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Application of composted urban residue enhanced the performance of afforested shrub species in a degraded semiarid land

F. Caravaca *, D. Figueroa, M.M. Alguacil, A. Roldán

Department of Soil and Water Conservation, CSIC-Centro de Edafología y Biología Aplicada del Segura, P.O. Box 4195, Campus de Espinardo, 30100 Murcia, Spain

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Abstract

Improvement of physical–chemical soil quality is a key step for carrying out revegetation programs of degraded lands in Mediterranean semiarid areas. Organic residue addition may restore the quality of these areas. A field experiment was conducted in a silt-loam soil (Typic Petrocalcid) from a degraded semiarid Mediterranean area to evaluate the effect of the addition of a composted urban residue on soil aggregate stability, bulk density and chemical properties and on the establishment of *Pistacia lentiscus* and *Retama sphaerocarpa* seedlings. The composted residue was applied at a rate of 6.7 kg m^{-2} before planting. The nutrient content (NPK), total organic C and water soluble C were increased and bulk density was decreased, in the rhizosphere soil of both shrub species, by the composted residue. The addition of composted residue significantly increased the soil aggregate stability by about 22% for both shrub species. The beneficial effect of the composted residue on soil quality still persisted 18 months after addition. Eighteen months after planting, the addition of composted residue to soil had increased significantly the production of shoot biomass by *P. lentiscus* and *R. sphaerocarpa*, by about 160% and 320% respectively, compared to control values. Composted residue addition to soil can be considered an effective preparation method of a degraded area for carrying out successful revegetation programs with Mediterranean shrubs under semiarid conditions.

Keywords: *Pistacia lentiscus*; *Retama sphaerocarpa*; Aggregate stability; Bulk density; Water soluble carbon

1. Introduction

The influence of organic matter on soil biological and physical fertility is well known. Indeed, organic matter affects soil productivity either directly, by supplying nutrients, or indirectly, by modifying soil physical properties such as stable aggregates and porosity that can improve the root environment and stimulate plant growth (Ouédraogo et al., 2001). Intensive arable farming and semiarid climatological conditions cause a progressive decline in soil organic matter levels (Caravaca et al., 2002a,b). The agronomic utilisation of organic refuse, such as urban solid refuse, has increased steadily in recent years as an alternative nutrient and organic matter source and as an acceptable method for its disposal. The effectiveness of such amendments greatly depends on their stability. For example, non-composted organic residues have been shown to be more effective than composted residue in activating the soil biomass which, in turn, can reactivate the biogeochemical cycles of the soil (Roldán et al., 1994). Nevertheless, some authors have suggested that organic amendments should be composted before they are applied to soil, to achieve biological transformations of the organic matter and avoid the presence of organic substances with a low molecular weight, which may be phytotoxic (Gliotti et al., 1997).

Soil structural stability is critical to control long erosion in semiarid areas and implement programs to restore vegetative cover (Caravaca et al., 2002a,b). Likewise, plant cover contributes to the formation and stability of soil aggregates by supplying organic matter from plant remains. Re-establishment of native shrub species such as *Pistacia lentiscus* (L.) and *Retama sphaerocarpa* (L.) Boissier in revegetation programs for abandoned agricultural lands has been encouraged recently by the agricultural policies of the European

* Corresponding author. Tel.: +34-968-396337; fax: +34-968-396213.
E-mail address: fcb@cebas.csic.es (F. Caravaca).

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Union as a means for regenerating the biodiversity of these areas. However, there are limited reports describing the effectiveness of organic refuse addition in the revegetation of a semiarid shrubland (Roldán et al., 1996; Querejeta et al., 2000). The improvements in soil quality expected following the addition of composted residue could also enhance natural vegetation (Díaz et al., 1997). Our objective was to evaluate the influence of composted residue addition on soil aggregate stability, bulk density and chemical properties during the establishment of *P. lentiscus* and *R. sphaerocarpa* seedlings in a degraded semiarid area.

2. Methods

2.1. Study area

The experimental area was located on the El Picarcho range, in the province of Murcia (southeast Spain) (coordinates: 1°10′ W and 38°23′ N). The climate is semiarid Mediterranean, with a mean annual rainfall of 233 mm and a mean annual temperature of 20 °C during the experiment. The soil used was a Typic Petrocalcid (Soil Survey Staff, 1999), developed from limestones, with a silt-loam texture.

2.2. Materials

The composted organic residue used was the organic fraction of a municipal solid waste obtained from a treatment plant in Murcia, Spain. The composted residue was produced mechanically by fast fermentation (60 d) and mixing the waste heap daily under aerobic conditions. The composted residue was sieved, ground to 0.5 mm particles and air-dried for analysis. The pH and electrical conductivity were measured in a 1:10 (w/v) aqueous extract. The organic matter content was determined by calcination at 750 °C for 4 h and the contents of total organic C and total N by dry combustion (Page et al., 1982). The contents of heavy metals were determined by atomic absorption in the extract after nitric–perchloric digestion. The analytical characteristics of the composted residue are shown in Table 1.

The plants used for the revegetation experiments were *P. lentiscus* and *R. sphaerocarpa*, low-growing shrubs widely distributed in the Mediterranean area. The shrubs are also well adapted to water stress conditions and, therefore, potentially could be used in the reafforestation of semiarid disturbed lands. Seedlings of both plant species were grown for eight months under nursery conditions without any fertilization treatment. Nursery procedures were conducted at Paisajes del Sur Ltd. (Granada, Spain).

Table 1
Analytical characteristics of the composted residue used in the experiment

Ash (%)	44.8
pH (1:10)	6.7
Electrical conductivity EC (1:10, $\mu S\,cm^{-1}$)	4700
Total organic C ($g\,kg^{-1}$)	276.0
Water soluble C ($\mu g\,g^{-1}$)	1950
Water soluble carbohydrates ($\mu g\,g^{-1}$)	76
Total N ($g\,kg^{-1}$)	14.5
N-NH_3 ($\mu g\,g^{-1}$)	3350
Total P ($g\,kg^{-1}$)	3.8
Total K ($g\,kg^{-1}$)	12.0
Cu ($\mu g\,g^{-1}$)	146
Zn ($\mu g\,g^{-1}$)	261
Ni ($\mu g\,g^{-1}$)	25
Cr ($\mu g\,g^{-1}$)	62.9
Cd ($\mu g\,g^{-1}$)	5
Pb ($\mu g\,g^{-1}$)	98

2.3. Experimental design and layout

The experiment was conducted as two independent one-factor factorials (one per plant species) with six replication blocks. The factor had two levels: non-addition and the addition of a composted organic residue to the soil. In September 1999, two adjacent plots of 1200 m^2 (one per plant species) were prepared mechanically with a subsoiler prior to planting. In both plots, 12 rows (1 m wide, 25 m long) were established (two rows per replicate block). In early December 1999, composted residue was added to half of the rows (0–20 cm depth) at a rate of 6.7 $kg\,m^{-2}$ by randomised design within each replicate block. This application rate corresponds to a 1% addition to soil total organic carbon content. Three weeks after the addition of the compost, *P. lentiscus* and *R. sphaerocarpa* seedlings were planted in individual holes, at least 1 m apart in a single row, with 3 m between blocks. At least 16 seedlings per replication block were planted (eight plants × two treatments in each block).

2.4. Sampling procedures

Immediately before planting, 16 soil samples were collected randomly, eight samples from the rows with composted residue and eight from the rows without residue. Every six months after planting, six soil samples of each treatment were collected (12 soil samples per species and 24 soil samples in total). Each sample consisted of eight bulked subsamples (200 cm^3 soil cores), randomly collected at 0–20 cm depth from eight planting holes (considered as rhizosphere soil). Eighteen months after planting, six plants (one per block) of each treatment were also harvested, excavating manually a hole 40 cm wide, 40 cm long and 40 cm deep. Basal stem diameters and heights of plants were measured with callipers and rules. Fresh and dry (105 °C, 5 h) weights of shoots and roots were recorded. Plant tissues were ground before chemical analysis. The foliar concentrations of nitrogen, phosphorus and potassium were determined after digestion in nitric–perchloric acid (5:3) for 6 h (Plank, 1992). The P was determined by colorimetry (Murphy and Riley, 1962), N was colorimetrically measured after Kjeldhal digestion and K was estimated by flame photometry (Schollemberger and Simon, 1954).

2.5. Soil physical–chemical analyses

Total nitrogen was determined by colorimetry after Kjeldhal digestion, and the total organic C according to Yeomans and Bremner (1988). In a 1:5 (w/v) soil aqueous extract, water soluble carbon was determined by wet oxidation with $K_2Cr_2O_7$ and measurement of the absorbance at 590 nm (Sims and Haby, 1971). Water soluble carbohydrates were determined by the method of Brink et al. (1960). Available P, extracted with 0.5 M $NaHCO_3$, was determined by colorimetry according to Murphy and Riley (1962). Extractable (with ammonium acetate) K was determined by flame photometry.

Soil bulk density was determined by method described by Barahona and Santos (1981) after to maintain soil moisture at 60% of field capacity for one month. The percentage of stable aggregates was determined by the method described by Lax et al. (1994). A 4 g aliquot of sieved (0.2–4 mm) soil was placed on a small 0.250 mm sieve and wetted by spray with distilled water. After 15 min the soil was subjected to an artificial rainfall of 150 ml with energy of 270 $J\,m^{-2}$. The remaining soil on the sieve was put in a previously weighed capsule (T), dried at 105 °C and weighed ($P1$). Then, the soil was soaked in distilled water and, after 2 h, passed through the same 0.250 mm sieve with the assistance of a small stick to break the remaining aggregates. The residue remaining on the sieve, which was made up of plant debris and sand particles, was dried at 105 °C and weighed ($P2$). The percentage of stable aggregates with regard to the total aggregates was calculated by $(P1 - P2) \times 100/(4 - P2 + T)$.

2.6. Statistical analysis

Aggregate stability was arcsin-transformed, and the other parameters were log-transformed, to compensate for variance heterogeneity, before analysis of variance. The effects of residue addition on the measured variables were tested by a one-way analysis of variance. Statistical procedures were carried out with the software package SPSS 10.0 for Windows (Ferrán Aranaz, 1996).

3. Results

3.1. Changes in soil physical–chemical properties

Soil pH of the rhizosphere of *P. lentiscus* and *R. sphaerocarpa* was not significantly affected by the addition of composted residue to soil, for the 18 months of the experiment (Table 2). Composted residue increased significantly the electrical conductivity of rhizosphere soil of *P. lentiscus* and *R. sphaerocarpa*, although a sharp decrease in electrical conductivity values for the amended soil was observed at the end of the growth period, for both shrub species (Table 2).

The addition of composted residue to the soil significantly increased the concentrations of total N, available

Table 2
Evolution of physical–chemical properties and nutrients of rhizosphere soil of *P. lentiscus* and *R. sphaerocarpa* in response to composted residue addition ($n = 6$)

	Months			
	0	6	12	18
P. lentiscus				
pH (H_2O)				
C	7.7 (0.0)	8.0 (0.2)	7.8 (0.0)	7.6 (0.1)
R	7.8 (0.1)	7.7 (0.1)	7.8 (0.1)	7.8 (0.1)
EC (1:5, $\mu S\,cm^{-1}$)				
C	327 (3)	300 (4)	270 (3)	167 (3)
R	678 (60)	1423 (42)	562 (9)	379 (16)
Total N ($g\,kg^{-1}$)				
C	0.7 (0.0)	0.7 (0.2)	1.0 (0.2)	1.4 (0.0)
R	1.2 (0.2)	1.8 (0.3)	2.7 (0.3)	3.4 (0.1)
Available P ($\mu g\,g^{-1}$)				
C	3 (0)	12 (2)	8 (1)	16 (1)
R	90 (5)	126 (6)	84 (3)	57 (2)
Extractable K ($\mu g\,g^{-1}$)				
C	702 (25)	443 (10)	470 (29)	563 (37)
R	1474 (34)	1915 (36)	1562 (45)	1573 (30)
R. sphaerocarpa				
pH (H_2O)				
C	7.7 (0.0)	8.1 (0.1)	8.0 (0.1)	7.7 (0.0)
R	7.8 (0.1)	7.9 (0.1)	7.9 (0.0)	7.7 (0.0)
EC (1:5, $\mu S\,cm^{-1}$)				
C	327 (3)	311 (5)	154 (6)	143 (0)
R	678 (60)	823 (46)	462 (35)	319 (10)
Total N ($g\,kg^{-1}$)				
C	0.7 (0.0)	1.3 (0.1)	1.1 (0.0)	1.0 (0.1)
R	1.2 (0.2)	2.0 (0.2)	2.4 (0.3)	2.2 (0.0)
Available P ($\mu g\,g^{-1}$)				
C	3 (0)	12 (3)	14 (3)	16 (1)
R	90 (5)	38 (4)	32 (3)	38 (1)
Extractable K ($\mu g\,g^{-1}$)				
C	702 (25)	544 (14)	520 (6)	414 (2)
R	1474 (34)	1446 (47)	1270 (22)	1444 (30)

Data in parenthesis indicate the standard error. C: control; R: composted residue addition; EC: electrical conductivity.

P, extractable K, total organic C, water soluble C and water soluble carbohydrates in rhizosphere soil of *P. lentiscus* and *R. sphaerocarpa* (Tables 2 and 3). Total N in rhizosphere soil of both shrub species increased with time in both non-amended and amended soil, although to a greater extent in the soil which received composted residue addition (Table 2). In general, assimilable nutrients (P and K) in rhizosphere soil of *P. lentiscus* and *R. sphaerocarpa* did not vary significantly with time (Table 2). Total organic C of rhizosphere soil of *P. lentiscus*, with or without composted residue addition, remained constant throughout the duration of the experiment (Table 3). Six months after planting, the concentrations of water soluble C and water soluble carbohydrates reached their highest values in the amended rhizosphere soil of *P. lentiscus*, decreasing significantly with time (Table 3). The concentration of water soluble C remained constant during the experiment with *R. sphaerocarpa*, whereas the concentration of water soluble carbohydrates, which is a subfraction of water soluble C, decreased in both the non-amended and amended soil, reaching negligible values at the end of the growth period.

Composted residue addition greatly increased the percentage of stable aggregates for rhizosphere soil of *P. lentiscus* and *R. sphaerocarpa* (Table 3). At all sampling dates, the increases in aggregate stability produced by the addition of composted residue were similar for both shrub species (on average, about 22% higher than control values). The highest increases in aggregate stability for rhizosphere soil of both shrub species, grown in the soil with or without addition of composted residue, were recorded one year after planting.

The bulk density of soil revegetated with *P. lentiscus* and *R. sphaerocarpa* was decreased by the addition of composted residue (Table 3). For both shrub species, bulk density of the soil, with or without composted residue addition, hardly varied with time.

Table 3
Evolution of carbon fractions and physical properties of rhizosphere soil of *P. lentiscus* and *R. sphaerocarpa* in response to composted residue addition ($n = 6$)

	Months			
	0	6	12	18
P. lentiscus				
Total organic C ($g\,kg^{-1}$)				
C	22.2 (0.2)	18.7 (0.5)	20.1 (0.7)	22.8 (0.3)
R	31.7 (0.4)	38.0 (0.7)	40.2 (0.9)	31.1 (0.8)
Water soluble C ($\mu g\,g^{-1}$)				
C	108 (2)	91 (2)	161 (3)	168 (1)
R	268 (6)	734 (10)	532 (8)	336 (7)
Water soluble CH ($\mu g\,g^{-1}$)				
C	14 (1)	10 (3)	4 (1)	1 (0)
R	29 (3)	47 (8)	25 (3)	17 (1)
Aggregate stability (%)				
C	44.5 (2.3)	36.2 (2.1)	59.2 (2.9)	43.5 (1.0)
R	53.5 (3.2)	44.9 (1.9)	69.2 (4.7)	55.1 (0.2)
Bulk density ($g\,cm^{-3}$)				
C	1.18 (0.01)	1.13 (0.01)	1.12 (0.00)	1.15 (0.01)
R	1.08 (0.02)	0.95 (0.02)	0.90 (0.01)	0.95 (0.02)
R. sphaerocarpa				
Total organic C ($g\,kg^{-1}$)				
C	22.2 (0.3)	21.6 (0.2)	20.8 (0.1)	21.4 (0.1)
R	31.7 (0.4)	39.5 (0.6)	35.4 (0.7)	26.7 (0.5)
Water soluble C ($\mu g\,g^{-1}$)				
C	108 (2)	80 (1)	110 (1)	178 (3)
R	268 (4)	274 (3)	285 (4)	266 (5)
Water soluble CH ($\mu g\,g^{-1}$)				
C	14 (1)	8 (2)	5 (0)	2 (0)
R	29 (4)	20 (1)	12 (1)	6 (0)
Aggregate stability (%)				
C	44.5 (2.8)	33.9 (4.1)	55.5 (2.9)	38.7 (0.4)
R	53.5 (2.6)	42.2 (2.9)	67.2 (4.7)	47.1 (0.5)
Bulk density ($g\,cm^{-3}$)				
C	1.18 (0.02)	1.18 (0.01)	1.14 (0.01)	1.17 (0.01)
R	1.08 (0.01)	1.03 (0.01)	1.04 (0.01)	1.09 (0.00)

Data in parenthesis indicate the standard error. C: control; R: composted residue addition; CH: carbohydrates.

3.2. Shoot and root biomass and foliar nutrient contents

Eighteen months after planting, the percentages of plant survival were about 90% for *P. lentiscus* and about 60% for *R. sphaerocarpa*, and there were no significant differences in mortality between plants grown in the

Table 4
Growth parameters and foliar nutrients of *P. lentiscus* and *R. sphaerocarpa* plants in response to composted residue addition 18 months after planting ($n = 6$)

	Shoot (g dw)	Root (g dw)	Root/shoot ratio	N ($mg\,plant^{-1}$)	P ($mg\,plant^{-1}$)	K ($mg\,plant^{-1}$)
P. lentiscus						
C	9.7 (0.7)	5.5 (0.5)	0.57 (0.05)	126 (13)	5 (1)	43 (3)
R	25.2 (1.1)	18.9 (1.7)	0.75 (0.08)	382 (24)	23 (1)	258 (12)
R. sphaerocarpa						
C	1.4 (0.1)	0.9 (0.1)	0.64 (0.01)	31 (3)	1 (0)	5 (0)
R	5.9 (0.5)	4.0 (0.4)	0.68 (0.01)	121 (13)	5 (0)	47 (5)

Data in parenthesis indicate the standard error. C: control; R: composted residue addition.

non-amended and the amended soil. The addition of composted organic residue to soil increased significantly the production of shoot biomass of *P. lentiscus* and *R. sphaerocarpa*, by about 160% and 320% respectively, compared to the controls (Table 4). Root biomass of *P. lentiscus* and *R. sphaerocarpa* was also greater for the amended soil than in the non-amended soil, but the addition of composted residue only increased the root/shoot ratio of *P. lentiscus*, relative to control plants.

As observed for the growth parameters, the N, P and K contents in shoot tissues of *P. lentiscus* and *R. sphaerocarpa* were increased significantly by composted residue addition (Table 4). The highest increases in foliar nutrients were recorded in *R. sphaerocarpa* plants, mainly in the foliar K content (about 840% higher than for control plants).

4. Discussion

This experiment showed that the addition of composted residue to soil can considerably improve the growth of *P. lentiscus* and *R. sphaerocarpa* in semiarid conditions. It is important to emphasise that composted residue addition was more effective for increasing the shoot biomass production of *R. sphaerocarpa* than that of *P. lentiscus*. This fact might be related to the differing physiological responses of the two shrub species during their establishment in an area where water is by far the most limiting resource for plant growth. The addition of composted residue increased the root/shoot ratio of *P. lentiscus* with respect to control plants, which may be considered a mechanism of drought tolerance (Lansac et al., 1995). However, shoot and root biomass of *R. sphaerocarpa* were increased in proportion, so that there was little net change in root/shoot ratio with the addition of composted residue. This woody legume has a deep root system, which is functional at depths of >25 m (Haase et al., 1996) and provides access to deep water sources, and is capable of resisting the frequent droughts of arid and semiarid zones.

Research published on the use of organic soil amendments in eroded soils shows that such amendments can improve soil productivity, increasing the soil nutrient status for several potentially limiting nutrients such as N, P and K (Cox et al., 2001). The fact that the highest contents of N, P and K in leaves occurred for *P. lentiscus* and *R. sphaerocarpa* seedlings grown in the amended soil demonstrated an increased root uptake of these nutrients, supplied by the composted residue. However, the benefits of organic amendments are due also to the improvement of soil physical characteristics, which in turn favours the establishment and viability of a stable plant cover (Roldán et al., 1996; Caravaca et al., 2002a). Such organic material has a cementing effect, due to the polysaccharides present (Lax and García-Orenes, 1993), and reactivates microbial populations (García et al., 2000; Borken et al., 2002). In our particular case, the addition of composted residue to soil produced a very significant increase in the levels of water soluble C and water soluble carbohydrates, which can be used as carbon and energy sources for soil microflora and may also have a structural function (Haynes and Swift, 1990). Reactivation of the microbial population leads to increased levels of bacteria, and particularly of fungal populations, which are principally responsible for the formation of aggregates larger than 0.2 mm (Lax et al., 1997; Andrade et al., 1998). Thus, the highest levels of stable aggregates for both shrub species, grown with or without addition of composted residue, were recorded after the autumn rainy season (in December 2000), when the highest microbial activity could be expected (Lax et al., 1997). On the other hand, Roldán et al. (1996) found that the restoration of soil structure may depend on the amount and nature of the organic matter added. Thus, the biological transformations that a compost undergoes in the waste treatment plant reduce the quantity of chemical aggregate-stabilising agents, such as polysaccharide or water soluble organic matter, and increase the number of carbon fractions more resistant to rapid decomposition (Pascual et al., 1999). This type of composted residue presumably can be less effective than uncomposted residue for improving soil structure (Caravaca et al., 2001). However, we have proved that the addition of composted residue significantly improved the structural stability of rhizosphere soil of *P. lentiscus* and *R. sphaerocarpa*. In addition, the use of composted residue leads to fewer problems related to toxic substances, which are eliminated during the composting process (Pascual et al., 1999).

The organic materials are less dense than the mineral fraction of soils and play an important role in improving soil structure. Thus, their application reduces the soil bulk density and leads to an increase in soil porosity, mainly involving the percentage of transmission and storage pores (Pagliai et al., 1981; Cox et al., 2001). In addition, the organic carbon of compost may affect the bulk density of a soil by improving its structural stability. This would explain the reduced bulk density measured in compost-amended soil. The decrease of soil bulk density can improve plant root growth and development, which in turn permits increased root penetration and exploration of a greater volume of soil. Thus, the combination of high fertility levels and low bulk density may also lead to the significantly enhanced shoot biomass of *P. lentiscus* and *R. sphaerocarpa* seedlings in the soil receiving compost.

In conclusion, the addition of a composted residue to soil was an effective preparation method for carrying out successful revegetation programs with *P. lentiscus* and *R. sphaerocarpa* in a degraded area under Mediterranean semiarid conditions. The beneficial effect of composted residue addition on the performance of afforested shrub species is based on the improvement of soil chemical and physical fertility.

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