Arboriculture & Urban Forestry 2008. 34(3):157–162.

Mulching of Ornamental Trees: Effects on Growth and Physiology

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Abstract. Two organic mulching materials applied to newly planted *Tilia* × *europaea* and *Aesculus* × *carnea* trees were evaluated for effects on tree growth and physiology. Both mulches were efficient in maintaining a cleared area around newly planted trees, although pine bark was more durable than coarse compost from mixed green material. Trees mulched with compost generally had greater height, trunk diameter, and current-year shoot growth. Differences were more evident in the first year in *Aesculus* and in the second year in *Tilia*. Mulching with compost increased carbon assimilation of linden leaves in 2005 when compared with pine bark and chemical weeding. Both mulching materials increased transpiration of horsechestnut in 2005. Little effect on gas exchange was found in 2006 in both species. However, because mulched trees were larger with longer shoots, whole plant leaf gas exchange was probably greater. Mulching had very limited effects on chlorophyll fluorescence. Results of this project have shown that mulching materials applied around trees after planting can positively affect tree growth without significantly affecting tree physiology.

Key Words. *Aesculus* × *carnea*; chlorophyll fluorescence; compost; leaf gas exchange; mulching; pine bark; *Tilia* × *europaea*.

A key to success for new tree planting both in open-field nurseries and in the urban environment is the protection of young plants from noncrop plant species (including some hardwoods, shrubs, grasses, and forbs). These fast-growing plants often kill or greatly suppress desired trees by competing with them for light, water, and nutrients needed to grow. As a result, nurserymen, arborists, and urban forest managers generally use herbicides to suppress noncrop vegetation.

However, the European Union's Fifth Environmental Action Program (5EAP) set out a series of targets for the year 2000, including "the significant reduction in pesticide use per unit of land under production, and the conversion to methods of integrated pest control."

As a consequence, to protect young trees, environmentally sound, effective, cost-efficient, and socially acceptable techniques for managing noncrop vegetation are needed.

In this scenario, we focused on the need for environmentally friendly establishment and low-cost management methods of the urban green areas. Mulching and its skilled use can contribute to such a development by improving organic matter content in the soils and by affecting other soil characteristics (Harris et al. 2004).

Even if mulching is a worldwide practice in urban green areas and different materials can be used for this purpose (mainly shredded wood, chipped woods, pine bark, and, above all, composted materials) (Rakow 1989), little research has been done in Italy to determine the effectiveness of this practice.

Positive effects after organic mulch application have been obtained by previous research, which has shown beneficial effects on soil physical and chemical properties (Fraedrich and Ham 1982; Litzow and Pellett 1983; Watson 1988; Appleton et al. 1990; Himelick and Watson 1990; Smith and Rakow 1992; Iles and Dosmann 1999; Tiquina et al. 2007; Dahiya et al. 2007) and on plant growth and physiology (Watson 1988; Green and Watson 1989; Appleton et al. 1990; Himelick and Watson 1990). Also, the invertebrate diversity can be positively affected by mulching (Jordan and Jones 2007). However, sometimes the results from mulching are variable being affected by the different environmental conditions and by the different tree species (Whitcomb 1979; Iles and Dosmann 1999). Moreover, if the quality of the mulching materials supplied by the producers is not satisfactory, tree performances can be affected in a negative way. This can be related either to its quality or to its misuse, i.e., adding too much material, which can negatively affect soil oxygen content (Gilman and Grabosky 2004; Hanslin et al. 2005), although Watson and Kupkowski (1991) found no detrimental effect from the application of 0.45 m (1.5 ft) of wood chip mulch over the soil in which the roots of trees were growing. The application of bark mulch can sometimes decrease growth in the first year, but the effect on plant growth is positive when examined in the long term (Samyn and de Vos 2002). This can be caused by a temporary nitrogen depression until the microorganisms are able to decompose a sufficient amount of organic material to provide the needed nitrogen (Craul 1992).

Composted materials need to be well characterized for nutrient values, stability, and other properties for the support of tree growth and effect against weeds. In a review of the use of composts for mulching and soil amendments, Sæbø and Ferrini (2006) suggest designing the composts to fit the specific effects that are wanted. For example, composts for mulching should consist of layers of compost of different particle sizes so that both nutrients can be supplied and weeds are not given good germination conditions.

The purpose of this study was to investigate the use of mulching materials and their possible influence on growth and physiology of two shade tree species widely grown in the urban environment.

MATERIALS AND METHODS

Plant Material

In 2004, before bud break, uniform, 2.5 to 3 m tall (8.3 to 9.9 ft), 3 to 4 cm (1.2 to 1.6 in) in diameter (measured at 1.3 m [4.3 ft] height), balled and burlapped (size of the root ball was approximately 30 cm [12 in] in diameter) *Aesculus* × *carnea* (red horsechestnut) and *Tilia* × *europaea* (european linden) trees were planted in an experimental plot located at the Fondazione Minoprio (Como) (45°44′N, 9°04′E). Planting holes were two times the width and one-and-a-half times the depth of the root ball to ensure a greater volume of loose soil within the planting hole. The sides of the planting pit were scarified with a shovel. Before planting, some soil mixed with peat (50% in volume) was placed at the bottom of the planting hole. At planting, care was taken that the root flare was not positioned below the soil level. All trees with almost identical size characteristics were obtained from the same nursery and planted at the same time.

Trees were planted in a randomized block design with three blocks and four plants per block (12 plants per each treatment, 36 plants per species) and provided supplemental irrigation. Treatments included:

- Mulching with coarse compost derived from green material left after sifting (coarse compost) (layer 5 to 8 cm [2 to 3 in]);
- Mulching with pine bark (layer 5 to 8 cm [2 to 3 in]); and
- Control (weeding by herbicide).

In 2004, no data were collected with the exception of plant height and trunk diameter at the end of the growing season. In 2005 and 2006, the following parameters were measured:

1) Plant height and trunk diameter (determined on each plant at the end of each growing season; plant diameter was also measured in 2007);
2) Shoot length (determined on 20 shoots/plant at the end of the growing season; shoot length was also measured in 2007);
3) Leaf gas exchange (instantaneous net photosynthesis [Pn], transpiration rate [E], water use efficiency [WUE, calculated by dividing Pn by E], stomatal conductance [*gs*], and internal CO_2 concentration [*ci*]; measured eight times in 2005 and five times in 2006); and
4) Chlorophyll fluorescence (measured four times in 2005 and three times in 2006).

Leaf gas exchange was measured during the whole growing season using the CIRAS-2 portable infrared gas analyzer (PP Systems, Hertfordshire, U.K.). The readings were taken between 8:00 A.M. and 1:00 P.M., which was presumed to be the diurnal period when photosynthetic rates would be maximal, in sunny days under fixed CO_2 concentration (360 ppm) and saturating irradiance (1300 μmol/m^{-2}/s^{-1} provided by a built-in red light-emitting diode radiation source) on six plant per each thesis on five fully expanded leaves from the outer part of the crown and at different heights per plant per treatment. Chlorophyll fluorescence was measured on the same plants by using a HandyPEA portable fluorescence spectrometer (Hansatech Instruments Ltd., King's Lynn, U.K.) four times from mid-May through the end of July (Percival 2005). Fluorescence values were obtained by placing leaves in darkness for 30 min by attaching light-exclusion clips to the leaf surface of whole trees. Upon the application of a saturating flash (3,000 μmol/m^{-2}/s^{-1} for 1 sec), fluorescence raises from the ground state value (Fo) to its maximum value, Fm. In this condition, QA, the first electron acceptor of photosystem II (PSII), is fully reduced. This allows the determination of the maximal or potential photochemical efficiency or optimal quantum yield of PSII given by Fv/Fm = (Fm−Fo)/Fm where Fm is the maximum value. Fv/Fm is considered a quantitative measure of the maximal or potential photochemical efficiency or optimal quantum yield of PSII. In healthy leaves, this value is always above 0.75 to 0.8, independent of the plant species studied. A lower value indicates that a proportion of PSII reaction centers are damaged, a phenomenon called photoinhibition, often observed in plants under stress conditions (Maxwell and Johnson 2000; Krause and Weis 1991; Percival 2005; Lazár 2006).

Statistical Analyses

All data were subjected to one-way analysis of variance using SPSS statistical package for Windows (SPSS Inc., Chicago, IL, U.S.). Difference between means of investigated parameters were tested with Duncan's multiple range test ($P \leq 0.05$). Data on leaf gas exchange and on chlorophyll fluorescence have been processed per single sampling date, merged together, and processed again to obtain the average value on an annual basis.

RESULTS AND DISCUSSION

Tables 1 and 2 summarize growth data for both species. In horsechestnut, height increment was higher in trees mulched with compost only in the first year, whereas no difference emerged either in the second year or considering the total height increment (Table 1). Similarly, trunk diameter was positively

Table 1. Effect of soil management techniques on and plant height (cm), trunk diameter (cm), and shoot length of *Aesculus* × *carnea*.[z]

Parameter	Year	Pine bark	Compost	Control	*P*
Height increment (cm)	2004–2005	3.28 ab	5.76 a	1.54 b	*
	2005–2006	32.95	38.81	33.75	NS
Total height increment (cm)	2004–2006	36.23	44.57	35.29	NS
Diameter increment (mm)	2004–2005	11.89 b	18.11 a	12.69 b	*
	2005–2006	15.23	17.24	16.3	NS
	2006–2007	14.45	15.81	13.91	NS
Total diameter increment (mm)	2004–2007	41.57 b	51.16 a	42.9 b	**
Shoot length (cm)	2005	9.57 b	13.94 a	13.72 a	**
	2006	47.37	46.98	45.34	NS
	2007	54.72 b	62.6 a	55.34 b	**

[z]Data are reported as means and subjected to analysis of variance. Different letters within the same row indicate statistical differences at $P \leq 0.05$ (*) or $P \leq 0.01$ (**) using Duncan test.
NS = nonsignificant.

Table 2. Effect of soil management techniques on and plant height (cm), trunk diameter (cm), and shoot length of *Tilia* × *europaea*.[z]

Parameter	Year	Pine bark	Compost	Control	*P*
Height increment (cm)	2004–2005	12.5	20	11.11	NS
	2005–2006	67.61 ab	77.83 a	51.08 b	**
Total height increment (cm)	2004–2006	80.11	97.83	62.19	NS
Diameter increment (mm)	2004–2005	9.5 ab	8.73 b	10.41 a	*
	2005–2006	16.3 b	19.17 a	14.09 b	**
	2006–2007	17.04	18.17	16.39	NS
Total diameter increment (mm)	2004–2007	42.84 b	46.07 a	40.89 b	*
Shoot length (cm)	2005	20.02 b	25.97 a	18.14 b	**
	2006	75.45 b	83.57 a	58.83 c	**
	2007	82.94 a	79.8 a	63.67 b	**

[z]Data are reported as means and subjected to analysis of variance. Different letters within the same row indicate statistical differences at $P \leq 0.05$ (*) or $P \leq 0.01$ (**) using Duncan test.
NS = nonsignificant.

affected by compost mulching in the first year compared with pine bark and control trees. This parameter was also higher considering the total increment after 3 years from planting. Shoot length was generally higher in trees mulched with compost.

In linden trees, the effects of mulching were more evident in the second year after planting when trees mulched with compost generally showed higher values of the parameters measured than control trees (Table 2). Total diameter increment was higher in trees mulched with compost, whereas plant height was not statistically affected.

In 2005, coarse compost was more effective to increase mean annual net photosynthesis of *Tilia* × *europaea* than pine bark and control. On *Aesculus* × *carnea,* no statistical differences were found among the different management techniques (Table 3). However, because mulched trees were larger with longer shoots, whole-plant leaf gas exchange was probably greater.

Mulching with both compost and pine bark increased transpiration of horsechestnut in 2005 compared with chemical weeding, whereas no effect was found in 2006. No differences were found on *Tilia* × *europaea* in both years for this parameter (Table 4).

Net photosynthesis also showed a declining trend over time in both species in 2005, whereas this trend was not observed in 2006. An explanation for this behavior is the higher rainfall during August in 2006 than in 2005. Differences were only noted in linden at the beginning and at the end of the growing season, when control trees showed lower Pn values compared with those mulched with compost (Figure 1). No differences were found in horsechestnut (Figure 2). Comparing the findings of the 2 separated years, the Pn for horsechestnut trees was higher in 2006, probably as a result of the different environmental conditions. In this regard, it needs to be stressed that individual leaf photosynthesis has demonstrated high variability compared with whole plant gas exchange, and it is sometimes complicated by a poor relationship of dry matter production to yield (Klingemann et al. 2005), but it is the only way to measure leaf gas exchange in adult trees.

Water use efficiency, in this research considered as the ratio of carbon gain during CO_2 assimilation (A, μmol/m^{-2}/s^{-1}) to water loss during transpiration (E, mmol/m^{-2}/s^{-1}), is of major importance to the survival, productivity, and fitness of individual plants and it was higher in control trees only in 2005 in *Tilia* and in 2006 in *Aesculus*. Actually, the two species showed different patterns in the 2 years. *Tilia* × *europaea* had higher Pn and E values in 2005 compared with *Aesculus* × *carnea*, which in 2006 showed higher values of photosynthesis but not a corresponding increase in transpiration, which was actually lower. As a consequence, this species showed higher values of WUE.

Table 3. Net photosynthesis (A), transpiration (E), water use efficiency (WUE), stomatal conductance (Gs), substomatal CO_2 concentration (Ci), and chlorophyll fluorescence values in *Aesculus* × *carnea* young trees under different cultivation techniques.[z]

Parameter	Year	Pine bark	Compost	Control	*P*
A (μmol/m^{-2}/s^{-1})	2005	6.75	6.91	6.95	NS
	2006	8.43	8.85	8.53	NS
E (mmol/m^{-2}/s^{-1})	2005	2.66 a	2.81 a	2.46 b	**
	2006	1.76	1.96	1.78	NS
WUE (A/E)	2005	2.65 ab	2.56 b	2.93 a	*
	2006	5.60	5.04	5.11	NS
Gs (mmol/m^{-2}/s^{-1})	2005	149.01 a	148.11 a	124.85	**
	2006	98.84	107.05	101.02	NS
Ci (ppm)	2005	178.06	171.75	160.58	NS
	2006	181.95	190.00	192.26	NS
Chlorophyll fluorescence (Fv/Fm)	2005	0.75	0.74	0.73	NS
	2006	0.75	0.74	0.74	NS

[z]Data are reported as means and subjected to analysis of variance. Different letters within the same row indicate statistical differences at $P \leq 0.05$ (*) or $P \leq 0.01$ (**) using Duncan test.
NS = nonsignificant.

Table 4. Net photosynthesis (A), transpiration (E), water use efficiency (WUE), stomatal conductance (Gs), Substomatal CO_2 concentration (Ci), and chlorophyll fluorescence values in *Tilia* × *europaea* young trees under different cultivation techniques.[z]

Parameter	Year	Pine bark	Compost	Control	*P*
A (μmol/m^{-2}/s^{-1})	2005	8.65 b	9.65 a	8.88 b	**
	2006	7.63	7.93	7.67	NS
E (mmol/m^{-2}/s^{-1})	2005	3.18	3.32	3.23	NS
	2006	1.84	1.75	1.69	NS
WUE (A/E)	2005	2.90	3.11	2.88	NS
	2006	4.32 b	4.9 ab	5.06 a	*
Gs (mmol/m^{-2}/s^{-1})	2005	187.65 b	199.54 a	186.78 b	*
	2006	111.67 a	108.59 a	97.46 b	*
Ci (ppm)	2005	178.63	169.89	175.01	NS
	2006	223.2 a	214.37 a	202.37 b	**
Chlorophyll fluorescence (Fv/Fm)	2005	0.76	0.75	0.77	NS
	2006	0.77	0.77	0.74	NS

[z]Data are reported as means and subjected to analysis of variance. Different letters within the same row indicate statistical differences at $P \leq 0.05$ (*) or $P \leq 0.01$ (**) using Duncan test.
NS = nonsignificant.

It has been generally demonstrated that increased WUE can be a water conservation measure indicating that more carbon can be accumulated for growth with the use of less water (Nilsen and Orcutt 1996; Jones 2004).

Stomatal conductance (Gs) was higher in trees mulched with compost in both species and it showed superior values in 2005 than 2006. The relation of WUE and Gs clearly indicates that these two variables are, in this case, inversely correlated. A decrease in stomatal conductance causes a proportionally larger decrease in transpiration than in carbon assimilation, with the net result being a higher WUE.

In this regard, it also has to be underlined that instantaneous WUE refers to a comparison of CO_2 assimilated versus H_2O transpired by individual leaves (or canopies) and is affected by environmental and genetic factors (Glenn et al. 2006) and it also varies among years considered (Fageria et al. 2006). Therefore, studies of instantaneous WUE by gas exchange techniques are difficult in field situations because environmental conditions around the leaves are always changing and it is hard to determine an average plant WUE (Nilsen and Orcutt 1996). Also, differences in WUE determined at the leaf level may be reduced substantially at the canopy level (Lambers et al. 1998), and it can be finally hypothesized that, being mulched trees bigger and with longer shoots, they would be expected to have a higher leaf gas exchange on a whole plant basis.

Leaf internal CO_2 concentration was not affected in both species in 2005, whereas it was higher in mulched *Tilia* trees in the second year and, in general, showed superior values in 2006.

Photochemical efficiencies of PSII (Fv/Fm) of the two species, measured during both growing seasons from June to September, were similar on an annual basis, and their values were comprised between 0.74 and 0.77 (Tables 1 and 2). No differences emerged among the different treatments, even when considering the single sampling date, except for the last measurements in 2006 on *Aesculus*, when mulched trees showed higher values. The highest Fv/Fm values were observed in July and were 0.8 on average among the treatments (data not shown).

CONCLUSION

Mulching significantly promoted growth of red horsechestnut and european linden trees and had limited influence on leaf gas

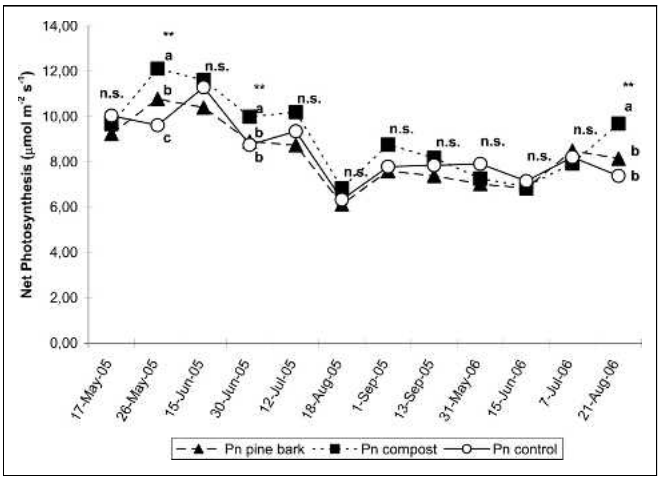

Figure 1. Net photosinthesis (µmol/m^{-2}/s^{-1}) in *Tilia* × *europaea* young trees under different cultivation techniques. Different letters indicate statistically differences at $P < 0.05$ using Duncan test.

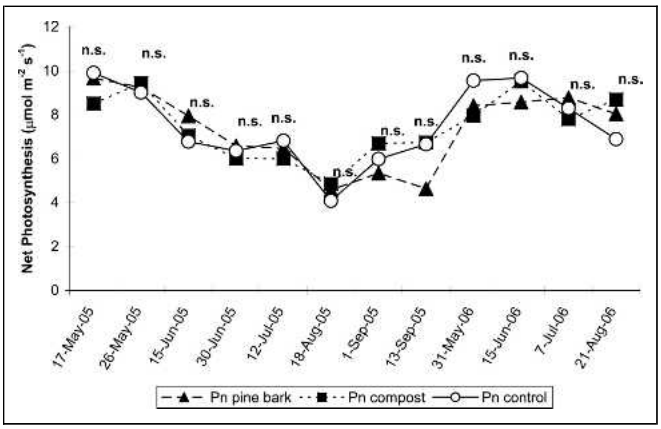

Figure 2. Net photosinthesis (µmol/m^{-2}/s^{-1}) in *Aesculus* × *carnea* young trees under different cultivation techniques. Different letters indicate statistically differences at $P < 0.05$ using Duncan test.

exchange and on internal fluorescence features of PSII. Therefore, we recommend application of mulching material obtained from composted wood chips and shredded wood to improve growth performance of the two species tested. Furthermore, as stated by Harris et al. (2004), several of the benefits, including improvements in soil structure, quality, and plant health, are accrued over time and are difficult to measure in short-term experiments.

In the 2 different years, some differences in physiological behavior were found between the two species; thus, further research is needed into the effect of different mulching materials in different species on leaf gas exchange as well as on soil characteristics, which can affect plant physiology.

Acknowledgments. We thank Regione Lombardia Project "Progetto di Sperimentazione Regionale sul Florovivaismo Tecniche eco-compatibili di gestione del vivaismo e del verde ornamentale" (TECOGEST). Support for this project also came in part from the Regione Toscana (Italy) inside the research project "Research on multipurpose green areas" (RISVEM).

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Résumé. Deux matériaux organiques servant de paillis, et qui ont été appliqués sur des *Tilia* × *europaea* et des *Aesculus* × *carnea*, ont été évalués en fonction de leurs effets sur la croissance et la physiologie des arbres. Les deux paillis étaient efficaces pour maintenir une surface propre autour des arbres nouvellement plantés, et ce même si le paillis d'écorces de pin était plus durable que le compost grossier provenant d'un mélange de matériaux verts. Les arbres avec un paillis de compost avaient généralement une hauteur, un diamètre de tronc et un taux de croissance annuel qui étaient supérieurs. Les différences étaient plus évidentes la première année avec *Aesculus* × *carnea* et la seconde année avec *Tilia* × *europaea*. Le paillis de compost augmentait l'assimilation en carbone chez les feuilles du tilleul en 2005, et ce si on comparait avec le paillis d'écorce de pin et le désherbage mécanique. Les deux paillis augmentaient la transpiration chez le marronnier en 2005. Peu d'effets ont été observés en regard des échanges gazeux pour les deux espèces en 2006. Quoiqu'il en soit, du fait que les arbres avec paillis avaient de plus longues pousses annuelles, l'échange foliaire gazeux global de la plante était probablement plus élevé. Le paillis avait des effets limités sur la fluorescence de la chlorophylle.

Zusammenfassung. Zwei organische Mulchmaterialien, die zur Pflanzng von Tilia x europea und Aesculus x carnea verwendet wurden, wurden bezüglich ihres Einflusses auf Wachstum und Physiologie bewertet. Beide Mulchmaterialien sorgten für eine saubere Fläche um die neu gepflanzten Bäume, aber die Kiefernrinde hielt länger als der grobe Kompost aus gemischten Grünabfällen. Mit Kompost gemuchte Bäume hatten allgemein eine größere Höhe, Stammdurchmesser und Triebwachstum. Die Unterschiede waren bei Aesculus im ersten Jahr, bei Tilia im zweiten Jahr sichtbar. Kompostmulch verstärkte die Kohlenstoffassimilation der Lindenblätter in 2005, verglichen zu Kiefernrinde und chemischer Unkrautbekämpfung. Beide Mulchmaterialien erhöhten die Transpiration von Kastanien in 2005. In 2006 wurden bei beiden Spezies nur kleine Effekte beim Gasaustausch gemessen. Trotzdem war der gesamte Blattgasaustausch wahrscheinlich größer, weil die gemulchten Bäume längere Triebe hatten. Mulchen hatte nur einen geringen Einfluss auf die Chlorophyllfluoreszenz.

Resumen. Se evaluaron dos materiales orgánicos de mulching aplicados a árboles recién plantados de *Tilia x europaea* y *Aesculus x carnea* para conocer los efectos en el crecimiento y fisiología. Ambos mulches fueron eficientes en mantener un área libre alrededor de los árboles, aunque la corteza de pino fue más durable que la composta gruesa de materiales verdes mezclados. Los árboles mulcheados con composta generalmente tuvieron mayor altura, diámetro del tronco y crecimiento corriente anual del tallo. Las diferencias fueron más evidentes en el primer año en *Aesculus* y en el segundo año en *Tilia*. El mulching con composta incrementó la asimilación de carbono de hojas de tilo en 2005, al comparar con corteza de pino y desmalezadores químicos. Ambos materiales del mulching incrementaron la transpiración del castaño en 2005. Se encontró poco efecto en intercambio de gases en 2006 en ambas especies. Sin embargo, debido a que los árboles mulcheados fueron más grandes con brotes más largos, el intercambio gaseoso de toda la planta fue probablemente más grande. El mulching tuvo efectos muy limitados en la fluorescencia de clorofila.