Comments by:
Referee 1
Authors

Response to Anonymous Referee #1

(i) GENERAL COMMENTS

This paper studies the effects of topsoil treatments on afforestation in a dry mediterranean climate in Spain.
The manuscript represents an interesting paper, with many interesting data. However, I consider that major changes should be addressed, and some problems should be solved before a new revision in Solid Earth journal.

Dear Referee 1:
Firstly, thank you so much for your response and positive feedback. During this first review, we have devoted great deal of attention to all your comments. Thus, we have tried to solve most of the problems detected.
This response to referee 1 is divided three blocks: (i) response to the general comments; (ii) response to the specific comments (as PDF.notes), (iii) a draft of the manuscript with the changes included.

Technical comments for the manuscript:

The scientific approach and applied methods are valid. However there are some key points that should be highlighted:

1. In my opinion, there is an important limitation in the results and discussion section. This section should be re-organized because in its present form, sometimes is really difficult to understand which are the main results.

According to your suggestion, in this version of the manuscript result and discussion section has been rewrite and re-organizes in order to better understand (Please, see draft of the manuscript attached in block 3- a draft of the manuscript with the changes included).

2. One of the key points is the statistical analysis. First of all, you should indicate if your dataset is normal (normality test) so you can carry out parametric or non-parametric analysis. It is not specified in the manuscript.

   In this version of the manuscript this gap has tried to solve. Please, see statistical analyses section. In general terms, the specific analyses performed were:
   a) Normality and variance homogeneity by Kolmogorov-Smirnov and Levenes test

b) Vegetation differences (normal and no-normal data) by generalized mixed model and posthoc test (Tukey ans Kruskal-Wallis).
c) Differences in soil properties by one-way Anova (Tukey and Games-Howell).

3. Then you should specify and clarify your statistical results in the text in a better way (check PDF).

According to the PDF-notes, the statistical results (p-values) have been included and commented among the results and discussion section.

4. Moreover, you only analyzed the differences between amendments and the control plot, but maybe it should be also interesting to evaluate the differences between the different amendments.

Based on the main goal of this research, we have refused this idea because we consider that it not relevant. The aim of this research is to test if the use of organic amendment on afforestation performance could enhance plant establishment comparing to an afforestation under bare soil.

According to our opinion, adding this comparison could difficult the understanding of this manuscript. It is due to the amount of different data that we have included in this manuscript (6 different soil treatments, 2 replicas per treatment and 5 different species). Besides, regarding to the results section currently we have 3 tables and 6 figures.

However, after this good recommendation, the differences between amendments are now being objective of a new manuscript.

5. Different comments have been added in the PDF (See also PDF)

The response of all this comment is included in the block-2: (ii) response to the specific comments (as PDF.notes).

6. There are different problems and small mistakes in the reference list and references in the manuscript. It should be checked and improved.

In this version of the manuscript reference list has been completed, checked and improved.

Technical comments for the figures and tables:

1. I consider that most of the figures, figure captions and tables should be improved (see PDF)

Thank you for your suggestion, we have tried to improve figures and figures caption according to your specific comments.

Comments by:
Referee 1
Authors

(ii) SPECIF COMMENTS

It has been replayed, one by one, to the referees like .pdf notes in the manuscript (please, see attached (**blue comments** have been made by the referees and **red comments** are the response of the autors)

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Solid Earth Discussions

EFFECTS OF TOPSOIL TREATMENTS ON AFFORESTATION IN A DRY-MEDITERRANEAN CLIMATE (SOUTHERN SPAIN)

P. Hueso-González[1]*, J.F. Martínez-Murillo[1], J.D. Ruiz-Sinoga[1]

[1] Physical Geography and Land Management Research Group RNM279, Department of Geography, University of Málaga, Andalucía Tech. Campus de Teatinos s/n, 29071, Málaga, Spain.

Correspondence to: P. Hueso González (phueso@uma.es)

Abstract. Revegetation programs in semiarid areas are associated with a high level of sapling mortality. Therefore, the development of alternative low cost and low environmental impact afforestation methods that ensure the survival of seedlings is necessary for the effective management of Mediterranean forest environments. This study assessed the effects of five types of soil amendment on the success of afforestation processes.

The amendments tested were: i) straw mulch (SM); ii) mulch containing chipped branches of Aleppo Pine (*Pinus halepensis* L.) (PM); iii) sheep manure compost from a wastewater treatment plant (SH); iv) sewage sludge (RU); and v) TerraCottem hydroabsorbent polymer (HP). We hypothesized that in the context of dry-Mediterranean climatic conditions, the use of organic amendments would enhance plant establishment and ensure successful afforestation. The results showed that afforestation success varied among the various soil amendment treatments in the experimental plots. The amendments had no effect on soil organic carbon, pH, or salinity, but the results indicate that the addition of mulch or hydroabsorbent polymer can reduced transplant stress by increasing the soil water available for plant growth throughout the hydrological year, and potentially improve the success of afforestation by reducing plant mortality.

1 Introduction

The combination of climate change, lithology, geomorphology, and human activities has resulted in much of the Mediterranean region being affected by soil and vegetation degradation, which has led to desertification (Pérez Trejo, 1994; Brandt and Thornes, 1996; Puigdefabregas and Mendizabal, 1998; Martínez-Murillo et al., 2016; Muñoz-Rojas et al., 2016a

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Página: 1

Página: 1

Autor: <Nada> Asunto: Nota adhesiva Fecha: 18/08/2016, 12:35:35

Afforestation

Autor: usuario Asunto: Nota Fecha: 02/09/2016, 12:24:20

Change was made by the authors

Página: 1

Autor: <Nada> Asunto: Nota adhesiva Fecha: 18/08/2016, 12:36:34

processes

Autor: usuario Asunto: Nota Fecha: 02/09/2016, 12:26:04

This change was made by the authors

Página: 1

Autor: Estela Asunto: Resaltado Fecha: 18/08/2016, 12:36:40

Autor: usuario Asunto: Nota Fecha: 02/09/2016, 12:30:02

Reference has been modified

Página: 1

Autor: Estela Asunto: Resaltado Fecha: 18/08/2016, 12:36:42

Página: 1

Autor: Estela Asunto: Resaltado Fecha: 18/08/2016, 12:36:37

Autor: usuario Asunto: Nota Fecha: 02/09/2016, 12:25:22

Página: 1

Autor: <Nada> Asunto: Nota adhesiva Fecha: 18/08/2016, 12:36:25

Avoid abbreviations in the Abstract. Moreover you don´t use it in the abstract so it is better to delete it and include it in the manuscript.

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The amendments tested were: i) straw mulch (SM); ii) mulch containing chipped branches of Aleppo Pine (*Pinus halepensis* L.) (PM); iii) sheep manure compost from a wastewater treatment plant (SH); iv) sewage sludge (RU); and v) TerraCottem hydroabsorbent polymer (HP). We hypothesized that in the context of dry-Mediterranean climatic conditions, the use of organic amendments would enhance plant establishment and ensure successful afforestation. The results showed that afforestation success varied among the various soil amendment treatments in the experimental plots. The amendments had no effect on soil organic carbon, pH, or salinity, but the results indicate that the addition of mulch or hydroabsorbent polymer can reduced transplant stress by increasing the soil water available for plant growth throughout the hydrological year, and potentially improve the success of afforestation by reducing plant mortality.

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Autor: usuario Asunto: Nota Fecha: 02/09/2016, 12:25:12
The abbreviations were removed

Página: 1

Autor: Estela Asunto: Resaltado Fecha: 18/08/2016, 12:33:05

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and c). These processes may not be spontaneously reversible, especially in forest environments, when certain thresholds are exceeded, being necessary to carry out restoration activities (Aronson et al., 1993; Whisenant, 1999).

Vegetation plays a fundamental role in soil conservation (Thornes, 1990; Castillo et al., 1997; Cerdà, 2001). In Mediterranean ecosystems, increasing forest cover has been commonly considered to be a technique for mitigating the effects of desertification (Nykvist, 1983; Vallejo et al., 2000; Le Honeuérou, 2000). However, in Mediterranean areas the conditions do not support natural colonization or artificial revegetation, because of previous soil erosion and the low levels of water and nutrient availability (Bratton et al., 2016).

All the environmental factors involved in afforestation processes must be taken into account in determining the responses of plants (Navarros and Fracios, 2004). Burdett (1990) considered that climatic conditions and soil parameters play key roles in the initial stages following transplantation during afforestation. It is assumed that the risk of mortality declines when the period of transplantation stress is passed, and physiological attributes return to normal levels (Maestre et al., 2003). Thus, the most important period during afforestation is that during which the plants adjust their morphology and physiology to the new environmental conditions (Maestre et al., 2002a, 2002b, 2003).

In semiarid conditions, revegetation programs are associated with a high level of sapling mortality (Castro et al., 2002). In this context, saplings transplanted to the natural environment are subject to very different conditions from those in the nursery environment (Grossnickle, 2000). Two factors that particularly limit the establishment and growth of seedlings in Mediterranean environments are: i) excessive radiation; and ii) the limited availability of water during summer droughts (Valladares and Pugnaire, 1999).

Several studies have investigated various techniques aimed at increasing the survival of seedlings, including irrigation in summer, artificial shade, opening holes large volume with heavy machinery, and the use of protective cloth (Maestre and Cortina, 2002a). Numerous studies have shown that afforestation success is greater when the above techniques are implemented, especially in the first months following transplantation (Arnold, 1997; Rey-Benayas, 1998; Linton et al., 2016). However, most of these techniques are focused only on seedling protection, and do not involve a holistic view of the environment. Therefore, in the short and medium terms, these techniques are not effective in improving soil quality or reducing soil loss (Rey., 2009; Burylo et al., 2014). In addition, the use of these techniques significantly increases the cost of

Página: 2

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Autor: <Nada> Asunto: Nota adhesiva Fecha: 18/08/2016, 12:37:11
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Autor: usuario Asunto: Nota Fecha: 02/09/2016, 12:34:13
Change was made

Página: 2

Autor: Estela Asunto: Resaltado Fecha: 18/08/2016, 12:38:24

Página: 2

Autor: <Nada> Asunto: Nota adhesiva Fecha: 18/08/2016, 12:40:07
Specify that it is the case in semiarid environments, because the processes in Humid Mediterranean environemnts could be different.

I suggest you to include semiarid Mediterranean in the manuscript in the different points, because it is not the same humid, submid, semiarid o arid Mediterranean conditions

Autor: usuario Asunto: Nota Fecha: 02/09/2016, 12:36:09
We are agree with referee 1. Changes were taken into consideration

Página: 2

Autor: Estela Asunto: Resaltado Fecha: 18/08/2016, 12:40:29

Autor: usuario Asunto: Nota Fecha: 02/09/2016, 12:37:11
Now it is written Rey, 2009

Página: 2

Autor: Estela Asunto: Resaltado Fecha: 18/08/2016, 12:40:21

Autor: usuario Asunto: Nota Fecha: 02/09/2016, 12:36:36
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Autor: <Nada> Asunto: Nota adhesiva Fecha: 18/08/2016,

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12:38:39
semiarid

Autor: usuario Asunto: Nota Fecha: 02/09/2016, 12:34:56
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Página: 2

Autor: <Nada> Asunto: Nota adhesiva Fecha: 18/08/2016, 12:38:20
Are you really sure? maybe in Mediterranean semiarid areas the natural colonization is really slow but it occurs even in semiarid environments. So please change this sentence.

Autor: usuario Asunto: Nota Fecha: 22/09/2016, 11:17:55
Now written: " However, a rapidly response of vegetation re-colonization could be limited on afforestation proposals due to the climatic conditions of semiarid areas. This is owing to the prevailing soil erosion processes and low levels of water and nutrient availability (Breton et al., 2016)"

Página: 2

Autor: Estela Asunto: Resaltado Fecha: 18/08/2016, 12:36:59

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afforestation, in many cases they are not applicable because of the topographic conditions (Bochet and García-Fayos, 2004), and they often have major impacts on the ecosystem, which limits their use in areas where landscape conservation is a priority.

For the proper management of Mediterranean forest environments, alternative low cost afforestation methods that ensure the survival of seedlings and have minimal environmental impact are needed (Eldridge et al., 2012; Benigno et al., 2013). One way to improve soil conditions is to apply organic amendments to the soil. Numerous studies have assessed the use of organic amendments for vegetation establishment and soil fertility, including agricultural soils (Ojeda et al., 2003; Jordan et al., 2010; Jiménez et al., 2013; Tejada and Gonzalez, 2013), eroded soils (Cohen Fernández and Naeth, 2013; Prats et al., 2013; Donn et al., 2014; Hoseini Bai et al., 2014), post-mining soils (Eldrigge et al., 2012; Benigno et al., 2013; Muñoz Rojas et al., 2016b), and afforested soils under Mediterranean conditions (Hueso-González et al., 2014, 2015).

However, more studies are needed to assess the effects of soil amendments in afforested areas under Mediterranean climate conditions. This study assessed the effects of five types of soil amendment on afforestation success. We hypothesized that, in a context of dry-Mediterranean climatic conditions, the use of organic amendments could enhance plant establishment and contribute to afforestation success. The main objectives were to: i) analyze the effect of various organic amendments on some chemical and hydrological soil properties; and ii) assess the effects of these parameters on afforestation under dry-Mediterranean climatic conditions.

2 Materials and methods

2.1 Experimental site

The study was conducted at the El Pinarillo experimental site (X: 424.240 m; Y: 4.073.098 m; UTM30N/ED50) located in South of Spain (Sierra Tejeda, Almijara y Alhama Natural Park). The surrounded area is characterized by very steep and marble mountains as well as dry Mediterranean climate (mean annual temperature: 18 °C; mean annual rainfall = 589 mm y^{-1}). The experimental site is set up in an alluvial fan which was cultivated with cereals until 1950s. After its abandonment, the area was recolonized by Mediterranean vegetal species of shrubs, mainly *Lavandula stoechas* L., *L. multifida* L., *Cistus albidus* D., *Rosmarinus officinalis* L., *Thymus capitatus* L., *Rhamnus alaternus* L. Currently, the vegetation cover is higher

Página: 3

Página: 3

Autor: Estela Asunto: Resaltado Fecha: 18/08/2016, 12:40:50

Autor: usuario Asunto: Nota Fecha: 02/09/2016, 12:47:54
Change was made. Now it is written Jiménez et al., 2013

Página: 3

Autor: Estela Asunto: Resaltado Fecha: 18/08/2016, 12:41:06

Autor: usuario Asunto: Nota Fecha: 02/09/2016, 12:48:38
Change was included

Página: 3

Autor: Estela Asunto: Resaltado Fecha: 18/08/2016, 12:41:29

Página: 3

Autor: Estela Asunto: Resaltado Fecha: 18/08/2016, 12:41:43

Autor: usuario Asunto: Nota Fecha: 02/09/2016, 12:49:05
Change was made

Página: 3

Autor: <Nada> Asunto: Nota adhesiva Fecha: 18/08/2016, 12:42:18
natural?

Página: 3

Autor: <Nada> Asunto: Nota adhesiva Fecha: 18/08/2016, 12:41:53
semiarid

Autor: usuario Asunto: Nota Fecha: 02/09/2016, 12:37:41
change was included

Página: 3

Autor: <Nada> Asunto: Nota adhesiva Fecha: 18/08/2016, 12:41:39
Check.

Autor: usuario Asunto: Nota Fecha: 02/09/2016, 12:48:20

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Reference has been modified

Página: 3

Autor: Estela Asunto: Resaltado Fecha: 18/08/2016, 12:41:25

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Autor: <Nada> Asunto: Nota adhesiva Fecha: 02/09/2016, 12:07:46
2016

Página: 3

Autor: Estela Asunto: Resaltado Fecha: 18/08/2016, 12:40:48

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than 70% despite of a wildfire occurred in 1991. Due to the previous land use and water erosion processes, soils are eutric Leptosolos (FAO-WRB, 2006) featured by a high level of rock fragment cover on the surface (> 50%), a high gravel content in the profile (total gravel content = 56%; gravel content > 10 mm = 31%; gravel content 2f mm = 10%; gravel content 1 mm = 15%), and a sandy–loam texture (sand = 60%, silt = 32%, clay = 8%).

2.2 Plots, amendments, and afforestation

In the experimental site, considering its homogeneous slope gradient (7.5%) and aspect (N170°), an experimental paired-plot layout was performed (plots size: 2 m width x 12 m length; 24 m^2). The natural vegetation cover was removed within the experimental to preserve similar and initial eco-geomorphic conditions for the whole plots. Afterwards, in May 2011, certain amendments and treatments were added to the soil of some plots, using two replicate plots for each of them. With a rate of application equal to 10 Mg ha^{-1}, straw mulching (SM), mulch composed of chipped branches of Aleppo pine (*Pinus halepensis* L.) (PM), sheep manure compost from a wastewater treatment plant (SH), sewage sludge (RU), and TerraCottem hydroabsorbent polymer (HP) were added to the soils from two-paired plots. Totally, one plot and its replicate with one of these amendments were obtained in order to conduct the experiment.

In November 2011, an afforestation plan was performed in the paired-plots following the same pattern of plantation in each of them (similar spatial pattern and vegetal species). The afforestation plan considered the same vegetal species that the managers from the natural park usually utilized.

The plant species used were *L. stoechas, L. dentatae, L. multifida, R. officinalis*, and *T. capitatus*. The plants were selected from a local nursery and were adapted to the type of environment under study. The plants were transplanted in a grid pattern at a spacing of 0.5 m between plants in each plot. During the afforestation process the soil was tilled to 25 cm depth from the surface. Two afforested control plots were included; these involved soil that received no amendment.

2.3 Monitoring of vegetation

The seedlings were assessed twice per year in the period 2011–2014: i) 6 months following transplantation (May 2012); ii) 12 months following transplantation (November 2012); iii) 20 months following transplantation (June 2013); and iv) 30 months following transplantation (May 2014). This frequency enabled assessment of growth and development of the plants

Página: 4

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Autor: <Nada> Asunto: Nota adhesiva Fecha: 18/08/2016, 12:42:44

Add/specify the total number of plots

Autor: usuario Asunto: Nota Fecha: 05/09/2016, 11:01:04

The total number of plots has been included

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during the dry and wet Mediterranean seasons, and to evaluate the effect of climatic (temperature and rainfall) and soil parameters including soil salinity (electrical conductivity: EC), soil organic carbon (SOC), and pH.

The number of surviving plants was determined during the field surveys, and the phenological state of plants was measured according to the criteria of Castro et al. (2002) and Gómez-Aparicio et al. (2004). A seedling was considered to be alive if living leaves, buds, or stems were observed. The plant height was measured from the ground to the terminal bud of the tallest stem. The maximum diameter of the canopy was also measured.

2.4 Soil analysis and measurements

Soil from the afforested plots was sampled in October 2010 and at 30 months following transplantation. The sampling strategy for each plot consisted in collecting four disturbed soil surface samples (0–10 cm depth). The soil properties analyzed were: i) EC, performed from deionized water suspension of soil particles (5:1), Crisol Micro CM 2200 conductivity meter (ISRIC, 2002); ii) pH, obtained from deionized water suspension of the soil (2.5:1) using a Crisol GLP 21 pH meter; iii) SOC, determined by means of the Walkley-Black method (FAO, 2006); and iv) water holding capacity (WHC), which was determined using a sand box (pF 2.0) and a Richards membrane (pF 4.2) (Richards, 1947; Stackman et al., 1969; Martinez-Fernandez, 1996). We measured the wilting point (WP) and field capacity (FC) to assess the hydrological state of the soil during the hydrological year, and its potential relationship to the water available for plants (AWC) (Caldwell, 1976).

Soil moisture probes (HOBO S-SMx-M005) were installed in the experimental area. Two probes were inserted into the soil profile in the middle of each plot, at 5 and 10 cm depths. Soil moisture was monitored and recorded at 10-min intervals. Because of the limited development of root systems by the afforested plants during the study period, analysis of the soil water content (SWC) included only the first 10 cm of soil profile (at 5 cm and 10 cm depths).

2.5 Statistical analysis

Differences between treatments were tested by means of the analysis of variance (ANOVA) for $p<0.05$. The Levene's test was calculated in order to assess the homoscedasticity. When no homoscedasticity were obtained (Levene test; $p < 0.05$) Tukey's and Games-Howell's tests were determined for $p<0.05$. Analyses were performed using SPSS (version 21) for Windows.

Página: 5

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have you inserted two probes in each plot and replicate? please add/inidicate the number of total probes.

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during the dry and wet Mediterranean seasons, and to evaluate the effect of climatic (temperature and rainfall) and soil parameters including soil salinity (electrical conductivity: EC), soil organic carbon (SOC), and pH.

The number of surviving plants was determined during the field surveys, and the phenological state of plants was measured according to the criteria of Castro et al. (2002) and Gómez-Aparicio et al. (2004). A seedling was considered to be alive if living leaves, buds, or stems were observed. The plant height was measured from the ground to the terminal bud of the tallest stem. The maximum diameter of the canopy was also measured.

2.4 Soil analysis and measurements

Soil from the afforested plots was sampled in October 2010 and at 30 months following transplantation. The sampling strategy for each plot consisted in collecting four disturbed soil surface samples (0–10 cm depth). The soil properties analyzed were: i) EC, performed from deionized water suspension of soil particles (5:1), Crisol Micro CM 2200 conductivity meter (ISRIC, 2002); ii) pH, obtained from deionized water suspension of the soil (2.5:1) using a Crisol GLP 21 pH meter; iii) SOC, determined by means of the Walkley-Black method (FAO, 2006); and iv) water holding capacity (WHC), which was determined using a sand box (pF 2.0) and a Richards membrane (pF 4.2) (Richards, 1947; Stackman et al., 1969; Martinez-Fernandez, 1996). We measured the wilting point (WP) and field capacity (FC) to assess the hydrological state of the soil during the hydrological year, and its potential relationship to the water available for plants (AWC) (Caldwell, 1976).

Soil moisture probes (HOBO S-SMx-M005) were installed in the experimental area. Two probes were inserted into the soil profile in the middle of each plot, at 5 and 10 cm depths. Soil moisture was monitored and recorded at 10-min intervals. Because of the limited development of root systems by the afforested plants during the study period, analysis of the soil water content (SWC) included only the first 10 cm of soil profile (at 5 cm and 10 cm depths).

2.5 Statistical analysis

Differences between treatments were tested by means of the analysis of variance (ANOVA) for $p<0.05$. The Levene's test was calculated in order to assess the homoscedasticity. When no homoscedasticity were obtained (Levene test; $p < 0.05$), Tukey's and Games-Howell's tests were determined for $p<0.05$. Analyses were performed using SPSS (version 21) for Windows.

Have you test the normality of your data?

because there are some results that are strange. You should test the normality of the data because depend on it you can carry out parametric or non-parametric statistical analysis

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Yes, normality and variance homogeneity were verified by Kolmogorov and Levene's tests, respectively. In all the analyses, the selected significance limit was $p < 0.05$. According to you suggestion, we have done some stadistical modification and improvements in the current version of the manuscript. We fitted generalized linear mixed models to analyze the significant effects of soil treatment, species and the random effects of plots. Beside, we have applied a Post-hoc multiple comparison for observed means (Tuckey's test or Kruskal-Wallys $p < 0.05$).

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3 Results and Discussion

3.1 Survival of plants

Figure 1 shows the species survival rates and soil management during the study period. After 30 months, the survival rates in the control plots were 74.4%, 75.0%, 58.0%, 56.0%, and 37.5% for *L. multifida, R. officinalis, L. stoechas, T. capitatus*, and *L. dentate*, respectively. In these plots most of the mortalities occurred during the first summer period (Figs 1 and 2), which was characterized by a major severe drought relative to the subsequent two years. Similar results were reported by Bochet et al. (2007) in a study under Mediterranean conditions.

A substantial positive effect on survival rates was evident in the SM, PM, and HP treatments for *Lavandula sp.* and *T. capitatus* (Fig. 1). Similar results were reported by Breton et al. (2016), who showed that under Mediterranean climate conditions the supply of organic material improves the establishment of young plants, and reduces the mortality rate. With respect to sapling growth, two positive significant effects were observed relative to the control, depending on the amendment type (Figs 3 and 4): i) the maximum canopy diameter and the terminal bud height were higher in the SM and PM treatments, especially for *Lavandula sp.*; and ii) in the HP plots, there was only an increase in maximum canopy diameter and no difference in height. Conversely, in the SH plots plant survival decreased rapidly or remained constant relative to the control, and at the end of the experiment the only sapling growth parameter that differed from the control was the maximum canopy diameter for *L. stoechas*.

Survivals in the afforestation were nearly 0% in the RU plots because of the growth of *Carlina hispanica* herbaceous plants which completely covered them along the first wet season (Fig. 5). This vegetal specie presents a rhizomatous root system overwintering buds at 1–10 cm depth in the soil profile from those plots. This plant is likely to be highly water absorbent being probably responsible for the mortality of the afforested saplings (Wahrmund et al., 2010).

3.2 Changes in SOC, pH and EC

SOC can be a limiting factor for plant establishment in lands with degraded soils (Almendros et al., 2010; Hueso-González et al., 2014). These conditions could imply vegetation survives better whether the soils are amended with an external source of organic matter (Jordán et al., 2010; Chaudhuri et al., 2013; Shazana et al., 2013; Srinivasarao et al., 2013). In fact, the addition of soil organic matter by means of crop either mulch, sewage sludge or animal manure enhances vegetation growth

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Moreover the presentation of the results and the statistical analysis should be improve too, because it is not clear when the differences are significant (you should add the p-value or add a table).

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and cover (Montgomery et al. (2007). Similar results have been reported by Ferreras et al. (2006), Franco-Otero et al. (2011), and González-Ubierna et al. (2012).

Table 1 shows that no significant differences in SOC where found in the SM, PM, RU, SH, and HP treatments relative to the control. One explanation for this is that there was a low rate of mineralization of these organic amendments because of three main factors: i) the lack of previous composting in the treatments added, which increased the time needed for decomposition processes to occur (García-Gomez et al., 2005); ii) the high content of lignin and cellulose in the amendments used (Durrca et al., 1999; Jensen, 2009); and iii) the medium-high rates applied (10 Mg ha^{-1}) (Young et al., 2015). Jordán et al. (2010) showed that mineralization rates in a cultivated area in southwest Spain were higher when amendments were applied at low rates (3–5 Mg ha^{-1}). González-Ubierna et al. (2012) achieved similar results as well when testing differences in SOC after the additions of three test organic residues. Hueso-González et al. (2014) noted that in excess of 30 months was needed to detect the effect of these amendments on SOC values.

Changes in pH and EC were measured to determine whether these reflected differences in the afforested vegetation at the end of the study period. In this regard, Guang-Ming et al. (2006) and Li et al. (2007) showed that the application of certain organic amendments can cause a change in the pH and a slight increase in EC. Similarly, Parida and Das (2005) showed that variations in salinity or acidity can affect plant growth and survival rates. Allakhverdiev et al. (2000) reported that plants adversely affected by salinity grew more slowly and were stunted. Some studies have reported that changes on soil salinity and acidity during afforestation may cause sapling mortality (Ferreras et al., 2006; Guang-Ming et al., 2006).

There was no direct relationship between amendment addition and changes in soil salinity or acidity. Such changes depend on the type of amendment, its application rate, and the climatic conditions (Li et al., 2007; Hueso González, 2014). In our study, no significant differences relative to the control plots were found. We only found significant differences in the RU treatment and at 30 months following afforestation (Table 2). However, based on previous studies the measured changes were not sufficient to cause the mortality of the afforested plants (Ferreras et al., 2006; Guang-Ming et al., 2006; Li et al., 2007).

In summary, there were no differences in SOC, pH, or EC among the treatments that could explain the differences in sapling survival described above.

Página: 7

Página: 7

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Página: 7

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Table

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Página: 7

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Página: 7

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3.1 Variability of available water content

In this section, we compare the variability of SWC and WHC during the study period in order to, specifically, identify the number of months with available water for plants. With respect to WHC, several studies have shown that inadequate soil water storage is the major limiting factor for the sapling establishment in semiarid areas (Hasee and Rose, 1993; Whisenant et al., 1999; South, 2000), and others have noted that new techniques are needed to increase the AWC in dryland soils (Tongway and Ludwing, 1996; Shachak et al., 1998). Ros et al. (2006) showed that the addition of certain amendments favored the development of vegetation cover in agricultural soils in Spain, because of increased soil moisture. Hueso-González et al. (2015) reported an increase in SWC following the addition of amendments to soils, because of an increase in the macro-porosity.

Table 2 shows the annual average and maximum SWC values during the study period. In the control plots the average SWC was 7.0 ± 6.0% and 4.0 ± 5.0% at 5 and 10 cm depths, respectively. However, high coefficients of variation were found (CV > 80%), indicating seasonality in Mediterranean climatic conditions affects the variability in SWC values (Fig. 2). In contrast to the control, in the SM plots the mean value of SWC remained relatively constant with depth. In addition, the coefficient of variation at 10 cm depth was low, indicating greater stability in the SWC during the hydrological year; this indicates that the soil profile remained wetter, especially during the dry Mediterranean drought period. The pattern of SWC in PM plots was similar to that in the SM plots.

Soils amended with polymer (HP treatment) also showed an increase in the average SWC relative to the control (Table 2), with mean SWC values of 10.0 ± 7.0 % and 5.0 ± 6.0% at 5 and 10 cm depths, respectively. A similar SWC trend was found for the RU plots. However, the average and maximum values of SWC measured in the SH plots (Table 2) were very similar to those for bare soil (control plots).

The low survival rates found in the control plots (Fig. 1) can be explained by the Mediterranean climatic conditions in the study area, which include heavy rainfall and long dry spells, which increase plant stress and the difficulties of seedling root establishment (Don et al., 2014; Young et al., 2015). Bochet and García-Fayos (2004) reported similar results in a study involving Mediterranean slope areas. In general, during the study period the SWC for sapling growth was below the wilting point (WP) for 6 months each year (Fig. 6). The seedling roots took up the water held in the soil at the beginning of the first

Página: 8

Página: 8

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dry season. The soil rapidly became dry, resulting in a shortage of AWC for plants. Besides, during the following months, the maximum evaporation process was due to the high temperature and the absence of rainfalls. Consequently, most of the mortality in the control plots occurred during the summer period of the first year (Fig. 2).

In plots that received soil amendments two patterns of AWC were observed (Fig. 6): i) the soils in the SM, PM, HP, and RU plots had higher AWC than in the control plots; and ii) the soils in the SH treatment had a lower AWC than in the control plots.

Figure 6 shows that in many months the AWC in soils amended with SM, PM, RU, or HP was higher than in the control plots, and consequently the water stress following afforestation was less. This was positively correlated with increased sapling survival rates in the SM, PM, and HP treatments (Fig. 1). Similar results were reported by Breton et al. (2016) in a study of soil amended with wood chips, where survival rates increased by 30%. The results are also consistent with those of Querejeta et al. (2001) and Castillo et al. (2001), who noted that revegetation programs in semiarid conditions needed previous soil preparation aimed at increasing water availability for plants.

An opposite trend was found in the SH treatment to that observed in the PM, SM, and HP treatments, with the soil in the former treatment having a soil AWC less than the WP for six months during the hydrological year (at 0-9 cm depth in the soil profile). This period, between April and August, coincided with the period in which maximum temperatures and minimum rainfall occurred (Fig. 2). Thus, evaporation processes were favored, and the afforested plants were subject to greater water stress. As a result, the plant survival rates in this treatment were less than in the others treatments (Fig. 1). The pattern of AWC in the SH treatment was similar to that found in the control plots (Fig. 6). This also explains the similarities in plant height and maximum diameter in the control and the SH treatment plots (Figs. 3 and 4).

In the RU plots, although there was 100% vegetation cover on the soil surface, this comprised an invasive nitrophilous grassland species introduced with the sewage sludge amendment (Fig. 5), even though the RU plots had been transplanted with the same number of plants and using the same spatial pattern of Mediterranean shrubs as in the other treatments. Previous studies at the experimental site indicated that this exogenous nitrophilous grassland outcompetes the afforestation species for nutrients and water (Hueso-Gonzalez et al., 2015), and this explains the high mortality measured in the RU plots.

Guerrero et al. (2001) and Ojeda et al. (2003) measured a change in the ammonium and nitrite content in agricultural soils

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following sewage sludge application, and interpreted this as resulting from an increase in soil salinity that reduced the number of nitrifying bacteria. At the end of the study period, very few *L. stoechas* and *T. capitatus* plants remained in the RU plots.

Figures 3 and 4 show the effect of AWC on the plant height and maximum diameter in the PM, SM, and HP plots. Plots amended with PM and SM showed the greatest plant survival. This may have been related to greater AWC following amendment addition (Fig. 6), and may be similar to the effect described by Calvo et al. (2003) and Gabarrón-Galeote et al. (2013), who investigated the effect of litter on the SWC. In this study, the addition of mulch caused an increase in soil roughness and macro-porosity, which increased infiltration processes (Hueso-González et al. 2015). Adekalu et al. (2007) and Jordán et al. (2010) reported a reduction in soil evapotranspiration resulting from the protective effect of mulching. Nevertheless, in this study we could not establish differences between the effects of the SM and PM treatments because the survival rates and the plant growth were quite similar (Figs. 1, 3 and 4).

The RU amendment had an opposite effect to that in the SM, PM, RU, and HP plots. In this treatment the AWC was lower during the study period (Fig. 6), and was less than the WP for more than five months each year, from April to August, which coincided with the highest temperature and evapotranspiration values (Fig. 2). Consequently, plants were subject to a lack of water, and this stress resulted in higher mortality rates (Fig. 1). No significant differences relative to the control were found in the height of the apical bud or the plant diameter (Figs. 3 and 4).

4 Conclusions

i) Under dry-Mediterranean climate conditions the afforestation success varied depending on the amendments applied to the soil in the experimental plots.

ii) The amendments, applied to the soil to improve plant survival, did not cause significant changes to the soil organic carbon content, pH, or electrical conductivity.

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iii) Significant differences in the water available for plants occurred among the various soil amendment treatments, with the straw mulch, Aleppo Pine, and TerraCottem hydroabsorbent polymer treatments having very positive effects on plant growth.

In terms of land management, this study shows that the addition of mulch or hydroabsorbent polymer can reduce transplanting stress, and improve the success of afforestation programs by reducing the mortality of plants.

5 Acknowledgments

The study was economically supported by the RNM-5057 research project (Autonomous Government of Andalusia, Spain) as well as by the Campus Andalucía Tech. Also, authors thanks to TRAGSA Company the technical support during the experimental site set-up.

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Página: 11

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Página: 13

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Página: 14

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Página: 15

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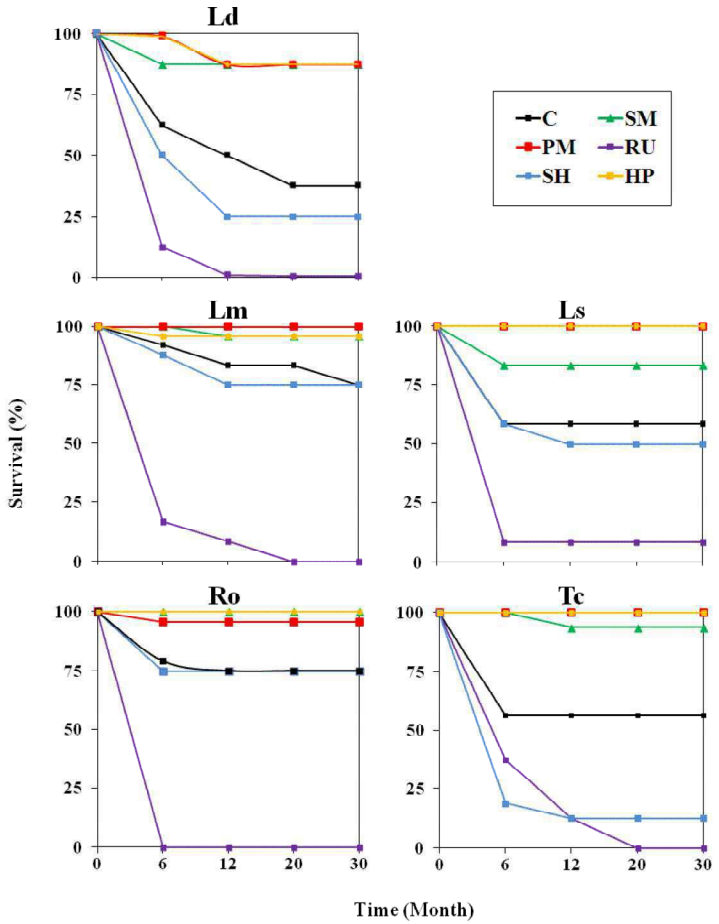

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Figure 1: Comparison of survival rates (%) between amendments and control in the period 2011-2014. Where: C: soil afforested. no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP: Terracottem hydroabsorbent polymers.

Página: 18

Página: 18

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which are the meaning os Ld, Lm, Ls, Ro, Tc... I know that they are the different species but it should be indicated or in the figures or in the figure captions (species and abbreviations)

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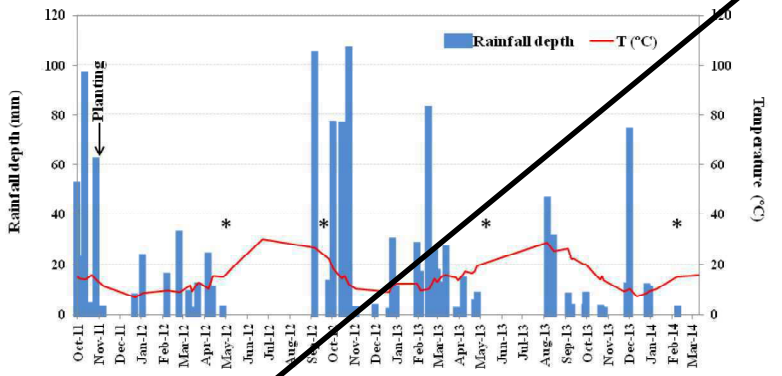

Figure 2: Temporal variability in rainfall and temperature from October 2011 to March 2014. Black astericks indicates the vegetation observation dates.

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Página: 19

Página: 19

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I recommend to change the figure. The scales should be different in both axes to explain and understand

Autor: usuario Asunto: Nota Fecha: 20/09/2016, 18:11:52

Different scales in box axes has been changed

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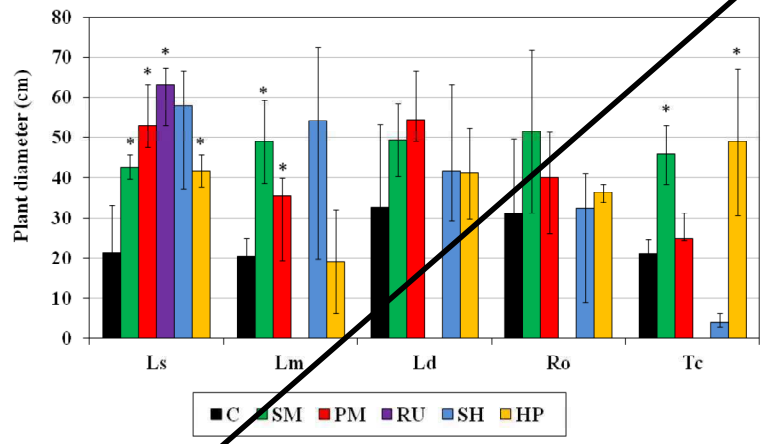

Figure 3: Maximun diameter of the canopy (cm), 30 months following transplantation, May 2014. Where: C: soil afforested. no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP: Terracottem hydroabsorbent polymers. * indicates a significant differences relative to the control (C) ($p < 0.05$).

Página: 20

Página: 20

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In all the cases, you specify the statistical differences with the control sites, but maybe it could be also interesting to check the differences between amendments

Autor: usuario Asunto: Nota Fecha: 22/09/2016, 11:10:30

Based on the main goal of this research, we have refused this idea because we consider that it not relevant. The aim of this research is to test if the use of organic amendment on afforestation performance could enhance plant establishment comparing to an afforestation under bare soil.
According to our opinion, adding this comparison could difficult the understanding of this manuscript. It is due to the amount of different data that we have included in this manuscript (6 different soil treatments, 2 replicas per treatment and 5 different species). Besides, regarding to the results secction currently we have 3 tables and 6 figures.

However, after this good recommendation, the differences between amendments are now being objective of a new manuscript. Thank you so much!

Página: 20

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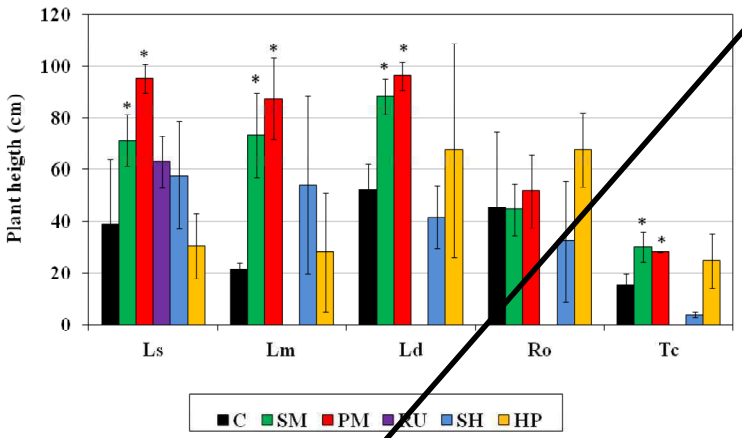

Figure 4: Plant height from ground to terminal bud of the tallest stem (cm), 30 months following transplantation, May 2014. Where: C: soil afforested. no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP: Terracottem hydroabsorbent polymers. * indicates a significant differences relative to the control (C) ($p < 0.05$).

Página: 21

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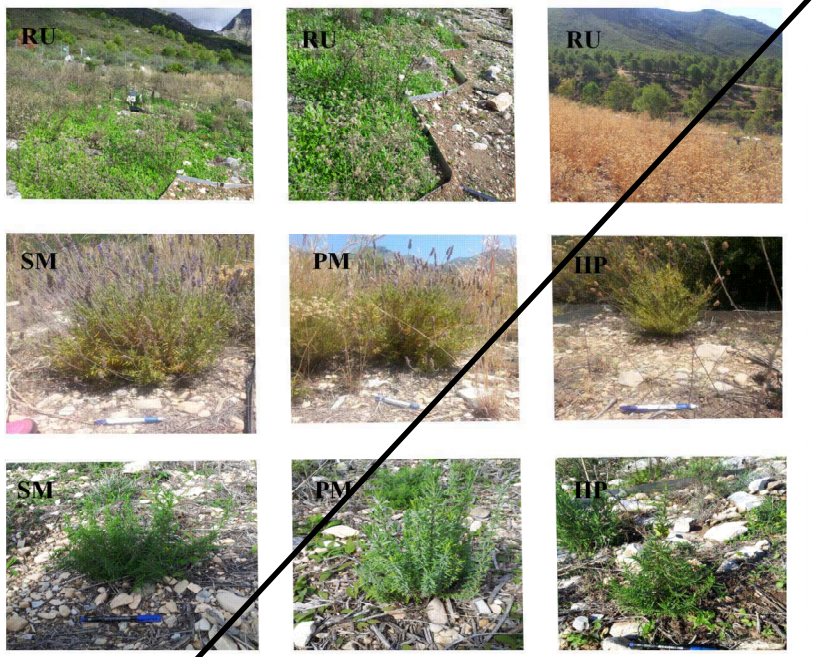

Figure 5: Pictures of the experimental plots. Where: PM: plots afforested and amendment with mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*) on June 2013; SM: plots afforested and amendment with straw mulch on June 2013; RU: plots afforested and amendment with sewage sludge at the end of the first dry and wet Mediterranean season; HP: plots afforested and amendment with Terracottem hydroabsorbent polymers on June 2013.

Página: 22

Página: 22

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Please, reorganice the photos and the figure caption. Is really difficult to follow the explanation because the order is different.

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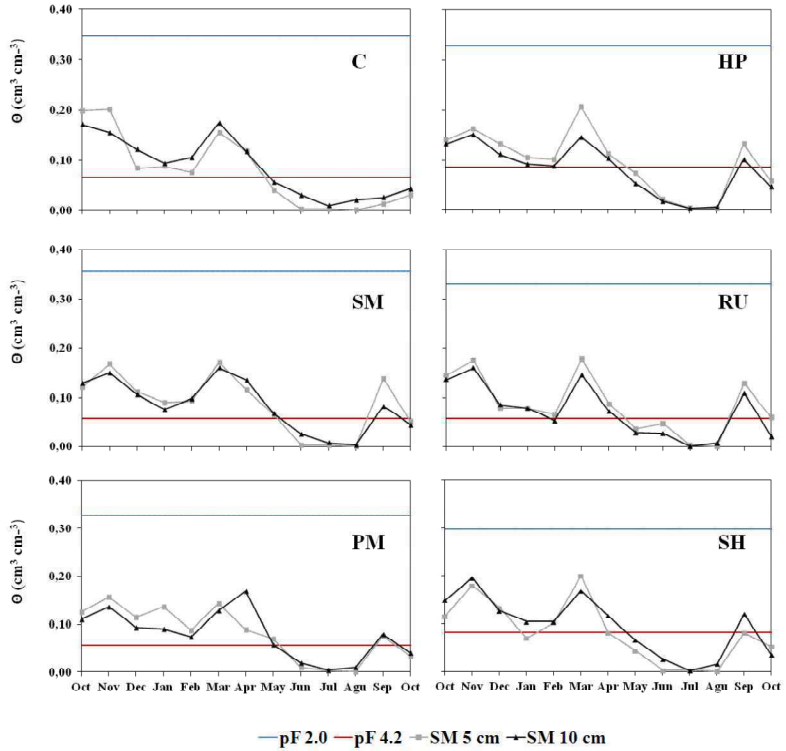

Figure 6: Soil moisture trends under different treatments and their relations with water retention capacity. Where: pF 2.0, Field capacity; pF 4.2, Wilting point ; C, control; SM, Straw mulch; PM, Chipped branches of *Aleppo pine*; RU, Sewage sludge; SH, Sheep manure; HP, Terracottem Hydroabsorbent polymers.

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		SOC (%)		pH		EC (µS cm^{-1})	
	n	Mean	SD±	Mean	SD±	Mean	SD±
C	8	3.0	0.4	7.7	0.0	374.0	31.5
PM	8	2.9	0.2	7.5	0.1	402.7	60.7
SM	8	2.5	0.2	7.6	0.0	385.2	54.8
RU	8	3.3	0.2	7.4*	0.1	507.2*	91.7
SH	8	3.7	0.4	7.7	0.0	389.2	111.8
HP	8	2.9	0.6	7.6	0.1	370.9	97.2

Table 1: Mean and standard deviation (SD) of soil organic carbon (SOC), soil acidity (pH) and soil salinity (EC) 30 months after the plots afforestation. Number of samples = 8. C: soil afforested. no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP. Terracottem hydroabsorbent polymers. * indicates a significant differences relative to the control (C) ($p < 0.05$).

		Depth 5 cm (cm^{-3} cm^{-3})				Depth 10 cm (cm^{-3} cm^{-3})			
Treatment	N	Mean	SD +	CV (%)	Max	Mean	SD +	CV (%)	Max
C	2	0.07	0.06	85.71	0.26	0.04	0.05	125.00	0.20
SM	2	0.08	0.07	87.50	0.23	0.07	0.05	71.43	0.22
PM	2	0.07	0.06	85.71	0.22	0.06	0.05	83.33	0.21
HP	2	0.10	0.07	70.00	0.31	0.05	0.06	120.00	0.21
RU	2	0.09	0.06	66.67	0.25	0.04	0.05	125.00	0.22
SH	2	0.08	0.07	87.50	0.23	0.05	0.04	80.00	0.20

Table 2: Annual average of Soil Water Content (cm^{-3} cm^{-3}) at 5 and 10 cm profile depths. The study period were form October 2011 to March 2014). N. number of replicas per treatment; SD±. Standar desviation; Max. Maximum Soil Water Content. Where: C: soil afforested. no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP. Terracottem hydroabsorbent polymers.

Página: 24

Página: 24

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You should specify that soil samples are for 0-10 cm.

I think that it should be also interesting to check if there are differences between amendments.

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In general line, as we have tested for amendments and control, no differeces beween amendments have been noted.The only difference tested was on RU plots for pH and EC with the rest of soil treatments (PM,SM, HP and SH).

Página: 24

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Página: 24

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EFFECTS OF TOPSOIL TREATMENTS ON AFFORESTATION IN A DRY-MEDITERRANEAN CLIMATE (SOUTHERN SPAIN)

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Abstract.

~~Revegetation programs in semiarid areas are associated with a high level of sapling mortality. Therefore, the development of alternative low cost and low environmental impact afforestation methods that ensure the survival of seedlings is necessary for the effective management of Mediterranean forest environments. This study assessed the effects of five types of soil amendment on the success of afforestation processes.~~

~~The amendments tested were: i) straw mulching (SM); ii) mulch containing chipped branches of Aleppo Pine (*Pinus halepensis* L.) (PM); iii) sheep manure compost from a wastewater treatment plant (SH); iv) sewage sludge (RU); and v) TerraCottem hydroabsorbent polymer (HP).~~ Afforestation programs in semiarid areas are associated with a high level of sapling mortality. Therefore, the development of alternative low cost and low environmental impact afforestation methods that ensure the survival of seedlings is crucial for improving the efficiency of Mediterranean forest management.

This study assessed the effects of five types of soil amendments on the success of afforestation processes. The amendments tested were: i) straw mulch; ii) mulch containing chipped branches of Aleppo Pine (*Pinus halepensis* L.); iii) sheep manure compost from a wastewater treatment plant; iv) sewage sludge; and v) TerraCottem hydroabsorbent polymer. We hypothesized that in the context of dry-Mediterranean climatic conditions, the use of organic amendments would enhance plant establishment and ensure successful afforestation. The results showed that afforestation success varied among the various soil amendment treatments in the experimental plots. The amendments had no effect on soil organic carbon, pH, or salinity, but the results indicate that the addition of mulch or hydroabsorbent polymer can reduced transplant stress by

increasing the soil water available for plant growth throughout the hydrological year, and potentially improve the success of afforestation by reducing plant mortality.

1 Introduction

~~The combination of climate change, lithology, geomorphology, and human activities has resulted in much of the Mediterranean region being affected by soil and vegetation degradation, which has led to desertification (Pérez Trejo, 1994; Brandt and Thornes, 1996; Puigdefabregas and Mendizabal, 1998; Muñoz Rojas et al., 2016a). These processes may not be spontaneously reversible, especially in forest environments, when certain thresholds are exceeded, being necessary to carry out restoration activities (Aronson et al., 1993; Whisenant, 1999).~~

The combination of climate change, lithology, geomorphology, and human activities has resulted in much of the Mediterranean region being affected by soil and vegetation degradation, which has led to desertification processes (Pérez Trejo, 1994; Brandt and Thornes, 1996; Puigdefábregas and Mendizábal, 1998; Martínez-Murillo et al., 2016; Muñoz-Rojas et al., 2016a and c, Martínez-Murillo et al., 2016). These processes may not be spontaneously reversible, especially in forest environments, when certain thresholds are exceeded, being necessary to carry out restoration activities (Aronson et al., 1993; Whisenant, 1999).

Vegetation plays a fundamental role in soil conservation (Thornes, 1990; Castillo et al., 1997; Cerdà, 2001). In Mediterranean ecosystems, increasing forest cover has been commonly considered to be a technique for mitigating the effects of desertification (Nykvist, 1983; Vallejo et al., 2000; ~~Le Honeuérou, 2000). However, in Mediterranean areas the conditions do not support natural colonization or artificial revegetation, because of previous soil erosion and the low levels of water and nutrient availability (Breton et al., 2016).~~ Le Honeuérou, 2000). However, a rapidly response of vegetation re-colonization could be limited on afforestation proposals due to the climatic conditions of semiarid areas. This is owing to the prevailing soil erosion processes and low levels of water and nutrient availability (Breton et al., 2016).

~~All the environmental factors involved in afforestation processes must be taken into account in determining the responses of plants (Navarros and Palacios, 2004).~~ All the environmental factors involved in afforestation processes must be taken into

account in determining the responses of plants (Navarro and Palacios, 2004). Burdett (1990) considered that climatic conditions and soil parameters play key roles in the initial stages following transplantation during afforestation. It is assumed that the risk of mortality declines when the period of transplantation stress is passed, and physiological attributes return to normal levels (Maestre et al., 2003). Thus, the most important period during afforestation is that during which the plants adjust their morphology and physiology to the new environmental conditions (Maestre et al., 2002a, 2002b, 2003).

In semiarid conditions, revegetation programs are associated with a high level of sapling mortality (Castro et al., 2002). In this context, saplings transplanted to the natural environment are subject to very different conditions from those in the nursery environment (Grossnickle, 2000). Two factors that particularly limit the establishment and growth of seedlings in Mediterranean environments are: i) excessive radiation; and ii) the limited availability of water during summer droughts (Valladares and Pugnaire, 1999).

Several studies have investigated various techniques aimed at increasing the survival of seedlings, including irrigation in summer, artificial shade, opening holes large volume with heavy machinery, and the use of protective cloth (Maestre and Cortina, 2002a). Numerous studies have shown that afforestation success is greater when the above techniques are implemented, especially in the first months following transplantation ~~(Arendt, 1997; Rey Benayas, 1998; Erktan et al., 2016).~~ (Arendt, 1997; Benayas, 1998; Erktan et al., 2016). However, most of these techniques are focused only on seedling protection, and do not involve a holistic view of the environment. Therefore, in the short and medium terms, these techniques are not effective in improving soil quality or reducing soil loss (Rey., 2009; Burylo et al., 2014). In addition, the use of these techniques significantly increases the cost of afforestation, in many cases they are not applicable because of the topographic conditions (Bochet and García-Fayos, 2004), and they often have major impacts on the ecosystem, which limits their use in areas where landscape conservation is a priority.

For the proper management of Mediterranean forest environments, alternative low cost afforestation methods that ensure the survival of seedlings and have minimal environmental impact are needed (Eldridge et al., 2012; Benigno et al., 2013). One way to improve soil conditions is to apply organic amendments to the soil. Numerous studies have assessed the use of organic amendments for vegetation establishment and soil fertility, including agricultural ~~soils (Ojeda et al., 2003; Jordan et al., 2010; Jiménez et al., 2013; Tejada and Gonzalez, 2013), eroded soils (Cohen Fernandez and Naeth, 2013; Prats et al.,~~

~~2013; Donn et al., 2014; Hoseini Bai et al., 2014), post mining soils (Eldrigge et al., 2012; Benigno et al., 2013; Muñoz Rojas et al.; 2016b), and afforested soils under Mediterranean conditions (Hueso González et al., 2014, 2015).~~ soils (Ojeda et al., 2003; Jordán et al., 2010; Jiménez et al., 2013; Tejada and Gonzalez, 2013), eroded soils (Cohen-Fernández and Naeth, 2013; Prats et al., 2013; Donn et al., 2014; Hosseini Bai et al., 2014; Cerdà et al., 2016; Prosdocimi et al., 2016), post-mining soils (Eldrigge et al., 2012; Benigno et al., 2013; Muñoz-Rojas et al., 2016b), and afforested soils under Mediterranean conditions (Hueso-González et al., 2014, 2015; Sadeghi et al., 2015).

~~However, more studies are needed to assess the effects of soil amendments in afforested areas under Mediterranean climate conditions.~~ However, more studies are needed to assess the effects of soil amendments in afforested areas under semiarid Mediterranean climatic conditions. This study assessed the effects of five types of soil amendment on afforestation success. We hypothesized that, in a context of dry-Mediterranean climatic conditions, the use of organic amendments could enhance plant establishment and contribute to afforestation success. The main objectives were to: i) analyze the effect of various organic amendments on some chemical and hydrological soil properties; and ii) assess the effects of these parameters on afforestation under dry-Mediterranean climatic conditions.

2 Materials and methods

2.1 Experimental site

The El Pinarillo experimental site is located in the Sierra Tejeda, Almijara and Alhama Natural Park (southern Spain). The site is located at 470 m a.s.l., in the upper part of an alluvial fan (calcareous conglomerates) surrounded by mountains having marble as the primary bedrock material (X: 424.240 m; Y: 4.073.098 m; UTM30N/ED50). The climate is dry-Mediterranean (mean annual temperature: 18 °C; mean annual rainfall = 589 mm y^{-1}). ~~The plots were located in an abandoned agriculture field recolonized by shrubs since at least the 1950s. The current vegetation consists of an open pine forest having Mediterranean scrubs and tussocks typical of degraded areas; the area was affected by a fire in 1991. The vegetation cover is > 70% and includes *Lavandula stoechas* L., *L. multifida* L., *Cistus albidus* D., *Rosmarinus officinalis* L., *Thymus capitatus* L., *Rhamnus alaternus* L., and annual plants. The soils are classified as lithic and eutric leptosols (FAO-WRB, 2006), and~~

~~are characterized by a high level of rock fragment cover on the surface (> 50%), a high gravel content in the profile (total gravel content = 56%; gravel content > 10 mm = 31%; gravel content 2f mm = 10%; gravel content 5f 1 mm = 15%), and a sandy loam texture (sand = 60%, silt = 32%, clay = 8%).~~ The experimental site is set up in an alluvial fan which was cultivated with cereals until 1950s. After its abandonment, the area was naturally recolonized by Mediterranean vegetal species of shrubs, mainly *Lavandula stoechas* L., *L. multifida* L., *Cistus albidus* D., *Rosmarinus officinalis* L., *Thymus capitatus* L., *Rhamnus alaternus* L. Currently, the vegetation cover is higher than 70% despite of a wildfire occurred in 1991. Due to the previous land use and water erosion processes, soils are eutric Leptosolos (FAO-WRB, 2006) featured by a high level of rock fragment cover on the surface (> 50%), a high gravel content in the profile (total gravel content = 56%; gravel content > 10 mm = 31%; gravel content 2f mm = 10%; gravel content 5f 1 mm = 15%), and a sandy–loam texture (sand = 60%, silt = 32%, clay = 8%).

2.2 Plots, amendments, and afforestation

~~An experimental paired plot layout was established (homogeneous slope gradient: 7.5%; aspect: N170°) in October 2010. The original vegetation cover was removed from the experimental area to avoid variation in the cover. Various management treatments and addition of organic amendments were applied in May 2011, using two replicate plots per treatment (24 m^2; 2 m wide × 12 m long). In November 2011, five organic soil amendments were tested: i) straw mulching (SM); ii) mulch composed of chipped branches of Aleppo pine (*Pinus halepensis* L.) (PM); iii) sheep manure compost from a wastewater treatment plant (SH); iv) sewage sludge (RU); and v) TerraCottem hydroabsorbent polymer (HP). The amendments were applied at a rate of 10 Mg ha^{-1}, and were replicated twice in a completed randomized block design.~~

~~Each plot was afforested with the same number of plants and the spatial pattern of Mediterranean shrubs used in management of the Natural Park of Sierra Tejeda, Almijara and Alhama.~~

In the experimental site, considering its homogeneous slope gradient (7.5%) and aspect (N170°), an experimental paired-plot layout was performed (12 plots; size: 2 m width x 12 m length; 24 m^2). The natural vegetation cover was removed within the experimental to preserve similar and initial eco-geomorphic conditions for the whole plots. Afterwards, in May 2011, certain amendments and treatments were added to soils in 10-paired replicate plots to the soil of the 12-plots ,with a rate of

application equal to 10 Mg ha^{-1} for all of them: straw mulching (SM), mulch composed of chipped branches of Aleppo pine (*Pinus halepensis* L.) (PM), sheep manure compost from a wastewater treatment plant (SH), sewage sludge (RU), and TerraCottem hydroabsorbent polymer (HP). Two control plots (C) with no amendments were also considered as an afforestation in natural conditions.

In November 2011, an afforestation plan was performed in these 12-plots following the same pattern of plantation in each of them (similar spatial pattern and vegetal species). The afforestation plan considered the same vegetal species that the managers from the natural park usually planted in their afforestation management.

The plant species used were *L. stoechas, L. dentatae, L. multifida, R. officinalis*, and *T. capitatus*. The plants were selected from a local nursery and were adapted to the type of environment under study. The plants were transplanted in a grid pattern at a spacing of 0.5 m between plants in each plot. During the afforestation process the soil was tilled to 25 cm depth from the surface. Two afforested control plots were included; these involved soil that received no amendment.

2.3 Monitoring of vegetation

The seedlings were assessed twice per year in the period 2011–2014: i) 6 months following transplantation (May 2012); ii) 12 months following transplantation (November 2012); iii) 20 months following transplantation (June 2013); and iv) 30 months following transplantation (May 2014). This frequency enabled assessment of growth and development of the plants during the dry and wet Mediterranean seasons, and to evaluate the effect of climatic (temperature and rainfall) and soil parameters including soil salinity (electrical conductivity: EC), soil organic carbon (SOC), and pH.

The number of surviving plants was determined during the field surveys, and the phenological state of plants was measured according to the criteria of Castro et al. (2002) and Gómez-Aparicio et al. (2004). A seedling was considered to be alive if living leaves, buds, or stems were observed. The plant height was measured from the ground to the terminal bud of the tallest stem. The maximum diameter of the canopy was also measured.

2.4 Soil analysis and measurements

~~Soil from the afforested plots was sampled in October 2010 and at 30 months following transplantation. The sampling strategy for each plot consisted in collecting four disturbed soil surface samples (0–10 cm depth).~~ Soil from the 12 afforested

plots was sampled in October 2010 and at 30 months following transplantation. The number of total soil samples was 48. The sampling strategy for each plot consisted in collecting four disturbed soil surface samples (0–10 cm depth). According to Pierce et al. (1994), this depth was chosen because it is where most of soil transformations occur. The soil properties analyzed were: i) EC, which was measured in a deionized water suspension of the soil (5:1) using a Crisol Micro CM 2200 conductivity meter (ISRIC, 2002); ii) soil acidity (pH), which was also measured in a deionized water suspension of the soil (2.5:1) using a Crisol GLP 21 pH meter; iii) SOC, which was determined using the Walkley-Black method, which involved oxidation using dichromate, and subsequent titration (FAO, 2006); and iv) water holding capacity (WHC), which was determined using a sand box (pF 2.0) and a Richards membrane (pF 4.2) (Richards, 1947; Stackman et al., 1969; Martinez-Fernandez, 1996). We measured the wilting point (WP) and field capacity (FC) to assess the hydrological state of the soil during the hydrological year, and its potential relationship to the water available for plants (AWC) (Caldwell, 1976).

~~Soil moisture probes (HOBO S-SMx-M005) were installed in the experimental area. Two probes were inserted into the soil profile in the middle of each plot, at 5 and 10 cm depths. Soil moisture was monitored and recorded at 10 min intervals. Because of the limited development of root systems by the afforested plants during the study period, analysis of the soil water content (SWC) included only the first 10 cm of soil profile (at 5 cm and 10 cm depths).~~ Soil moisture probes (HOBO S-SMx-M005) were installed within every amended and not amended paired-plots. Two probes were inserted into the soil profile in the middle of each plot at 5 and 10 cm depths. The total number of probes was 24 in the experimental area. Soil moisture was monitored and recorded at 10-min intervals. The depths were selected according to Hueso-Gonzalez et al. (2015) as well as to the limited development of root systems in depth by the afforested plants during the study period. The analysis of the soil water content (SWC) included only the first 10 cm of soil profile (at 5 cm and 10 cm depths).

2.5 Statistical analysis

~~Statistically significant differences were determined using analysis of variance (ANOVA). The assumption of homoscedasticity was tested using Levene's test. In cases of nonhomoscedasticity (Levene test; $p < 0.05$), nonparametric tests were used. Mean differences between the various experimental soil treatments were determined using Tukey's test or the Games Howell test. In all analyses the selected significance limit was $p < 0.05$. Analyses were performed using SPSS~~

~~(version 21) for Windows.~~

Normality and variance homogeneity were verified by Kolmogorov-Smirnov and Levene's tests, respectively. In all the analyses, the selected significance limit was $p < 0.05$. Most of vegetation data were non-normal, following different distributions and requiring nonparametric analysis. Sapling survival and growth, at 30 months from the planting stage, were analyzed using generalized linear mixed models (GLMMs, Bólker et al., 2009) that can be performed on both normal and non-normal data and allowed us to analyze both fixed effects (soil treatment, specie) and random effects (plots). Tukey's posthoc test were used to identify significant differences at $p < 0.05$ in growth for the different species among amendments. Nonparametric Kruskal–Wallis tests were used for variables that did not meet the assumptions of normality and variance homogeneity.

Differences in soil properties were tested by means of the analysis of variance (one-way ANOVA). The assumption of homoscedasticity was tested using Levene's test. In cases of nonhomoscedasticity (Levene test; $p < 0.05$), nonparametric tests were used. Mean differences between the various experimental soil treatments were determined using Tukey's test or the Games-Howell test. In all analyses the selected significance limit was $p < 0.05$.

Analyses were performed using SPSS (version 21) for Windows.

3 Results and Discussion

~~3.1 Survival of plants~~

~~Figure 1 shows the species survival rates and soil management during the study period. After 30 months, the survival rates in the control plots were 74.4%, 75.0%, 58.0%, 56.0%, and 37.5% for *L. multifida, R. officinalis, L. stoechas, T. capitatus*, and *L. dentate*, respectively. In these plots most of the mortalities occurred during the first summer period (Figs 1 and 2), which was characterized by a major severe drought relative to the subsequent two years. Similar results were reported by Bochet et al. (2007) in a study under Mediterranean conditions.~~

~~A substantial positive effect on survival rates was evident in the SM, PM, and HP treatments for *Lavandula sp.* and *T. capitatus* (Fig. 1). Similar results were reported by Breton et al. (2016), who showed that under Mediterranean climate conditions the supply of organic material improves the establishment of young plants, and reduces the mortality rate. With~~

respect to sapling growth, two positive significant effects were observed relative to the control, depending on the amendment type (Figs 3 and 4): i) the maximum canopy diameter and the terminal bud height were higher in the SM and PM treatments, especially for *Lavandula sp.*; and ii) in the HP plots, there was only an increase in maximum canopy diameter and no difference in height. Conversely, in the SH plots plant survival decreased rapidly or remained constant relative to the control, and at the end of the experiment the only sapling growth parameter that differed from the control was the maximum canopy diameter for *L. stoechas*.

For all afforestation species the survival rates approached 0% in the RU plots. This was because of growth of the herbaceous plant *Carlina hispanica*, which entirely covered the RU plots after the first wet season (Fig. 5). The root system of this plant is rhizomatous, and overwintering buds at 1–10 cm depth in the soil profile were observed during the field surveys. The thick root system of this plant is likely to be highly water absorbent, and was probably responsible for the mortality of the afforested saplings (Wahrmund et al., 2010).

3.2 Changes in SOC, pH and EC

SOC can be a limiting factor for plant establishment in degraded lands (Almendros et al., 2010; Hueso González et al., 2014). Many studies have shown that under these conditions, vegetation in areas having degraded soils may be better sustained if the soil is amended using an external source of organic matter (Jordán et al., 2010; Chaudhuri et al., 2013; Shazana et al., 2013; Srinivasarao et al., 2013). Montgomery et al. (2007) demonstrated that the application of crop mulch, sewage sludge, or animal manure positively affected plant cover because of an increase in SOC. Similar results have been reported by Ferreras et al. (2006), Franco-Otero et al. (2011), and González-Ubierna et al. (2012).

Table 1 shows that no significant differences in SOC where found in the SM, PM, RU, SH, and HP treatments relative to the control. One explanation for this is that there was a low rate of mineralization of these organic amendments because of three main factors: i) the lack of previous composting in the treatments added, which increased the time needed for decomposition processes to occur (García-Gomez et al., 2005); ii) the high content of lignin and cellulose in the amendments used (Duryea et al., 1999; Jensen, 2009); and iii) the medium high rates applied (10 Mg ha^{-1}) (Young et al., 2015). Jordán et al. (2010) showed that mineralization rates in a cultivated area in southwest Spain were higher when amendments were applied at low rates (3–5 Mg ha^{-1}). These results are consistent with those of González-Ubierna et al. (2012), who assessed SOC in the

months following addition of three test organic residues, but found no differences in SOC relative to that of the initial soil sample. Hueso-González et al. (2014) noted that in excess of 30 months was needed to detect the effect of these amendments on SOC values.

Changes in pH and EC were measured to determine whether these reflected differences in the afforested vegetation at the end of the study period. In this regard, Guang-Ming et al. (2006) and Li et al. (2007) showed that the application of certain organic amendments can cause a change in the pH and a slight increase in EC. Similarly, Parida and Das (2005) showed that variations in salinity or acidity can affect plant growth and survival rates. Allakhverdiev et al. (2000) reported that plants adversely affected by salinity grew more slowly and were stunted. Some studies have reported that changes on soil salinity and acidity during afforestation may cause sapling mortality (Ferreras et al., 2006; Guang-Ming et al., 2006).

There was no direct relationship between amendment addition and changes in soil salinity or acidity. Such changes depend on the type of amendment, its application rate, and the climatic conditions (Li et al., 2007; Hueso-González, 2014). In our study, no significant differences relative to the control plots were found. We only found significant differences in the RU treatment and at 30 months following afforestation (Table 2). However, based on previous studies the measured changes were not sufficient to cause the mortality of the afforested plants (Ferreras et al., 2006; Guang-Ming et al., 2006; Li et al., 2007).

In summary, there were no differences in SOC, pH, or EC among the treatments that could explain the differences in sapling survival described above.

3.1 Variability of available water content

In this section, we compare the variability of SWC and WHC during the study period in order to, specifically, identify the number of months with available water for plants. With respect to WHC, several studies have shown that inadequate soil water storage is the major limiting factor for the sapling establishment in semiarid areas (Hasee and Rose, 1993; Whisenant et al., 1999; South, 2000), and others have noted that new techniques are needed to increase the AWC in dryland soils (Tongway and Ludwing, 1996; Shachak et al., 1998). Ros et al. (2006) showed that the addition of certain amendments favored the development of vegetation cover in agricultural soils in Spain, because of increased soil moisture. Hueso-

González et al. (2015) reported an increase in SWC following the addition of amendments to soils, because of an increase in the macro-porosity.

Table 2 shows the annual average and maximum SWC values during the study period. In the control plots the average SWC was 7.0 ± 6.0% and 4.0 ± 5.0% at 5 and 10 cm depths, respectively. However, high coefficients of variation were found (CV > 80%), indicating seasonality in Mediterranean climatic conditions affects the variability in SWC values (Fig. 2). In contrast to the control, in the SM plots the mean value of SWC remained relatively constant with depth. In addition, the coefficient of variation at 10 cm depth was low, indicating greater stability in the SWC during the hydrological year; this indicates that the soil profile remained wetter, especially during the dry Mediterranean drought period. The pattern of SWC in PM plots was similar to that in the SM plots.

Soils amended with polymer (HP treatment) also showed an increase in the average SWC relative to the control (Table 2), with mean SWC values of 10.0 ± 7.0 % and 5.0 ± 6.0% at 5 and 10 cm depths, respectively. A similar SWC trend was found for the RU plots. However, the average and maximum values of SWC measured in the SH plots (Table 2) were very similar to those for bare soil (control plots).

The low survival rates found in the control plots (Fig. 1) can be explained by the Mediterranean climatic conditions in the study area, which include heavy rainfall and long dry spells, which increase plant stress and the difficulties of seedling root establishment (Don et al., 2014; Young et al., 2015). Bochet and García Fayos (2004) reported similar results in a study involving Mediterranean slope areas. In general, during the study period the SWC for sapling growth was below the wilting point (WP) for 6 months each year (Fig. 6). The seedling roots took up the water held in the soil at the beginning of the first dry season. The soil rapidly became dry, resulting in a shortage of AWC for plants. Besides, during the following months, the maximum evaporation process was due to the high temperature and the absence of rainfalls. Consequently, most of the mortality in the control plots occurred during the summer period of the first year (Fig. 2).

In plots that received soil amendments two patterns of AWC were observed (Fig. 6): i) the soils in the SM, PM, HP, and RU plots had higher AWC than in the control plots; and ii) the soils in the SH treatment had a lower AWC than in the control plots.

Figure 6 shows that in many months the AWC in soils amended with SM, PM, RU, or HP was higher than in the control plots, and consequently the water stress following afforestation was less. This was positively correlated with increased sapling survival rates in the SM, PM, and HP treatments (Fig. 1). Similar results were reported by Breton et al. (2016) in a study of soil amended with wood chips, where survival rates increased by 30%. The results are also consistent with those of Querejeta et al. (2001) and Castillo et al. (2001), who noted that revegetation programs in semiarid conditions needed previous soil preparation aimed at increasing water availability for plants.

An opposite trend was found in the SH treatment to that observed in the PM, SM, and HP treatments, with the soil in the former treatment having a soil AWC less than the WP for six months during the hydrological year (at 0-9 cm depth in the soil profile). This period, between April and August, coincided with the period in which maximum temperatures and minimum rainfall occurred (Fig. 2). Thus, evaporation processes were favored, and the afforested plants were subject to greater water stress. As a result, the plant survival rates in this treatment were less than in the others treatments (Fig. 1). The pattern of AWC in the SH treatment was similar to that found in the control plots (Fig. 6). This also explains the similarities in plant height and maximum diameter in the control and the SH treatment plots (Figs. 3 and 4).

In the RU plots, although there was 100% vegetation cover on the soil surface, this comprised an invasive nitrophilous grassland species introduced with the sewage sludge amendment (Fig. 5), even though the RU plots had been transplanted with the same number of plants and using the same spatial pattern of Mediterranean shrubs as in the other treatments. Previous studies at the experimental site indicated that this exogenous nitrophilous grassland outcompetes the afforestation species for nutrients and water (Hueso-Gonzalez et al., 2015), and this explains the high mortality measured in the RU plots. Guerrero et al. (2001) and Ojeda et al. (2003) measured a change in the ammonium and nitrite content in agricultural soils following sewage sludge application, and interpreted this as resulting from an increase in soil salinity that reduced the number of nitrifying bacteria. At the end of the study period, very few *L. stoechas* and *T. capitatus* plants remained in the RU plots.

Figures 3 and 4 show the effect of AWC on the plant height and maximum diameter in the PM, SM, and HP plots. Plots amended with PM and SM showed the greatest plant survival. This may have been related to greater AWC following amendment addition (Fig. 6), and may be similar to the effect described by Calvo et al. (2003) and Gabarrón Galeote et al.

~~(2013), who investigated the effect of litter on the SWC. In this study, the addition of mulch caused an increase in soil roughness and macro porosity, which increased infiltration processes (Hueso González et al. 2015). Adekalu et al. (2007) and Jordán et al. (2010) reported a reduction in soil evapotranspiration resulting from the protective effect of mulching. Nevertheless, in this study we could not establish differences between the effects of the SM and PM treatments because the survival rates and the plant growth were quite similar (Figs. 1, 3 and 4).~~

~~The RU amendment had an opposite effect to that in the SM, PM, RU, and HP plots. In this treatment the AWC was lower during the study period (Fig. 6), and was less than the WP for more than five months each year, from April to August, which coincided with the highest temperature and evapotranspiration values (Fig. 2). Consequently, plants were subject to a lack of water, and this stress resulted in higher mortality rates (Fig. 1). No significant differences relative to the control were found in the height of the apical bud or the plant diameter (Figs. 3 and 4).~~

3.1 Plant establishment. Differences on survival rates

Fig. 1 shows the species survival rates during the study period (2011-2014). According to our results, independently of the applied amendment, most of mortalities occurred during the first summer, between 6 and 12 months after plantation (Fig. 1 and 2). In this context, the plant stress can be defined through the physiological stress suffered by the sapling due to the limitation of nutrient and water after transplantation (Grossnickle., 2000). In Mediterranean and some semiarid regions with summer drought or very little rainfalls in this season, this plant stress could be the responsible of the initial increase of the plant mortality due to the limited root development of the saplings and their inability to access the water contained in the lower layers of the soil profile (Maestre et al., 2002a; Maestre et al., 2002b, Bochet et al., 2007).

According to Hasse and Rose (1993), in those regions, soil preparation could be a powerful tool for reducing the possible plant stress suffered during the lack of water in summer. Several studies demonstrated the supply of organic material could interfere with the establishment of young plants and, in some cases, can reduce the mortality rate in the initial moments (Woods et al., 2012; Benigno et al., 2013; Hoseini Bai et al., 2014; Breton et al., 2016).

Considering plant survival, the experiment showed a significant effect of the type of vegetal species (p = 0.008) and soil amendment (p = 0.000, Table 1.a). Thus, comparing to the control plots, different trends on survival rate were observed when the afforestation was supported by the addition of organic amendments. Firstly, a positive effect on survival rates for all the species were significantly evident in the case of SM, PM, and HP treatments (Table 1b). Namely, the best survival

rates were observed for *Lavandula dentatae* and *Thymus capitatus* which exceed 40% comparing to control (Fig. 1). The other species presented intermediate results, with an increase of 20-25% regarding to control condition. Secondly, the opposite trend on survival rates was registered for the soil amended with SH or RU. In these plots, the results showed a negative effect for the sapling establishment. Specifically, regarding to control plots, not significant difference on survival rates was tested for SH (Table 1.b). Thus, plant survival was slightly decreased (*L. dentatae, L. stoechas or Thymus capitatus*) or remained constant (*L. multifida* and *Rosmarinus officinalis*) (Fig.1).

Concerning to RU, the situation was more dramatic that in the case of SH due to significant differences were noted regarding to the control plots (Table 1.b). Namely, the survival rates approached to 0% independently of the vegetal specie tested. These data were removed for further analysis. This fact was justified due to the growth of herbaceous plants, named *Carlina hispanica*, which entirely covered the RU plots after the first wet season (Fig.5). Its root system is rhizomatous and overwintering buds at 1-10 cm depth in the soil profile were observed during the field surveys, and is likely to be highly water absorbent being responsible for the mortality of the afforested saplings (Wahrmund et al., 2010).

3.2 Plant establishment. Differences on growth (diameter and height)

In relation to the growth of young plants, significant effects were observed between soil amendments and vegetal species respect to diameter and height, the former (p= 0.000; p= 0.000, respectively), and height, the latter (p= 0.000) (Table 1.a). Besides, results for Table 1.b showed marked differences on plant growth depending of the species and amendment used. Thus, independently of the vegetal specie, differences in plant architectural form (height and diameter) were obvious. These differences were significant for SM and PM and have been ignored in SH or RU (Table 1.b). In the case of HP plots, the significant differences on diameter and height were shown depending to the specie used (Table 1.b).

Focusing on each vegetal species, the specific differences tested on diameter and height were significant in the case of *Lavandula sp*. and *Thymus capitatus* after SM, PM and HP addition (Fig. 3 and 4). An increase in maximum canopy diameter was registered for most of afforested species (Fig.4). Thereby, significant differences were specifically tested in *L. stoechas, L. multifida, L. dentatae and Thymus capitatus* (Fig.4; one-way ANOVA; $p < 0.050$). Also, concerning to maximum terminal bud (Fig. 3), a significant positive effect ($p < 0.050$) were also registered for *L. stoechas* (in SM, PM and HP), *L. multifida* (in SM and PM) and *Thymus capitatus* (SM and HP).

3.3 Chemical properties and their impact on plant establishment

3.3.1 Changes in SOC

In this study, changes in SOC were measured to determine whether these reflected differences in the afforested vegetation at the end of the study period. SOC can be a limiting factor for plant establishment in semiarid lands with degraded soils (Almendros et al., 2010; Hueso-González et al., 2014). These conditions could imply major vegetation survivals whether the soils are amended with an external source of organic matter (Jordán et al., 2010; Chaudhuri et al., 2015; Shazana et al., 2013; Srinivasarao et al., 2013). In fact, the addition of soil organic matter by means of crop either mulch, sewage sludge or animal manure enhances vegetation growth and cover (Montgomery et al. (2007). Similar results were reported by Ferreras et al. (2006), Franco-Otero et al. (2011), and González-Ubierna et al. (2012).

Table 2 shows that there were no significant differences in SOC in the case of SM, PM, RU, SH, and HP treatments compared to the control ($p \geq 0.05$) 30 months after the amendment addition. It is pointed out that there was a low rate of mineralization of these organic amendments because of three main factors: i) the lack of previous composting in the treatments added, which increased the time needed for decomposition processes to occur (García-Gomez et al., 2005); ii) the high content of lignin and cellulose in the amendments used (Duryea et al., 1999; Jensen, 2009); and iii) the medium-high rates applied (10 Mg ha^{-1}) (Young et al., 2015). Jordán et al. (2010) showed that mineralization rates in a cultivated area in southwest Spain were higher when amendments were applied at low rates (3–5 Mg ha^{-1}). González-Ubierna et al. (2012) achieved similar results as well when testing differences in SOC after the additions of three test organic residues. Hueso-González et al. (2014) noted that more than 30 months were needed to detect the effect of these amendments on SOC values.

3.3.2 Changes in pH and EC

Changes in pH and EC were measured to determine whether these reflected differences in growth of the afforested vegetation at the end of the study period (Table 2). ,Guang-Ming et al. (2006) and Li et al. (2007) showed that the application of certain organic amendments could cause a change in the pH and a slight increase in EC. Similarly, Parida and Das (2005) showed that variations in salinity or acidity can affect plant growth and survival rates. Allakhverdiev et al. (2000) reported that plants adversely affected by salinity grew more slowly and were stunted. Some studies have reported that

changes on soil salinity and acidity during afforestation may cause sapling mortality (Ferreras et al., 2006; Guang-Ming et al., 2006).

According to others authors, after certain soil treatment, there is not a direct relationship between the amendment addition and the increment in soil salinity or acidity (Ferreras et al., 2006). These changes depend on the type and application rate of amendment as well as the climatic conditions (Li et al., 2007; Hueso-González et al., 2014). In our study, amendments were applied mixed with soil at the rate of 10 Mg ha^{-1} and no significant differences regarding the control plots were found. We only detected significant differences in the RU treatment 30 months after the afforestation (Table 3). However, based on previous studies, the measured changes were not sufficient to cause the mortality of the afforested plants (Ferreras et al., 2006; Guang-Ming et al., 2006; Li et al., 2007).

3.4 Available water for plants and their impact on vegetation establishment

In summary, a positive effect on afforestation performance, survival and growth was previously described when the soil were amended with SM, PM and HP and no benefit were noted after the SH and RU addition (Table 1, Figs. 1, 3 and 4). Besides, the lack of differences founded in SOC, pH or EC among the treatments could not justify the differences on survival rates and plant growth previous described (Table 2).

Subsequently, we aim to analyze the variability of SWC after the amendment addition and its relation with the WHC during the study period. Namely, this was carried out in order to identify the number of months with available water for plants and their relation with the establishment and growth of plants. With respect to WHC, several studies have shown that inadequate soil water storage is the major limiting factor for the sapling establishment in semiarid areas (Hasee and Rose, 1993; Whisenant et al., 1999; South, 2000), whilst others have reported new techniques are needed to increase the AWC in dryland soils (Tongway and Ludwing, 1996; Shachak et al., 1998). Ros et al. (2006) showed that the addition of certain amendments favoured the development of vegetation cover in Spain, because of increased soil moisture. Accordingly, Hueso-González et al. (2015) reported an increase in SWC following the addition of amendments to soils due to an increase in the macro-porosity.

Table 3 shows the annual average and maximum SWC values during the study period. In the control plots the average SWC was 7.0 ± 6.0% and 4.0 ± 5.0% at 5 and 10 cm depths, respectively. However, high coefficients of variation were found (CV

> 80%) indicating a likely effect of the rainfall seasonality in Mediterranean climatic conditions affecting the variability in SWC (Fig. 2). The low survival rates found in the control (Fig. 1) can be explained by this seasonality, which include heavy rainfall and long dry spells in the initial months after the afforestal proposal (Don et al., 2014; Young et al., 2015). Bochet and García-Fayos (2004) reported similar results in a study involving Mediterranean slope areas. Generally, during the study period the SWC for sapling growth was below the wilting point (WP) for 6 months each year (Fig. 6). The seedling roots took up the water held in the soil at the beginning of the first dry season. The soil rapidly became dry, resulting in a shortage of AWC for plants. Besides, during the following months, in summer, the maximum evaporation process took place due to the high temperature and the absence of rainfalls. Consequently, most of the mortality in the control plots occurred during the summer period of the first year (Fig. 2).

In plots that received soil amendments, two contrasted patterns of AWC were observed (Fig. 6): i) the soils in the SM, PM, HP, and RU plots presented higher AWC than in the control plots, whilst ii) lower in the soils treated with SH treatment. In general terms, the trends observed were coincident with the patterns previously reported for survival rates and plant growth (diameter and height) (Table 1 and Figs. 1, 3 and 4).

SM, PM, RU and HP treatments showed an increase in the average SWC respect to the control conditions (Table 3). In this sense, Figure 6 shows the AWC in soils amended with SM, PM, RU, or HP was higher than in the control during most of time, and, consequently, there was less water stress following afforestation. This was well related with the increment in sapling survival rates founded in the SM, PM, and HP treatments (Table 1b, p= 0.000, and Fig. 1). Similar results were reported by Breton et al. (2016) in a study of soil amended with wood chips, where survival rates increased by 30%. The results are also consistent with those of Querejeta et al. (2001) and Castillo et al. (2001), who noted that revegetation programs in semiarid conditions needed previous soil preparation aimed at increasing water availability for plants. Figures 3 and 4 show the effect of AWC on the plant height and maximum diameter in the PM, SM, and HP plots. Regarding the control, the plots amended with PM and SM also showed significant differences on plant growth (height and diameter) (Table 1b, p =0.000; p = 0.00; p =0.002; p =0.040, respectively). In SM and PM plots the mean value of SWC remained relatively constant with depth (Table 3). In addition, the coefficient of variation at 10 cm depth was low, indicating greater stability in the SWC during the hydrological year. This indicated the soil moisture remained higher in the profile,, especially,

during the dry Mediterranean drought period. This may have been related to greater AWC following amendment addition (Fig. 6), and may be similar to the effect described by Calvo et al. (2003) and Gabarrón-Galeote et al. (2013), who investigated the effect of litter on the SWC. In this study, the addition of mulch caused an increase in soil roughness and macro-porosity, which increased infiltration processes (Hueso-González et al. 2015). Adekalu et al. (2007) and Jordán et al. (2010) reported a reduction in soil evapotranspiration resulting from the protective effect of mulching. Nevertheless, in this study we could not establish differences between the effects of the SM and PM treatments because the survival rates and the plant growth were quite similar (Figs. 1, 3 and 4).

RU needs a different explanation to that described for soils with SM, PM and HP. In this treatment, AWC for plant were increase regarding to control (Fig. 6). However, the survival rates were close to 0% (Fig. 1). In the RU plots, although there was vegetation cover of 100%, this occurred due to an invasive nitrophilous grassland species introduced with the sewage sludge amendment (Fig. 5), even though the RU plots had been transplanted with the same number of plants and using the same spatial pattern of Mediterranean shrubs as in the other treatments. Previous studies at the experimental site indicated that this exogenous nitrophilous grassland outcompetes the afforestation species for nutrients and water (Hueso-Gonzalez et al., 2015), and this explains the high mortality measured in the RU plots. Guerrero et al. (2001) and Ojeda et al. (2003) measured a change in the ammonium and nitrite content in agricultural soils following sewage sludge application, and interpreted this as resulting from an increase in soil salinity that reduced the number of nitrifying bacteria. At the end of the study period, very few *L. stoechas* and *T. capitatus* plants remained in the RU plots.

The SH amendment showed the opposite effect on SWC and WHC that have been reported for SM, PM, RU, and HP plots. The AWC was lower during the study period (Table 3 and Fig. 6) and below the wilting point for more than five months in every year, from April to August, coinciding with the highest temperature and evapotranspiration values (Fig. 2). Consequently, the plants suffered lack of water into the soil and this stress resulted in higher mortality rates (Fig. 1). This period of water stress, under the WP, was between April and August and coincided with the Mediterranean dry-period in which maximum temperatures and minimum rainfall occurred (Fig. 2). As a result, the plant survival rates noted in this treatment were lesser than in the others treatments (Table 1 and Fig. 1). Besides, the pattern of AWC in the SH treatment

was similar to that found in the control plots (Fig. 6). This also explains the similarities, not significant differences, in plant height and maximum diameter in the control and the SH treatment plots (Table 1b, p =0.197; p =0.089, respectively).

4 Conclusions

i) Under dry-Mediterranean climate conditions the afforestation success varied depending on the amendments applied to the soil in the experimental plots.

ii) The amendments, applied to the soil to improve plant survival, did not cause significant changes to the soil organic carbon content, pH, or electrical conductivity.

iii) Significant differences in the water available for plants occurred among the various soil amendment treatments, with the straw mulch, Aleppo Pine, and TerraCottem hydroabsorbent polymer treatments having very positive effects on plant growth.

In terms of land management, this study shows that the addition of mulch or hydroabsorbent polymer can reduce transplanting stress, and improve the success of afforestation programs by reducing the mortality of plants.

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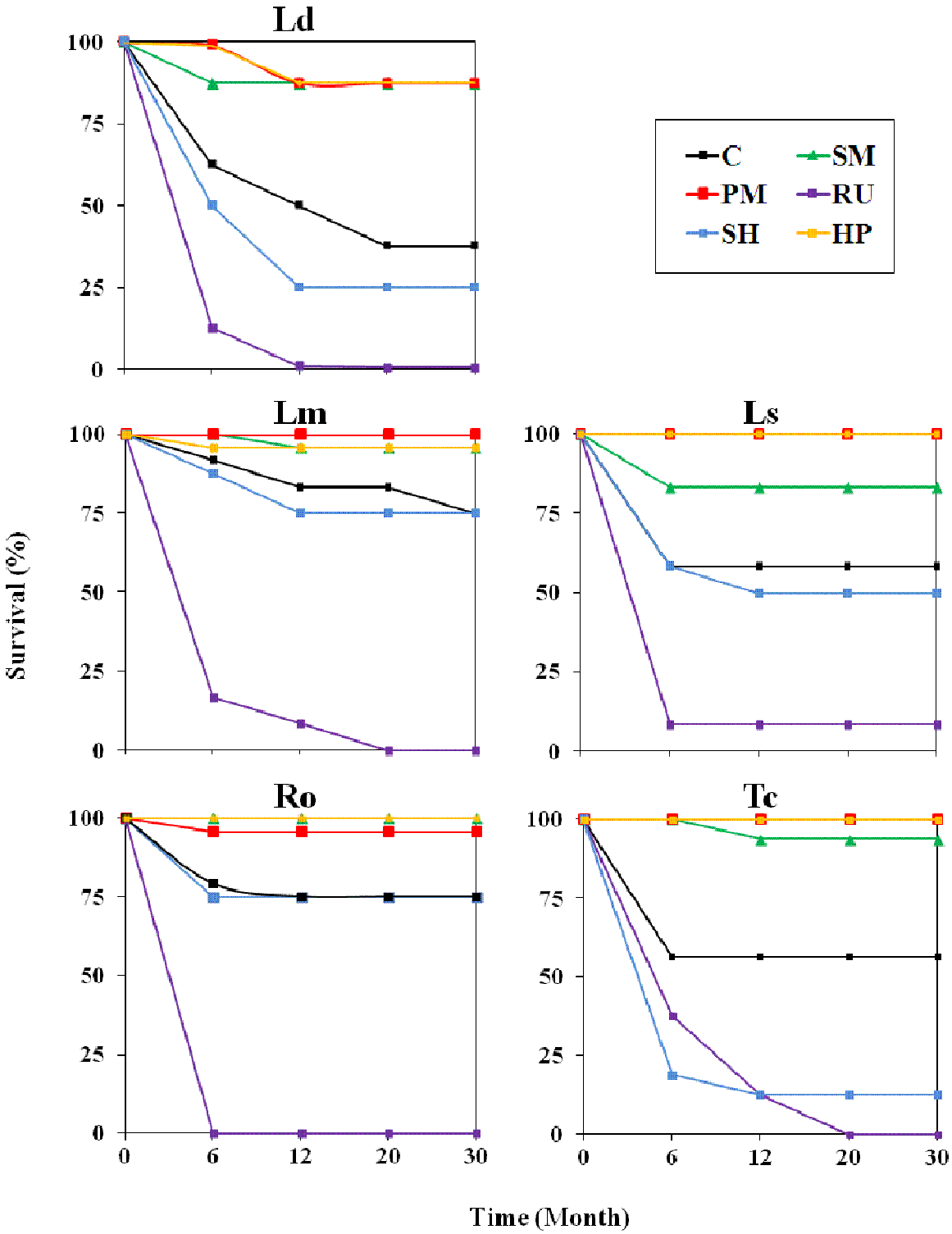
Ld
Lm
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Survival (%)
Time (Month)
100
75
50
25
0
0
6
12
20
30

~~**Figure 1: Comparison of survival rates (%) between amendments and control in the period 2011-2014. Where: C: soil afforested. no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP: Terracottem hydroabsorbent polymers.**~~ **Figure 1: Comparison of survival rates (%) between amendments and control in the period 2011-2014. Where: C: soil afforested and no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP: Terracottem hydroabsorbent polymers; Ls: Lavandula stoechas; Lm: Lavandula multifida; Ld: Lavandula dentatae; Ro: Rosmarinus officinalis; Tc: Thymus capitatus.**

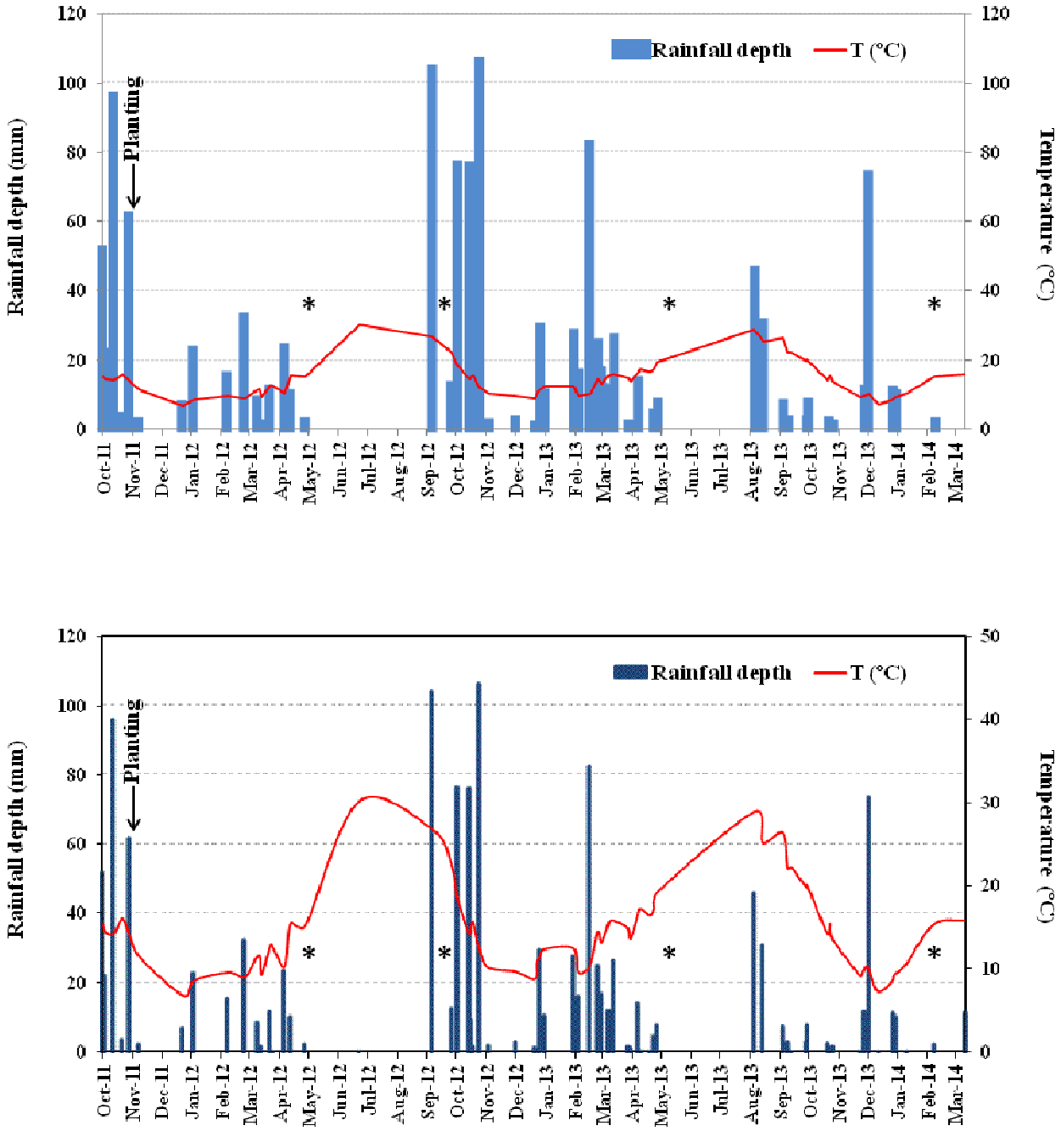
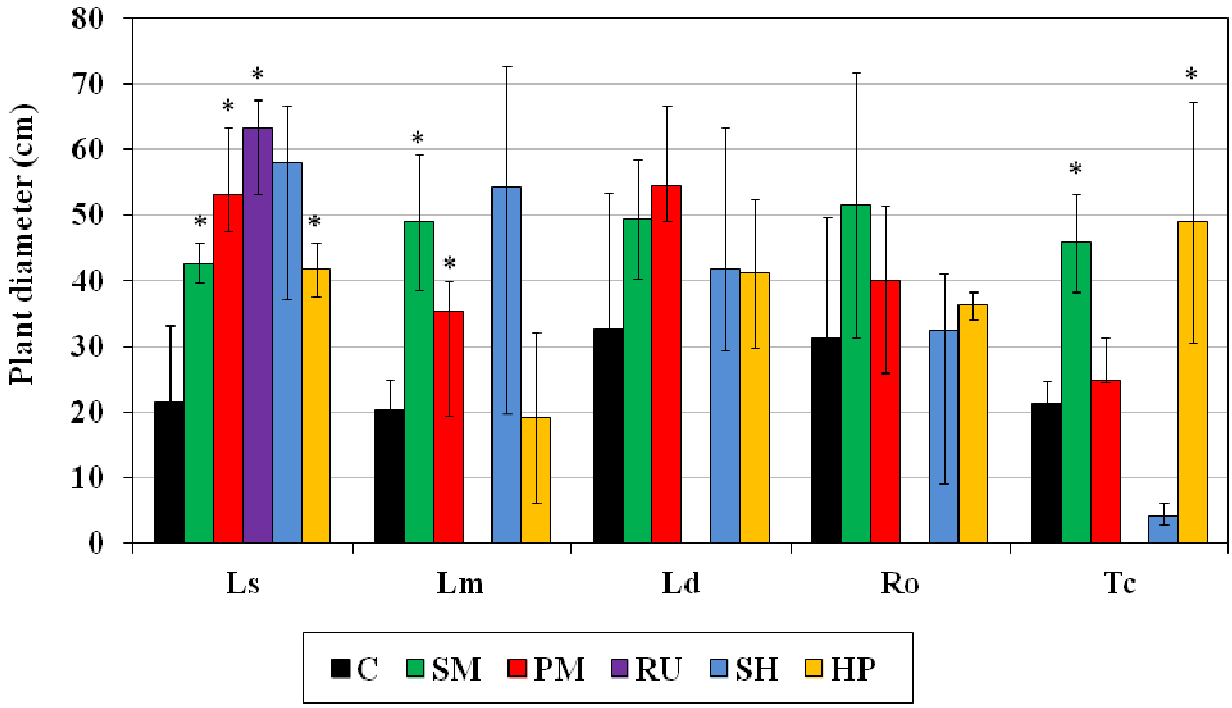
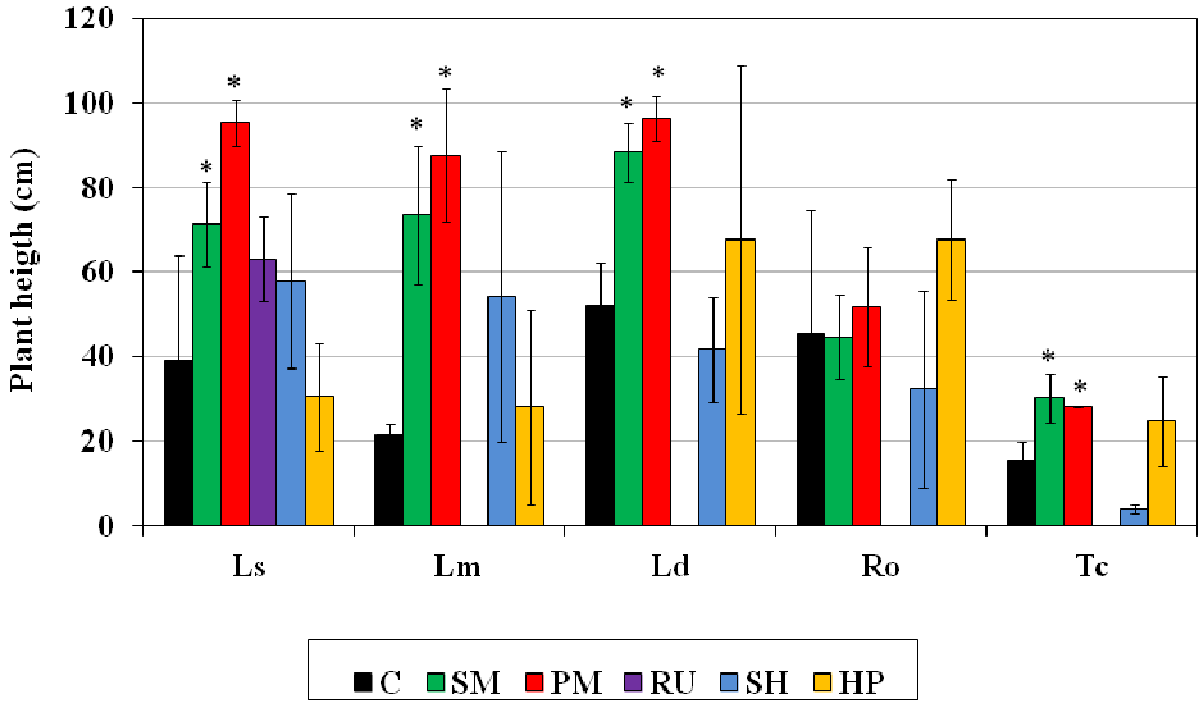


Figure 2: Temporal variability in rainfall and temperature from October 2011 to March 2014. Black astericks indicates the vegetation observation dates.



~~**Figure 3: Maximun diameter of the canopy (cm), 30 months following transplantation, May 2014. Where: C: soil afforested, no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP: Terracottem hydroabsorbent polymers. * indicates a significant differences relative to the control (C) ($p < 0.05$).**~~



~~**Figure 4: Plant height from ground to terminal bud of the tallest stem (cm), 30 months following transplantation, May 2014. Where: C: soil afforested, no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP: Terracottem hydroabsorbent polymers. * indicates a significant differences relative to the control (C) ($p < 0.05$).**~~

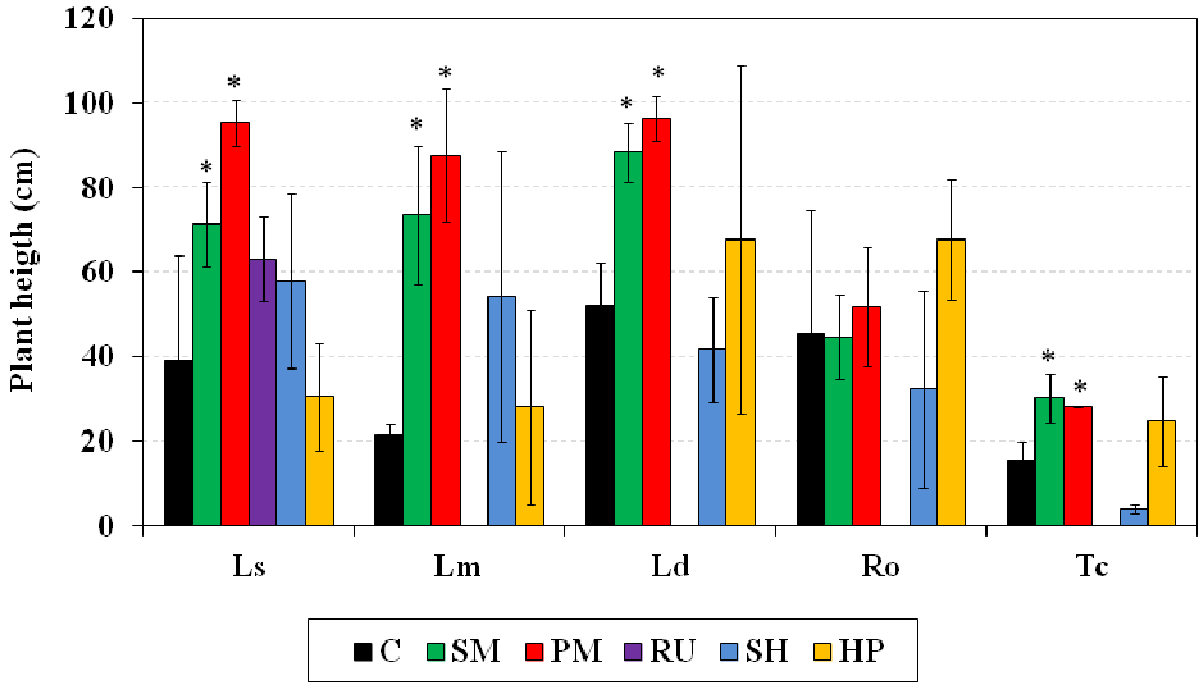


Figure 3: Plant height from ground to terminal bud of the tallest stem (cm), 30 months following transplantation, May 2014. Where: C: soil afforested and no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP: Terracottem hydroabsorbent polymers; Ls: Lavandula stoechas; Lm: Lavandula multifida; Ld: Lavandula dentatae; Ro: Rosmarinus officinalis; Tc: Thymus capitatus. * indicates a significant differences relative to the control (C) ($p < 0.05$).

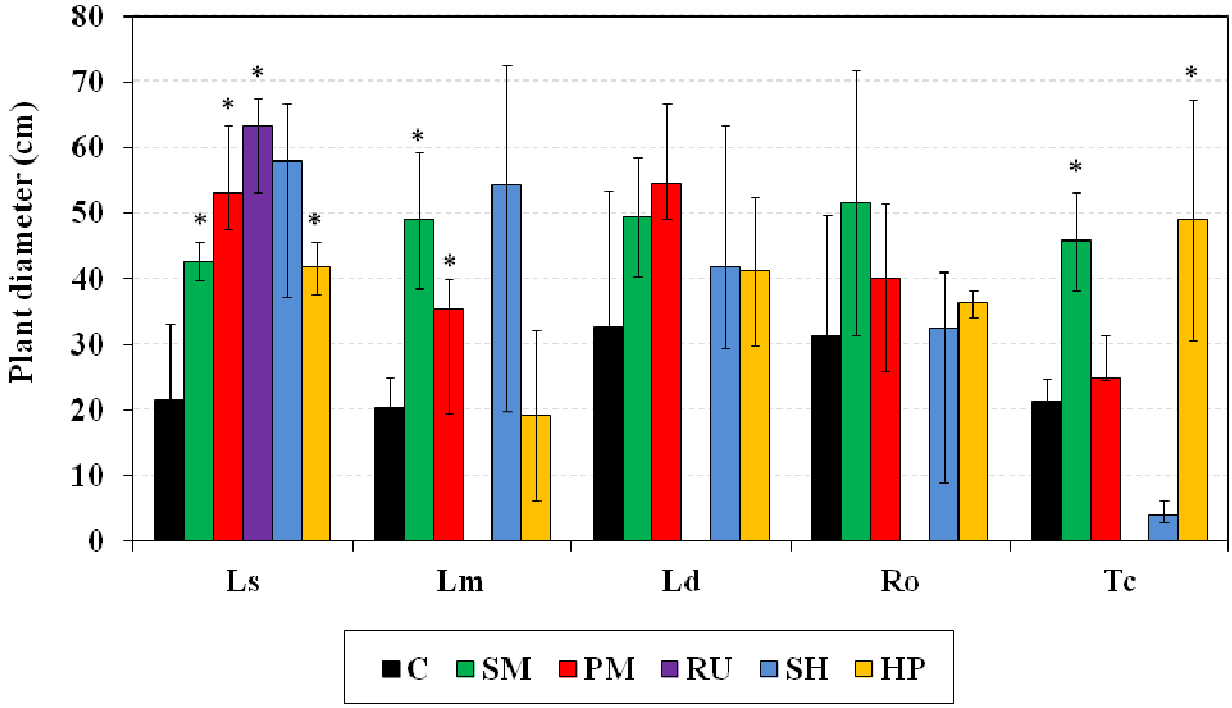


Figure 4: Maximun diameter of the canopy (cm), 30 months following transplantation, May 2014. Where: C: soil afforested and no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP: Terracottem hydroabsorbent polymers; Ls: Lavandula stoechas; Lm: Lavandula multifida; Ld: Lavandula dentatae; Ro: Rosmarinus officinalis; Tc: Thymus capitatus. * indicates a significant differences relative to the control (C) ($p < 0.05$).

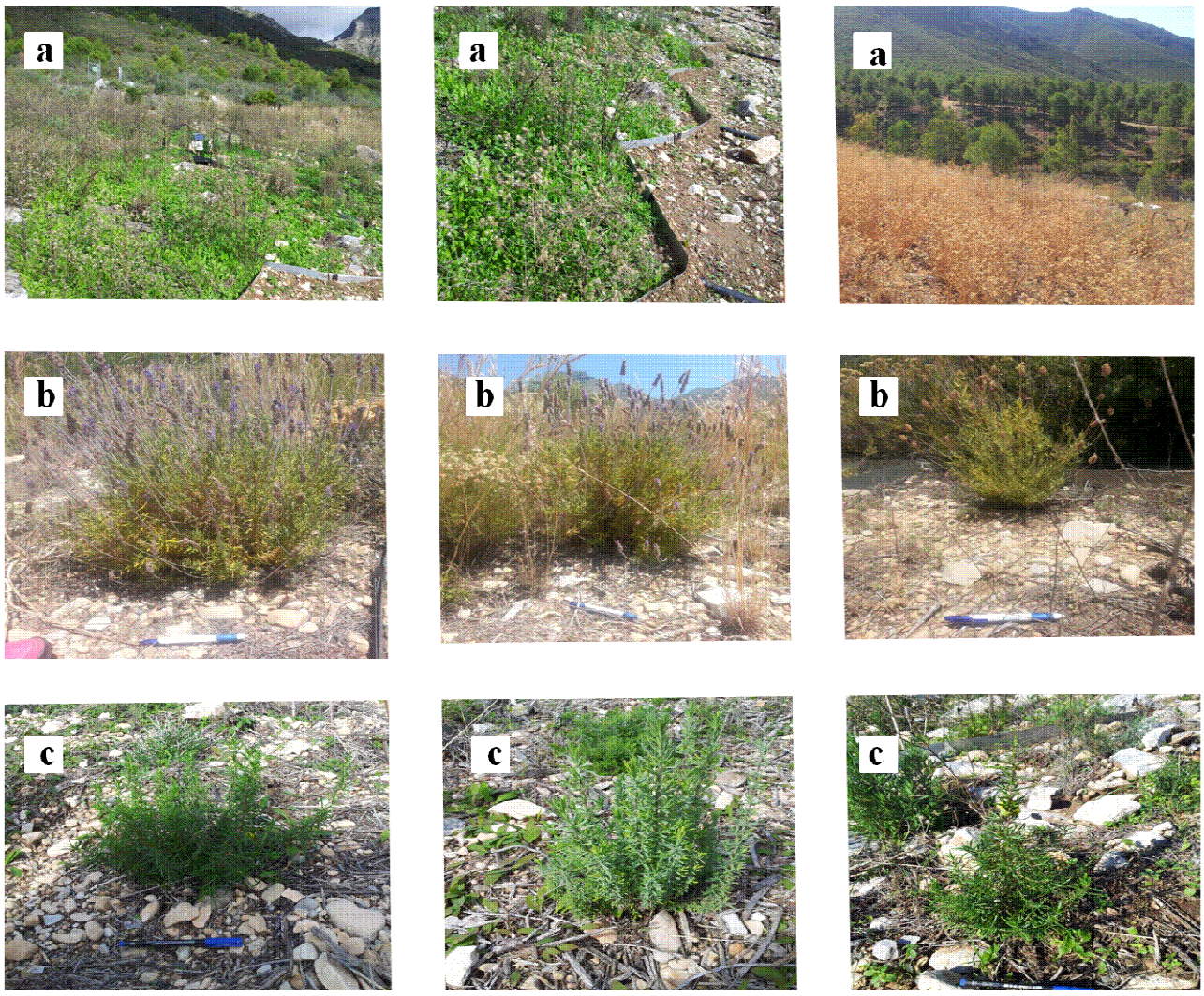
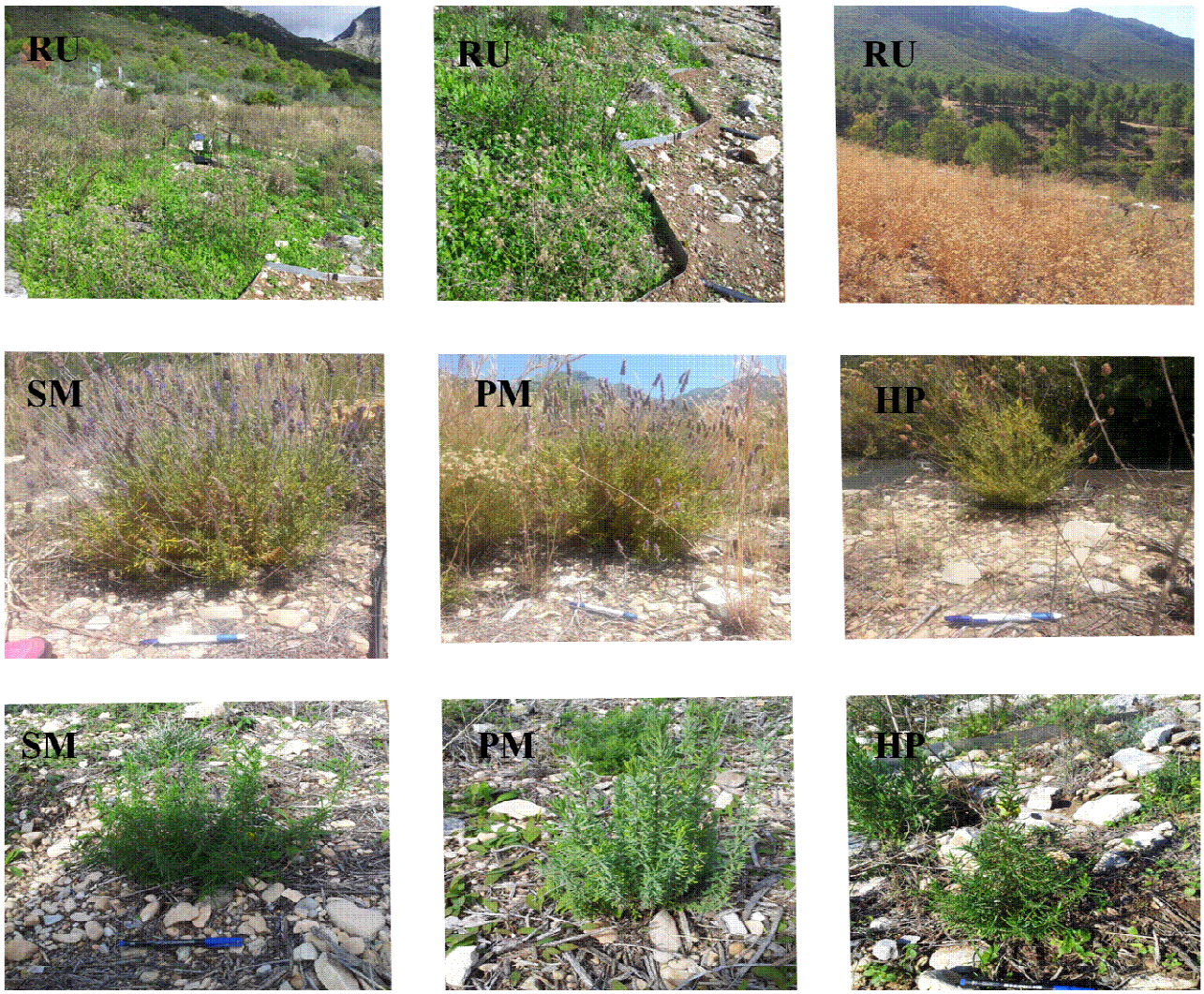


Figure 5: Pictures of the experimental plots. Where: From left to right; a) plots amendment with sewage sludge covered by *Carlina hispanica* Lam. in May 2012; June 2012 and September 2012, respectively; b) Lavandula dentatae individuals, June 2013, for straw mulch, pinus mulch and hydroabsorbent polymers plots, respectively; c) Rosmarinus officinalis individuals, June 2013, for straw mulch, pinus mulch and hydroabsorbent polymers plots, respectively



~~**Figure 5: Pictures of the experimental plots. Where: PM: plots afforested and amendment with mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*) on June 2013; SM: plots afforested and amendment with straw mulch on June 2013; RU: plots afforested and amendment with sewage sludge at the end of the first dry and wet Mediterranean season; HP: plots afforested and amendment with Terracottem hydroabsorbent polymers on June 2013.**~~

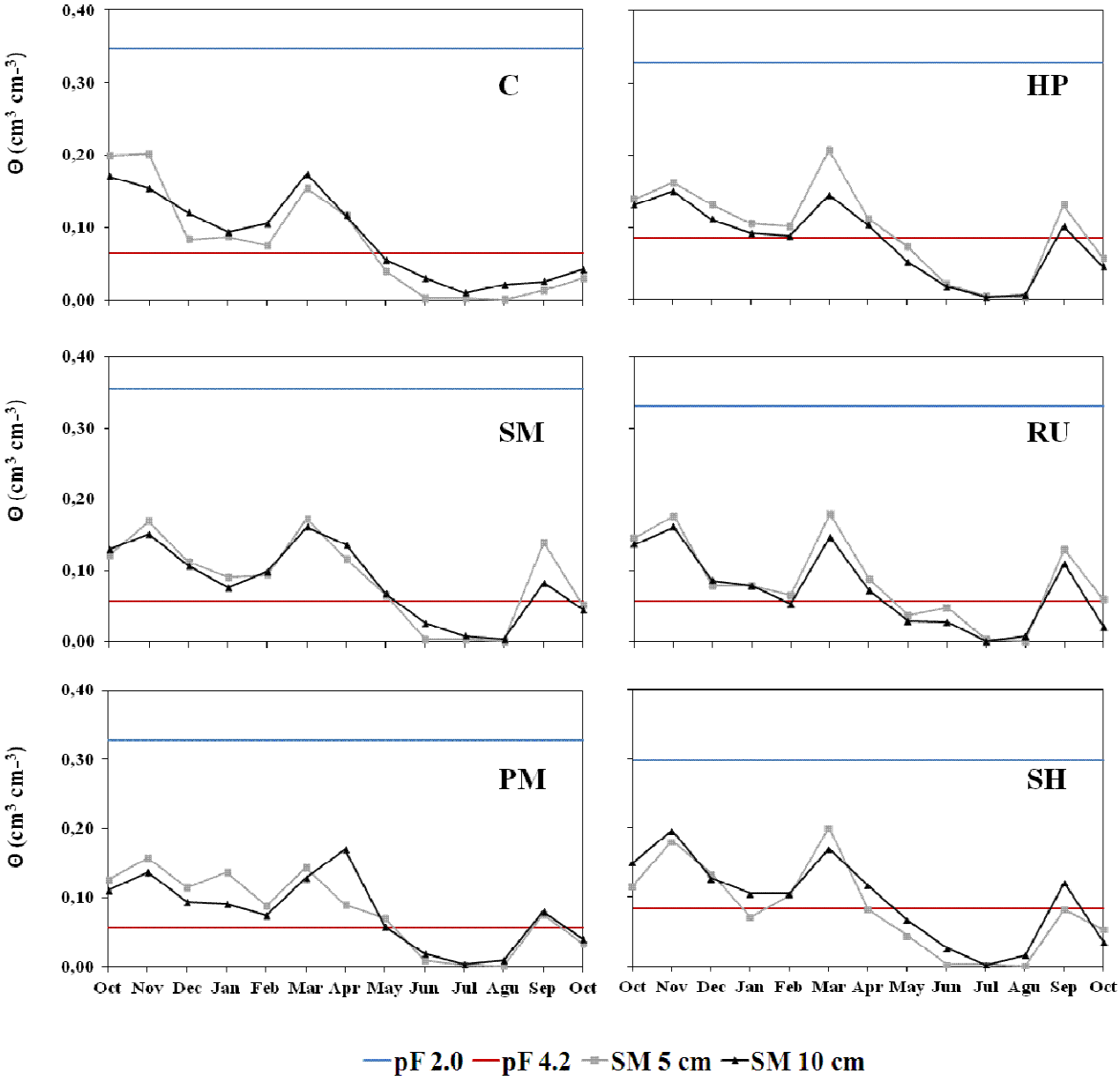


Figure 6: Soil moisture trends under different treatments and their relations with water retention capacity. Where: pF 2.0, Field capacity; pF 4.2, Wilting point ; C, control; SM, Straw mulch; PM, Chipped branches of *Aleppo pine*; RU, Sewage sludge; SH, Sheep manure; HP, Terracottem Hydroabsorbent polymers.

Table 1: Mean and standard deviation (SD) of soil organic carbon (SOC), soil acidity (pH) and soil salinity (EC) 30 months after the plots afforestation. Number of samples = 8. C: soil afforested. no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP. Terracottem hydroabsorbent polymers. * indicates a significant differences relative to the control (C) ($p < 0.05$).

		SOC (%)		pH		EC (µS cm^{-1})	
	n	Mean	SD±	Mean	SD±	Mean	SD±
C	8	3.0	0.4	7.7	0.0	374.0	31.5
PM	8	2.9	0.2	7.5	0.1	402.7	60.7
SM	8	2.5	0.2	7.6	0.0	385.2	54.5
RU	8	3.3	0.2	7.4*	0.1	507.2*	91.7
SH	8	3.7	0.4	7.7	0.0	389.2	111.8
HP	8	2.9	0.6	7.6	0.1	370.9	97.2

		Depth 5 cm (cm^{-3} cm^{-3})				Depth 10 cm (cm^{-3} cm^{-3})			
Treatment	N	Mean	SD ±	CV (%)	Max	Mean	SD ±	CV (%)	Max
C	2	0.07	0.06	85.71	0.26	0.04	0.05	125.00	0.20

SM	2	0.08	0.07	87.50	0.23	-	0.07	0.05	71.43	0.22	-
PM	2	0.07	0.06	85.71	0.22	-	0.06	0.05	83.33	0.21	-
HP	2	0.10	0.07	70.00	0.31	-	0.05	0.06	120.00	0.21	-
RU	2	0.09	0.06	66.67	0.25	-	0.04	0.05	125.00	0.22	-
SH	2	0.08	0.07	87.50	0.23	-	0.05	0.04	80.00	0.20	-

Table 2: Annual average of Soil Water Content (cm^{-3} cm^{-3}) at 5 and 10 cm profile depths. The study period were form October 2011 to March 2014). N. number of replicas per treatment; SD=. Standar desviation; Max. Maximum Soil Water Content. Where: C: soil afforested. no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP. Terracottem hydroabsorbent polymers.

Table 1. (a) Vegetation measurement: likelihood ratio test for fixed effects on fixed effects soil treatment in species based on generalizated mixed effect models (GLMMs) for plant survival and growth 30 months after the afforestation. (b) Post-hoc multiple comparison for observed means (Tuckey's test; $p < 0.05$). PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP. Terracottem hydroabsorbent polymers.

(a)	Effect				X^2	*p*-value
	Survival					
	Soil amendment				43.94	**0.000**
	Species				13.73	**0.008**
	Growth in heigth					
	Soil amendment				61.38	**0.000**
	Species				38.79	**0.000**
	Growth in diameter					
	Soil amendment				64.66	**0.000**
	Species				07.92	0.094

(b)		SM	PM	RU	SH	HP
	Survival	**0.000**	**0.000**	**0.000**	0.079	**0.000**
	Growth in heigth	**0.049**	**0.002**	0.197	0.998	0.909
	Growth in diameter	**0.007**	**0.040**	0.089	1.000	0.357

p values in bold indicate a significant effect (< 0.05)

Table 2. Mean and standard deviation (SD) of soil organic carbon (SOC). soil acidity (pH) and soil salinity (EC) 30 months after the plots afforestation. Number of samples = 8. C: soil afforested. no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP. Terracottem hydroabsorbent polymers. * indicates a significant differences relative to the control (C) ($p < 0.05$).

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Table 3. Annual average of Soil Water Content (%) at 5 and 10 cm profile depths. The study period were form October 2011 to March 2014). N. number of replicas per treatment; SD±. Standar desviation; Max. Maximum Soil Water Content. Where: C: soil afforested. no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis L.*); SM: straw mulch; RU: sewage sludge; SH: sheep manure compost; HP. Terracottem hydroabsorbent polymers.

		Depth 5 cm (cm^{-3} cm^{-3})				Depth 10 cm (cm^{-3} cm^{-3})			
Treatment	N	Mean	SD ±	CV (%)	Max	Mean	SD ±	CV (%)	Max
C	2	07.0	06.0	85.71	26.0	04.0	05.0	125.00	20.0
SM	2	08.0	07.0	87.50	23.0	07.0	05.0	71.43	22.0
PM	2	07.0	06.0	85.71	22.0	06.0	05.0	83.33	21.0
HP	2	10.0	07.0	70.00	31.0	05.0	06.0	120.00	21.0
RU	2	09.0	06.0	66.67	25.0	04.0	05.0	125.00	22.0
SH	2	08.8	07.0	87.50	23.0	05.0	04.0	80.00	20.0