INNOVATIVE SOIL CONDITIONING AND MULCHING TECHNIQUES FOR FOREST RESTORATION IN MEDITERRANEAN CONDITIONS

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Abstract: In the framework of Sustaffor project (FP7-Research for SMEs, 2013-2015) a network of 8 field trials was installed, comprising almost 4,000 trees in four strongly contrasted bioclimatic areas: Semiarid, Mediterranean continental, Mediterranean humid and Montane.

These trials aim at assessing the individual and combined effects of innovative novel techniques targeting at improving the environmental, technical and economic outcomes of tree planting projects at Mediterranean and temperate conditions. These techniques were developed by 4 European SMEs:

- A new soil conditioner developed by TerraCottem Internacional, with an improved mixture of hydroabsorbent polymers, root growth precursors and fertilizer: this technique improves water and nutrient availability at micro-site level, being an alternative to existing soil conditioners, soil amendments and emergency irrigation.
- Four new mulching models: two versions of a new biopolymer-based biodegradable mulch (DTC); a woven jute biodegradable mulch treated with bio-based resins for enhanced durability (La Zeloise) and a long-lasting (reusable) mulch made with recycled rubber (EcoRub). These models pretend to avoid weed competition during the first years of plantation, being an alternative to chemical or mechanical weeding and to plastic mulching.

We present and discuss the performance of these novel techniques, compared to reference ones, during the first vegetative period (2014) on tree survival, growth & physiology and soil moisture. The novel techniques have proven to be a feasible alternative under different circumstances: soil conditioner was especially effective in limited sites (semiarid and montane) while mulching resulted in noticeable gains at the most productive sites (Med continental and Med humid).

Key words: eco-innovation, environmental friendly, groundcovers, SMEs, biodegradable.

INTRODUCTION

Mediterranean areas are characterized by a period of water shortage during summer, which is the most critical phase for a newly established reforestation because of the combined effect of high temperatures and low water availability (Vallejo et al. 2005). The extent and intensity of this dry period varies largely with the physiography, latitude and altitude. The impact of drought is expected to worsen in the upcoming decades in the context of climate change, with projected longer and more severe episodes of high temperatures and a more irregular distribution of precipitation (Resco de Dios et al. 2007). In other temperate and wetter regions such as Central Europe it is expected that drought will also become a seasonal phenomenon, accompanied by a rise of temperatures (IPCC, 2007). The negative effects of drought on young trees include losses of growth and vigour and ultimately the dead of the seedling.

Competitive vegetation, especially herbaceous species, can exacerbate the negative effect of drought on juvenile trees (Olivera et al. 2014). This vegetation can intercept most water from a scarce rain episode, typical in Mediterranean conditions, and reduce considerably soil water reserve especially during spring season.

The single or combined effect of drought (especially in areas with poor precipitation and limiting physiography, but of growing importance elsewhere) and competitive vegetation (especially harmful in medium to high quality sites) results in the failure of many reforestation projects unless appropriate techniques are applied. The other major menace in our conditions is browsing damage from growing herbivore populations.

Most plantation techniques aim at mitigating the effects of drought or weeds independently, resulting in a general decrease in their effectiveness. Moreover, they oftenrely on recurrent interventions, implying a massive use of resources: emergency or periodic watering against drought, mechanical and chemical weeding against competitive vegetation, etc. The high costs and the need to program these interventions often lead to theirinapplicability, especially in poorly accessible sites. Moreover, the environmental impact of some of these practices, especially herbicide application, raises increasing social concern and legal restrictions (Willoughby et al. 2009).

The success of modern reforestations in Mediterranean conditions, and to be increasingly considered in Central Europe, require an integrative approach to overcome the negative effects of both drought and weeds with the development of cost-effective (considering purchase, transport, install and disposal costs) and environmentally friendly techniques with durable effect. With this intention, this study aims at evaluating the effect of innovative plantation techniques in young reforestations:

- new soil conditioners, aiming at improvement conditions at micro-site level, in terms of water and nutrients availability and soil properties (Sloup and Salaš 2009);
- innovative mulching techniques based on biodegradable and/or recycled materials, avoiding weed growth and proliferation besides the tree and mitigating soil water evaporation (Barajas-Guzmán et al. 2011, Maggard et al. 2012).

These techniques are evaluated alone and combined, and compared to reference ones, i.e., those currently applied for the same purpose, across a range of four strongly contrasted bioclimates in NE Spain: Semiarid, Mediterranean Continental, Mediterranean Humid and Montane.These techniques pretend to complement a successful reforestation, based on an adequate choice of species, provenance and seedling quality, continuing with a proper soil preparation and a satisfactory protection against herbivores.

MATERIALS AND METHODS

Field trials description

This study is performed in four field trials (Table 1) installed in NE Spain in early 2014.

Table 1. Main features of field trials.

Bioclimate	Semiarid	Med continental	Med humid	Montane
Location name	*Mequinenza*	*Solsona*	*Banyoles*	*Fontanals*
UTM (N31) coordinates	261.245, 4.580.245	378.506, 4.651.456	477.893, 4.660.733	412.053, 4.693.256
Altitude	210 m	672 m	215 m	1,430 m
Site type	Forest area burnt in 2005	Abandoned arable field	Abandoned arable field	Abandoned grazing area
Aspect, slope	South, 40%	Flat	Flat	North, 30%
Mean annual temp.	15.0°C	12.0°C	14.0°C	7.5°C
Mean annual prec.	371 mm	683 mm	872 mm	887 mm
Mean summer prec.	69 mm	165 mm	213 mm	272 mm
Climate type (Köppen)	BS: Steppe climate, cold	Csb: temperate, dry mild summer	Cfb: Maritime temperate	Cfc Temperate/ Dfb Continental
Soil texture	Loamy-sandy	Loamy-clayish	Loamy-silty	Loamy-sandy
Species chosen	Aleppo pine (*Pinus halepensis*)	Hybrid walnut (*Juglans x intermedia*)	Hybrid walnut (*Juglans x intermedia*)	Mountain ash (*Fraxinus excelsior*)

Experimental design of each field trial

The experimental design follows an incomplete factorial scheme, with combinations of soil conditioning and weeding techniques (Table 2) resulting in a total of 17 treatments (Table 3). Each treatment is applied to 30 trees per field trial, distributed following a full random block design, with 6 blocks per treatment.

Table 2. Soil conditioning and weeding techniques applied.

Technique	Description	Code
Soil conditioners	Innovative soil conditioner comprising 23 ingredients including a new complex of hydroabsorbent polymers Utilized at 3 doses: 20, 40 and 80 g/tree	ISC20 ISC40 ISC80
	Commercially available soil conditioner TerraCottem Universal®. Dose: 40 g/tree	CommSC40
	No application of soil conditioner	NoSC
Weeding techniques*	Black new biopolymer-based frame, 100% biodegradable, fused to a commercially available black biodegradable film	BIOFRA
	Woven jute cloth treated with furan bio-based resin for increased lifetime, 100% biodegradable	JUTE
	Recycled rubber based mulch, anti-UV treated, reusable in successive tree plantation projects, 1.5 mm thick,	RUBBER
	Commercial black polyethylene film, anti-UV treated, 80 µ	CommPE
	Commercial green biodegradable woven biofilm	CommBF
	Herbicide application (glyphosate, 14.4 cm^3/tree at 1.25%) applied in May via backpack sprayer**	CommHER
	No application of weeding	NoWeeding

* The weeded area per tree was 80x80 cm in Med continental and Med humid conditions, and 40x40 cm in Semiarid and Montane conditions

** Herbicide was not applied in Semiarid nor in Montane conditions, because of the absence of significant weed competition during 2014.

Table 3. Experimental treatments tested: combination of soil conditioning and weeding techniques. The implemented treatments are those indicated by an X.

Soil conditioner / **Weeding technique**	**ISC20**	**ISC40**	**ISC80**	**CommSC40**	**NoSC**
BIOFRA		X			X
JUTE		X			X
RUBBER		X			X
CommPE	X	X	X	X	X
CommBF		X			X
CommHER		X			X
NoWeeding		X			X

Data gathering

During the first vegetative period (2014) weather was registered hourly with in-site stations recording temperature, precipitation, relative humidity, wind and solar radiation. Survival was assessed visually at the end of the vegetative period. Tree growth was calculated as the difference between tree volume at the end and at the beginning of the vegetative period. Basal diameter was measured with digital calliper while height was obtained with measuring tape. Tree volume (mm^3) was calculated as: $Basal\_radius^2 \cdot height \cdot \pi \cdot 3^{-1}$, with all variables expressed in mm.

Tree water status was obtained 4 times (2 times in Med humid site) during summer, as needle relative water content (RWC) in pine, and as midday leaf water potential in broadleaves. RWC was obtained from 8 sets of 10-15 needles per treatment, and calculated as: $RWC = (FW-DW)\cdot(SW-DW)^{-1}$; where FW is fresh weight, DW is dry weight (after 72 h at 70°C) and SW is saturated weight (after 24 h in distilled water). Midday leaf water potential was measured with pressure chamber, in 6 fully developed leaves exposed to sunlight from the upper crown from 6 different trees.

Soil moisture was measured with TDR probe guided through pre-installed access tubes. We performed 7 measurements (May, June, July - 2x, August - 2x, September) each at two different depths: 0-20 cm and 20-40 cm.

RESULTS

Weather

The summer of 2014 was much wetter than the historical average: in both August and September, precipitation was, for Semiarid, Med continental and Med humid conditions, above percentile 95 considering the last 35 years. Summer precipitation was, respectively, 151 mm (+120% with respect to the historical average), 258 mm (+56%) and 320 mm (+50%). Only in Montane conditions the summer precipitation was similar to historical mean (278 mm, +2%).

Tree survival

Survival rates were very high, over 99% with the only exception of Semiarid field trial (93%). In these conditions, the treatments including soil conditioner led to higher survival rates (95%) than those without this technique (90%).

Tree growth

The effect of the different treatments on tree growth varied significantly among the different conditions (Figure 1).

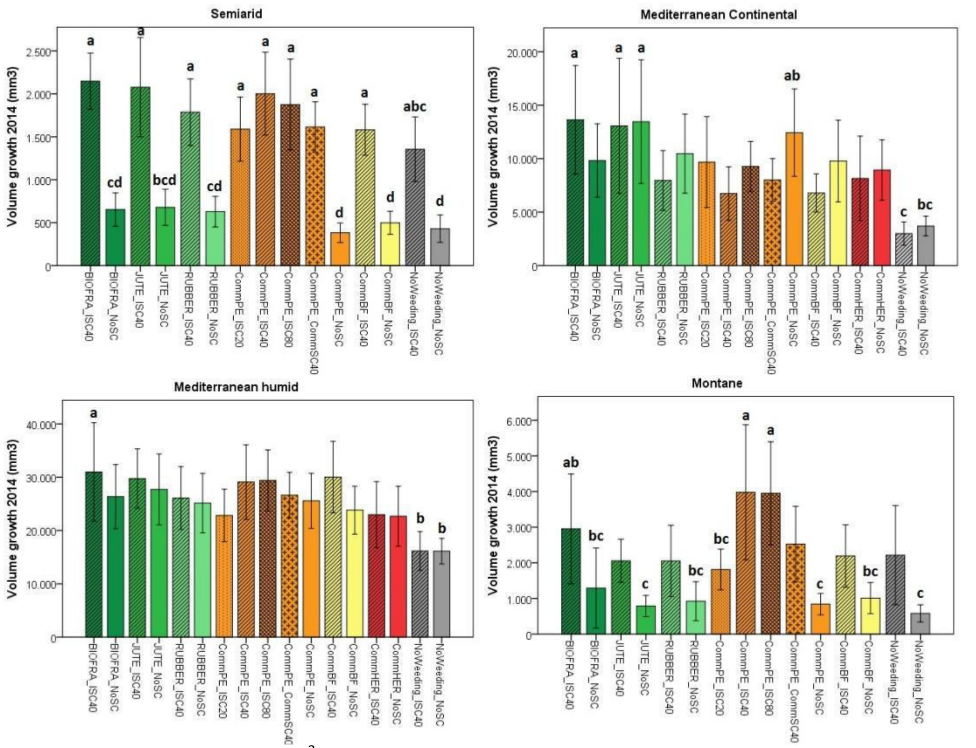

Figure 1. Seedling growth (mm^3) during the first vegetative period. The different letters correspond to grouping based on Tukey test (p>0.05), for those treatments leading to results significantly different to others.

In Semiarid site soil conditioningwas the leading factor determining tree growth: the presence of any formulationordose of this technique led to significantly higher tree growththan NoSC. There were no significant differences between the different products or doses. In these conditions weeding was also positive: CommPE ("a" group, according to Tukey test, p<0.05, considering weeding treatments only), BIOFRA (ab) and JUTE (ab) resulted in higher tree growth rates than NoWeeding (c).

In Med Continental and Med Humid conditionssoil conditioningdid not affect tree growth significantly. However, weeding techniques had a clear effect: all weeding techniques except for CommBF in Med Continental and except for CommHER in Med Humid resulted in higher growth rates than NoWeeding. There were no significant differences between the different weeding techniques.

Finally, in Montane conditions soil conditioner applied in doses of 40 or 80 g had a significantly positive effect on tree growth: NoSC ("c" group, according to Tukey test, p<0.05, considering soil conditioning treatments only) led to lower tree growth than ISC40

(b) and CommSC40 (b) and that ISC80 (a). In this site the only weeding treatment increasing tree growth with respect to NoWeeding was CommPE.

Tree water status

The effect of the different treatments on tree water status was especially dependent on the weeding treatment, while soil conditioner did not have, in general, a remarkable effect. Figure 2 shows the summary of results of tree water status for the different field trials, measurement dates and weeding treatments.

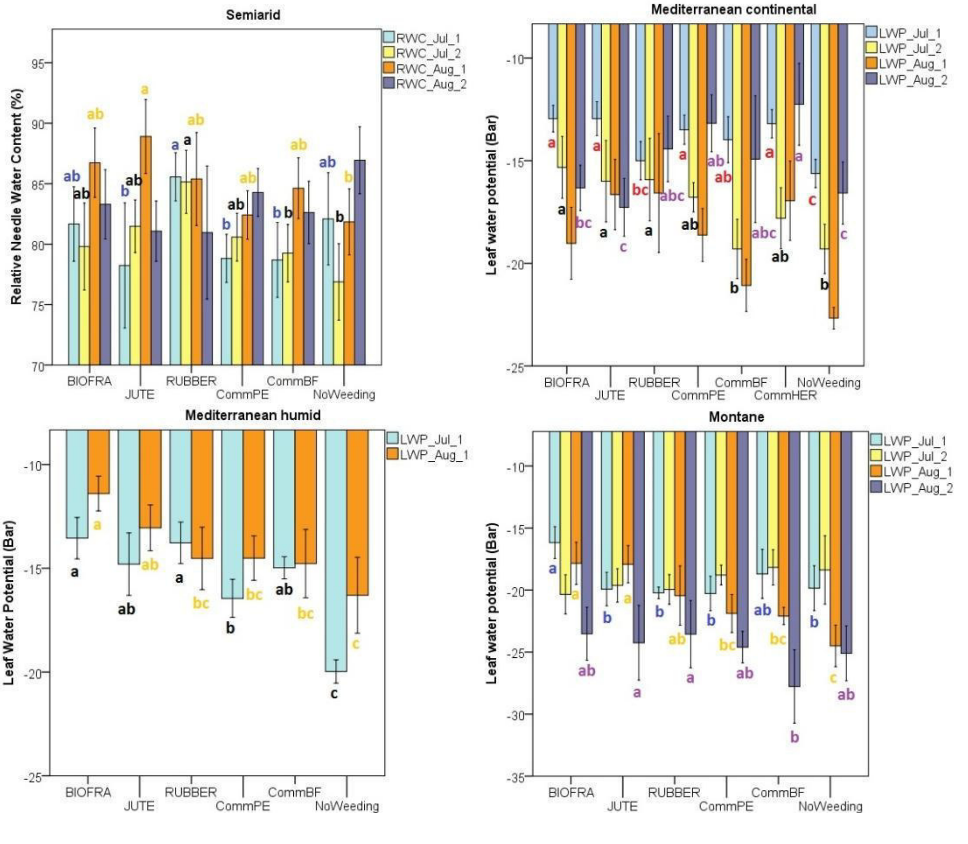

Figure 2. Tree water status at different moments of summer 2014. The different letters correspond to grouping based on Tukey test ($p<0.05$).

In Semiarid conditions RUBBER provided the overall best tree water status, superior to at least 2 alternative treatments in July measurements. JUTE also providedsuperior results to NoWeeding in the first August measurement. On the other hand, CommBF and NoWeeding resulted in lower Relative Water Content than RUBBERand/or JUTE in two of the measurements.

In Med Continental conditions the best water status was provided by CommPE and CommHER, which resulted in lower leaf water potential than the othertreatments in at least one measurement. NoWeeding provided the poorest tree waterstatus in all measurement except for one, when the treatments did not provide significant differences between them.

In Med Humid conditions the treatment resultingin best water status was BIOFRA, while NoWeeding resulted in the pooresttree water status. CommPE also led to results significantly worse than BIOFRA. Likewise, Montane conditions witnessed BIOFRA providing the best tree water status ofall weeding treatments, together with JUTE and RUBBER, while NoWeeding and to a lesser extent CommPE andCommBF showed poorer tree water status.

Regarding the effect of soil conditioners on tree water status, the only difference found for all measurements and field trials was in the second measurement of August, when ISC80 led to highertree water status than ISC20 in Semiarid and Med Continental sites.

Soil moisture

Soil moisture measurements provided few significant differences between treatments, among the measurements performed (Table 4).

Table 4. Significant differences of soil moisture between treatments found for all conditions, measurement date and soil depth.

Conditions	Date	Depth (cm)	Treatment(s) leading to higher soil moisture	Treatment(s) leading to lower soil moisture
Semiarid	May	0-20	JUTE	BIOFRA
	September		NoWeeding_ISC40, CommPE_NoSC, JUTE_ISC40, RUBBER_ISC40	NoWeeding_NoSC
Med Continental	August_2	20-40	JUTE	CommBF, NoWeeding, CommPE, CommHER
		0-20	BIOFRA, CommPE	CommHER
		20-40	JUTE_NoSC	CommHER_NoSC, CommHER_ISC40, NoWeeding_ISC40, CommPE_NoSC, CommPE_ISC20, CommPE_CommSC40
Med Humid	August_2	0-20	ISC40	CommSC40
Montane	July_2	0-20	BIOFRA	CommBF
	August_2		ISC40	CommSC40

The most common significant difference found in Semiarid and Med Continental conditions was JUTE mulching providinghigher soil moisture than CommHER. In both Med Humid and in Montane conditions ISC40 resulted in higher soil moisture than CommSC40 in one measurement.

DISCUSSION

The abnormally high rainfall during summer 2014 reduced the intensity of the drought period typical from each site, posing a difficulty on extracting conclusions related to the performance of the different treatments in the bioclimates chosen.

The effects on tree growth were consistent and stable, with soil conditioner being the most relevant technique in Semiarid and Montane conditions and weeding techniques having a major positive effect in Med Continental and Med Humid sites, and a minor positive effect in Semiarid and Montane conditions.

Although very different in terms of climate, Semiarid and Montane field trials sharethree relevant features: the use of small mulches (40x40 cm), the predominant lack of weed competition during 2014 and a thick texture soil (loamy-sandy), with poor nutrient content and water retention capacity. In these circumstances, soil conditioners significantly improved tree growth, as found by Viero (2002). The additional gain in tree growth because of mulching (CommPE, JUTE and BIOFRA in Semiarid, CommPE in Montane) and tree water status (RUBBER and JUTE; BIOFRA, JUTE and RUBBER, respectively) in comparison with NoWeeding can be related with the effect of mulch on mitigating soil water evaporation (McConkey 2013). The positive results of CommPE in these sites in comparison with other mulching options can be associated with the incomplete factorial experimental design, where 80% of trees with CommPE included a soil conditioner (ISC20, ISC40, ISC80, CommSC40), while 50% of trees from other weeding treatments were combined with soil conditioner (ISC40).

Med Continental and Med Humid field trialsshare some features: they are both former agricultural fields with high quality conditions, planted with the same species, and subjected to severe weed proliferation. Weeding treatments resulted in significant growth increment compared to NoWeeding, while water-related variables followed the same trend although less manifestly.

CONCLUSIONS

Weeding and soil conditioning proved to be effective for enhancing tree growth and tree water status already during the first year of plantation and despite the partially masked effect of summer drought because of the abnormally high precipitation regime of 2014. The effect of the different treatments depended largely on site conditions:

- In conditions especially limited poor precipitation and/or thick textured soil with poor water holding capacity, soil conditioning significantly enhances tree growth. In these conditions, mulching can also enhance tree growth and water status, thank to the mitigation of soil water evaporation.
- In high quality sites, with rich soils well supplied with water and where weed competition is a major menace for reforestation, weeding results in significant growth gains since the first year, while soil conditioning does not lead to significant effects.

The innovative soil conditioner proved to be at least as effective as the commercial version, being a very promising alternative. Regarding the dose, the prescribed 40g/tree seems to be appropriate.

Among the evaluated weeding techniques, the novel mulches developed during Sustaffor project led in general to outcomes similar to polyethylene mulching and herbicide application, and often superior (especially in terms of tree water status and soil moisture) to the commercially available biofilm. With this regard, Jute mulch provided best results in Med continental and Montane conditions, Rubber mulch was especially effective in Semiarid and Montane sites and the new biopolymer-based framed mulch performed especially well in Med humid and Montane conditions. These new models might become a feasible alternative to current weeding techniques considering their technical, social and environmental advantages.

In any case, these results come from the first vegetative period, and thus they must be considered as preliminary. The monitoring of these experiences during the next years will allow assessing the effects of the different techniques in the mid term, including their performance under years with weather similar to the historical average, as well as their durability and service life

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