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Impact of straw and rock-fragment mulches on soil moisture and early growth of holm oaks in a semiarid area

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ABSTRACT

Planted seedlings and saplings usually exh\ibit low survival and growth rates under dry Mediterranean environments, especially late-successional species such as *Quercus*. In this work, we studied the effects of straw and rock-fragment mulches on the establishment conditions of holm oak (*Quercus ilex* L. subsp. *ballota* (Def.) Samp.) in SE Spain. Soil moisture was characterized at 4 soil depths (10, 20, 40, and 70 cm) for 3 treatments applied over 1 × 1 m plantation beds (rock-fragment cover [caliche], straw mulch, and control) where holm oak saplings were outplanted. Digital dendrometers were used to characterize sapling-growth characteristics including: physiological stress, cumulative growth, and number of days of growth. The results showed that straw mulch favored water infiltration and soil-water storage at 20, 40, and 70 cm in depth. By contrast, the rock fragments improved soil moisture only at 10 and 20 cm in depth with respect to the control, decreasing the water storage in deeper soil layers. Despite the absence of significant total growth differences after 20 months of tree monitoring, both types of mulch lengthened the number of days of plant growth and shortened the number of days of physiological stress in our holm oak saplings. The application of straw mulch or a rock-fragment cover changed the spatial and temporal soil-moisture distribution pattern throughout the soil profile. Straw mulch would be recommended for seedlings or saplings with deeper initial root systems (i.e. containers >20 cm high), whereas caliche-type rock fragments could be more suitable for small seedlings with shallower initial root systems (i.e. containers <20 cm high), or species with superficial root systems, such as *Pinus* species or other conifers.

1. Introduction

Areas with Mediterranean-type climate show a hot dry season (summer) and a wet cool season (winter). In dry and semiarid Mediterranean areas, artificially regenerated plantations are characterized by low survival and slow growth, apparently due to environmental factors (Pausas et al., 2004). Low amounts of rainfall, uneven spatial and temporal rain distribution, isolated and sometimes heavy storms, extreme temperatures, and high evapotranspiration rates represent the main abiotic limitations in these areas together with topography and land use (Larcher, 1995; Vallejo et al., 2012). Thus, it is vital to boost the soil-water holding capacity and mitigate evaporation losses.

Under these limiting conditions, it becomes critical for seedlings to grow new roots to a depth where water is sufficient to survive the first few summers (Padilla and Pugnaire, 2007; Villar-Salvador et al., 2012). Therefore, the ecological restoration of semiarid and dry degraded lands involving seedling or sapling plantations of woody species should develop field techniques to maximize water availability for introduced species, especially during the first post-planting period (Cortina et al., 2011; Vallejo et al., 2012). Field techniques to improve seedling establishment commonly prioritize the increase in rootable soil volume, nutrient availability, precipitation runoff collection, and water conservation, while controlling competition with existing vegetation (Chirino et al., 2009; Cortina et al., 2011).

Mulch to conserve soil moisture is commonly used in semiarid regions, as well as subhumid and humid regions, mainly due to its positive effect on soil temperature and infiltration, and its reduction of soil evaporation by breaking the capillarity (Russel, 1939; Ji and Unger, 2001; Jordán et al., 2010; Ma and Li, 2011; Cerdà et al., 2016; Keesstra et al., 2016). Mulch has been widely used as a post-planting treatment in agriculture, forestry systems, and environmental restoration to improve seedling establishment (Navarro et al., 2010; García-Moreno et al., 2013). In general, mulching the soil surface with straw, plastic, rock fragments, forest debris, etc., can improve the soil conditions, such as moisture, temperature, and available nutrients (Truax and Gagnon, 1993; Devine et al., 2007; Katra et al., 2008; Laliberté et al., 2008; Guo et al., 2010). It also improves the soil physical properties, such as bulk

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density, porosity, and aggregate stability (Jordán et al., 2010; Jordán et al., 2011), while increasing infiltration and decreasing runoff rates, as well as reducing soil-moisture loss from evaporation (Díaz et al., 2005). However, the effects depend on the thickness of the mulch and the fraction of soil surface covered (Allen et al., 2008). Some authors have pointed out that mulches are effective for post-planting preservation and conservation of soil water (Jiménez et al., 2007; Valdecantos et al., 2009).

In Mediterranean environments, different mulches (e.g. slash, black polyethylene, compost) have been tested as post-planting techniques in beds around oak seedlings to enhance survival and growth of the seedlings (Navarro-Cerrillo et al., 2005; Larchevêque et al., 2006; Valdecantos et al., 2009; Ceacero et al., 2012). The effects of rock fragments and plastic mulch on soil-water conservation have been systematically studied in dry-area crops as well as in forestry (Devine et al., 2007; Katra et al., 2008; Laliberté et al., 2008; Guo et al., 2010; Bakker et al., 2012; Valdecantos et al., 2014), but these studies have not documented how different mulching techniques affect to the soil-water content and its temporal dynamics (Jiménez et al., 2007; Jiménez et al., 2016).

Another way to improve survival and growth of containerized stock planted under dry conditions is to increase plant size. In fact, some studies claim that bigger or taller containers than conventional sizes (200–350 cm^3, 15–20 cm deep) increase efficiency in the field performance of Mediterranean species (Oliet et al., 2012). However, very few outplanting studies have been done using the 'target plant concept' (sensu Pinto et al., 2012) to restore Mediterranean environments with holm oak and other oak saplings grown in non-conventional volumes of containers (but see Tsakaldimi et al., 2005; González-Rodríguez et al., 2011; Jiménez et al., 2014). Although out of our goals, the higher prize per plant versus higher probability of survival and growth, together with the fact to obtain an adult and productive tree in less time should be tested in the near future. In any case, all progress of knowledge about restoration of oak woodlands and savannas (dehesas) in Mediterranean areas should be a priority for the environmental management, since they constitute biodiversity-rich habitats, priority ecoregions for global conservation, as well as protected ecosystems under the Pan-European network "Natura 2000" (Sánchez-González et al., 2015).

The aim of this study was to evaluate the impact of mulch treatments on soil moisture and early growth of holm oaks in a semi-arid environment. Specifically, we analyzed the effectiveness of rock-fragment and straw mulch over the planting beds with respect to water content through the soil profile and analyzed the early field response of holm oak saplings cultivated in non-conventional container sizes.

2. Material and methods

2.1. Study area

The experiment was conducted in the Dehesas de Becerra (Guadix-Baza Basin, Granada), in the SE Iberian Peninsula (37°25′11″N and 3°05′16″W) at 1032 m a.s.l. The climate is semiarid Mediterranean, with cold winters and hot, dry summers. According to the classification of Rivas-Martínez and Loidi (1999), the area is in the xeric-oceanic bioclimate, mesomediterranean thermotype, and semiarid ombrotype. Precipitation and air-temperature data have been recorded every 30 min in the nearby weather station since 1998 (Cortijo Becerra, 37°25′58″N, 3°06′05″ W; 972 m a.s.l.; THIES model DL-15). Precipitation patterns show high inter-annual variability, with an annual mean of 320 mm. Data collected during the study period (March 2010 to November 2012) exhibited this variability with means of 480.0 mm (1 Oct. 2009–30 Sept. 2010), 465.6, and 162.8 mm for following hydrological years, respectively. The minimum and maximum mean monthly temperatures are −2 °C in January and 33 °C in July. In winter, the temperature can drop to as low as −19 °C (January 2005) and in summer can reach 40 °C (August 2012).

The study area was a flat, tilled agricultural zone with scattered holm oaks from the end of the 19th century until 1993, when plowing ceased. Prior to this, it was a communal land with an alpha-grass steppe mixed with open holm oak woodlands ("dehesa" in Spanish). It was used by the local population to feed livestock, hunt, and gather firewood (Camarero and Campos, 1991; Huntsinger et al., 2004; Olea et al., 2004; Paniza Cabrera, 2015). Currently, it has a tree density of 10 trees per hectare. The soil is classified as a Petric Calcisol (IUSS Working Group, 2006) with a sandy clay loam texture (54.5% sand, 19% silt, and 22.7% clay), and is very homogeneous throughout the assay area. The main characteristics for the post-tilled (1993), undisturbed soil in the first 30 cm of profile are the following: 38.2% $CaCO_3$ content, 38.4% gravel content, 0.88 $g \cdot cm^3$ average bulk density, 8.4 pH, and electrical conductivity assumed to be <1 dS m^{-1}.

2.2. Experimental design, soil moisture, and growth monitoring

In February 2010, 9 planting holes with 3-m spacing were dug by an excavator (bucket dimensions of 50 × 80 cm). In March 2010, 6- to 7-year-old holm oak saplings (*Quercus ilex* L. subsp. *ballota* (Samp.) Desf.) in 24 l pots (32 cm deep and 35 cm in diameter) were planted with ECH_2O® soil moisture sensors (20 × 3.2 cm, Decagon Devices©, Pullman, WA, USA) installed at 10, 20, 40, and 70 cm depths in each planting hole ($n = 36$). The sensors were placed horizontally and slightly inclined into the disturbed soil, simulating the planting conditions. Volumetric soil-moisture data (m^3 m^{-3}; hereafter, θ) were recorded with HOBO® dataloggers (U12 of 4 external channels, Meteo-U12–006), every 30 min from March 2010 to November 2012 (988 days). Wilting point (measured at 1500 KPa, hereafter WP) and field capacity (at 33 KPa, hereafter FC) were measured in soil samples taken at 0–30 and 30–70 cm, but the average (WP = 10.2%, FC = 14.2%) was used since very similar values were found at both soil depths, likely due to the homogenization of the soil horizons by the soil preparation treatment for planting. WP and FC were measured at the laboratory, by means of the Richards's pressure chamber (Richards, 1965).

Sapling growth between May 2011 and November 2012 was also monitored by measuring changes in the stem circumference variation (SCV), using digital circumference DC2 dendrometers (range 15 mm; accuracy ± 2 μm, Ecomatik©, Munich, Germany). These SCVs correspond to diurnal circumference variations composed of diurnal rhythms of water storage depletion and replenishment (Kozlowski and Winget, 1964; Offenthaler et al., 2001; Deslauriers et al., 2007) and seasonal tree growth (Deslauriers et al., 2003; Bouriaud et al., 2005). Dendrometers were installed on the nine saplings (3 per mulch treatment plus control) at 60 cm above the soil level. SCV was recorded every 30 min and stored in dataloggers (HOBO® U12). The following SCV-derived indexes were calculated (according to Fernández and Cuevas, 2010): daily maximum stem circumference (MXSC), and cumulative growth ($CG = \sum_{DOY-N}^{DOY} DG$; for N days), where DG = daily growth ($DG = MXSC_{DOY+1} - MXSC_{DOY}$), and DOY = day of year.

Focusing on daily growth data over the growing seasons, we monitored the growing periods (those starting when at least two days show positive daily growth within three consecutive days; GP) and the decreasing growth periods (those starting when at least two days show zero or negative growth within three consecutive days, indicating water stress processes; DP). In our study period, GPs were detected mainly in spring 2011 and 2012, and fall 2012, while DPs corresponded with summer drought of 2011 and 2012. The number of days of growth and the decrease were counted within these periods to be analyzed.

2.3. Mulching treatments

Three treatments were considered in this experiment: straw mulch (here-in-after, straw; $n = 3$), rock-fragment mulch (rock fragments;