Effects of Two Organic Mulches on Soil Physical, Chemical, and Biological Properties

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Previous research showed that organic mulches, especially coarse green compost, increased growth of some widely used shade tree species. The aim of this work was to evaluate changes in soil physical, chemical, and biological properties induced by mulch, which led to increased plant growth. In 2004, 72 *Aesculus × carnea* Hayne (red horsechestnut) and 72 *Tilia × europaea* D.C. (European linden) were planted in an experimental plot following the randomized block design. Two organic mulches were distributed in the rows and compared to an unmulched treatment. Soil respiration, soil oxygen content, and soil temperature were recorded using a soil respiration chamber and a temperature sensor applied to an infrared gas analyzer. In 2007, at the end of the trial, soil bulk density, soil moisture, soil temperature, total organic carbon, total nitrogen content, microbial biomass, and nitrous oxide emissions were measured. Result showed that, in 2006, summer soil temperature under both mulches was significantly lower than in the unmulched treatment. Soil biological activity was also enhanced by mulches. No difference in soil oxygen content was found among the treatments. Conversely, soil moisture, total organic carbon, carbon:nitrogen ratio, and microbial biomass were significantly higher under mulch. Composting also had a fertilizing action, as showed by higher total soil nitrogen content and nitrous oxide emission. In conclusion, mulch affected soil properties and created a more favorable environment for roots, which resulted in enhanced plant growth.

With increasing population expansion, poor soil physical and chemical conditions are becoming more common in the urban environment; therefore, enhancing soil characteristics and organic matter content on a sustainable basis is one of the most vital problems we face. For this reason, it is of outmost importance to enhance our knowledge of the properties and behavior of the soil system in relation to different cultivation techniques.

Organic mulching with different materials (mainly shredded wood, chipped wood, pine bark, and composted materials), correctly applied, is an environmentally friendly way of establishing, protecting, and managing young trees at a low cost in a new plantation. A recent review compared the costs and benefits of landscape mulches as reported in the technical and scientific literature, emphasizing how plants and soil can both benefit from weed suppression, evaporation reduction, and other environmental modifications (Chalker-Scott 2007).

In fact, mulching is known to reduce erosion and soil evaporation, to mitigate soil temperatures in summer (Fraedrich and Ham 1982; Iles and Dosmann 1999), to increase soil water content (Fraedrich and Ham 1982; Litzow and Pellet 1983; Watson 1988; Appleton et al. 1990; Himelick and Watson 1990; Iles and Dosmann 1999) and soil water conductivity, and to contribute to better long-term growth by improving the organic matter content then by releasing minerals into the soil (Dahiya et al. 2007), although this latter effect is influenced by the nature of organic mulch. Mulching with wood chips has also shown to reduce bulk density and pH value, thus allowing better root development (Fraedrich and Ham 1982; Watson 1988; Himelick and Watson 1990).

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Experimental work carried out in Italy has shown that although soil respiration was unaffected by management technique, soil temperature and oxygen content were significantly lower in mulched plots compared to other treatments (Fini et al. 2008).

Improvements in soil physical properties such as porosity and the development of a stable soil structure have frequently been reported for soil mulched with organic materials (Delver 1980; Hayes 1980). Mulch can also act as feeding material and strongly impact soil microbial activity and nutrient availability, although this effect vary depending on the composition of the mulching materials (Herms et al. 2001; Tiquina et al. 2007).

It has to be stressed that results from mulching are sometimes not as good as expected, especially when the material is of insufficient quality to support satisfactory plant growth and tree aesthetic value. Some mulch materials can negatively affect tree growth or soil physical characteristics and gas exchange (Hanslin et al. 2005); this can be related either to their low quality or to their misuse (Sæbø and Ferrini 2006). Several authors have discussed the drawbacks of overmulching, although not all reports agree (Watson and Kupkowski 1991; Herms et al. 2001).

In Europe, limited information exists about the effects of mulching on soil characteristics and, due to the different environments throughout the continent, there is a need to carry out experimental trials to acquire data to be used for practical application. The aim of this work was to evaluate changes in soil physical, chemical, and biological properties induced by mulch and which lead to increased plant growth.

Materials and Methods

Prior to budbreak in 2004, uniform [2.5 to 3 m (8–10 ft) tall, 3–4 cm (1.2–1.5 in) diameter, measured at a height of 1.3 m (4 ft)], balled-and-burlapped [the size of the root ball was about 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) on a moderately acid sandy loam soil with a moderate total nitrogen content, exchangeable potassium, and plant-available phosphorus (see Ferrini et al. 2008). Trees were planted in a randomized block design with three blocks and four plants of each treatment in each block. Plants were irrigated when needed. Treatments applied at the time of planting were

- Coarse green compost derived from green material left after sifting [in a layer 5–8 cm (2–3 in) deep]
- Pine bark mulch [in a layer 5 to 8 cm deep]
- Unmulched

Physical Analysis

The bulk density and the volumetric soil water content were measured at sampling time in 2007. Undisturbed soil samples [100 cm^3 (6 in^3)] were collected at depths of 0–10 cm (0–4 in) using the core method and oven-dried at 105°C (225°F) for 24 hours (Blake and Hartge 1986). Samples were taken between two trees of the same treatment in each block.

Soil water retention was determined in 2007 using a pressure plate apparatus (Klute 1986). Water retention at field capacity and wilting point [–10 and –1,500 kPa (–1.5 and -217 psi) matric potential, respectively] was measured on undisturbed soil samples extracted with metal cylinders [70 mm (3 in) diameter, 30 mm (1 in) height] with a sharpened edge. Material > 2 mm (0.08 in) in diameter was determined by sieving in order to correct the data obtained for the presence of stones. For each sample, the corresponding bulk density value was used to convert –10 and –1,500 kPa gravimetric water content to a volumetric basis. Plant-available water capacity (AWC) was determined as the difference between water content (v/v) at field capacity (FC) and wilting point (WP).

Soil temperature was measured four times during the growing season in 2006 and once in 2007 with a temperature probe (STP-1, PP-System, New Hertfordshire, UK) at a depth of 10 cm (4 in) below soil surface. Temperatures were measured between two trees of the same treatment. Readings were taken between 11:00am and 1:00pm.

Chemical and Biological Analyses

In 2006, once the plants were considered fully established, soil respiration and soil oxygen content were measured with a soil respiration chamber (SRC, PP-System, New Hertfordshire, UK) at a depth of 5 cm (2 in) below soil surface. The layer of mulch was removed in order to expose a sufficient area of soil for placing the soil respiration chamber. Measurements were taken at the midpoint between two trees on the same row in order to minimize the influence of roots on soil respiration reading.

Total organic carbon (TOC) and total N (nitrogen) content were determined in 2007 using a CHNS elemental analyzer (model EA 1108, Carlo Erba Instruments, Milan, Italy) as described by Nelson and Sommers (1996). Two mm (0.08 in) of air-dried soil samples were crushed, sieved [0.5 mm (0.02 in)] and weighed [10–40 mg (0.0004–0.001 oz)] in tin capsules. The samples were combusted in a reactor, and the combustion products [CO_2 (carbon dioxide) and N_2 (nitrogen gas)] were quantified with a thermal conductivity detector (TCD).

Microbial biomass C (bio-C) was estimated by the substrate induced respiration (SIR) method (West and Sparling 1986), adapted as follows: 1 g (2 mm) of soil (sieved at field moisture conditions) was combined with 1 mL (0.03 fl oz) glucose solution [30 mg/mL (4 oz/gal)] in a sealed vessel and shaken (80 rpm) for 2 hours in an incubation cell. After 2 hours incubation at 24°C (75.2°F), CO_2 concentration was estimated by sampling 100 µl (0.006 in^3) of vessel headspace gas and analyzing with gas chromatography. The biomass was expressed as mg bio-C/100 g dry soil.

In 2007, to quantify the NO_2 direct emission of the soil, *in situ* steel cylinders chambers were used as described in Gamba et al. (1998). Air samples from the cylinders were stored in vials, and the gas analysis was performed by gas chromatography. Nitrogen dioxide was expressed as mg $NO_2/m^2/d$. A Shimadzu GC-17A gas chromatograph was used to quantify both SIR and *in situ* gas emissions. Electron capture detector (ECD) and TCD configurations were used to quantify NO_2 and CO_2, respectively.

The data were analyzed with ANOVA, or MANOVA when two effects acted in combination, using Statistica software (StatSoft Inc., Tulsa, OK). Treatment means were separated by HSD Tukey test at a $P \leq 0.05$ level of significance.

Results and Discussion

Soil Physical Properties

Soil temperature was influenced by mulching. In the summer months, between June 2006 and July 2007, soil temperature, measured at 10 cm (4 in) below soil surface, was significantly lower in the mulched treatments than in the unmulched treatment. No differences were found between the two mulching treatments (Figure 1). These results confirm the efficacy of mulching in reducing high soil temperature extremes, a beneficial outcome, especially in urban areas, where soil can reach very high temperatures because of paved surfaces and reduced air exchange. Soil temperature may partially control individual root longevity—generally longer at cooler sites (Lauenroth and Gill 2003)—directly by altering root respiration or, more likely, indirectly through controlling rates of nitrogen mineralization or pathogen activity (Hendrick and Pregitzer 1993; Graves 1998; BassiRad 2000).

Measurements of soil physical parameters are summarized in Table 1. Statistical analysis showed that soil bulk density in coarse green compost plots was significantly lower compared to unmulched treatment plots, whereas no statistical differences were found between the unmulched treatment and pine bark–mulched plots. Other authors have obtained similar results when comparing the effect of different soil management systems (Himelick and Watson 1990; Oliveira and Merwin 2001).

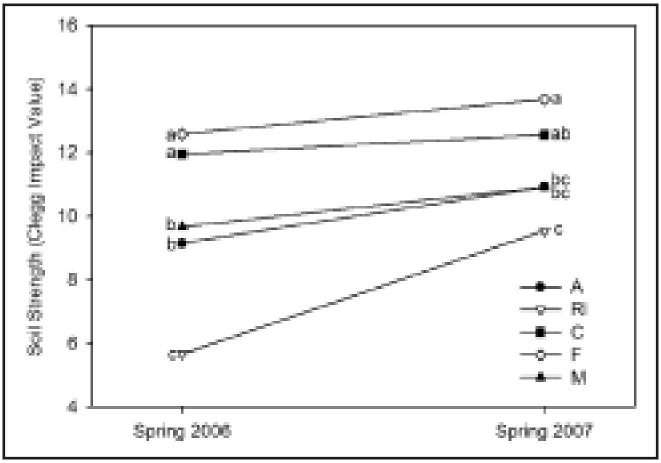

Figure 1. Soil temperature measured at 10 cm (4 in) below soil surface in 2006 and 2007. Different letters on the same date indicate statistical differences at $P \leq 0.05$ using HSD Tukey test.

Table 1. Effect of soil management techniques on some soil physical properties (July 2007).

Parameter	Pine bark mulch	Coarse green compost	Unmulched treatment	P
Bulk density (g/cm^3)	1.23 ab	1.18 b	1.26 a	*
Soil moisture (% v/v)	17.2 b	19.8 a	6.7 c	*
Wilting point (% v/v)	7.9 a	8.7 a	8.1 a	NS
Field capacity (% v/v)	22.1 b	26.7 a	25.3 ab	*
AWC (% v/v)	14.2 b	18.0 a	17.2 ab	*

Different letters within the same row indicate statistical differences at $P \leq 0.05$ (*) using HSD Tukey test.

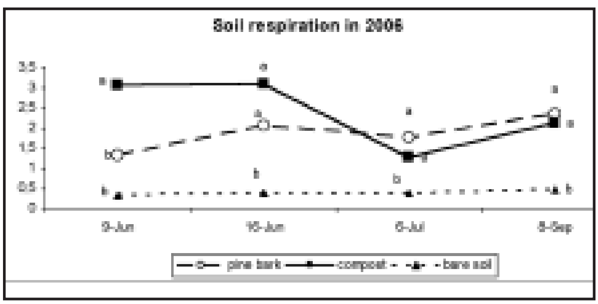

Figure 2. Soil respiration measured at 5 cm (2 in) below soil surface from June to September 2006. Different letters on the same date indicate statistical differences at $P \leq 0.05$ using HSD Tukey test.

The positive effect of organic mulching seems to be related to the increase in soil TOC content (Table 2). A general improvement of soil structural features, such as porosity, due to organic matter supply to the soil surface, is a known phenomenon (Harris et al. 2004). Among all the influencing factors, the role of macrofauna activity is of paramount importance (Jongmans et al. 2003). The study authors did not characterize soil macrofauna in terms of species and population density, but during field sampling observed the presence of many earthworms in the mulched plots, almost certainly due to the increased food supply and to nonlimiting moisture conditions.

Organic mulching induced a general improvement of soil moisture regime; significantly higher water content was recorded in the soil beneath the coarse green compost and pine bark mulch. As reported by previous research (e.g., Erhart and Hartl 2003; Cook et al. 2006; Mulumba and Lal 2008), mulching acts as a barrier against moisture losses by soil surface evaporation. Moreover, mulching prevents crust formation by reducing the raindrop impact energy, increases

Table 2. Effect of soil management techniques on chemical and biological soil properties (July 2007).

Parameter	Pine bark mulch	Coarse green compost	Unmulched treatment	P
TOC (g/100g)	1.62 ab	1.82 a	1.49 b	**
Total N (g/kg)	1.11 b	1.32 a	1.18b	**
C:N ratio	14.6 a	13.8 ab	12.6 b	*
N_2O emission (mg/m^2/d)	2.8 b	6.2 a	3.1 b	**
Biomass C (mg/100g dry soil)	75.4 a	82.5 a	48.0 b	**

Different letters within the same row indicate statistical differences at $P \leq 0.05$ (*) or $P \leq 0.01$ (**) using HSD Tukey test.

water infiltration, hampers water capillary rise (Salau et al. 1992; Savabi and Stott 1994), moderates soil temperature and lessens soil penetration resistance, inducing an enhanced root growth (Rathore et al. 1998).

Data analysis also shows the effect of the two different species on soil moisture. Soil under *Tilia × europaea* exhibited lower ($p < 0.01$) mean moisture content than under *Aesculus × carnea* (12.3% versus 17.1% v/v, respectively); this was probably due to the different growth rate and physiological behavior of the tested species, with *Tilia* showing higher shoot growth and leaf gas exchange compared to *Aesculus* (Ferrini et al. 2008). No significant species/treatment interaction was observed ($p < 0.70$ by MANOVA; data not shown).

The effects of mulching on soil moisture varied with soil water status. At the wilting point (WP) [–1,500 kPa (217 psi) matric potential], there was no difference in soil water content among treatments. At high suctions, the dominant mechanism of water retention is adsorptive, so the textural characteristics of the soil are more important than the structural ones in determining the affinity of the water to the soil matrix (Hillel 1980).

Soil moisture content at field capacity (FC) [–10 kPa (–1.5 psi) matric potential) didn't differ between unmulched treatment and coarse green compost and between the unmulched treatment and pine bark mulch. Soil moisture at FC was higher in coarse green compost when compared to pine bark mulch treatment. It is well-known that organic matter can act as a hydrophobic material, depending on water content (Doerr et al. 2000), hence affecting the physical and hydraulic properties of the soil by inducing difficulties during the rewetting phase (Dekker and Ritsema 1996). When dry, the fine fraction of pine bark mulch exhibits a low wettability (Michel 2001); the presence of sawdust-sized material, originated by degradation of the bark mulch, particularly in the uppermost soil layer, may have hampered the complete saturation of the soil samples. In fact, pores become highly hydrophobic during soil drying and maintain their hydrophobic character during the wetting process (Naasz et al. 2008). However, it is important to stress that both the organic mulches were able to maintain soil water content above WP even during the hottest and driest period of the year.

Soil Chemical and Biological Properties

Significant differences were found among the treatments for soil respiration (Figure 2). Organic mulching induced higher CO_2 efflux than the unmulched treatment from June to September 2006. Soil mulched with pine bark mulch showed lower respiration than soil mulched with coarse green compost on June 9, 2006, the first sampling date. From June 66 to September, there was no difference in soil respiration between the two mulching treatments. The lower value of respiration found on June 9 in the pine bark mulch treatment and the increasing trend shown by this treatment during the season may be explained by a slower degradation of this material if compared with coarse green compost. No difference was found for soil oxygen content (data not shown).

Chemical and biological soil property data are reported in Table 2. On the whole, mulching positively affected the soil organic C pool, although significant differences for TOC were found only between the unmulched treatment and coarse green compost treatment. Compared to coarse green compost, pine bark mulch has a higher C:N ratio and a higher quantity of recalcitrant compounds (Lorenz et al. 2007). As a consequence, the stability against microbial decomposition is greater and the buildup of soil organic matter in the topsoil layer under the mulch is slowed down (McColl and Powers 2003). This effect of mulching is particularly remarkable when considering that this coarse-textured soil lacks aggregation due to low clay content. The resulting low physical organic matter protection is a major factor that limits the soil C storage capacity.

Coarse green compost also had a fertilizing action, as showed by a significant increase in total soil N content with respect to both pine bark mulch and the unmulched treatment. This finding suggests that 3 years after the beginning of the trial, application of coarse green compost on the soil surface improved its nitrogen fertility, indicating that a good incorporation of the mulch into the topsoil. Similar results were obtained by Pickering and Shepherd (2000) and Pinamonti (1998). On the contrary, as documented by Craul (1992), pine bark mulching failed to increase the soil N pool, and no significant difference was found between the unmulched treatment and pine bark mulch treatments. Materials, such as pine bark mulch, with a high C:N ratio can induce nitrogen immobilization until the microbial activity decreases due to carbon limitation. Data on tree growth showed that shoot elongation was generally higher in trees with coarse green compost compared to the unmulched treatment, while pine bark mulch showed intermediate values (Ferrini et al. 2008), which can be also explained by the higher N content in the coarse green compost plots. The chemical composition of the mulching materials is responsible as well for the observed values of the soil C:N ratio; a pronounced effect of mulch application is a general increase in the C:N ratio, with pine bark mulch soil showing a significantly higher value compared to the unmulched treatment. The observed C:N ratios for mulched treatments suggest rapid humification processes (Sequi 1989), possibly due to the acid reaction and the base saturation of this soil type. Such processes are further promoted by a more intense microbial activity, as confirmed by significantly ($P < 0.01$) greater microbial biomass C in coarse green compost and pine bark mulch soils compared to the unmulched treatment (Table 2).

The N_2O emission under coarse green compost was significantly higher compared to pine bark mulch and the unmulched treatment. The observed results are a consequence of both the higher nitrogen content of the coarse green compost soil and of nitrogen immobilization induced by microbial biomass during bark decomposition. This study's results are consistent with the findings of Larsson et al. (1998), indicating that N_2O emissions following the surface application of herbaceous mulches were affected by the N content of the mulching material. Jarecky and Lal (2006) found similar daily N_2O fluxes in a trial intended to evaluate the soil-restorative effect of coarse green compost and wheat residue mulch. Because N_2O is a powerful greenhouse gas, these data may deserve further investigation. Increases in N_2O fluxes were commonly found in response to greater soil water content (Six et al. 2004), greater NO_3^- content (Hellebrand 1998), and increased organic matter (Ebertseder et al. 2001).

Conclusion

Results showed that soil temperature under both mulches was significantly lower than in the unmulched treatment during the summer months. Soil biological activity was also enhanced by mulches. No difference in soil oxygen content was found among the treatments. This indicates the use of a mulch layer up to 8 cm (3 in) thick did not diminish gas exchange between soil and atmosphere. Soil bulk density was significantly lower under coarse green compost. Conversely, soil moisture, C:N ratio and microbial biomass were significantly higher. Composting also had a fertilizing action, as indicated by higher TOC, total soil N content, and N_2O emission.

In conclusion, mulch affected soil properties and created a more favorable environment for roots, which resulted in enhanced plant growth. Based on the results, compost appears to release more nitrogen into the soil than pine bark mulch. Cost and maintenance considerations dictate which mulch materials are used. The price of coarse green compost and the amount of time needed to distribute it render its use cheaper compared to pine bark mulch.

The study of organic mulch effects on soil characteristics is being continued in the future on different species and in different environments. Pilot studies are also under way to investigate the long-term effects on trees in the urban landscape.

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