Science of the Total Environment 615 (2018) 796–804

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Benefits of adding forestry clearance residues for the soil and vegetation of a Mediterranean mountain forest

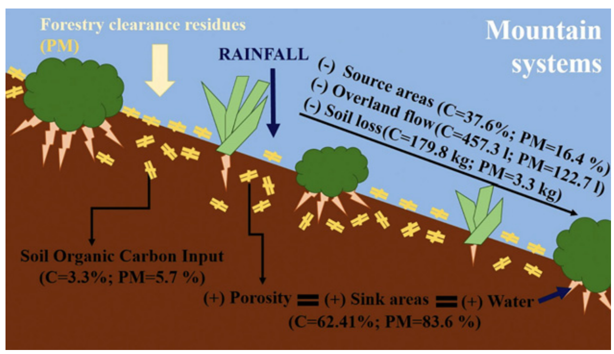
P. Hueso-González *, J.F. Martínez-Murillo, J.D. Ruiz-Sinoga

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

HIGHLIGHTS

- Forest managers in dry forests commonly clear vegetation as a fire control measure.
- The European Strategy of Circular Economy requires all waste to be recycled.
- Vegetation residue could provide systemic benefits to Mediterranean forests.
- Addition of vegetation residue to an area reduces overland flow and sediment yield.
- Addition of vegetation residue to a dry area increases vegetation and organic carbon.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 17 August 2017
Received in revised form 27 September 2017
Accepted 27 September 2017
Available online 7 October 2017

Keywords:
Circular Economy
Organic mulch
Mediterranean areas
System restoration
Soil amendment

ABSTRACT

Desertification is occurring throughout the mountainous areas of the Mediterranean. These processes lead to reduced soil fertility, increased soil loss, and reduced vegetation cover and species richness. To prevent further damage, it is recommendable to use low-cost approaches that are compatible with the European Strategy of Circular Economy guidelines. We investigated the systemic benefits from recycling of forest clearance residue by adding it to a dry Mediterranean mountainous area. More specifically, we performed afforestation without addition of residue in two control plots (C plots), and afforestation with addition of 10 Mg ha^{-1} of clearance residue from a nearby region dominated by Aleppo pine (*Pinus halepensis* Mill.) in two other plots (PM plots). We conducted the experiments throughout 30 months after the afforestation process. Eighteen months after the intervention, the PM plots had significant increases in the soil organic carbon (SOC), and related increases in ecosystem productivity and stability. More generally, addition of clearance residues improved soil and vegetation recovery, and contributed to more successful afforestation. The improvements may be explained by an increase of infiltration process due to the physical changes in the soil following bio-waste addition. Addition of the forest residues increased the formation of soil macrochannels, and also increased the sink area, thereby improving the hydrodynamics of the ecosystem. Thus, soil loss was reduced by 98.2% in the PM plots relative to the C plots. Our study indicates that application of forest clearance residues to Mediterranean mountainous areas is an effective land management practice that produces very little waste, and it is in accordance with European policy.

1. Introduction

Desertification in the Mediterranean region has increased due to climate change, its unique lithology and geomorphology, and human

* Corresponding author.
E-mail address: phueso@uma.es (P. Hueso-González).

https://doi.org/10.1016/j.scitotenv.2017.09.301
0048-9697/

activities (Lavee et al., 1998; COM, 2002; Eaton et al., 2008; Martínez-Murillo et al., 2016). Desertification leads to reduced soil fertility, increased soil loss, and reduced vegetation cover and species richness (García-Orenes et al., 2009). This problem is particularly serious in mountainous forest areas, where soil organic carbon (SOC) dynamics are particularly sensitive to climate change (Olaya-Abril et al., 2017). Thus, when these regions pass certain thresholds of change, the ecological damage may be not be reversible, making active restoration activities necessary (Vallejo et al., 2000; Hueso-González et al., 2016; Muñoz-Rojas et al., 2016).

Forest managers commonly use revegetation programs to restore the function of mountainous forest ecosystems (Bretón et al., 2016; Nadal-Romero et al., 2016), because vegetation improves soil conservation by increasing SOC and reducing soil loss (Cerdà, 2001; Van Hall et al., 2017). Mountain forest soils with reduced natural vegetation experience decreases in organic matter and nutrients (Marqués et al., 2005; Hueso-González et al., 2015), which can make vegetation recovery more difficult and lead to ecosystem degradation by a positive feedback loop (Lavee et al., 1998; Ruiz-Sinoga and Martínez Murillo, 2009). However, afforestation programs for dry Mediterranean mountain areas have only had limited success (Castro et al., 2002; Navarro and Palacios, 2004). This is because the dry Mediterranean environment has limited water during summer droughts (Maestre et al., 2003; Gouveia et al., 2017) and also has excessive radiation (Pumo et al., 2010), both of which impede seedling establishment and growth. Thus, alternative low-cost afforestation methods are needed that increase seedling survival and growth and do not have negative environmental impacts (Eldridge et al., 2012; Benigno et al., 2013).

The unique characteristics of the Mediterranean mountains contribute to the rapid spread of highly severe fires that are difficult to control (Francos et al., 2016; Tessler et al., 2016). Thus, before the summer drought, forest managers often clear vegetation to reduce the amount of combustibles, to counteract the losses from land management practices that consume biomass, and to reduce the overall risk of fire (Tedimm et al., 2016; Pereira et al., 2014). However, these vegetation residues are often subjected to prescribed burning or moved to a waste plant, activities with significant economic and environmental costs. Moreover, this land management practice is not in accordance with the Circular Economy Strategy of the European Union (COM, 2017a). This European guideline urges all member states to transition to a "circular economy", in which resources are conserved and waste is reused. Within the framework of the Circular Economy Strategy, it is particularly important ensure the proper management of organic waste (bio-waste), due to the large volume generated and the environmental implications of mismanagement (COM, 2017b). According to the National Statistics Institute of Spain, waste management companies collected 21.3 million of metric tons of residues in 2015 (INE, 2016). The global emissions generated from the treatment and elimination of solid organic waste represent 4.0% of greenhouse gas emissions and 6.5% of emissions from diffuse sectors (CONAMA, 2016). Thus, it is necessary to find new approaches for clearance and recycling of mountainous forests that are compatible with the European Strategy of Circular Economy (Ghisellini et al., 2016).

We investigated the effect of reuse of forestry residues (bio-waste) as a restoration method in a dry Mediterranean mountainous forest. We hypothesized that use of forestry clearance residues in this region could enhance ecosystem productivity, stability, and hydrodynamics, and also improve vegetation recovery.

2. Materials and methods

2.1. Study area

The experimental plots are in a mountainous region of southern Spain, inside the Sierra Tejeda, Almijara and Alhama Natural Park (Fig. 1; 36.7985173° N 3.8511693° W; WGCS84). These plots are in the upper part of an alluvial fan that has calcareous conglomerates, and they are located at an elevation of 470 m.a.s.l. This region has a dry Mediterranean climate (mean annual temperature: 18 °C, mean annual rainfall: 589 mm). The plots are in an agriculture field that was abandoned and then recolonized by shrubs since the 1950s, and it was subjected to natural burns during the summers of 1975 and 1991. The surrounding region has an open forest of *Pinus halepensis* Mill. (Aleppo pine), and an understory of degraded Mediterranean scrub and tussocks. FAO (2006) describes these soils as lithic and eutric leptosols. >50% of rock fragments are on the surface, with 56% gravel content in the soil profile. The soil has 60% sand, 32% silt, and 8% clay, and has a sandy-loam texture.

2.2. Experimental design

The four plots were 2 m × 12 m in size, had slope gradients of 7.5%, aspects of N170°, and were parallel to the line of maximum slope. We enclosed the plots with steel strips (50 cm × 1 m) that were 30 cm deep. The vegetation cover of each plot was cut uniformly in October 2010. A 250 L container was used to collect overland flow and sediment at the point of lowest elevation in each plot.

A HOBO weather station was installed in the experimental region in April 2011. We monitored rainfall with a tipping-bucket rain gauge (accuracy: 0.2 mm) every 15 min.

In May of 2011, we applied clearance residues (application rate: 10 Mg ha^{-1}; max. chipped diameter: 3 cm^2; max. chipped length: 8.5 cm) from a nearby Aleppo pine forest to the surface of two plots (PM plots), and used the other two plots as controls (C plots). In November 2011, we afforested all four plots with 9 species (*Chamaerops humilis* L., *L. stoechas* Lam., *L. dentata* L., *L. multifida* L., *Pistacea lentiscus* L., *Rosmarinus officinalis* L., *Rhamnus alaternus* L., *Rhamnus oleoides* L., and *Thymus capitatus* L.) using the same number of plants and spatial pattern as previously used by managers of this park. The vegetation was planted in a grid, and the plants were 0.5 m apart. The soil was tilled to a depth of 25 cm during the afforestation procedure.

2.3. System productivity and stability

System productivity and stability were evaluated by measuring SOC (Hussain et al., 2016; Garau et al., 2017; Sarma et al., 2017). Soil samples from the afforested plots were sampled in: (i) spring 2012 (6 months after afforestation); (ii) fall 2012 (12 months after afforestation); (iii) spring 2013 (18 months after afforestation); (iv) fall 2013 (24 months after afforestation); and (v) spring 14 (30 months after afforestation) (Fig. 1). Four samples were collected from each plot (40 soil samples in total) from the soil surface, *e.g.*, 0–10 cm depth, in which according to Pierce et al. (1994), most soil transformation occur. The SOC (%) was measured using the Walkley-Black method of oxidation with dichromate, and subsequent titration (FAO, 2006).

2.4. Soil vegetation recovery

The effect of the intervention on soil vegetation recovery was evaluated by measuring afforestation and different components of the soil surface. Measurements of the soil surface were taken at the end of the wet season (May 2013) and at the end of the dry season (September 13) (Fig. 2), according to procedures of Calvo-Cases et al. (2005) and Arnau-Rosalén et al. (2008). For analysis of soil surface components, a 12 m wide strip was marked within each plot; this strip extended from the highest elevation to the lowest elevation of each plot. This region was photographed using a camera placed 6 m above the center of each 4 × 2 m grid, along a transect. A Global Navigation Satellite System (Leica GPS1200) was used to geo-reference the four grid knots. Then, the ArcGis 10.2 Georeferencing Tool was used to rectify the images to the topographical grid, based on the four grid knots of each photograph. This analysis considered rainfall infiltration (sinks, *i.e.* bare soil with embedded rock fragments accounting for >70% of cover, high density shrubs, low density shrubs, litter, dead plants, and annual plants) and