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Innovative soil conditioners and mulches for forest restoration in semiarid conditions in northeast Spain

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ABSTRACT

Restoring degraded ecosystems is a global challenge. Wherever applicable, forest restoration is one of the most effective tools for reversing degradation processes and enhancing multiple ecosystem services. In Mediterranean semiarid conditions the main limiting factor for tree establishment is the low and irregular precipitation regime, which has a particularly harmful effect in areas where the soil has a poor water retention capacity. We tested, alone and combined, two types of cost-effective and locally applied plantation techniques that aim to promote early seedling establishment: i) various mulches including biodegradable and reusable prototypes and commercial models; ii) two soil conditioners with water-superabsorbing polymers in their formulation, one of which includes a new polyacrylamide-free polymer, which was tested at various doses. In a three-year study we examined their effects on *Pinus halepensis* performance (survival, shoot and root growth and tree water status) and on soil moisture on a north-facing and a south-facing slope in Mequinenza, NE Spain. The use of mulches led to slight increases in seedling growth and soil moisture compared to untreated seedlings, without great differences between the models tested. Therefore the new prototypes can be considered as suitable alternatives to commercially available ones. On the other hand, the new soil conditioner led to much clearer positive effects. Compared to untreated seedlings, the new soil conditioner improved seedling survival, root and shoot growth and water status, as well as soil moisture. The benefits of the new soil conditioner were highest when applied at doses of 40 or 80 g per seedling. We found that this new formulation achieved similar performance as the commercially available one. Combining mulches and soil conditioners resulted in additive outcomes, rather than in synergistic ones. We conclude that in conditions limited by low precipitation and coarse textured soils the use of small mulches does not seem a priority technique, in contrast with the application of soil conditioners, which seems an effective option for enhancing early seedling performance.

1. Introduction

Land degradation affects more than 2 billion hectares worldwide (Potapov et al., 2011), with a range of drivers varying among regions. In the Mediterranean basin land has been overexploited for millennia (Blondel and Aronson, 1999), which has involved massive land use changes for promoting agriculture and grazing in areas recurrently affected by wildfires (Shakesby, 2011). This has put many areas under threat of erosion and desertification. In these conditions, and particularly in the semiarid areas, the spontaneous recovery of the forest cover is limited by the slow growth dynamics linked to irregular and low water availability and high evapotranspiration rates (Vallejo et al., 2012). These conditions are expected to worsen in the coming decades due to the forecasted rise in temperatures and heat waves and the decrease in precipitation in this area (IPCC, 2014). The spontaneous recovery of these areas is severely limited due to the cumulative effects of drought, wildfires and soil erosion and will strongly depend on weather and site conditions such as soil features, slope steepness and aspect (Alrababah et al., 2007).

At present, there is a wide range of eco-technological tools used to restore semiarid environments that make it possible to improve (micro) site conditions, resource availability and the capacity of plants to endure stress (Cortina et al., 2011), particularly during their first years (Vallejo et al., 2012).

One of these tools are soil conditioners, i.e. products mixed with the soil in the planting pit to improve the soil chemical and/or physical properties at micro-site level for improving early seedling performance (Coello and Piqué, 2016). The application dosage has a major effect on the cost and the performance of this technique (Del Campo et al., 2011) and therefore it should be tuned up to balance its cost-effectiveness.

Abbreviations: relative water content, RWC; super-absorbing polymers, SAP; soil conditioner with super-absorbing polymers, SCwSAP

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Table 1
Summary of reference (Ninyerola et al., 2005) and annual values of the main meteorological features at the study site. GS_n indicates the correlative growing season.

Year	Mean daily temperature in summer (°C)	Mean maximum daily temperature in summer (°C)	Annual precipitation (mm)	Summer precipitation (mm)	Summer precipitation events > 10 mm (#)
Reference (1951–1999)	23.7	30.6	367	69	–
2014 (GS1)	24.2	31.8	370	62	2
2015 (GS2)	25.8	33.1	330	120	3
2016 (GS3)	25.0	31.9	361	11	0

One of the most successful components of soil conditioners are water superabsorbent polymers (SAP), also referred to as hydrogels or superabsorbers, synthetic compounds that can absorb up to 400 times their weight in water (Rowe et al., 2005). The use of SAP – alone or combined with fertilizers and other components – has proven effective in agriculture and forestry, increasing soil water availability, reducing evaporation and enhancing early survival and growth in a wide range of species (Hüttermann et al., 2009). Most SAP are based mainly on cross-linked polyacrylamide, which is becoming less socially accepted because of the potential traces of unpolymerized acrylamide. Despite being considered environmentally compatible (Holliman et al., 2005; Hüttermann et al., 2009) and meeting the legal limits of free acrylamide, producers are developing new, polyacrylamide-free SAP (DRI, 2008); however, their optimal dosage and effectiveness in the field is yet to be established.

One limitation of soil conditioners and similar techniques in afforestation is that the improvement in site conditions often enhances competition from spontaneous vegetation, masking the potential benefits of this technique and increasing the need for weeding (Cogliastro et al., 2001, Fuentes et al., 2010). A possible solution is the use of mulches, also known as groundcovers or weeding mats, to reduce competition from unwanted vegetation. This technique involves covering the soil around the seedlings with an opaque layer that impedes weeds from germinating and becoming established near the seedling (Maggard et al., 2012). In addition to weed control, mulches regulate soil temperature and reduce soil water evaporative losses, thus increasing soil moisture (Benigno et al., 2013, Jiménez et al., 2014). They also improve soil aggregate stability and nutrient availability (Jiménez et al., 2016), which ultimately limits soil erosion. These factors have increased the interest in this single-application technique as an alternative to recurrent chemical or mechanical weeding (Coello et al., 2017). The wide range of mulch materials, colors and structures available allows fine-tuning the desired properties with regard to water and air permeability and temperature dynamics.

The most common mulching material is plastic, because of its low retail, transport and install costs (Arentoft et al., 2013). However, it has as main drawbacks its unsustainable origin, poor aesthetic value and the need to be removed at the end of its service life to avoid polluting soil and water. To tackle these limitations there is an incipient availability of biodegradable mulches in the market, made of renewable raw materials i.e. vegetal fibers and bio-based plastics (Álvarez-Chávez et al., 2012) and that do not result in a negative impact during their degradation. Another approach to enhance the sustainability of mulching is the use of waste or recycled products as raw materials, in the framework of a circular economy (European Commission, 2015). Many of these new options are at the prototype stage and require field testing to assess their potential.

The combined application of mulches and soil conditioners would make it possible to address the five priority factors proposed by Cortina et al. (2011) for field techniques that aim to improve seedling establishment: increase (i) the rootable soil volume, (ii) nutrient availability, (iii) runoff collection, (iv) water conservation and (v) control competition from extant vegetation. Although the combined application of mulches and soil conditioners with SAP (SCwSAP) seems promising, only few studies have analyzed the joint effect of these techniques on seedling performance and soil parameters, on broadleaved species (Navarro et al., 2005). Furthermore, SCwSAP containing polyacrylamide-free SAP have not yet been field-tested.

In this study we tested different combinations of five mulches, three of which were at the prototype stage, and various SCwSAP applications: a commercial one, containing polyacrylamide, and a new polyacrylamide-free formulation at various doses. We assessed their effectiveness in promoting early seedling performance and soil moisture in conditions limited by water shortage as a result of a semiarid climate and a poor, coarse-textured soil at two sites: a N-facing and a S-facing slope. We tested their effect on Aleppo pine (*Pinus halepensis*) seedlings, the most abundant species in semiarid conditions in the western Mediterranean (Quézel, 2000) in terms of distribution and use for afforestation purposes (Rincón et al., 2007). We hypothesized that:

(i) both mulches and SCwSAP should have a positive effect on seedling performance and soil moisture, while the combined use of both techniques should lead to a synergistic performance;
(ii) the performance of SCwSAP should be proportional to the application dose, which should allow determining the most cost-effective dosage;
(iii) the commercial and the new SCwSAP should have a similar performance when applied at the same dose.

2. Materials and methods

2.1. Study area and weather summary

The study area is located in Mequinenza (Aragón region, inland northeast Spain, 41.3374 N; 0.1429 E) and has a semiarid climate (mean annual temperature = 15.0 °C, annual rainfall = 367 mm, Köppen classification: BS – Steppe cold). The mean altitude is 198 m o.s.l. We installed a twin trial in two nearby sites (500 m from each other): the first S-facing (aspect 210°) and the second N-facing (aspect: 30°), with a total area of 1.2 ha. Both plots are on steep slopes (40% and 50% inclination respectively). The soil is a Calcisol (FAO, 2015), with a sandy-loam texture, pH 7.9 and scattered gypsum veins.

During the study period, temperatures were warmer than the historical reference (Ninyerola et al., 2005). The annual precipitation was mostly in line with the reference values, although the summer precipitation varied drastically from year to year (Table 1). Daily temperature and precipitation data were obtained from the nearest weather station of the Catalan Meteorological Service, representative of the study site.

The whole area was covered by Aleppo pine (*Pinus halepensis*) and had been affected by a high intensity wildfire in summer 2003. At the beginning of the experiment (2014) the area showed very poor spontaneous recovery, limited to scattered bushes of *Quercus coccifera*, *Pistacia lentiscus* and *Rosmarinus officinalis*. In the least covered areas, which were predominant in the S-facing trial, there were erosion problems including active ravines and gullies.

2.2. Experimental design

We applied the same design in the two trials: a randomized incomplete block design. Each trial consisted of six blocks, each including 75 seedlings that were randomly assigned to one of the 15 possible