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Abstract

The restoration of highly disturbed soils like those in abandoned quarries is a particularly difficult task in semiarid Mediterranean areas because of limitations in soil fertility and water availability. The addition of inorganic and organic amendments together with the selection of native plants is a key factor for success in edaphic and ecological soil restoration. The current study addresses the increase in the fertility of a semiarid bare soil from a quarry and the growth and survival of several native plant species (Olea europaea var. Sylvestris, Pistacia lentiscos, Rosmarinus officinalis, Quercus coccifera) through the addition of organic (compost derived from horticultural crop residues and poultry manure) and inorganic (three types of zeolites: mordenite, cliptonolite, and ZeoPro) amendments. Several combinations of the amendments (compost (C), zeolite ZeoPro (Z), mordenite zeolite plus compost (MZ+C), cliptonolite zeolite plus compost (CZ+C), and cliptonolite zeolite plus poultry manure (CZ+PM)) of different doses (5%, 10%, 20%, 30%) were analyzed. Most of the doses in all treatments increased the fertility of the soils (measured by macronutrients and organic matter content) to guarantee optimal rates of growth and survival of the different plant species, although cliptonolite zeolite and compost were the more successful treatments for the plants' development. These results are of great interest in the understanding of the interactions between physico-chemical soil parameters and plant performance in soil restoration.

Keywords	zeolite, compost, chicken manure, soil restoration, Mediterranean plants
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Improving the fertility of degraded soils from a limestone quarry with organic and inorganic amendments to support vegetation restoration with semiarid Mediterranean plants.

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Highlights:

- Soil amendments and native plant species are key to restoring fully degraded soils in quarries.
- Cliptonolite zeolite and horticultural waste compost best support species' development.
- Different percentages of amendments produce varying responses in plant growth.

ABSTRACT

The restoration of highly disturbed soils like those in abandoned quarries is a particularly difficult task in semiarid Mediterranean areas because of limitations in soil fertility and water availability. The addition of inorganic and organic amendments together with the selection of native plants is a key factor for success in edaphic and ecological soil restoration. The current study addresses the increase in the fertility of a semiarid bare soil from a quarry and the growth and survival of several native plant species (*Olea europaea var. Sylvestris*, *Pistacia lentiscos*, *Rosmarinus officinalis*, *Quercus coccifera*) through the addition of organic (compost derived from horticultural crop residues and poultry manure) and inorganic (three types of zeolites: mordenite, cliptonolite, and ZeoPro) amendments. Several combinations of the amendments (compost (C), zeolite ZeoPro (Z), mordenite zeolite plus compost (MZ+C), cliptonolite zeolite plus compost (CZ+C), and cliptonolite zeolite plus poultry manure (CZ+PM)) of different doses (5%, 10%, 20%, 30%) were analyzed. Most of the doses in all treatments increased the fertility of the soils (measured by macronutrients and organic matter content) to guarantee optimal rates of growth and survival of the different plant species, although cliptonolite zeolite and compost were the more successful treatments for the plants' development. These results are of great interest in the understanding of the interactions between physico-chemical soil parameters and plant performance in soil restoration.

Keywords: zeolite, compost, chicken manure, soil restoration, Mediterranean plants

1. Introduction

Soil is a critical component of the biosphere that is not naturally renewable on a human scale. The proper management of soil resources is thus vital to guarantee the functioning of ecosystems. Aggressive human activities such as mining have led to soil degradation and negative visual impacts on the landscape (Bradshaw and Chadwick, 1980; Gunn and Bailey, 1993; Sort and Alcañiz, 1996; Wall et al., 2015). The soil characteristics at the end of the extractive activities in a quarry are not usually suitable for the recovery of plant cover because of changes in the original physical, chemical, biochemical, and biological soil properties; nutrient loss; structural deterioration; and decreased water retention capacity (Luna et al., 2016a, 2016b, 2017). Legislation in many countries requires mining companies to minimize the negative impacts on the affected landscapes and to carry out ecological restoration to assist in the prompt restoration of degraded, damaged, or destroyed ecosystems to their original quality (Luna, 2016a).

Nevertheless, in disturbed drylands, some important ecological factors greatly limit the success of ecological restoration such as i) the absence of fertile soil containing essential nutrients for the development of plant coverage; ii) high water scarcity associated with low annual rainfall values (below 300 mm), high interannual variability, periods of water deficit longer than 6 months, and high evaporative demand; and iii) the need to select plants with special physiological characteristics to deal with the previous constraints.

Regarding the first issue, to develop fertile soil, it is crucial to ensure the success of ecological processes to sustain the colonizing vegetation (Bradshaw, 1997; Vilagrosa et al., 2003a). A strategical key to enhance the fertility of a substrate is the addition of organic amendments (sewage sludge, compost, manures, etc.), which also has implications for the improvement of physical soil properties such soil structure, structural stability of soil aggregates, porosity, and bulk density (Caravaca et al., 2002; Luna et al., 2016a, 2016b). Applying organic amendments in degraded soils is also a very effective way to ensure an immediate increase in water retention capacity and in turn the plant survival during the first critical months of development (Zancada et al., 2004). Chemical and microbiological soil properties are also improved, enriching soils with compounds similar to humic substances and essential macro- and micronutrients for plants (Doni et al., 2014; Mendoza-Hernández et al., 2014), which also stimulates the development and activity of soil microbial communities (Luna et al., 2016a; Macci et al., 2012; Ros et al., 2003; Tejada et al., 2006). However, adding organic amendments is not free of risks such as excessive salinization and increased electrical soil conductivity. High soluble salt levels in the soil can provoke plant drought stress, causing plant cells to dehydrate, plant stems to wilt, and roots to absorb salts, possibly in toxic amounts, which can lead to higher plant mortality rates (Ferreras et al., 2006; Morugán-Coronado et al., 2011). However, it has been observed that electrical soil conductivity decreases with time in soil restored with organic amendments by rainfall and nutrient uptake by the new vegetation (Bastida et al., 2007; Ros et al., 2003).

With respect to the second issue, in disturbed drylands, it is necessary to guarantee enough water for plant survival. In these unfavorable weather conditions, plants are subjected to high water stress (Di Castri, 1973; Kramer and Boyer, 1995), leading to generally high seedling mortality rates after planting (Vallejo and Alloza, 1998; Vilagrosa et al., 1997). Therefore, irrigation during plant establishment or during extremely dry periods (Jorba and Vallejo, 2008; Lovich and Bainbridge, 1999; Luna et al., 2016a; Rey-Benayas, 1998) and the use of mulches (organic, mineral, or synthetic materials) to increase infiltration and reduce soil evaporation (Mulumba and Lal, 2008) are often undertaken in ecological restoration in arid and semiarid zones. It has been shown, however, that not all mulches ensure adequate soil moisture. Those with fine texture decrease infiltration, whereas others, such as woodchip mulch, facilitate infiltration but limit the wetting front to just a few centimeters of the soil, provoking water scarcity (Luna et al., 2016a). Possible solutions to increase water retention capacity include using a variety of organic and inorganic materials including peat, coir, sand, and clays such as vermiculite, sepiolite (Chirino et al., 2011). “Zeolite” refers to a group of minerals belonging to the tectosilicate family, which boasts excellent water retention due to a) the molecular sieve action of its open channel network and b) its TO_4 tetrahedra (where T is an aluminum or silicon atom) composition linking with oxygen to share the negative charge created by the presence of

AlO_2 that in turn is balanced by cations neutralizing the charge deficiency (Gruener et al., 2003). As result, zeolites allow the adsorption and storage of water and nutrients and can increase cation exchange capacity (CEC). Moreover, in zeolites, unlike phyllosilicates, the exchange of water and nutrients hardly alters their structure (Boettinger and Ming, 2002), which favors the maintenance of undisturbed soil.

Finally, regarding the third issue, it is important to select the right plant species to increase the chance of success in soil restoration. Primarily native species should be considered because they are more adapted to the specific site conditions. If plants are not adapted, the consequences can include low initial survival, high mortality before reaching reproductive age, or maladaptation to the site, for example, through reduced growth rates, low competitiveness, and poor seed production (Thomas et al., 2014). As noted before, the addition of organic amendments can introduce toxic compounds (Mendoza-Hernández et al., 2014), which necessitates the use of tolerant plants. However, this problem can be alleviated by establishing irrigation that washes soluble salts away.

Given the main issues concerning the development of soils and vegetation cover on disturbed or newly formed soils in drylands, it is of great interest to test different combinations of soil amendments and drought-adapted plants to determine optimum soil restoration treatments. This article’s objective is to select optimal restoration treatments to increase the quality and fertility of highly degraded soils from a quarry in a semiarid area and facilitate the establishment of a stable vegetation cover in the shortest possible time. To this end, the following partial objectives were carried out: i) the design of several restoration treatments based on combinations of different types and doses of organic and inorganic amendments mixed with a highly degraded substrate from a limestone quarry in a semiarid zone, ii) analysis of the physical and chemical soil properties of the different treatments to determine changes in the soil quality and fertility, iii) the planting of different Mediterranean plants species in microcosms with the restored soils and determination of their survival rates and biovolume to identify species with optimal responses to the different combinations of the restoration treatments applied.

2. Material and methods

2.1 Field site and experimental design

Tests were designed and carried out at the Experimental Station Cajamar las Palmerillas in El Ejido, Almería, Spain (36.7934N, 2.7198W) in 2009.

The experimental design involved the creation of 252 microcosms with 48 replicates for each different treatment with soil amendments plus 12 controls without amendments. The microcosms consisted of 25 l pots with mixtures of bare soil from a limestone quarry and the following organic and inorganic amendments: i) compost processed with fresh waste material from horticultural crops in the area, ii) poultry manure mixed with sawdust from a chicken farm, iii) cliptonolite zeolite from a Turkish quarry, iv) modernite zeolite from a local quarry in Almería, Spain, and v) ZeoPro, a commercial cliptonolite zeolite cationically charged and with apatite added as a source of phosphorus. Because the texture of the soil substrate from the limestone quarry was heavy (38.50% clay content on average), it was slightly corrected by adding sand obtained from the same quarry.

The organic and inorganic amendments were used alone or combined in five different treatments: i) compost (C), ii) ZeoPro (Z), iii) mordenite zeolite plus compost (MZ+C), iv) cliptonolite zeolite plus compost (CZ+C), and v) cliptonolite zeolite plus poultry manure (CZ+PM).

Moreover, for each treatment, four different amendment volumes were also considered in the experimental design: 5% (L1), 10% (L2), 20% (L3), and 30% (L4). The resulting mixes for these levels were as follows:

i) Level 1 (5%). Treatments C and Z: 20 l bare soil, 3.75 l sand, and 1.25 l amendment. Treatments MZ+C, CZ+C, and CZ+PM: 20 l bare soil, 3.75 l sand, 0.85 l organic amendment, and 0.4 l inorganic amendment.
ii) Level 2 (10%). Treatments C and Z: 20 l bare soil, 2.5 l sand, and 2.5 l amendment. Treatments MZ+C, CZ+C, and CZ+PM: 20 l bare soil, 3.75 l sand, 1.7 l organic amendment, and 0.8 l inorganic amendment.
iii) Level 3 (20%). Treatments C and Z: 18 l bare soil, 2 l sand, and 5 l amendment. Treatments MZ+C, CZ+C, and CZ+PM: 18 l bare soil, 2 l sand, 3.4 l organic amendment, and 1.6 l inorganic amendment.
iv) Level 4 (30%). Treatments C and Z: 15.75 l bare soil, 1.75 l sand, and 7.5 l amendment. Treatments MZ+C, CZ+C, and CZ+PM: 15.75 l bare soil, 2 l sand, 5 l organic amendment, and 2.5 l inorganic amendment.

Four native bush-like plant species (*Olea europaea* L. *var*. *Sylvestris*, *Pistacia lentiscos* L., *Rosmarinus officinalis* L., and *Quercus coccifera* L.) were selected for the experiment. For each of the four plant species, three replicates for treatment and level were monitored. This required 240 plants, but three control replicates without any amendment were also studied for each plant species, for a total number of 252 plants (63 for each species). The selected plants are characterized by survival of the dry summers and cold winters of the Mediterranean climate, and they can live in poor soils, contributing with their important root systems a protective effect against erosion in an area where the risk of erosion caused by torrential rainfall is high. In January 2009, seedlings were germinated in a nursery, and 1 week after soil preparation in the microcosms, seedlings were transplanted from the nursery to the plant pots together with irrigation. Subsequently, the microcosms were settled in a plastic multilayer greenhouse 24.5 m in length and 16 m in width, accounting for a surface of 392 m^2, to protect the plants from extreme climatic events. During the experiment, the climatic conditions inside the greenhouse were as similar as possible to outdoor conditions, so that irrigation matched the rainfall recorded in the weather station of the Experimental Station Cajamar las Palmerillas (98 mm during the study period). The only difference from natural conditions was that when high-precipitation events occurred, the irrigation was fractionated to avoid oversaturation of the pots, and, in the summer, additional emergency irrigation was conducted when the evapotranspiration inside the greenhouse significantly exceeded that outside. The biovolume of the plants was measured 30, 105, 147, 218, and 295 days after planting, and their survival rates were assessed after 147, 218, and 295 days.

Humidity and temperature were monitored inside and outside the greenhouse. Humidity in the greenhouse was controlled using a system of nebulizers, and three lateral fans were used to control the temperature; in addition, one of the greenhouse's lateral facades was open. Precipitation was measured by an automatic station with a rain gauge with 0.1 mm precision. Irrigation was done using a series of self-compensating drippers with a flow rate of 3 l h^{-1}, with uniformity coefficients of 98%. The humidity of the substrates was monitored by ECHO2 probes and the relative air humidity by 4–20 mA probes. The air temperature was recorded with pt 100 probes. All these environmental parameters were measured every two seconds using an AMBITROL automatic data acquisition system.

2.2. Physical and chemical analyses

Bare substrate from the limestone quarry, the organic and inorganic amendments, and the resulting soils formed from the mixture were physico-chemically characterized. The pH and electrical conductivity (EC) were measured in a suspension solid-water 1:5 (weight/volume) with a pH and ion meter GLP 22+ and one EC-Meter Basic 30+ CRISON. Total nitrogen was determined by the Kjeldhal method (Bremmer and Mulvaney, 1982). Texture was determined by Robinson's pipette method. Particle density was measured with a pycnometer. Soil organic matter (SOM) was determined by oxidation with potassium dichromate by Walkey and Black's (1934) method. Available phosphorous was analyzed by the Burriel-Hernando (1974) method, which is suitable for soils with carbonate calcium content over 10%. Carbonate quantification was measured by back-titration using H_2SO_4 0.5N to dissolve $CaCO_3$ and NaOH 0.5N to measure the excess acid. Soil-exchangeable cations were extracted with ammonium acetate 1N (pH 7) (Soil Conservation Service, 1972). CEC was analyzed by saturation with sodium acetate 1N (pH 8.2) and later extraction with ammonium acetate. Cations and CEC were measured by atomic absorption with a 1100B Perkin Elmer spectrophotometer. Chloride anions were measured through a titration reaction after precipitation with silver nitrate (Mohr, 1856). Nitrate and sulphate content were measured by spectrometry in acid media (sulphate after precipitation with Barium chloride) using a Helios Omega spectrometer.

2.3. Statistical analyses

To evaluate the treatment with amendments supporting the greatest development of each plant species, linear mixed models (LMMs) were applied using the "nlme" (Piñeiro et al., 2009) and "lme4" (Bates and Sarkar, 2007) libraries in R 3.0.2-. The plants' biovolume was set as the response variable and the type of treatment as the explanatory variable. Treatments with a considerable number of deaths (> 33%) were discarded. After the best treatment was selected, an ANOVA and an LSD Fisher test were performed to check for significant differences between different levels using the "stats" and "agricolae" (Mendiburu, 2019) libraries in R 3.0.2-. To select the ideal level of the treatment, we chose the treatment that produced the greatest plant growth during the study period. The mean biovolume value of the plants for each level could not be considered the more relevant parameter because the plants could decrease in size at the end of the period, or other plants could have a slower but ultimately more sustainable growth. That is why the geometric growth rate (equation 1) of plants by level of amendments was also analyzed to select the most appropriate dose.

Equation 1: Geometric growth rate

$$\gamma = \left(\frac{Xn}{Xo}\right)^{\frac{1}{n}} - 1$$

γ: Geometric growth rate; Xn: final value; Xo: initial value, n: number of periods (days)

3. Results and discussion

3.1. Characterization of bare substrate from the limestone quarry and organic and inorganic amendments

Soils with a high clay fraction and SOM content have a higher CEC, which represents the soil's total capacity to hold exchangeable cations and is related to soil fertility. CEC influences the soil's ability to hold essential nutrients and provides a buffer against soil acidification (Bache, 1984). The bare soil at the limestone quarry showed very low soil fertility, with SOM content of 0.5 ± 0.2% and a CEC value of 4.61 (cmol(+) kg^{-1}). Moreover, the macronutrient content (N, P, K, Ca, Mg) were low (Table 1). The high carbonate content (26.5 ± 4.6%) resulted in basic pH (8.61 ± 0.07), which could produce insolubility of the plant nutrients. Salt content was not high (EC = 1.19 ± 0.16 dScm^{-1}), and the soil texture was clay-loam (35.65% ± 1.20 clay, 25.85% ± 17.88 sand, 38.5% ± 19.09 silt).

Inorganic amendments (zeolites) must mainly improve soil fertility by increasing the CEC because this parameter ranged between 157 and 190 (cmol(+) kg^{-1}) for the different zeolite types (Table 2). However, the mordenite zeolite content in Na$^+$ (210.49 cmol(+) kg^{-1}) and Cl$^-$ (289.98 cmol(+) kg^{-1}) was high, which could increase the salinity of the resulting soils, causing a dispersing effect in the soil and damaging the formation of soil structure and stable soil aggregates. Clinoptilolite zeolite can also influence the adsorption of ammonia (Bernal, 1993), so clinoptilolite could be very effective to trap the ammonia lost during the composting process. ZeoPro zeolite stands out especially for the highest CEC (190 cmol(+) kg^{-1}) among all the zeolites, but it also showed the highest values of K$^+$ (11.15 cmol(+) kg^{-1}) (Table 2).

Organic amendments promote soil fertility, increasing organic matter content and providing essential nutrients for plants such as nitrogen and phosphorus, which in turn improve the activity and size of the soil microbial communities, stimulating the biochemical cycles of the restored soil (Bastida et al., 2008, 2012; Vilagrosa et al., 2016a, 2016b). The results showed that the chicken manure amendment had lower OM values (44.08 ± 4.70%) than the compost amendments (54.24 ± 7.69%) (Table 3). The chicken manure contained sawdust, used as an absorbent on chicken farms, and it is not easily oxidable and quantified. Water content was also higher in the compost than in the chicken manure (Table 3), possibly because of the higher OM content in the compost, suggesting that the application of this amendment to degraded soils could guarantee an immediate increase in soil water retention capacity (Zancada et al., 2004), which is a handicap in arid zones because of its climatic peculiarities. The pH values were similar for the two amendment types, but EC was three times higher in the chicken manure (19 ± 2.81 dS cm^{-1}). The application of this amendment could contribute to salinity problems in soils and possible problems of plant toxicity. The C/N ratio was almost three times higher in the compost than in the chicken manure (Table 3), with values of 18.34 ± 2.84. Values between 15 and 20 denote a compost of good quality and a balance between mineralization and humification

(Kayhanian and Tehobanoglous, 1993). Thus, the application of a compost amendment to a degraded soil could provide greater soil fertility than a chicken manure amendment.

3.2. Characterization of amended soils

Amended soils resulted from the mixes among bare soils from the quarry and organic and inorganic amendments as described in section 2.2. All treatments except the ZeoPro treatment (only an inorganic amendment) increased the SOM content in the amended soils, especially those with compost (Table 4). From 0.5% SOM in the bare soil, the contents increased to values from 1.15% (5% amendments) to 6.6% (30% amendments) (Table 4). All these values exceed the fertility requirements for the native plants considered in these experiments, so this parameter was not a limiting factor for plant survival (Motsara and Roy, 2008).

Treatments with organic amendments and zeolites produced a high and significant increase in the CEC. Natural soils with a medium particle size composition are usually characterized by CEC values around 15 to 40 cmol(+) kg^{-1} (Fernández et al., 2014), and this range was achieved in all treatment levels except for the treatment with the 5% ZeoPro mineral amendment, although the CEC values were in the above-mentioned range at the 10% level. Additionally, organic inputs, especially compost, were very effective in increasing soil fertility, with CEC values up to 55 cmol(+) kg^{-1} (Table 4).

The most frequently studied exchangeable cations are base cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}). The high content of carbonates coming from the soil substrate caused Ca^{2+} to be the dominant base in bare substrate, although the content was low (1.11±0.15 cmol(+) kg^{-1}), possibly because of its low CEC. As noted before, amendments increased the CEC in the studied soils, which permitted Ca^{2+} retained in the exchange complex to increase substantially. In relation to the plant requirements of this cation, for all treatments and levels, the content was high (> 6 (cmol(+) kg^{-1}), according to the values reported by Fernández et al. (2014), except for ZeoPro at the 5% and 10% levels. The Mg^{2+} cation also increased in the exchange complex in the amended soils, although the increments were not as important as with calcium (Tables 1 and 4). In the case of the MZ+C treatment, the Mg^{2+} content was also reduced when the level of amendment increased (Table 4). Except for the 5% level of the zeolite amendment, Mg^{2+} values were higher than 1.5 cmol(+) kg^{-1} in all treatments, suggesting an adequate value with respect to plant fertility for this element (Fernández et al., 2014). Regarding the Na^{+} content, the amendments did not produce important increases of this cation in the exchange complex; even though the case of mordenite zeolite had a striking Na^{+} value of 210 cmol(+) kg^{-1}. This suggests that the sodium was in the form of soluble salts that could be washed away with irrigation. Then, the Na^{+} content in amended soils did not exceed the values considered adequate (< 1 cmol(+) kg^{-1}; Fernández et al., 2014) except for the MZ+C and ZeoPro treatments at the 30% amendment level. Finally, K^{+} increased in all treatments proportionally to the concentration level, up to five times the value of substrate soil from 0.70 to 3.75 cmol(+) kg^{-1}) (Table 4). In any case, the content suggested in the literature for this macronutrient (> 0.5 cmol(+) kg^{-1}, Fernández et al., 2014) was exceeded in all treatments and levels.

The calcium carbonate equivalent content (%$CaCO_3$) increased only slightly with the amendments up to an average value of 27.53 ± 4.77% (26.50 ± 4.62% on bare substrate). Although carbonates exert a positive action on soil structure, promoting the formation of stable aggregates because of their cementing action, as well as on the activity of microorganisms (Miralles, 2007), these high $CaCO_3$ values produce alkaline soils that can cause nutritional problems in plants because of the insolubility of nutrients. Then, all amended soils exhibited basic pH (ranging between 8.06 and 8.70), with the lowest values corresponding to the treatments with higher inputs of organic amendments.

Soil nutrients such as potassium, ammonium, and nitric salts could be solubilized at a basic pH, but the availability of phosphorus may be greatly reduced because it would be in the form of insolubilized phosphates of Fe, Ca, or Al (Jensen, 2010). To increase the values of phosphorus available for plants, mordenite ZeoPro (Z) was used because it incorporates apatite as a source of phosphorus. However, soils amended with this zeolite did not show increased levels of this soil nutrient. Indeed, the available phosphorus values were the lowest of all the treatments, suggesting a more important role for organic amendments as P fertilizer. Between organic amendments, chicken manure was more effective in increasing soil P than the compost, although at 10% concentrations of these amendments, phosphorus levels (> 1 cmol(+) kg^{-1}) were already adequate for successful plant development (Fernandez et al., 2014).

In relation to macronutrients, Ca and Mg are more assimilable at high pH, but very little of micronutrients such as Fe, Mn, Cu, and Zn will be available to plants (Donahue et al., 1977), but this can be alleviated by supplying organic amendments. However, these amendments could increase the salinity in soils (Reddy and Chron, 2012), which could be especially problematic in arid and semiarid zones, where soils are particularly vulnerable to the problem of soil degradation, leading to a serious advance desertification in these regions (Jabbar and Chen, 2008). Compost of horticultural waste tends to have high K^+ content (Mendoza-Hernandez et al., 2014). Our results showed that EC was high (6.37 ± 2.26 dS/cm) in the compost and very high (19.08 ± 2.81 dS/cm) in the chicken manure. Moreover, mordenite zeolite also contained large amounts of Na^+ and Cl^- (210 and 290 cmol (+) kg^{-1}, respectively). However, it was striking that higher concentrations of compost and mordenite resulted in slightly saline soils (> 2 dS/m) (20% amendment) to saline soils (> 4 dS/m) (30% amendment) (Table 4), whereas the ZeoPro and chicken manure amendments did not result in saline soils, suggesting that salts on the amendments could be easily washed away and controlled using irrigation.

To correct the clayey texture of the bare substrates, inputs of sand were added in all the treatments. Then, on average, the texture of amended soils (36.31 ± 0.78% clay, 36.67 ± 6.19% sand, 27.01 ± 7.42% silt) resulted in an increase of the sand fraction and a decrease in silt. Among all levels, the mean proportion of sand increased from 33.70% (5% amendment) to 40.52% (30% amendment) (Table 4). Despite the sand input, soils were still classified as clay loam characterized as heavy soils with high bulk density. Though clays promote nutrient retention, increasing the CEC, the texture can cause poor drainage in soils and reduce their infiltration capacity, promoting water erosion processes and loss of nutrients. In the arid and semiarid Mediterranean areas, these soil degradation problems are especially important because of the climatic peculiarities and the torrential character of rainfall (Miralles et al., 2009). Moreover, another problem that could result from the texture is the formation of dense clods when the clay contracts when soils are drying, limiting root development. Nevertheless, the soil structure could be improved with increased SOM content because of the organic amendments, which promote the formation of a structure with a balanced volume of micro- and macropores, facilitating drainage and infiltration in the soil (Miralles et al., 2009).

3.3. Selection of the best treatments and doses for the growth and survival of the Mediterranean plants

The selection of the amended soils that promoted better development in the different plant species was based on biovolume measurements (Table 5) and the survival rates along the study period. According to LMM analyses (Table 6), the best treatments were CZ+C for *Pistacia lentiscus* (1/12) and *Quercus coccifera* (1/12), MZ+C for *Olea europaea var. Sylvestris* (0/12), and Z for *Rosmarinus officinalis* (5/12). Numbers between brackets indicate the number of plants that died as well as the total number of plants per treatment (n = 12). In the case of *Rosmarinus* *officinalis*, the number was nearly half, so this treatment was discarded, and the next best treatment proposed by the LMM, CZ+PM (0/12), was considered.

ANOVA analyses (Table 7) showed that the best treatment selected for the development of *Quercus coccifera* did not show significant differences between the different dose levels. In contrast, the rest of the selected optimal treatments for each type of plant species showed significant differences between some of their dose levels (Table 7). The best treatment for *Pistacia lentiscus* (CZ+C) was significantly different between the 10% dose level and the other levels, whereas the optimal treatment selected for *Olea europaea* (MZ+C) differed significantly between the 20% dose and the other doses (Table 7). The optimal treatment for *Rosmarinus officinalis* (CZ+PM) presented a greater number of significant differences among all dose levels.

Though the mean biovolume value (Table 7) along the study period could be a good indicator to discern the best amendment level, some plants decreased in freightage during the summer and did not recover afterward (Figure 1). Therefore, the geometric growth rate (equation 1, section 2.4) along the study period was also used to determine the best treatment level for each plant species (Table 8).

Pistacia lentiscus obtained the highest mean biovolume (4941 ± 418 cm^3) in soils with a 10% amendment of cliptonolite zeolite and compost (10% CZ+C) (Table 6). However, these plants at this level of treatment grew very fast during the spring, but during the summer had an important decay, and they did not exhibit a good recovery afterward. Therefore, considering the growth rate of *Pistacia lentiscus*, the best amendment level was 20% (0.40%day^{-1} across the whole study period) (Table 8). Along the different seasons, the plants experienced important growth (1.11%/day^{-1}) after planting in winter, but during the spring and summer, the growth was low (0.19–0.33%/day) or even negative (-0.30%/day^{-1}) (Table 8, Figure 1.a). During autumn, when rains are more frequent, the plants exhibited a good growth rate (1.30%/day^{-1}), suggesting that these species suffered hydric stress during summer and lost some of the leaves on secondary branches, but they coped and recovered the growth when water was again available. It has previously been shown that this species is very resistant to the summer drought typical of the Mediterranean climate because of low osmotic potential and reduced transpiration rates, partly because of the presence of thick leaf cuticles (Zohary, 1962). Other authors (Trubat et al., 2006; Vilagrosa et al., 2003a, b) have considered *P. lentiscus* a drought-resistant species because under drought conditions, this species reduces its stomatal conductance and displays a water-saving mechanism.

In the case of *Olea europaea*, the 20% level of mordenite zeolite plus compost (20% MZ+C) was the soil amendment that obtained the highest mean biovolume value (7071 ± 419 cm^3) (Table 7) and the best growth rates (2.05 ± 0.08%/day^{-1}) (Table 8). This species was the one that obtained the higher freightage of all the species involved in this study, reaching values of 24,277 ± 4094 cm^3 by the end of the study period. However, initially, the biovolumes of the seedlings were the lowest, and they experienced growth rates of 7.62 ± 1.07%/day^{-1} after planting (Table 8, Figure 1.b). At the beginning of the spring, the growth was not so strong (~ 1%/day^{-1}), but as the spring progressed, it increased considerably (3.73 ± 1.03%/day^{-1}). After that period, the growth of *O. europaea* was again around 1%/day^{-1} during summer and autumn (Figure 1.b). This species showed no plant mortality and grew throughout the monitoring period, which denotes an extremely good adaptation to the semiarid Mediterranean, as Olivera et al. (2011) reported in a long-term study (eight years) of a revegetated area in a limestone quarry. The high rates of survival of this plant species result from adaptation strategies developed against stress conditions that prevail in arid and semiarid areas. Regarding these adaptation strategies, Sofo et al. (2007) described how olive plants subjected to water deficit lower the water content and water potential of their tissues, establishing a particularly high potential gradient between the leaves and roots, and they stop canopy growth but not photosynthetic activity and transpiration. This allows the continuous production of assimilates as well as their accumulation in the various plant parts even during the drought season. Padilla and Pugnaire (2007) observed how the roots of seedlings of this species grew vertically and none spread horizontally, developing root systems that penetrate into deeper, more reliable water sources.

The best soil treatment that supported *Quercus coccifera* was the 30% level of cliptonolite zeolite plus compost (CZ+C) (Table 6) because it allowed the higher growth rates (0.76 ± 0.14%/day^{-1}) of this species (Table 8). However, this species showed a particular behavior because during favorable weather conditions at the beginning of the spring, the growth was even negative, but during summer and autumn, the growth rate increased continuously (1.82 ± 0.93/day^{-1}) (Figure 1.c). This could be explained by the physiology of this plant because it is a sclerophyllous resprouter that can increase biomass allocation belowground, enlarging its root capacity (Trabot et al., 2011) and developing a high nutrient and water absorption capacity during extreme droughts (Larchevêque et al., 2010). This ability to access deep underground water, together with sclerophyllous leaves, which limit water losses through leaf transpiration, gives a special adaptative advantage to this plant, permitting its development during the drought season.

The best soil amendment for *Rossamarinus officinalis* was 30% CZ+PM (cliptonolite zeolite plus poultry manure) promoting the positive growth rates of the plants throughout the study period, except in summer (Table 8, Figure 1.d). This could be because the soils enriched with this amendment showed the highest P content (3.11 ± 0.75 cmol(+) kg^{-1}), which according to Sardans et al. (2005) has the largest positive effect on the growth of this species in calcareous environments because of the P fertilization because basic soils promote the strong immobilization of calcareous phosphates. The growth limitation during summer can be explained by the fact that the *R. officinalis* root system is short and cannot access deep water during drought periods (Gratani and Varone, 2004b).

4. Conclusions

Bare substrate from a limestone quarry in a semiarid Mediterranean area showed poor fertility parameters for SOM (0.50 ± 0.20%) and CEC (4.61 ± 0.90 (cmol(+)kg^{-1}), together with high carbonate content (26.50 ± 4.62%) that results in a basic pH that can produce nutrient insolubility. A combination of inorganic (zeolites) and organic amendments (compost of horticultural crop residues and poultry manure) substantially improved the fertility of the bare soil, reaching maximum values of 6.6% (SOM) and 55 cmol(+)kg^{-1} (CEC), without a particular increase in the average carbonate content.

ZeoPro was used without organic amendments to check its properties as a source of P. However organic amendments resulted in better fertilizers for this nutrient. Mordenite and compost could produce salinization because of their high Na^+, Cl^-, and K^+ content. However, only soils with higher concentrations of compost and mordenite resulted in slightly saline soils to saline soils, suggesting that most of the salts can be washed away through irrigation.

Based on growth and survival rates, the best treatments were CZ+C for *Pistacia lentiscus* (20% level) and *Quercus coccifera* (30% level), MZ+C for *Olea europaea var. Sylvestris* (20% level), and CZ+PM for *Rosmarinus officinalis* (30% level). These results showed that cliptonolite zeolite and compost provided inorganic and organic amendments that better supported the development of the Mediterranean semiarid species studied.

With these treatments and levels, selected seedlings of all species experienced important growth after planting in winter and late spring, except *R. officinalis*, which grew more at the end of winter and the beginning of spring. During summer, *O. europaea* and *Q. coccifera* were able to maintain positive growing rates, whereas *P. lentiscus* and *R. officinalis* lost their freightage. This denotes different strategies to deal with summer drought in the Mediterranean climate. Finally, all species showed important growth rates in autumn, when the wet season starts.

However, we found that other treatments and levels did not show good results with respect to the growth and survival of the species studied, especially because plants were unable to recover after the summer drought. This shows the need for ecological restorations to ensure the appropriate physico-chemical and fertility properties of degraded or newly formed soils through the addition of inorganic and organic amendments in appropriate quantities.

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Figure 1.

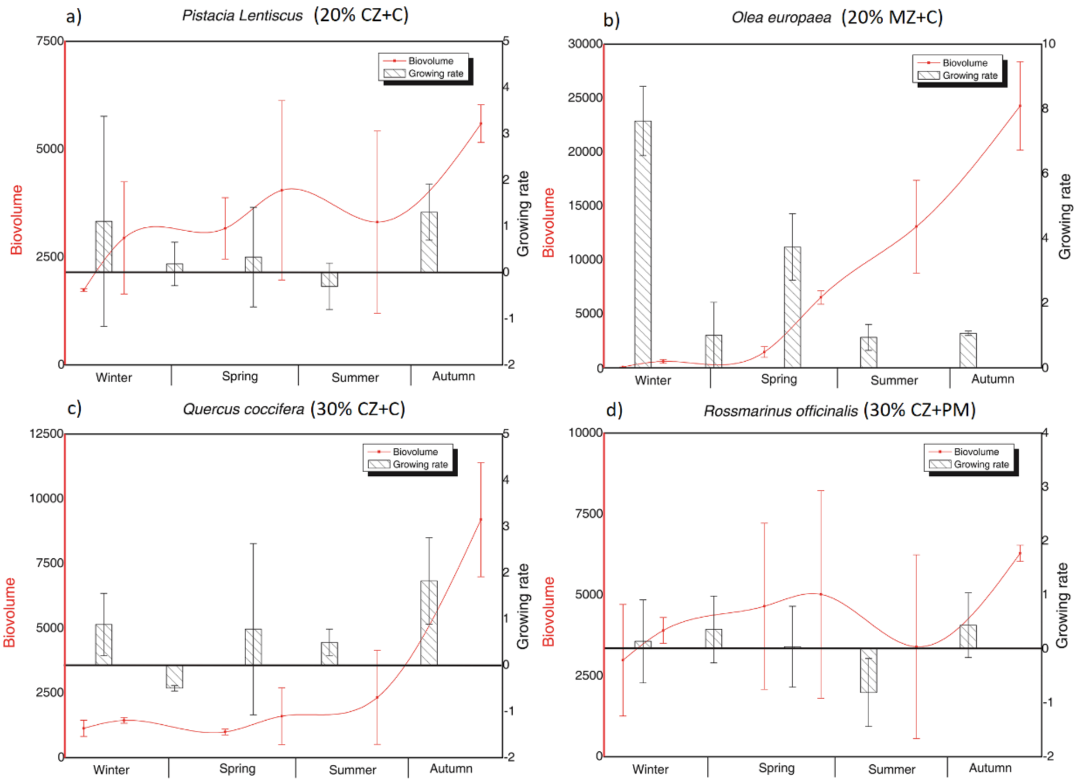

a) *Pistacia Lentiscus* (20% CZ+C)
b) *Olea europaea* (20% MZ+C)
c) *Quercus coccifera* (30% CZ+C)
d) *Rossmarinus officinalis* (30% CZ+PM)
Biovolume
Growing rate
Winter
Spring
Summer
Autumn
7500
5000
2500
0
30000
25000
20000
15000
10000
12500
5
4
3
2
1
0
-1
-2
10
8
6

Figure 1. Best treatments of and levels of amendments for the evolution of the growth of plants along the study period.

Red line represents mean biovolume of plants (cm^3). Columns show geometric growing rates (% day^{-1}) between two consecutive biovolume measurements. Error bars are determined by one standard deviation.

Table 1. Physical-chemical characterization of bare substrate in a limestone quarry.

Parameters	**Bare soil**
% SOM	0.50±0.20
$CaCO_3$ %	26.50±4.62
pH	8.61±0.07
EC (dS/cm)	1.19±0.16
P_2O_5 (cmol(+) kg^{-1})	0.72±0.26
NO_3^- (cmol(+) kg^{-1})	1.65±0.83
Na^+ (cmol(+) kg^{-1})	0.08±0.01
K^+ (cmol(+) kg^{-1})	0.71±0.22
Ca^{2+} (cmol(+) kg^{-1})	1.11±0.15
Mg^{2+} (cmol(+) kg^{-1})	0.32±0.08
CEC (cmol(+) kg^{-1})	4.61±0.90
% sand	35.65±1.20
% silt	25.85±17.88
% clay	38.50±19.09

SOM: Soil Organic Matter, $CaCO_3$%: Calcium Carbonate equivalent, EC: Electrical conductivity, CEC: Cation exchange capacity. Mean values ± standar deviation (n = 6)

Table 2. Physical-chemical characterization of inorganic amendments (zeolites).

Inorganic amendments (Zeolites)	**pH**	**EC (dS/cm)**	**Soluble cations (cmol(+) kg^{-1})**				**Soluble anions (cmol(+) kg^{-1})**			**CEC (cmol(+) kg^{-1})**	**ESP (%)**	**SAR**
			Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	NO_3^-			
Clinoptilolite	8.86±0.05	0.19±0.09	5.46±0.35	2.44±0.15	3.99±0.08	0.99±0.04	6.64±0.45	7.61±0.66	0	170±28.28	0.01±0.00	0.86±0.04
Mordenite	8.72±0.03	2.23±0.08	210.49±8.96	3.91±0.26	4.73±0.09	4.96±0.04	289.98±20.12	82.50±5.12	0	157±24.75	29.38±5.45	20.57±2.35
ZeoPro	7.88±0.04	1.44±0.09	2.89±0.37	11.15±0.05	4.74±0.08	4.86±0.05	1.29±0.09	0.39±0.05	0	190±22.75	0.36±0.10	1.1±0.03

EC: Electrical conductivity, CEC: Cation exchange capacity, ESP: Exchangeable Sodium Percentage, SAR: sodium adsorption ratio. Mean values ± standard deviation (n=6)

Table 3. Physical-chemical characterization of organic amendments.

Organic amendments	**WC (%)**	**pH**	**EC (dS cm^{-1})**	**OM (%)**	**N (%)**	**C/N**	**P_2O_5 (%)**	**K_2O (%)**	**Ca (%)**	**Na (%)**
Compost	54.24 ± 7.69	8.02 ± 0.22	6.37 ± 2.26	59.15 ± 11.2	1.87 ± 0.82	18.34 ± 2.84	0.85 ± 0.35	2.51 ± 1.52	6.7 ± 1.6	0.31 ± 0.03
Chicken manure	44.08 ± 4.7	7.82 ± 1.25	19.08 ± 2.81	40.00 ± 5.25	1.23 ± 0.75	5.70 ± 2.1	0.43 ± 0.15	1.55 ± 0.50	7.8 ± 1.2	0.26 ± 0.05

WC: Water content; EC: Electrical conductivity, OM: Organic matter. Mean values ± standard deviation (n=6)

Table 4. Characterization of bare and amended soils.

Treatments	Parameters	SOM (%)	$CaCO_3$ (%)	pH	EC (dS/cm)	P_2O_5 (cmol(+) kg^{-1})	NO_3^- (cmol(+) kg^{-1})	Na^+ (cmol(+) kg^{-1})	K^+ (cmol(+) kg^{-1})	Ca^{2+} (cmol(+) kg^{-1})	Mg^{2+} (cmol(+) kg^{-1})	CEC. (cmol(+) kg^{-1})	% sand	% silt	% clay
	Bare soil	0.50±0.20	26.50±4.62	8.61±0.07	1.19±0.16	0.72±0.26	1.65±0.83	0.08±0.01	0.71±0.22	1.10±0.15	0.32±0.08	4.61±0.90	35.65±1.20	25.85±17.88	38.50±19.09
MZ+C	5%	1.86±0.60	29.72±4.83	8.55±0.07	1.00±0.16	0.46±0.17	4.45±0.91	1.23±0.15	0.61±0.22	11.4±0.22	2.69±0.45	34.25±2.30	39.00±2.30	24.99±3.50	36.00±5.40
	10%	2.41±0.23	28.75±4.52	8.41±0.09	1.76±0.36	1.08±0.38	25.11±4.77	1.17±0.05	1.38±0.05	18.60±0.62	2.94±0.37	45.64±1.20	27.74±3.88	37.50±3.53	34.75±0.35
	20%	4.06±0.76	26.01±4.70	8.26±0.11	2.67±0.29	1.9±0.33	27.34±6.26	1.30±0.25	2.50±0.35	20.10±0.65	3.10±0.49	50.20±1.50	36.75±9.54	27.49±10.60	35.75±1.06
	30%	4.76±1.81	23.40±4.76	8.14±0.06	3.64±0.47	2.63±0.19	37.54±4.58	1.45±0.05	3.45±0.05	21.15±0.75	3.43±0.37	54.07±1.35	37.75±6.71	24.99±7.07	37.25±0.35
CZ+C	5%	1.83±0.29	32.11±4.31	8.54±0.07	0.94±0.12	0.53±0.1	3.71±0.25	0.35±0.45	0.87±0.36	16.85±0.55	2.45±0.32	39.82±0.40	39.00±1.20	24.99±2.80	36.00±6.10
	10%	2.26±0.48	26.67±4.62	8.43±0.07	1.10±0.14	1.1±0.17	6.93±0.15	0.27±0.06	1.15±0.05	17.75±0.72	2.07±0.48	41.07±0.30	36.50±2.12	27.49±3.53	36.00±1.41
	20%	4.18±0.65	27.35±4.80	8.19±0.06	2.34±0.24	1.29±2.2	25.91±3.34	0.21±0.32	1.36±0.11	19.3±1.15	1.85±0.49	43.87±0.20	43.49±0.70	20.00±0.90	36.50±0.70
	30%	5.52±0.05	23.67±4.72	8.06±0.04	3.27±0.33	2.61±0.64	36.29±5.97	0.23±0.60	2.20±0.02	20.6±0.56	1.75±0.17	47.14±0.20	40.25±3.88	22.49±3.53	37.25±0.35
C	5%	1.72±0.10	23.32±5.15	8.57±0.04	0.84±0.07	0.67±0.18	2.42±0.35	0.16±0.03	0.95±0.06	11.6±0.61	1.63±0.32	27.57±0.17	24.24±13.08	40.00±14.14	35.75±1.06
	10%	2.60±0.47	29.54±4.90	8.47±0.06	1.32±0.25	1.08±0.33	2.90±0.26	0.23±0.04	1.48±0.03	19.8±0.48	2.06±0.07	45.43±0.20	38.74±0.35	25.00±1.57	36.25±0.35
	20%	4.98±0.61	25.08±5.12	8.28±0.06	2.27±0.61	1.91±0.33	29.26±5.80	0.49±0.96	3.50±0.65	21±1.18	3.39±0.56	52.78±0.50	36.24±10.25	27.50±10.60	36.25±0.35
	30%	6.58±0.68	32.28±4.45	8.15±0.06	4.10±0.46	2.63±0.19	38.90±7.75	0.95±0.05	3.75±0.05	22±0.62	3.40±0.37	55.50±10	37.37±1.59	26.25±1.76	36.37±0.17
CZ+PM	5%	1.16±0.17	25.80±4.59	8.70±0.06	0.44±0.05	0.65±0.21	3.39±0.18	0.26±0.08	0.85±0.12	7.625±0.42	1.75±0.17	19.86±0.5	38.99±7.07	25.00±7.07	360±3.20
	10%	1.62±0.34	33.50±4.68	8.44±0.03	0.69±0.06	1.17±0.22	4.52±0.65	0.34±0.04	0.97±0.05	10.15±0.67	2.28±0.49	26.18±0.40	36.75±3.18	27.49±3.53	35.75±0.35
	20%	1.62±0.34	33.36±5.26	8.17±0.13	0.69±0.06	1.17±0.22	11.61±0.94	0.90±0.05	1.70±0.06	13.7±1.06	2.82±0.50	26.18±0.40	41.00±2.82	22.49±3.53	36.50±0.70
	30%	3.09±0.29	24.32±4.87	8.09±0.09	1.15±0.14	3.11±0.75	19.03±0.96	1.03±0.23	1.85±0.56	16.7±0.82	2.95±0.33	42.18±0.95	40.24±9.54	22.5±10.6	37.25±1.06
Z	5%	1.01±0.13	22.78±5.47	8.71±0.08	0.43±0.05	0.23±0.34	0.97±0.20	0.32±0.05	0.94±0.05	2.175±0.62	0.75±0.37	7.11±0.97	33.49±2.10	30.00±2.30	36.50±4.80
	10%	0.91±0.11	25.08±4.52	8.70±0.09	0.43±0.05	0.2±0.02	3.06±0.15	0.46±0.04	1.10±0.06	4.85±0.57	1.82±0.34	14.91±1.10	28.74±0.35	35.00±2.10	36.25±0.35
	20%	1.06±0.30	30.79±4.62	8.54±0.06	0.45±0.07	0.17±0.05	14.52±1.25	0.87±0.05	2.05±0.05	13.85±0.62	2.01±0.37	34.85±1.23	28.49±1.50	35.00±2.30	36.50±4.20
	30%	0.69±0.08	27.14±4.54	8.46±0.05	0.54±0.09	0.13±0.1	6.29±0.38	1.33±0.10	3.06±0.15	19±0.94	2.51±0.27	47.41±1.30	46.90±5.65	15.50±6.36	37.50±0.70

SOM: Soil organic matter, EC: Electrical conductivity, CEC: Cation exchange capacity. Mean values ± standard deviation (n=3)

Table 5. Biovolume values (cm3) of plants along the study period on the different treatments and levels of amended soils.

DAP	***Olea europaea***				***Pistacia lentiscus***				***Quercus coccifera***				***Rosmarinus officinalis***			
	MZ+C				**CZ+C**				**CZ+C**				**CZ+PM**			
	5%	**10%**	**20%**	**30%**	**5%**	**10%**	**20%**	**30%**	**5%**	**10%**	**20%**	**30%**	**5%**	**10%**	**20%**	**30%**
0	66±8	62±10	62±3	62±9	2929±1123	2234±954	1735±34	4011±206	2485±1647	1439±131	1563±658	1135±315	2609±880	2494±639	3333±550	2981±1726
30	1546±812	1689±423	592±171	514±498	2112±836	6463±1481	2945±1299	2493±396	2592±1976	973±332	1834±619	1441±107	5890±877	3007±433	3134±904	3902±400
105	1956±1532	1718±705	1464±504	1969±895	2776±876	5914±2006	3167±709	3088±613	3019±1638	2215±1668	1320±491	993±113	4787±1040	3051±572	3494±1985	4649±2567
147	1942±192	1899±131	6519±623	1667±581	3076±1702	6280±2121	4049±2077	4410±1607	2189±1400	1711±616	1883±728	1599±1098	6684±1002	3568±1035	1849±393	5016±3207
218	1927±848	2937±635	13086±4308	4400±4379	3074±1531	3252±1538	3310±2112	3099±1054	2152±1565	749±154	2282±1753	2327±1815	6034±1916	2861±3486	1116±54	3400±2841
295	2669±543	4624±873	24277±4094	5013±1188	2936±2846	3592±526	5593±437	5398±1664	1061±86	973±786	5974±7242	9193±2204	4832±4089	2692±2359	2851±1532	6288±251

DAP: Days after plantation

Table 6. Linear mixed model (LMM) parameters, based on biovolume values of plants, for the selection of the best treatment for amended soils.

Treatment	***Pistacia Lentiscus***		***Olea europaea***		***Quercus coccifera***		***Rosamarinus officinalis***	
	Estimate	**p-value**	**Estimate**	**p-value**	**Estimate**	**p-value**	**Estimate**	**p-value**
0	2118	0.00***	1008	0.45	876	0.01**	2863	0.00***
C	2894	0.00***	2944	0.00***	1268	0.00***	1620	0.00***
MZ+C	2265	0.00***	3263	0.00***	1371	0.00***	2350	0.00***
CZ+C	3709	0.00***	2709	0.00***	2124	0.00***	1749	0.00***
CZ+PM	3294	0.00***	1040	0.13	1035	0.00***	3839	0.00***
Z	3546	0.00***	979	0.15	988	0.00***	5434	0.00***

0: No treatment, C: Compost, MZ+C: Mordenite zeolite plus compost, CZ+C: Cliptonolite zeolite plus compost; CZ+PM: Cliptonolite zeolite plus poultry manure; Z: Zeopro

Table 7. Analysis of variance (ANOVA) and LSD test (letters in brackets) based on biovolume values of plants to check for significant differences between levels of the best treatment selected of amended soils.

Level	***Pistacia Lentiscus* †**		***Olea europae*‡**		***Quercus coccifera*§**		***Rosamarinus officinalis*♯**	
	CZ+C		**MZ+C**		**CZ+C**		**CZ+PM**	
	Mean biovolume	**Error standar**	**Mean biovolume**	**Error standar**	**Mean biovolume**	**Error standar**	**Mean biovolume**	**Error standar**
5%	2793 (a)	405	1610 (a)	1214	2249 (a)	525	5267 (a)	492
10%	4941 (b)	418	1777 (a)	1357	1338 (a)	540	2969 (bc)	476
20%	3441(a)	405	7070 (b)	1175	2476 (a)	525	2717 (b)	529
30%	3734 (a)	393	2118 (a)	1175	2404 (a)	540	4282 (ac)	476
	n = 11		n =12		n = 11		n = 12	

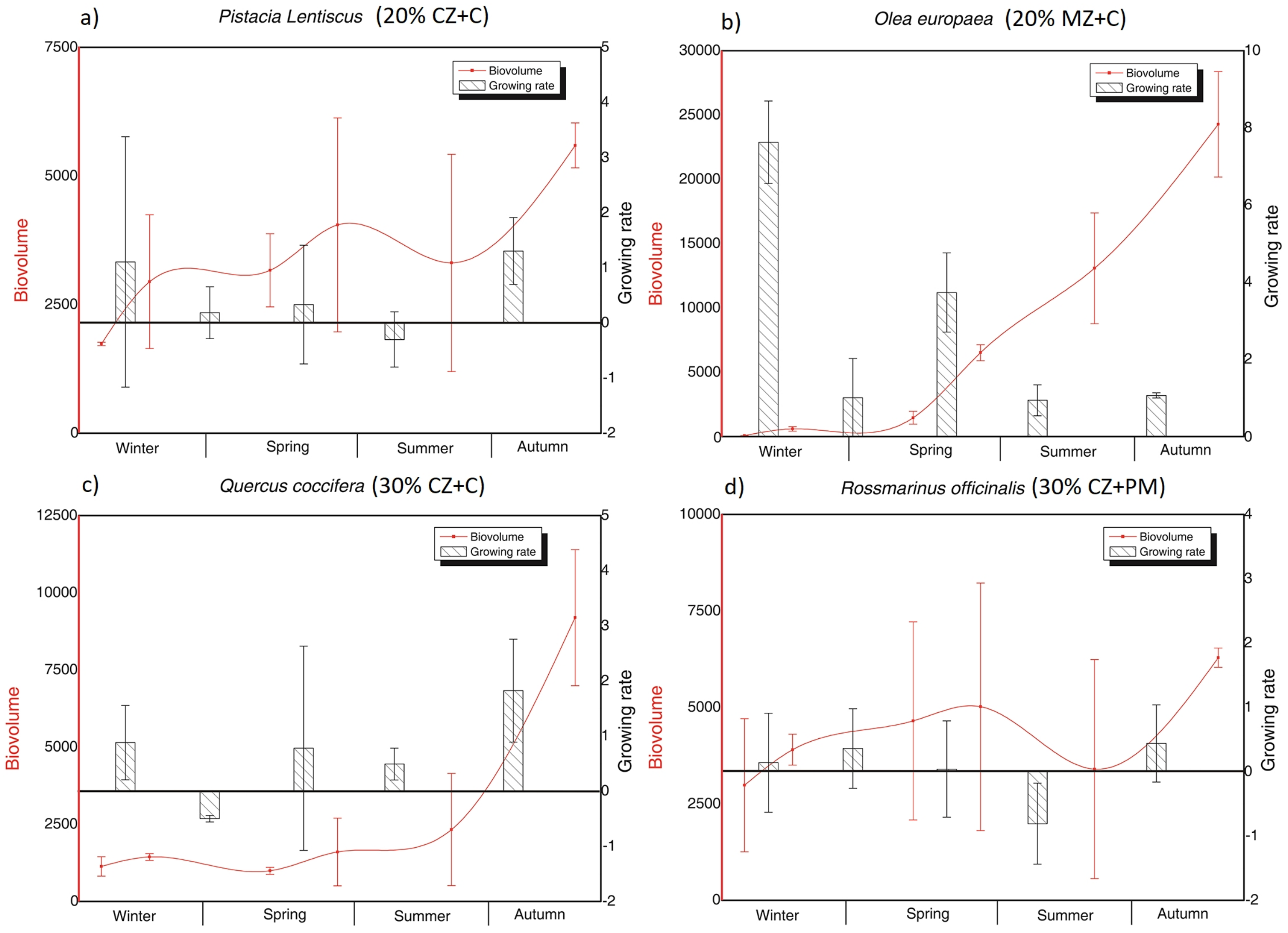
CZ+C: Cliptonolite zeolite plus compost, MZ+C: Mordenite zeolite plus compost; CZ+PM: Cliptonolite zeolite plus poultry manure.

†ANOVA F-Test: 4.73 p-value: 0.005***
‡ANOVA F-Test: 4.83 p-value: 0.004***
§ANOVA F-Test: 0.96 p-value: 0.4160
♯ANOVA F-Test: 5.69 p-value: 0.002***

Table 8. Geometric growing rates (%/day) of plants along the study period on the different treatments and levels of amended soils.

DAP	***Olea europaea***				***Pistacia lentiscus***				***Quercus coccifera***				***Rosmarinus officinalis***			
	MZ+C				**CZ+C**				**CZ+C**				**CZ+PM**			
	5%	**10%**	**20%**	**30%**	**5%**	**10%**	**20%**	**30%**	**5%**	**10%**	**20%**	**30%**	**5%**	**10%**	**20%**	**30%**
0-30	10.86±2.64	11.38±2.20	7.62±1.07	5.73±4.20	-1.10±0.85	3.63±0.37	1.11±2.27	-1.30±0.37	-0.18±0.75	-0.85±1.13	0.60±0.28	0.88±0.67	2.74±0.46	0.66±0.38	0.33±0.53	0.14±0.77
30-105	0.81±0.22	-0.11±0.03	1.01±1.02	2.56±1.91	0.40±0.32	-0.15±0.16	0.19±0.47	0.28±0.08	0.40±0.47	0.77±0.94	-0.44±0.19	-0.50±0.06	-0.20±0.08	-0.34±0.12	-0.02±0.57	0.36±0.62
105-147	-0.73±0.69	0.33±1.54	3.73±1.03	0.17±1.28	0.05±1.00	0.16±0.43	0.33±1.08	0.78±0.78	-0.72±1.22	-0.05±1.51	0.84±0.10	0.78±1.85	0.91±0.10	0.97±0.15	-0.53±1.46	0.04±0.75
147-218	-0.05±1.00	0.60±0.21	0.94±0.40	0.97±1.02	0.16±0.50	-1.05±0.10	-0.30±0.5	-0.48±0.18	-0.13±0.51	-1.10±0.33	0.00±0.91	0.49±0.29	-0.19±0.39	-1.04±1.43	-0.69±0.23	-0.81±0.63
218-295	0.23±0.21	0.41±0.15	1.06±0.07	1.30±0.81	-0.38±0.86	-0.39±0.56	1.30±0.61	0.72±0.28	-0.65±1.06	0.04±0.38	0.86±1.64	1.82±0.93	-0.53±0.90	0.23±0.57	1.18±0.25	0.44±0.60
0-295	**1.24±0.05**	**1.43±0.12**	**2.05±0.08**	**1.47±0.08**	**-0.03±0.27**	**0.03±0.14**	**0.40±0.03**	**0.15±0.02**	**-0.23±0.28**	**-0.06±0.21**	**0.29±0.54**	**0.76±0.14**	**0.19±0.48**	**-0.08±0.19**	**-0.09±0.13**	**0.18±0.10**

DAP: Days after plantation


a)
Pistacia Lentiscus (20% CZ+C)
Biovolume
Growing rate
7500
5000
2500
0
5
4
3
2
1
0
-1
-2
Winter
Spring
Summer
Autumn
b)
Olea europaea (20% MZ+C)
Biovolume
Growing rate
30000
25000
20000
15000
10000
5000
0
10
8
6
4
2
0
Winter
Spring
Summer
Autumn
c)
Quercus coccifera (30% CZ+C)
Biovolume
Growing rate
12500
10000
7500
5000
2500
0
5
4
3
2
1
0
-1
-2
Winter
Spring
Summer
Autumn
d)
Rossmarinus officinalis (30% CZ+PM)
Biovolume
Growing rate
10000
7500
5000
2500
0
4
3
2
1
0
-1
-2
Winter
Spring
Summer
Autumn