Ecological Engineering 105 (2017) 15–20

Contents lists available at ScienceDirect

Ecological Engineering

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

Species and provenance trial conducted for selection of conifers to be used in the restoration of mine dumps

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ARTICLE INFO

Article history:
Received 24 January 2017
Received in revised form 27 March 2017
Accepted 27 April 2017
Available online 9 May 2017

Keywords:
Environmental restoration
Plant stress
Temperate forests
Mine spoils
Clay

ABSTRACT

Mining produces large quantities of metal residues (mine spoils) which, when left abandoned become a source of environmental pollution and have a significant impact on local environments. It therefore becomes necessary to devise different management strategies, the speeding up revegetation being one of them. A mesocosm trial was conducted to select conifer species to be used in the environmental restoration of mine dumps. Five conifer species were tested: *Pinus leiophylla, P. pseudostrobus, P. devoniana,* each one of these from two provenances, and *P. martinezii* and *Juniperus deppeana* each one from a single provenance. A randomized complete block design of four mesocosm blocks was used. Mesocosms were divided into two groups according to the substrate: one control substrate (sedimentary material mixed with organic matter used as forest soil proxy) and a mine-spoil substrate obtained from the Los Cedros mine dumps, in Tlalpujahua, state of Michoacán, Mexico. The plants were left to grow in the nursery for nine months and then transplanted to mesocosms, after which their growth was measured for each of the substrate treatments for a period of fifteen months (two years of age upon trial completion). At the end of the trial the plants were harvested and dry weight and cover were measured for each individual.

Significant differences among species and between substrates were detected ($P < 0.003$), but none were detected between provenances ($P = 0.3215$). The growth of individuals of all species in the control substrate was thrice that of those in the mine-spoil substrate. *P. leiophylla* grew the most; and although *P. pseudostrobus* was second in the control substrate, it was next to the last in the mine-spoil substrate. In contrast, *J. deppeana* showed the worst growth performance in the control substrate but was third in the mine-spoil substrate. This last species together with *P. martinezii* showed best growth performance in the mine-spoil substrate when compared to growth performance in the control substrate; in other words, they showed greatest resistance to mine dump conditions. Our suggestion is to revegetate mine dumps with species like *J. deppeana* and *P. martinezii*, that tolerate low water availability and other physical and chemical characteristics of fine particulated substrates.

1. Introduction

The increase in mining activity to satisfy human needs has given rise to large scale environmental problems (Ramos Arroyo and Siebe, 2007). Both surface and underground mining may leave large tracts of desolate terrain that in many instances can no longer be used for other purposes. Substrates created by mining activities have physical and chemical characteristics that severely slow down natural revegetation, since plant species need to overcome multiple barriers for establishment (Martínez-Ruíz and Fernández-Santos, 2005). These barriers include adverse conditions for seed dispersion, that result from lack of connectivity with remnant native vegetation (Ash et al., 1994) that in many cases limit the arrival of appropriate plant species (Bradshaw 2000). Even when seeds or other plant propagules arrive, inappropriate substrate characteristics can limit establishment. Mine dump substrate characteristics that can prevent plant establishment include bad texture, lack of organic matter, pH, lack of macro and micronutrients (Bradshaw 1984) and high concentrations of heavy metals (Martínez-Trinidad et al., 2013; Jochimsen 2001). Fine texture and no organic matter

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http://dx.doi.org/10.1016/j.ecoleng.2017.04.065

may lead to high bulk densities, extreme compaction, low water infiltration rates, and surface waterlogging (Johnson et al., 1994). Mine spoils, depending on their origin, can present extremely low or high pH values, that have direct effects on plant growth as well as indirect effects by modifying nutrient availability (Cooke and Johnson, 2002). Finally, when present, heavy metals can limit plant growth because of their toxicity that in general causes oxidative stress in plants (Schützendübe and Andrea, 2002). The barriers imposed by mine-spoil substrates can be very difficult to overcome and for this reason it is desirable to salvage topsoil during mining operations (Skousen and Zipper, 2014; Zipper et al., 2011).

It is important to speed up revegetation to reduce the impact of mining activities conducted in the past, because their negative effects are still being felt in the present, affecting diverse ecosystem services. Moreover, even though recovery of most of the elements of the destroyed ecosystem is not possible, vegetation protects the soil, plays an important role in carbon capture processes and in climate regulation (Martínez-Ruíz and Fernández-Santos, 2005). Consequently the rehabilitation of mining sites results in environmental benefits, even if only partial.

Careful planning of restoration efforts is required to achieve effective plant recovery, and this implies choosing species capable of tolerating adverse substrate conditions which generally include an inadequate structure (Bradshaw, 1997), pH levels that are far from being optimal for the plants and high concentrations of heavy metals (Hernández-Acosta et al., 2009).

The town of Tlalpujahua, in the state of Michoacán has a well documented mining history of more than 400 years (1558–1959). During this period gold and silver were extracted and dumps and spoils were generated of which the most recent ones have been abandoned for at least sixty years (Corona Chávez and Uribe Salas, 2009). The physical and chemical characteristics of these mine dumps are: pH that varies from almost neutral to alkaline (7.8–8.46), variable electrical conductivity (>800 moh cm^{-1}), and a limelike texture, since particles of this type represent up to 80% of the total, with significant variations in clay (7–10%) and fine sand (7–38%) (Corona-Chávez et al., 2010). In addition, contents of silica which vary between 56 and 92%, aluminum 5–13%, iron 3–5%, calcium 2.5–5% and potassium 1–2%. In regard to recoverable metals, Chávez et al. (2010) report values in tailings of 0.6–4.4 g/ton for gold and of 1.8–178.33 g/ton for silver. Some of the potentially toxic elements are: arsenic (3.0–83.9 ppm) and lead (16.5–317.5 ppm). We would like to underscore that mining spoils in the study zone do not produce acidic drainage (Corona-Chávez et al., 2010).

Our examination of the mine dumps allowed us to conclude that existing vegetation is scarce and is dominated by some grass species such as *Muhlenbergia* spp., plus a few individuals of different weed species of the Ericaceae, Asteraceae, Hypericaceae, Rubiaceae, Caprifoliaceae and Polygalaceae families. *Juniperus monticola* and *Ageratina* sp. are the dominant shrubs. Scattered about are a few *Juniperus deppeana* trees and isolated individuals of other six species. The most abundant tree species found on mine dumps is *J. deppeana* which has been described by various authors as a drought-resistant species that is able to grow in alkaline soils with poor drainage (Batis et al., 1999; Puga et al., 2006).

Given that mine-dump tree cover is almost non-existent and that there is a need for mine dump reforestation, this study focused on assessing the performance of five conifer species in a mesocosm trial using mine spoils extracted from the Los Cedros tailing dam in the town of Tlalpujahua, in the state of Michoacán, Mexico. The selected species have an increasing tolerance to xeric conditions as follows: *P. pseudostrobus* Lindl., *P. devoniana* Lindl., *P. martinezii* Larsen, *Pinus leiophylla* Schl. et Cham., and *Juniperus deppeana* Steud. (Farjón et al., 1997; Batis et al., 1999), and we hypothesized that the best overall performance under the conditions imposed by the mine dump material (low water availability mainly) will favor the species more tolerant to xeric conditions.

2. Materials and methods

We conducted a mesocosm experiment (170 l tanks) in June 2014 in the Morelia Campus of the National Autonomous University of Mexico (19°38′55.89 N, 100°13′42.10 W, 1971 m a.s.l.) in the State of Michoacan (Fig. 1), with five conifer species: *Pinus leiophylla* Schl. et Cham., *P. pseudostrobus* Lindl., *P. devoniana* Lindl., *P. martinezii* Larsen and *Juniperus deppeana* Steud. These are species present in the forests surrounding the study area. Three species have a wide geographical and altitudinal distribution in México: *P. leiophylla, P. pseudostrobu*s and *P. devoniana* (Farjon et al., 1997).

We used a randomized complete block design of four mesocosm blocks. The mesocosms were distributed as follows: block one 14 mesocosms; block two 16, block three 18, and block four 12 mesocosms. These were divided into two different substrate treatments: an organic one (sedimentary material mixed with organic matter used as a forest soil *proxy*) and a mine-spoil substrate obtained from the Los Cedros mine dump in Tlalpujahua, Michoacán (19°48′30.25 N, 100°10′06.71 W, 2569 m a.s.l.). Three species were planted in each mesocosm, each represented by two nine-month plants from two provenances, except that in the case of *P. martinezii* and *J. deppeana,* both individuals planted came from the only provenance available. The mesocosms were placed in an outdoors facility and therefore they were subjected to natural weather conditions. During the dry season (October to May), the plants were watered every two weeks to avoid drought stress.

Growth was measured during fifteen months (until the plants were two years old). At the end of this period one out of every two plants were harvested randomly. Before removing the plants canopy cover was measured. Aerial and root biomass were harvested, placed in paper bags and dried in an oven at 60 °C for a minimum of 72 h or until constant weight was achieved. In addition we calculated the root/shoot ratio, defined as the root biomass divided by aerial biomass (Monk 1966; Mokany et al., 2006).

In order to detect statistical differences in the substrate treatment response variables, a mixed model analysis was carried out by means of the PROC MIXED procedure of the SAS (Statistican Analysys System with the reference: SAS Institute, 2004) package (Blanca-Mena 2004). Species was considered as a fixed effect and population within the species (i.e., provenance), block and substrate were considered as random effects. The full model was specified as follows:

$$Y_{ijkl} = \mu + T_i + S_j + T_i{*}S_j + B_k + P_l(S_j) + T_i{*}B_k + S_j{*}B_k + e_{ijklm}$$

where Y_{ijklm} = Seedling trait (biomass or height) corresponding to the m^{th} seedling from the l^{th} population on the k^{th} block, of the j^{th} specie growing under the i^{th} soil treatment.

μ = Effect of the overall mean.

T_i = effect of the soil treatment.

S_j = effect of the species.

B_k = effect of the block.

$P_l(S_j)$ = effect of the population nested in the corresponding species.

$T_i{}^*B_k$ = Effect of the interaction between treatment of soil and species.

$S_j{}^*B_k$ = = Effect of the interaction between treatment of soil and block.

e_{ikjlm} = error term.