resistance values (lowest transpiration rates) although these were usually not significantly greater than most other mulch treatments. Diffusive resistance rates of unmulched sycamores were best associated with increasing reference evapotranspiration over the dry down periods (Table 4, linear regressions). Mulching reduced soil moisture loss thus reduced the r^2 value in the linear comparisons between transpiration and evaporative demand (reference Et_o).

Mulching provided effective control of annual weeds (Table 5).

Table 4. Effect of mulches on transpiration of sycamore during a dry down period

Treatment	Diffusive resistance^z					Linear regression^y
Date	7/29	8/17	8/21	8/26	10/6	
Et_o^{x}	111	192	214	0	134	r^2
Unmulched	2.16ab	2.78a	3.90a	1.26a	2.49ab	0.88
Pine bark	1.83ab	2.07ab	2.40a	0.97ab	2.89ab	0.55
Biosolids	2.29a	2.36ab	3.46a	1.19ab	3.39a	0.64
Composted eucalyptus	1.86ab	1.46ab	2.22a	0.94b	2.25ab	0.47
Fresh eucalyptus large chips	1.49b	1.33b	2.02a	0.97ab	2.16ab	0.40
Fresh eucalyptus small chips	1.84ab	1.62ab	2.66a	0.95b	2.07b	0.67

^{z}Means followed by the same letter not significantly different according to ANOVA and Tukeys' $HSD_{0.05}$. Readings from second season
^{y}Linear regression is the linear relationship between diffusive resistance means in a treatment row and the corresponding Et_0 values at each date. All r^2 values significant P < 0.01.
^{x}Reference evapotranspiration estimated (as mm of water demanded) by Livingston atmometer.

All mulches reduced the percent of the plot covered by weeds. All mulches except biosolids on April 3 reduced abundance of weeds in the plot. Biosolids mulched plots allowed more weed cover and abundance than other mulched plots. There were no differences in weed cover or abundance between pine bark, and fresh or composted eucalyptus chips (Table 5).

Some plant derived chemicals act as allelochemicals inhibiting the growth of other plants. There are many studies that refer to allelopathic affects of plant parts (Putnam, 1988). Yet, most allelopathy studies are *in vitro* studies without the presence of soil (Nishimura *et al.*, 1984; Igboanugo, 1986; Kohli and Singh, 1991). References to allelopathic effects of eucalyptus trees are common, yet none consider use of mulch prepared from eucalyptus residues physically separated from the tree(s) that produced it. Eucalyptus foliage is known for its extensive content of organic oils and acids, some of which are toxic to other plants especially in seedlings stage (Baker, 1966; Nishimura *et al.*, 1984; Igboanugo, 1986; Molina *et al.*, 1991; Kohli and Singh, 1991; and Duryea *et al.*, 1999). These sensitive bio-assays may detect activities in eucalyptus litter but are not indicative of the effects that eucalyptus phytochemicals have on plants growing in soil away from the eucalyptus trees.

Table 5. Weed densities in *Eucalyptus cladocalyx* mulched and unmulched plots

Treatment	Coverage[z] (%)		Aabundance[y] (Number m^{-2})	
	4/3	11/3	4/3	11/3
Unmulched	67.2a	71.3a	77.9a	104.3a
Pine bark	7.6c	1.4c	2.4b	0.5c
Biosolids compost	32.9b	19.4b	60.6a	18.3b
Composted eucalyptus	8.0c	2.1c	4.5b	0.6c
Fresh eucalyptus large chips	10.3c	1.9c	4.9b	1.1c
Fresh eucalyptus small chips	9.5c	5.6c	6.9b	4.8c

[z]Percent coverage is a visual estimate of the area of the plot covered by weeds 4/3 (spring) and 11/3 (fall) of the first season.
[y]Abundance is number of weeds present per m^2 in each plot. Column means followed by the same letter not significantly different according to ANOVA and Tukey's $HSD_{0.01}$.

In this study, sycamore growth was not affected by mulch sources, compost status or chip size. The effects of mulching were more generic; mulch presence promoted more growth for sycamore than bare soil. Allelopathy is defined as a biochemical interaction between live plants. While plant residues (mulches) are not considered living and thus not allelopathic, they may contain chemicals toxic to other plants (phytotoxins) (Ozores-Hampton, 1998). Eucalyptus when shredded, applied as fresh mulch to soil and moistened, is immediately attacked by fungi and bacteria that initiate decomposition—the organic acids and terpenes of eucalyptus exocrines become subject to microbial decomposition. Thus, the phytotoxic nature of fresh eucalyptus mulch when in contact with soil may be quickly lost. Composted eucalyptus mulch did not enhance tree growth beyond that of fresh eucalyptus mulch of either fine or coarse chips suggesting that *E. camaldulensis* either lacks toxic phytochemicals, or that their breakdown is very rapid without composting.

Sycamore growth may be stimulated by mulch reflective qualities. Reflective mulches increase growth of vegetable crops (Decoteau, *et al.*, 1988, 1990; Mahmoudpour and Stapleton, 1997). In our study, fresh eucalyptus (large chips) reflected more PAR than other mulches while biosolids (due to its dark color) reflected significantly less PAR. Reduced growth of biosolids mulched trees may be partly due to absorbed PAR and higher temperatures associated with absorptions characteristics of the dark colored mulch.

Mulch promoted growth of sycamore may be due to increased moisture levels in underlying soils. Increases in soil moisture under mulches were demonstrated in newly planted orchards (Stephenson and Schuster, 1945), and on palm growth (Downer and Hodel, 2001). Mulch reduces surface evaporation and prevents water use by weeds (Ashworth and Harrison, 1983; Litzow and Pellet, 1983; Robinson, 1988; Skroch *et al.*, 1992, Downer and Hodel, 2001). In our study, soils under mulches conserved more water than unmulched soils and weeds grew abundantly in unmulched and biosolids mulched plots, suggesting these plots were most likely to impose moisture stress on the sycamore trees. Weed growth increased moisture depletion in upper soil layers of unmulched trees depriving sycamores in these treatments of water conserved by mulches in other mulch treatments.

Increased transpiration of mulched trees reduces ambient air temperature around tree canopies and reduces stem temperatures (Zajicek and Heilman, 1991). Decreasing transpiration of unumulched sycamores was best associated with reference evapotranspiration estimates in our study while mulched trees were not as well correlated (lower r^2 values, Table 4) affirming the observation that mulches without weeds reduced soil moisture depletion and tree moisture stress. Some mulch treatments also delayed sycamore dormancy (a sign of reduced stress). The effectiveness of biosolids for delaying leaf fall in the first season may have been due to the large patch of black color causing greater warming of the soil. As tree canopies increased and weeds grew in the biosolids mulch, the effects of these treatments reversed in the second year.

Shade tree root growth usually increases under organic mulches (Fraedrich and Ham, 1982, Watson, 1988, Green and Watson, 1989). In this study, coarse and fine textured mulches were used; however, effects on root length were quite variable. Mulch texture affects water holding capacity of the mulch. Biosolids mulch was the finest textured mulch of this study and also promoted the greatest rooting at the interface zone, although it did not have the highest value of total roots. Coarse mulches such as pine bark and coarse fresh eucalyptus chips had numerically, the greatest root lengths. Mulching increased sycamore rooting and coarse textured mulches were the most effective root stimulators.

Eucalyptus cladocalyx and pine bark mulches effectively controlled weeds and increased soil moisture resulting in larger trees than in unmulched plots. Since no sycamores died or showed symptoms of phytotoxicity, the benefits of fresh or composted *E. cladocalyx* mulch outweigh any perceived hazards.

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