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RESEARCH ARTICLE

Effectiveness of Low-Cost Planting Techniques for Improving Water Availability to *Olea europaea* Seedlings in Degraded Drylands

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Abstract

Reforestation projects in semiarid lands often yield poor results. Water scarcity, poor soil fertility, and structure strongly limit the survival and growth of planted seedlings in these areas. At two experimental semiarid sites, we evaluated a variety of low-cost planting techniques in order to increase water availability to plants. Treatments included various combinations of traditional planting holes; water-harvesting microcatchments; stone or plastic mulches; small waterproof sheets to increase water harvesting; dry wells; buried clay pots; and deep irrigation. Some of these treatments were also combined with addition of composted biosolids. Waterproof sheets significantly enhanced water harvesting (43%) and soil moisture in the planting hole (40%), especially for low-intensity rainfall events. Treatment effects on the survival and growth of *Olea europaea* seedlings varied between experimental sites. At the most water-limited site, clay pots, and dry wells improved seedling survival, while no treatment enhanced seedling growth. At the least water-stressed site, the application of composted sludge significantly improved seedling growth. We conclude that nutrient-mediated stress is subordinate to water stress in arid and semiarid environments, and we suggest modifications on the microsite scale to address these limiting conditions in Mediterranean drylands.

Key words: **Mediterranean, organic fertilization, seedling growth, seedling survival, soil moisture, water harvesting.**

Introduction

Reforestation projects in degraded drylands often yield poor results. In the short term, the survival rates of planted seedlings are typically poor, especially when planting is followed by an extended period without significant rainfall. Thus, it is well-established that the most critical period to reforestation success in Mediterranean drylands is the first summer after planting (Vallejo et al. 2005). The potential for improvement relies on developing field techniques that reduce water stress and nutrient limitations.

In the Mediterranean Basin, summer drought usually lasts 3–5 months and potential evapotranspiration is high throughout the year. Climate change projections for this region show trends toward less precipitation and a more heterogeneous rainfall temporal pattern (IPCC 2007), which may increase uncertainty for restoration success. The use of other sources of water, such as fog or runoff, is an increasing challenge for dryland restoration (Whisenant et al. 1995; Estrela et al. 2009). In addition to water stress, seedlings often face nutrient limitations when transferred to the field (Valdecantos et al. 2006). Soil organic matter content is usually poor in Mediterranean lands (Díaz-Hernández et al. 2003) and Mediterranean vegetation frequently responds positively to addition of nutrients from organic amendments (Larcheveque et al. 2010; Valdecantos et al. 2011).

Microtopography plays an important role in the artificial establishment of woody plants (Simmons et al. 2011) as heterogeneity and resource concentration increase (Biederman & Whisenant 2011). Field preparation techniques aim to capture runoff, and to improve infiltration and soil water holding capacity in an attempt to mimic natural resource redistribution and patterns in drylands. The use of run-on water in planting microsites can prove to be a cost-effective method. Simple structures that slightly alter the terrain microtopography can create individual microcatchments that drive surface runoff toward planting holes. This technique significantly decreases water stress, enhances plant survival and growth (Whisenant et al. 1995; Edwards et al. 2000). Other vertical water pathways (gravel-filled dry wells) close to the planted seedling may promote water infiltration and reduce evaporation (Bainbridge 2007).

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In semiarid areas of the western Mediterranean Basin, rainfall events are scarce and follow a heavily skewed distribution, with rainfall below 10 mm being the most frequent (90% of total events, Mayor et al. 2011). Although these small water pulses may trigger important processes in the uppermost soil layer (Schwinning & Sala 2004), they are not used effectively by woody plants. Waterproof surfaces upslope of planted seedlings may produce runoff, which represents crucial water inputs from very weak rainfall events (Li et al. 2000; Wang et al. 2005). Other techniques that have proven to enhance reforestation success under strong water limitation conditions include furrow and drip irrigation, buried clay pots, and mulching (Bainbridge 2001; Jiménez et al. 2007; Siles et al. 2010; Bakker et al. 2012). Buried clay pots slowly diffuse water to soil (Vasudevan et al. 2011), based partially on biological water demand.

Mulching the soil surface with plastic, stones or chopped plant debris is an effective measure to promote water infiltration (Devine et al. 2007; Bakker et al. 2012). At the same time, these mulches reduce soil water evaporation (Laliberté et al. 2008), which results in a very efficient water-conservation technique (Jiménez et al. 2007; Valdecantos et al. 2009).

The effectiveness of this variety of low-cost techniques has been tested for a number of sites. However before using them broadly, these techniques require a comparative assessment to test their performance under different conditions. Furthermore, by assessing the relative role of a variety of techniques that influence different components of the source-sink dynamics in resource redistribution, we can gain insights into the critical processes that affect restoration success in drylands. The main objectives of this study were to: (1) comparatively assess a wide variety of low-cost field preparation techniques for dryland restoration in order to increase water and nutrient inputs and conservation; (2) identify the critical components in the source-sink dynamics of dryland ecosystems that determine restoration success. We hypothesized that simple techniques which increase either water inputs from runoff-source areas or the supply and conservation of water and nutrients in sink areas can alleviate climatic and edaphic constraints to dryland restoration.

Methods

Study Sites and Field Treatments

In February 2009, we established two experimental sites in Alicante, SE Spain, approximately 4 km apart under semiarid thermo-Mediterranean climate (Rivas-Martínez 1987). The Albatera site (38°13′48″N, 0°54′35″W) is a degraded low shrubland area dominated by the small shrub *Globularia alypum* (66%) and scattered *Anthyllis cytisoides* (8%). Small and sparse individuals of Aleppo pine (*Pinus halepensis*) from former reforestation processes are found at this site. The Crevillente site (38°14′37″N, 0°52′16″W) is an alpha-grass steppe (*Stipa tenacissima*, 83% cover) with scattered shrubs (*G. alypum* and *A. cytisoides*, 7 and 4% cover, respectively). Long-term records of the mean annual rainfall and temperature in the closest weather station (11.5 and 10.2 km from the Albatera and Crevillente sites, respectively) are 278 mm and 18.2°C (Pérez-Cueva 1994). Soil surface and plant cover were estimated at each site by the point intercept method in 5 × 20-m randomly placed transects by recording contacts at 50-cm intervals (Table 1). Albatera soils develop over conglomerate and clays, and in Crevillente over marls, conglomerates, and calcareous crusts (IGME 1975), both corresponding to *Calcaric Regosol* (IUSS Working Group WRB 2006). The texture at both sites is sandy loam. Five soil samples (0–15 cm) were collected in control planting holes at the beginning of the study to determine soil organic matter (Walkley-Black method, Nelson & Sommers 1996), total nitrogen (TruSpec CN analyser) and available phosphorus (Olsen & Sommers 1982). Ten additional 0–15 cm (162 cm^3) of unaltered soil samples were collected at each site with a volumetric bore auger to determine soil and root density.

Table 1. General characterization of experimental sites (mean ± SE).

	Albatera	*Crevillente*	F	p
Soil OM (%)*	2.20 ± 0.64	1.67 ± 0.49	0.73	0.404
Total N (%)*	0.18 ± 0.02	0.16 ± 0.02	3.25	0.090
P_{asim} (mg/kg)*	4.50 ± 1.24	4.60 ± 1.21	2.27	0.151
Vegetation cover (%)	23.4 ± 4.9	66.0 ± 4.8	38.8	<0.001
Bare soil (%)	50.4 ± 5.9	20.8 ± 4.6	15.5	0.004
Surface stones (%)	25.6 ± 4.1	22.8 ± 5.7	0.16	0.699
Roots (g/dm^3)	0.61 ± 0.15	1.38 ± 0.22	8.70	0.009
Soil density (g/cm^3)	1.17 ± 0.05	1.26 ± 0.06	1.85	0.192

*In the soil of planting holes (0–15 cm).

We used *Olea europaea* var. *sylvestris* (wild olive) from a nearby nursery (Viveros Retamar, Fortuna, Spain) as the target species for the planting experiments. Wild olive is a tall native shrub that is characteristic of late successional communities in Mediterranean drylands.

Site preparation was carried out using a walking excavator, which minimized disturbances on the standing vegetation and the soil surface. We randomly distributed 1-year-old wild olive seedlings among 11 different field treatments ($n = 50$ per treatment; 550 seedlings per site). Treatments were interspersed within sites in such a way that the spatial heterogeneity in soil and vegetation was recovered by treatments to allow rigorous in-site comparisons. A few weeks after planting, seedling height (32.6 cm) and basal diameter (4.48 mm) were measured in all the planted individuals ($n = 1{,}100$). The aim of the experimental treatments was to increase water availability to seedlings by enhancing and redirecting runoff, improving infiltration, or reducing evaporation (hereafter, passive treatments) or by the direct supply of small water pulses in the planting hole (Table 2). Seedlings were planted in 40 × 40 × 40 cm holes (Control Treatment), and additional features were prepared that created the following treatments (Appendix S1, Supporting Information): Microcatchment (M), which consisted of two small sideward channels (1–1.5 m in length) that directed runoff water toward the planting hole; Improved microcatchment (IM), M with a small waterproof surface (0.30 m^2, Rootbarrier® 325, Comercial Projar, Valencia, Spain) upslope

Table 2. Description of the experimental field treatments.

Treatment	*Description*	*Processes Involved (in relation to the control treatment)*
Control*	Traditional planting holes	—
M	Microcatchment	RR
IM*	M + waterproof surface upslope of holes	RR, ER, RE
PM	M + plastic mulch on soil surface	RR, RE
SM	M + stone mulch on soil surface	RR, RE, EI
DW	IM + stone mulch + 2 preferential water pathways	RR, ER, RE, EI
CP	≈2.5 L buried clay plot (filled twice)	WI
W*	Deep water application (1.5 L, twice)	WI

EI, enhancing infiltration; ER, enhancing runoff; RR, redirecting runoff, RE, reducing evaporation; WI, water input.
*With and without the composted sewage sludge application at an equivalent rate of 22.5 Mg/ha.

of the planting hole; Plastic mulch (PM), M with a plastic layer (0.16 m^2, HORSOL®, Comercial Projar) around the seedling base; M with a Stone mulch (SM) covering the soil surface of the planting hole; Dry wells (DW), which combined the IM and SM treatments, and added two vertical water pathways (20–25 cm deep). The treatments based on direct water supply included holes with buried clay pots (volume of 2–3 L; CP), and holes with 1.5 L water pulses in depth (25–40 cm depth; W). Both CP and W manually received water twice during summer by filling bottles with predetermined volumes. The Control, IM, and W treatments were also combined with the localized application of biosolid compost (C) at an equivalent rate to 22.5 Mg/ha, which was mixed with soil at planting.

Monitoring Seedlings and Soil Moisture

The survival, height, and basal diameter of all the planted seedlings were monitored in late autumn (December). For each treatment and site, the basal area (BA) was calculated as the sum of the cross-section area of the stems of all surviving plants.

Soil volumetric water content was measured in all passive treatments without compost at two soil profiles (0–10 and 0–25 cm depth) by Time Domain Reflectometry (TDR Tektronik 1502C Cable Tester). Ten holes per treatment and planting site were monitored, which implied 240 measurements per sampling date in all. Four sampling dates were selected to represent contrasting soil moisture: May (with 12 mm and 8 mm precipitation in the previous 30 days in Albatera and Crevillente, respectively), July (0.5 mm and 3.6 mm), and October (120 mm and 89 mm) 2009, and June 2010 (54 mm and 41 mm).

We also monitored continuous soil water content in the Control and IM treatments ($n = 3$) at the Albatera site by Hydra Probe II soil moisture sensors SDI-12 (Stevens Water Monitoring Systems Inc., Portland, OR, U.S.A.) at two different soil depths (10 cm and 20 cm).

To evaluate the capacity of the M and IM treatments to increase water inputs to planting holes, we installed 15 runoff gauges at the planting holes (the Control, M, and IM treatments, $n = 5$) only at the Albatera site. The runoff gauges (50 cm wide, 20 cm height, 5 cm buried) collected the runoff produced upslope of the planting holes and transferred it to a 25-L deposit. Runoff volume was measured soon after every rainfall event. The precipitation data were obtained from standard rain gauges that automatically recorded amount of rainfall every minute.

Statistical Analysis

The site and treatment effects on seedling survival were tested by log-linear models (χ^2), and seedling morphology by two-way ANOVAs with one fixed (Treatment at 11 levels) and one random factor (Site). If there were significant interactions, one-way analyses of variance (ANOVAs) for the Treatment factor were performed at each site. Runoff production was evaluated by a one-way ANOVA with one fixed factor (Treatment) at three levels (Control, M, and IM). Soil moisture was analyzed by a repeated-measure ANOVA with two between-subjects (Site and Treatment at 2 and 6 levels, respectively) and one within-subject (Time) factors. On certain dates data were missing, hence the number of replicates in the analysis ranged between 7 and 9 per treatment. When data did not comply with the assumption of sphericity, the degrees of freedom were adjusted using the Greenhouse-Geisser epsilon. Data were log-transformed when required to avoid variance heteroscedasticity. *Post-hoc* pair-wise comparisons were made at the 0.05 level of significance using Bonferroni adjustment for multiple comparisons. All the analyses were carried out with the SPSS v.15.0 statistical package (SPSS Inc., Chicago, IL, U.S.A.).

Results

Efficiency for Runoff Interception and Soil Moisture

The total rainfall recorded at the Crevillente and Albatera experimental sites during the 9 March to 31 December period was 258 and 288 mm, respectively. That is, the precipitation in Albatera was 11% higher than that in Crevillente. During this period, runoff yield was significantly higher in the IM treatment than in the Control and M holes ($p = 0.038$). The total runoff collected from the Control holes and M holes were 78 and 82 L, respectively, while the IM treatment records indicated a volume of up to 112 L. Ten rainfall events produced runoff from the Control and M treatments, while 14 events produced runoff from the IM holes. When considering only the events below 10 mm, the average runoff from IM was more than twice that of the controls (10, 13, and 25 L from the Control, M, and IM holes, respectively). Improved microcatchment treatment efficiency was more evident when events were split into high- and low-intensity events (Fig. 1). The implementation of a microcatchment alone did not significantly increase runoff interception (run-on water) at any rainfall intensity, but

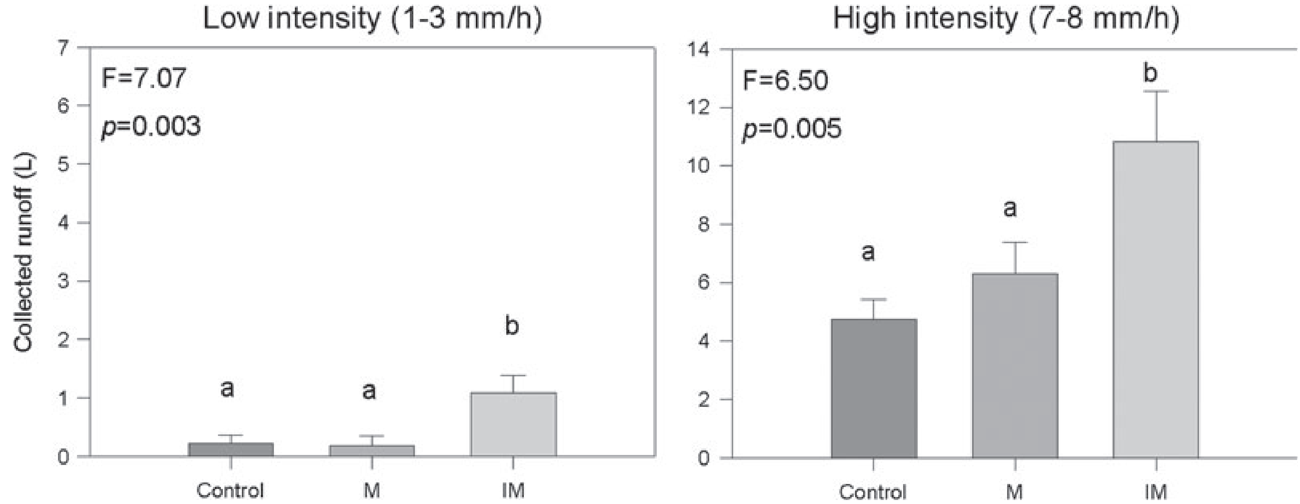

Figure 1. Runoff collection at the Albatera site for rain events lower than 10 mm, and with low (left) and high (right) intensity in the C, M and IM (mean and SE, $n = 5$). Note the different scale on the y-axis. The ANOVA results are shown. Different letters indicate significant differences ($p < 0.05$).

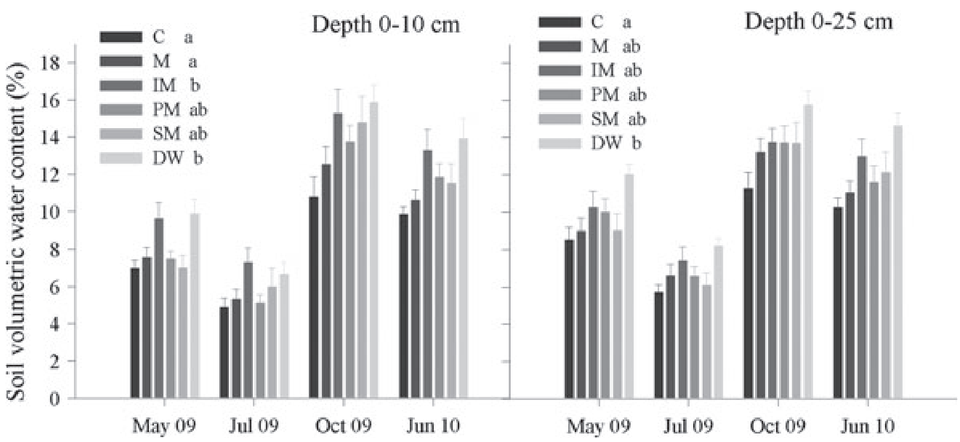

Figure 2. Soil volumetric water content in the 0–10 (left) and 0–25 (right) soil profiles affected by the passive experimental treatments during post-planting years 1 and 2. See Table 1 for treatment details. The different letters in the legends indicate significant differences between treatments (repeated-measures ANOVA, $p < 0.05$).

the improved microcatchment multiplied run-on by 2 and 5 times in the high- and low-intensity events, respectively, as compared with the control planting holes.

Passive treatments significantly altered soil water content in the profile of the planting hole at the two depths considered ($p = 0.001$ and $p = 0.009$ in the 0–10 and 0–25 cm profiles, respectively; Appendix S2; Fig. 2). The DW treatment proved to be the most effective in increasing soil moisture, with a 40% average relative increase as compared to the control holes at the 0–25 cm soil depth. At the 0–10 cm profile, both DW and IM treatments, with a waterproof sheet, increased soil moisture by 42 and 43% of the average relative increase, respectively, as compared to the control holes.

The continuous data of soil water content of the IM treatment showed that small rainfall events, below 5 mm, were followed by peaks in soil moisture at the 10-cm depth which lasted weeks (Fig. 3). In deeper soil layers (20 cm), soil moisture after spring rainfalls was greater in the IM treatment than in the control holes, and this difference continued until the late-summer rains. For instance, in the control holes, soil moisture decreased by 7% on 31 July, whereas the IM treatment achieved this value on 20 August, 20 days later.

Seedling Survival and Growth

After the first summer in the field, seedling survival significantly differed between the experimental sites ($p < 0.001$). Overall survival in Albatera was 94.8%, while it was 79.1% in Crevillente. We observed a significant interaction between factors site and treatment ($p = 0.016$), which suggests contrasting effects of the treatments at both sites (Fig. 4). The survival rates of the control seedlings were 69.2 and 95.8% in Crevillente and Albatera, respectively. In Crevillente, DW and CP significantly improved seedling survival as compared to control and M. In Albatera, no treatment significantly increased

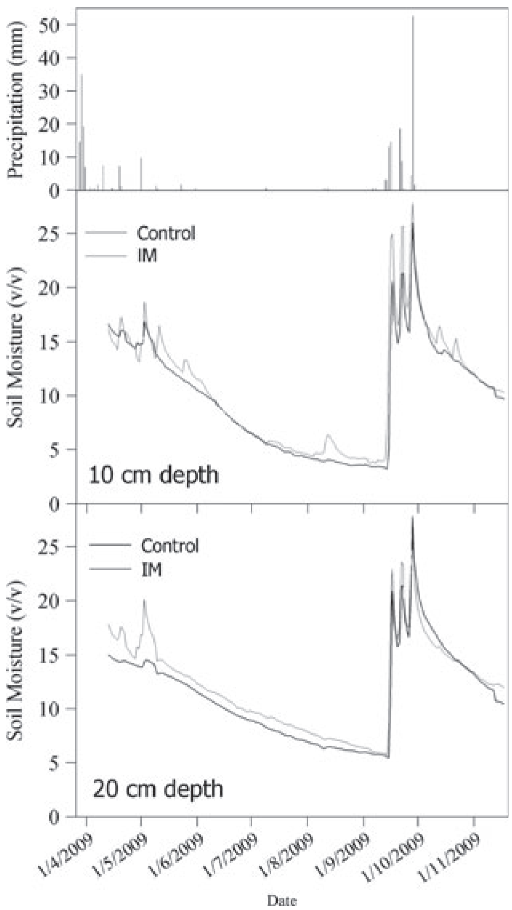

Figure 3. Soil moisture at the depths of 10 cm (middle) and 20 cm (bottom) in traditional planting holes + compost (solid line) and improved microcatchments + compost (IM, dotted line). The figure at the top shows the precipitation records during the April–October 2009 period (mean of 3 holes per treatment).

the seedling survival in relation to control as survival was very high in all cases. However, the highest survival rate was achieved in those treatments that entailed an exogenous extra water input: CP (96.0%), W, and WC (100%). PM reduced the survival of controls, but high values were maintained (82.6%).

Once again, a marked site effect was observed in relation to seedling morphology. The basal diameter was significantly higher in Albatera than in Crevillente (6.7 ± 0.1 vs. 5.3 ± 0.1 mm—mean and SE, respectively, which represents an increase of more than 25%; $p < 0.001$; Appendix S2), while treatments were not significant ($p = 0.138$). However, the interaction between site and treatment was significant ($p = 0.020$), suggesting different effects of treatments on each site. At the drier Crevillente site, no significant effect of treatments was observed on the seedling basal diameter ($p = 0.352$). In contrast in Albatera, all three treatments which included composted sewage sludge significantly increased seedling growth by 26.5, 18.5, and 16.9% (IMC, Control C, and WC, respectively) as compared to the non-composted Control ($p < 0.001$). All the other treatments yielded similar results and did not significantly differ from the controls (Fig. 5). The basal area ranged from 8.3 to 27.1 cm^2 (Fig. 6). A noticeable difference was found between the two experimental sites, with the highest value in Crevillente (DW) being lower than the lowest value in Albatera (PM). It is also worth noting that the absolute best results were achieved by those treatments which involved compost application in Albatera, as the BA incremented by 52 (IMC), 48 (WC), and 42% (Control C) as compared to the Control treatment. The best results in Crevillente were achieved by the complete passive treatment, DW (69% increase from the control), and also by the W and CP treatments (44% and 32% higher than the control, respectively), involving a punctual and slow release of water extra inputs.

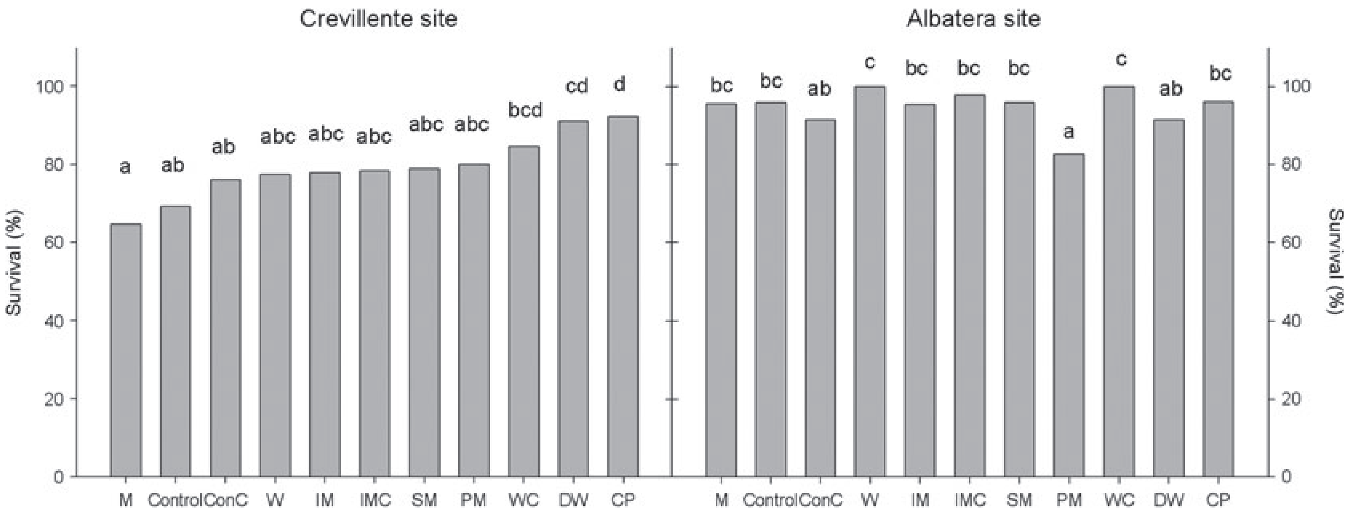

Figure 4. Survival (%) of the *Olea europaea* seedlings in December 2009 (10 months after planting) as affected by the experimental treatments at the Crevillente (left) and Albatera (right) sites under semiarid Mediterranean conditions. See Table 1 for treatment details. Different letters indicate significant differences by the log-linear analysis ($p < 0.05$).

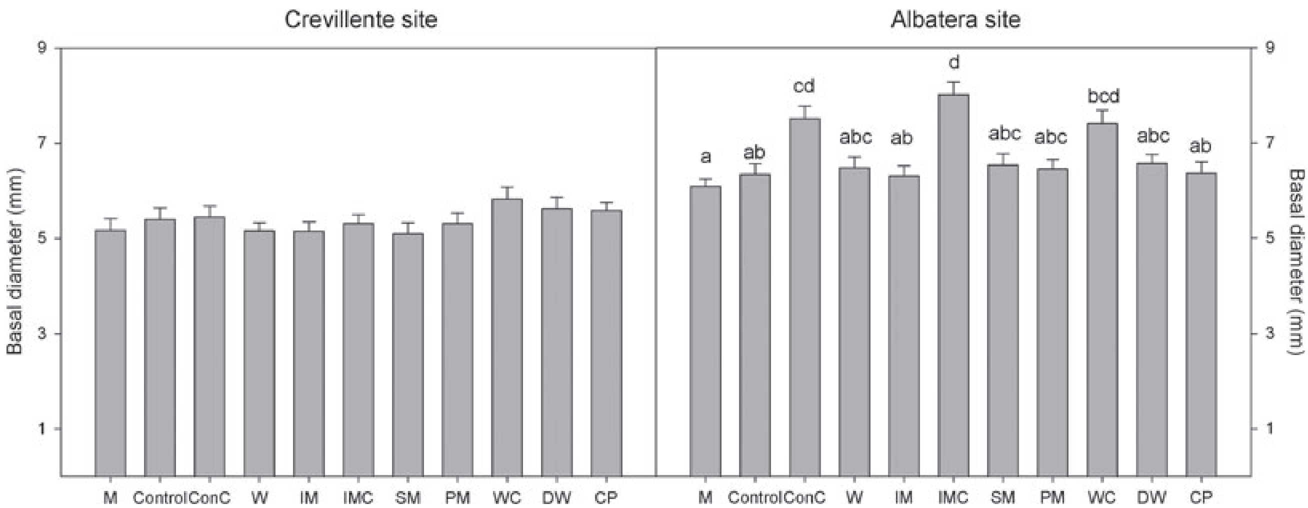

Figure 5. Basal diameter of the *Olea europaea* seedlings in December 2009 (10 months after planting) as affected by the experimental treatments at the Crevillente (left) and Albatera (right) sites under semiarid Mediterranean conditions. See Table 1 for treatment details. Different letters indicate significant differences (Bonferroni adjustment, $p < 0.05$).

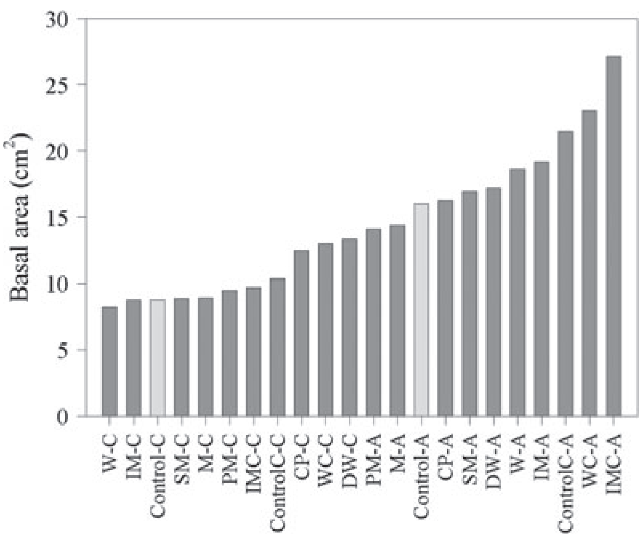

Figure 6. Basal area projection of the *Olea europaea* seedlings in December 2009 (10 months after planting) according to the experimental conditions. Light grey bars correspond to the control treatments at each planting site (C, Crevillente site; A, Albatera site). See Table 1 for treatment details.

Discussion

Many studies carried out in semiarid environments reported low seedling survival during the first post-planting periods (Maestre et al. 2003; Bakker et al. 2012) and a major effect of local variation in-site conditions (Cortina et al. 2011). Our results agree with the latter observations, as our two experimental sites provided contrasting results for seedling survival and growth despite being spatially close and sharing many abiotic features. This can be ascribed to the slightly higher (11%) precipitation recorded during the first 10 post-planting months in Albatera as compared to Crevillente. At both sites, however, the survival rates of the wild olive seedlings may be considered high (Padilla & Pugnaire 2007, 2009), especially in Albatera where some treatments showed no short-term mortality.

Small microcatchments have been successfully used to establish woody shrub and tree species under semiarid conditions (Whisenant et al. 1995; Bocio et al. 2004). However, it did not play a relevant role at our experimental sites. It is known that only a small number of rainfall events produce runoff in semiarid lands (Li et al. 2005; Mayor et al. 2011). De Simón et al. (2006) established 6.6–10.8 mm as the minimum volume of rainfall needed to produce runoff at a semiarid site in southern Spain. These observations agree with our data as the runoff yield in the Control and M treatments was usually nil or very low for events lower than 8 mm. In contrast, the use of a small plastic sheet upwards of the planting bench (IM) proved effective to collect and also retain runoff and rainfall water. Li et al. (2000) observed runoff production in rainfall events of 0.8 mm when a plastic cover was deployed on ridges. Oweis and Hachum (2006) reported that the runoff coefficient in microcatchments with a plastic sheet was considerably higher than in uncovered microcatchments. The IM treatment produced runoff from rain events of 2.5 mm, and was effective for both low and high intensity events, despite the magnitude of improvement being greater in the former. This is crucial in Mediterranean semiarid environments as most summer rainfalls are very poor (Lázaro et al. 2001). In summer 2009, there were 9 and 11 events in Albatera and Crevillente, respectively, and 80% of them were smaller than 5 mm. Higher soil moisture in IM as compared with the control treatment was maintained throughout spring and summer, with differences eventually fading at the end of summer when high-intensity rainfalls occurred. This increased water availability did not translate into a significant improvement in seedling survival and growth. Similarly, the marginal effect of SM on soil moisture did not contribute to significantly increase seedling survival. However, the further increase in soil moisture that resulted from the DW treatment appeared to have a positive effect on survival in Crevillente. Dry well was the most successful treatment at the driest site, as observed from the BA results obtained, which were similar or even more successful than those treatments implying ex situ water inputs. The combination of gravel mulch on the soil surface and a plastic cover has proven more effective in increasing plant growth than singly applying each one (Li et al. 2008). The DW treatment combines the IM and SM treatments and adds two vertical water pathways in depth, thus it contributes to increase both the water inputs from runoff and water infiltration and conservation in the planting hole. Runoff water inputs from upslope bare soil areas and increased infiltration under vegetation patches are crucial for dryland productivity (Shachak et al. 1998). By enhancing this type of source-sink dynamic, the DW treatment helped overcome the water scarcity at the driest site and increased water availability at the planting hole, thus benefiting seedling establishment and growth.

The artificial application of water pulses had some positive effects on seedling establishment and performance, especially buried clay pots. Watering in summer has traditionally enhanced seedling survival in Mediterranean drylands (Jiménez et al. 2007; Padilla & Pugnaire 2009; Siles et al. 2010). However, under less stressful (Estrela et al. 2009) or low-water volume (Padilla et al. 2011) conditions, seedling survival may not be as sensitive to the summer water pulses that were similar to those we assessed. The frequency and volume of every watering event may determine the effect of this technique, and the 2×1.5-L pulses we tested did not seem enough to significantly improve reforestation success.

The treatments that included compost amendment in planting holes promoted only seedling growth at the least water-stressed site. Application of organic refuse in Mediterranean drylands restoration commonly produces net positive results on seedling growth (Fuentes et al. 2007; Valdecantos et al. 2011). However, negative effects may also arise during extreme drought periods, leading plants to physiological collapse (Fuentes et al. 2010). Nevertheless, such extreme conditions did not occur at our study sites.

Under strong water stress, plants did not benefit from the advantage of increasing nutrient availability, whereas this limitation may arise by poor soil nutrient pools under less stressful situations (Powers & Reynolds 1999). This was the case in Crevillente and Albatera, respectively. Water availability in Albatera was enough for seedling survival, hence the treatments that included compost application significantly improved reforestation success. Conversely, the poorer natural water availability in Crevillente did not allow massive seedling survival, and the treatments that aimed to reduce water stress were the most successful ones. Under such circumstances, extra nutrient inputs did not improve the overall restoration results. The contrasting results from the two experimental areas indicate a hierarchy of abiotic thresholds that determine the establishment and further performance of woody seedlings in degraded Mediterranean drylands: a water availability threshold that limits survival and a nutrient availability threshold that limits growth. Our findings agree with the argument that nutrient-mediated stress is subordinate to water stress in arid and semiarid environments (Maestre et al. 2005), and they suggest ways in which restoration can address these limiting conditions in Mediterranean drylands.

Implications for Practice

- The use of small waterproof sheets upslope of planting holes in drylands of the Mediterranean basin increases the number of rainfall events producing runoff by 40%, which cuts the critical post-planting period without effective water input.
- Treatments that enhance water availability (dry wells, buried clay pots, and watering) are the most effective on *Olea europaea* plantations under the most water-limited conditions, while composted biosolids can greatly contribute to dryland restoration success at sites where water availability allows high seedling survival rates.
- Treatments that exploit and enhance source-sink dynamics on dryland slopes via simple, low-cost soil preparation techniques can largely improve the re-introduction of native shrubs into areas under strong water-stress conditions. The use of waterproof surfaces, dry wells, and gravel mulch has increased water availability in planting holes and, when combined, has significantly enhanced plant establishment.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Different water harvesting and conservation treatments applied in the experimental sites.

Appendix S2. Results of the repeated measures ANOVA to evaluate the effect of passive treatments on soil volumetric water content in the two experimental sites.