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Soil physical characteristics and understory management in a walnut (*Juglans regia* L.) plantation in central Italy

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Abstract. Early and significant influences on soil physical properties are expected in temperate agroforests as a consequence of various soil and/or understory management practises. Soil physical characteristics were studied in an agroforestry trial of common walnut (*Juglans regia* L.) set up on a volcanic soil in central Italy, where clean cultivation, polyethylene mulching along tree rows and intercropping of walnut with alfalfa (*Medicago sativa* L.) were tested. Soil total porosity, size distribution and morphology of pores, and available water were evaluated during the second and the fourth growing season of the plantation to determine the possible influence and duration of the treatments on soil physical properties. In the first sampling the total porosity was two to three times greater than in the second one and no significant differences were found between treatments. Seasonal variation in total porosity was observed, with a maximum in summer. All dimensional classes of pores > 50 μm were well represented, thus indicating an adequate soil structure. In the fourth growing season total porosity and pore size distribution were very similar in clean cultivation and mulching so that the mulching effect on the structural characteristics of this soil was equivalent to that of repeated rototilling in clean-cultivated plots. Moreover, mulching stimulated more biological activity, resulting in a higher proportion of rounded pores. Alfalfa roots created a more homogeneous environment to a depth of 35 cm, with a greater presence of elongated pores in the range 50–500 μm that could make movement of water easier. Most of the water retained was unavailable for plants, so that competition between walnuts and alfalfa took place and could be associated with the lower stem growth of intercropped walnuts.

Introduction

The soil is an important factor influencing interactions that occur between woody and herbaceous components of agroforestry systems (Young, 1997). Negative interactions may be related to competition for nutrients and water retained and released by the soil. On the other hand, herbaceous plants can positively affect some physical and chemical parameters such as water and nutrient penetration and storage in the soil profile, amount of organic matter and soil structure (aggregation and porosity), thus positively affecting the development and productivity of the trees. The balance between the benefits and competitive interactions depends on many factors, such as site conditions, tree age, vegetative cycle of each component, as well the management of the tree-herbs interface. In climates with strong summer drought, where evapotranspiration is higher than precipitation, competition for soil moisture between trees and associated herbs could be extremely limiting for tree growth and performance, especially in young forest plantations, when tree crowns are not developed enough to shade associated herbs (Nambiar and Sands, 1993; Paris et al., 1998). Polyethylene mulching can be used to improve tree growth in young plantations, by mitigating soil thermal variations (Liakatas et al., 1986) and improving nutrient availability (Truax and Gagnon, 1993), and as an effective alternative to clean cultivation and herbicide spraying for weed control (McDonald and Helgerson, 1990). Polyethylene mulching has also been successfully used in controlling the competition for soil water between alfalfa (*Medicago sativa* L.) and young walnut (*Juglans regia* L.) trees in an agroforestry trial in central Italy (Paris et al., 1998).

Whatever agroforestry management is applied, the type and frequency of the required agricultural practices influence soil conditions (Pini et al., 1991). Knowledge of the extent to which the soil physical-structural characteristics are modified is therefore necessary in order to assess the efficiency of these cultural practices. If consideration is taken of the particular sensitivity of some tree species, like walnut, to the water conditions of the soil, it is also necessary to understand the soil-water relationships. A clear identification of the most effective cultural practices for the optimization of water use is then possible. This is particularly important in Mediterranean climates, where water could be a limiting factor for tree growth.

In conjunction with the above-mentioned agroforestry trial of common walnut in central Italy (Paris et al., 1995 and 1998), the aim of this research was to evaluate (i) the effects of intercropping with alfalfa and polyethylene mulching on soil physical characteristics; (ii) the intensity of these possible modifications and (iii) the possible interactions with the growth of seedlings of common walnut.

Materials and methods

The experiment was conducted in test plots of an experimental plantation established on the south-west facing side of an open valley at about 500 m a.s.l., in a volcanic hilly area (lat. N 42°40′; long. E 12°02′) of Central Italy with a sub-humid/humid Mediterranean climate. The soil was a slightly acidic (pH = 6.5) loamy-sand Dystric Xerocrept (Soil Survey Staff, 1992), with a cation exchange capacity of 19 meq/100 g, an absence of $CaCO_3$ and an organic carbon content of 1.2%. A detailed description of the region and of the experimental design is in Paris et al. (1995). Briefly, the experimental layout was organized in 900 m^2 plots, grouped into three blocks (replications). In each plot sixteen trees were planted at a 6 m × 7 m spacing with a north-west/south-east orientation of walnut rows. Three types of plantation floor management were compared in this paper: clean cultivation (CC), polyethylene mulching (PM) and alfalfa intercropping (IC).

Before the plantation of walnut seedlings was established, a common set of cultural operations was performed in all the plots that included cross ripping (100 cm depth), ploughing (30 cm depth) and rototilling (15 cm depth). In the PM treatment a polyethylene film (2 m wide and 0.2 mm thick) was spread out along tree rows. In the IC treatment alfalfa was sown at a rate of 90 kg/ha, 0.7 m on either side of the walnut seedlings. Alfalfa was mechanically harvested three or four times per season. CC plots were maintained free of weed vegetation by means of three periodical rototillings in each growing season.

Soil sampling

Samplings were conducted in the spring of the second growing season and in spring, summer and autumn of the fourth growing season. Soil samples were collected in triplicate from each plot at depths of 0–5 cm, 25–30 cm and 55–60 cm. These depths were chosen because they were representative of different soil conditions: the 0–5 cm depth was affected primarily by atmospheric agents and by tillage practices; the 25–30 cm depth may have undergone compaction as a result of tillage or machinery traffic; the 55–60 cm depth was the least affected by external forces, but its physical characteristics were important for root growth and penetration, because common walnut and alfalfa were expected to develop a root system at least to that depth in a short time (Parrini, 1989; Jie and Rongting, 1990).

Soil analytical determinations

Undisturbed samples were air dried by acetone replacement of the water, impregnated with a polyester resin and made into 5 × 5 cm, vertically oriented thin sections (Murphy, 1986). Photographs of the sections were analyzed by image analysis to measure total porosity, pore shape and size distribution of pores greater than 50 μm (Pagliai et al., 1983). Pores were measured by their shape, which is expressed by the shape factor (perimeter/4π(area)), and divided into rounded (shape factor 1–2), irregular (shape factor 2–5) and elongated (shape factor greater than 5) pores. Pores were also subdivided into size classes according to either the equivalent pore diameter (rounded and irregular pores) or to their width (elongated pores) (Pagliai et al., 1988).

Available water was calculated from soil water characteristics measured with a pressure plate apparatus (ASA-SSSA, 1986), as the difference between water retained at 0.033 MPa (field capacity) and at 1.5 MPa (wilting point).

Analysis of variance was performed on all data, at a probability level of 0.05.

Results and discussion

Total porosity

Mean values of total porosity, expressed as percent of total area of thin sections occupied by pores > 50 μm, are reported in Table 1. When interpreting the data in Table 1 it is important to remember that, according to the micromorphometric method, a soil is considered very dense with a total porosity less than 5%, dense with a total porosity of 5–10%, moderately porous at 10–25%, highly porous at 25–40% and extremely porous with a total porosity greater than 40% (Pagliai, 1988).

As expected, total porosity decreased progressively with depth in all cases.

In the first sampling there were no significant differences between the three treatments. This could be explained by the fact that at the first sampling date the soil porosity was more affected by pre-planting soil preparation than by the experimental treatments applied for less than one year. Two years later, the total porosity sharply decreased. This behaviour may be the result of the natural compaction that followed the rise of porosity due to the heavy tillage practices (cross ripping and ploughing) at the beginning of the plantation. This decrease in total porosity could be regarded as problematic because the soil passed from highly porous to moderately porous and even dense, so that a careful evaluation of pore shape and size distribution was needed.

Table 1. Soil total porosity of pores > 50 μm, in a walnut plantation in central Italy, measured on thin sections.

Treatment	Season/year			
	Spring II	Spring IV	Summer IV	Autumn IV
	Porosity as % of total area of thin sections			
Clean cultivation				
0–5 cm	30.5 Aa*	10.2 Ba	15.3 Ca	14.2 Ca
25–30 cm	13.0 Ab	4.9 Bb	6.1 Bc	4.7 Bcd
55–60 cm	6.9 Ac	3.2 Bc	2.2 Bd	3.4 Bd
Mulching				
0–5 cm	28.7 Aa	9.5 Ba	15.9 Ca	11.8 Ba
25–30 cm	15.2 Ab	5.5 Bb	5.9 Bc	5.2 Bbc
55–60 cm	7.3 Ac	3.6 Bc	2.3 Bd	4.2 Bd
Intercropping				
0–5 cm	30.2 Aa	7.4 Bab	10.0 Cb	6.7 Bb
25–30 cm	16.4 Ab	6.1 Bb	7.4 Bc	5.7 Bbc
55–60 cm	11.7 Abc	3.3 Bc	3.1 Bd	3.9 Bd

* Values in the same row with the same upper case letter are not significantly different at the 0.05 level. Values in the same column with the same lower case letter are not significantly different at the 0.05 level.

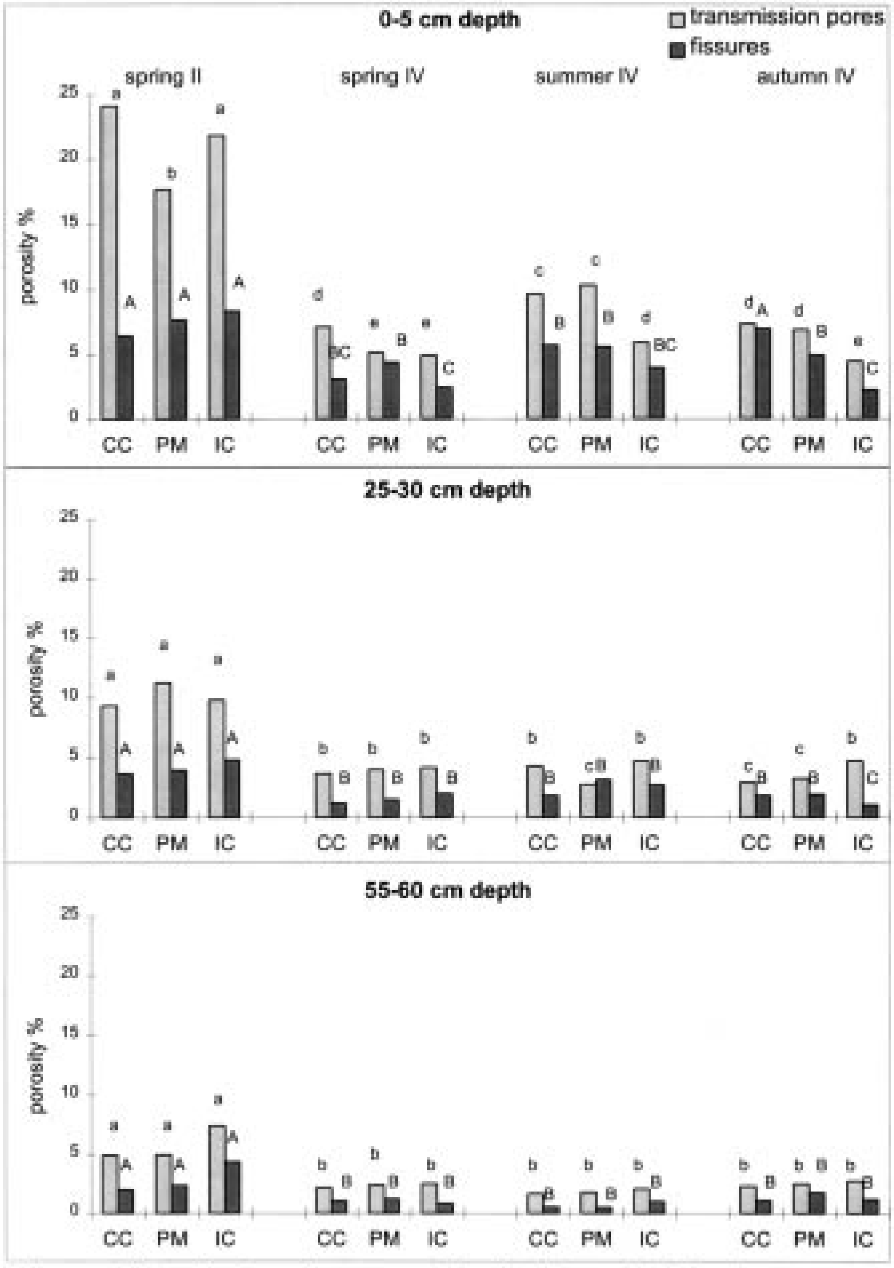
All the treatments showed a similar trend of total porosity during the fourth growing season; in fact down to a 30 cm depth the total porosity increased in summer and then decreased again in autumn. Such a trend is usual for soil porosity, because soil structure can be influenced by seasonal variations of biological activity (Guidi et al., 1988). Moreover, differences between the 0–5 cm and the 25–30 cm depth were more pronounced in the clean cultivation and mulching treatments than in the intercropping treatment. In this treatment the presence of alfalfa roots probably created a more homogeneous structure of the soil layers investigated, by compacting the more porous surficial layer and creating void spaces in the more compacted deeper layer.

Size distribution and morphology of pores

Pore size distribution and shape needs to be considered in addition to total porosity because they help to explain the agronomic significance of the soil pore system. In fact, many of the most important phenomena directly related to plant growth, such as ease of root penetration, storage and movement of water and gases, depend on pore size distribution. In this paper we used the classification of pores proposed by Greenland (1977). According to this classification, residual pores (smaller than 0.5 µm) retain water with a potential that makes it unavailable for roots; storage pores (in the range of 0.5–50 µm) hold the water necessary for growth of plants and micro-organisms; transmission pores (in the range of 50–500 µm) regulate transmission of water and exchange of gases and allow the growth of most feeding roots; fissures (pores greater than 500 µm) can have some useful effects on root penetration and movement of water and air, even if a high percentage of them is usually an index of poor soil structure. Pore size distributions from image analysis are reported in Figure 1. Only transmission pores and fissures are considered here because the thin section analysis only measures pores > 50 µm.

As a general trend, the dimensional classes reflected the differences of total porosity between sampling dates and treatments. Each dimensional class was adequately represented and well above the 10% of total porosity, that is the minimum percentage required for an adequate soil structure (Pagliai, 1988). In particular, during the fourth growing season, the amount of transmission pores was higher in the 25–30 cm layer of intercropped plots with respect to the other treatments. This can be regarded as an evidence of better soil structure, because damage to soil structure can be recognized by the decrease in the proportion of total pore space in transmission pores (Pagliai et al., 1995).

In Table 2 pores were also divided in three shape groups, hereafter described. The rounded pores, spherical and originated mainly from the carbon dioxide liberated by biological activity (Pagliai, 1988), were regularly distributed in all size classes. At all sampling dates, in the 0–5 cm layer the rounded pores were higher in the mulching than in the other treatments. This could be related to a higher biological activity that took place in the undisturbed and potentially more favourable environment under the mulching films.



* histograms followed by the same letter are not significantly different at the 0.05 level

Figure 1. Soil pore size distributions in a walnut plantation in central Italy, at three depths under three treatments (CC = clean cultivation; PM = polyethylene mulching; IC = intercropping) and over a four year period.

Table 2. Distribution of soil porosity > 50 μm in the different shape classes in a walnut plantation in central Italy, under three treatments and over a four year period.

	Rounded pores				Irregular pores				Elongated pores			
	Spring II	Spring IV	Summer IV	Autumn IV	Spring II	Spring IV	Summer IV	Autumn IV	Spring II	Spring IV	Summer IV	Autumn IV
0–5												
CC	2.89 c*	2.44 a	2.15 b	1.37 cd	4.92 ab	3.15 a	4.57 b	2.34 b	22.72 a	4.64 a	8.62 a	10.59 a
PM	3.59 b	2.52 a	2.54 a	2.02 a	5.25 a	3.57 a	5.36 a	3.07 a	16.52 b	3.40 b	8.02 a	6.73 b
IC	3.39 b	2.33 a	2.17 b	1.13 d	4.52 bc	2.65 b	4.02 b	1.59 de	22.34 a	2.40 c	3.70 b	4.03 c
25–30												
CC	4.18 a	1.91 b	1.71 c	1.90 a	4.36 c	1.68 cd	1.93 cd	1.18 e	4.49 c	1.26 d	2.44 c	1.67 e
PM	4.02 a	1.99 b	2.25 ab	1.51 bc	4.85 ab	1.87 c	2.32 c	1.99 bc	6.34 c	1.64 d	1.32 d	1.70 e
IC	4.03 a	1.95 b	1.61 c	1.77 ab	4.67 b	1.97 c	1.89 d	1.78 cd	5.96 c	2.24 c	3.94 b	2.23 d
55–60												
CC	3.40 b	1.51 c	1.05 d	1.39 cd	2.35 d	0.97 e	0.75 e	1.25 e	1.14 d	0.75 e	0.42 e	0.75 f
PM	3.51 b	1.45 c	1.33 d	1.68 ab	2.69 d	1.45 d	0.67 e	1.77 cd	1.10 d	0.78 e	0.34 e	0.84 f
IC	2.96 c	1.59 c	1.23 d	1.41 cd	3.18 c	0.94 e	1.19 e	1.70 cd	5.58 c	0.76 e	0.67 e	0.83 f

* Values in the same column followed by the same letter are not significantly different at the 0.05 level.
CC = clean cultivation; PM = polyethylene mulching; IC = intercropping.

The irregular pores were evenly distributed in both size classes and their maximum was in the > 500 µm class.

The elongated pores are represented by cracks and thin fissures. The former are the largest ones (> 500 µm), they arise mainly from shrinkage phenomena, after rainfall, when the stability of soil aggregates is poor and they can also be seen on the soil surface. Their presence is an index of poor structural conditions. Thin fissures are the most important from an agronomic point of view and sometimes they traverse the soil in a fairly regular pattern. In our samples, as a general trend, elongated pores represented the highest area proportion of the three shape groups down to a depth of 30 cm. In the 0–5 cm layer, they were prevalent in the clean cultivation treatment with respect to the other treatments as a consequence of surficial tillage, whilst in the 25–30 cm layer they were more present in intercropping treatment, probably due to the effect of root penetration. In all treatments most elongated pores were in the 50–500 µm range, so that they could be classified as thin fissures and represented mainly transmission pores, indicating a good structural status (Pagliai et al., 1995).

Available water

Soil pore size distribution calculated from soil water characteristics is presented in Table 3. These data are obtained with a method less sophisticated than image analysis and they give only a size distribution without any distiction between shape classes. Notwithstanding, these data make possible a more direct evaluation of soil porosity in terms of water availability. Only mean values of all treatments are reported because no significant differences among treatments were detected. These data confirm the presence of a good proportion of transmission pores in this soil, which allows water and air movements. Their trend is similar to that found with image analysis. In the pore classes that retain water, the residual pores are mostly predominant, as

Table 3. Soil pore size distributions at different soil depth in a walnut agroforestry trial in central Italy in the second growing season, classified according their function with respect the water in soil.

	Residual pores < 0.5 µm (unavailable water)	Storage pores 0.5–50 µm (available water)	Transmission pores 50–500 µm (drainage water)
	% of total soil volume		
0–5	20.6 a*	8.9 a	31.2 a
25–30	25.2 b	7.1 a	24.3 b
55–60	24.5 b	3.2 b	14.7 c

* Values in the same column followed by the same letter are not significantly different at the 0.05 level.

one could expect in such a volcanic soil. They are bound more to the type of soil, so that their amount is independent of soil depth and treatment. Storage pores, that can contain water available to plants represented the lower proportion of total pores and were not influenced by the three treatments. The relative proportions of residual and storage pores showed that most of the water retained was unavailable to plants so that a competition for water between the alfalfa and walnut plants could be expected, particularly in the periods of maximum growth rate.

Implications for walnut growth

The general characteristics of the investigated soil matched the requirements of common walnut, in terms of texture, low content of carbonates and structural conditions that can assure a sufficient permeability, as indirectly confirmed by the growth rates (1.13 mm/year for stem basal diameter and 0.57 m/year for stem height increments) recorded in this plantation (Pisanelli et al., 1998) and consistent with those typical for common walnut growing in good site conditions for Italy (ARF, 1993).

In the same trial, leaf water potentials of mulched and unmulched walnut did not differ (Paris et al., 1998), thus providing little evidence of higher soil moisture availability in the rizosphere of the mulched walnut. Mulched walnut did have higher stem growth rates than the unmulched one. Thus, neither improved soil physical properties, nor higher soil moisture availability can be associated to the higher stem growth rate of mulched walnut, based on the results of these studies.

The water retention data showed that most soil water was held in a form unavailable to the plants, and this was not affected by any of the experimental treatments. This may be related to the fact that the intercropped walnut showed much lower leaf water potentials and lower soil moisture availability than non-intercropped walnut during summer dry periods, thus indicating water stress in the intercropped walnut, which contributed to low stem growth rates (Paris et al., 1998). In our experiment we found that alfalfa improved soil physical properties by producing a more similar physical structure between the two surficial layers, with a higher proportion of transmission pores. Thus, in this experiment the balance between the benefits of alfalfa and its water competitiveness was towards the latter, which was associated with lower stem growth rates of intercropped walnut. In conclusion, soil physical improvement attributable to alfalfa cultivation was completely masked by a decrease in soil moisture due to increased competition for water by the alfalfa understory. Such decreases in soil moisture may be limiting for the growth and development of young walnut trees.

Conclusions

Pre-planting soil preparations (1 m depth cross-ripping and 0.3 m depth ploughing) caused a more porous structure, but this effect diminished with time in all treatments. Thus, special care should be given to pre-planting soil preparation, to create the best soil structural conditions which allow easy tree root penetration. Furthermore, all operations increasing soil compaction (e.g. grazing, machinery traffic) should be minimized during early root system development of young trees.

Plastic mulching showed an effect on the structural characteristics of the studied soil equivalent to that of repeated annual rototillings. Thus plastic mulching could be regarded as an effective soil management, at least in the studied soil. In this experimental trial, neither improved soil structure nor higher soil moisture in walnut rizosphere could be associated to plastic mulching, although this treatment caused higher stem growth rates (Paris et al., 1998). Indeed, the causes of the improved growth of mulched trees are not often fully understood (McDonald and Helgerson, 1990). Moreover, we observed that mulching seemed to stimulate more biological activity in the soil underneath the plastic film. For this reason soil nutrient availability, which is affected by different levels of soil biological activities, should be taken in more consideration.

Competition for water between alfalfa and walnut plants was to be expected, particularly in periods of maximum growth rates during the growing season. In the site conditions (sub-humid/humid Mediterranean climate and medium-high soil fertility) of this experimental trial, early intercropping of walnut with alfalfa should not be recommended at all, because alfalfa competition with young trees can be much stronger than alfalfa improvement of soil chemical and physical fertility. Early intercropping of walnut could be possible only throughout careful management of the tree-intercrop interface (tillage, herbicide spraying and mulching as well as the width of weed-herbs free strip along tree rows) (Paris et al, 1998 and 1995; Dupraz and Newman, 1997; Garret et al., 1991). This should mitigate below-ground competitive interactions between trees and intercrops, attaining a good growth of the tree stems and leaving the intercrops enough time to positively affect soil fertility.

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