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Reclamation of a copper tailing in Chile

Revegetación de un relave de cobre en Chile

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ABSTRACT

Investigations were conducted to determine the feasibility of establishing plant cover on copper tailing located in Central Chile (32°40'S, 71°10'W). Chemical analysis of the tailings indicated low concentrations of major nutrients (e.g., phosphorus and nitrogen) and an excess of normally trace metals. A number of plant species which were sown or planted on the tailings became established. Application of fertilizers increased shrub growth compared to non-fertilized plants but had an inhibiting effect on seed germination.

Key words: Reclamation, copper tailing, soil nutrients, fertilizers.

RESUMEN

Se investigó la factibilidad de establecer una cubierta vegetal en un sitio con depósitos de relave de cobre en la zona central de Chile (32°40'S, 71°10'W). El análisis químico de muestras tomadas en los relaves indicaron bajas concentraciones de nutrientes (principalmente fósforo y nitrógeno) y un exceso de metales trazas. Algunas especies vegetales que fueron sembradas o plantadas en las relaves se establecieron exitosamente. La aplicación de fertilizantes aumentó el crecimiento de arbustos comparado a plantas no fertilizadas, pero inhibieron la germinación de semillas.

Palabras claves: Revegetación, relave de cobre, nutrientes del suelo, fertilizantes.

INTRODUCTION

Disposal of copper tailings has long been recognized as an environmental problem entailing risks of soil and water pollution, and soil erosion (Solbrig 1984). The establishment of plant cover on the tailings seems to be the best method to ameliorate these effects. Although many studies on the reclamation of coppper tailings have been conducted in developed countries (e.g., Ludeke 1977), this is the first published study on the subject in Chile, one of the largest copper producers in the world. The aim of this report is to present results after one year of field experiments with native and introduced plants on copper tailing located in central Chile. The study area is located in the Intermediate Depression where a typical mediterranean climate prevails.

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MATERIAL AND METHODS

Description of the site and copper ore

The copper mine, El Soldado, is in the foothills of the Coastal Mountain Range, 130 km NW of Sntiago (32°40'S, 71°10'W), at 800 m elevation. The mine has been operated by EXXON Minerals Co. since 1977.

Mine ore of volcanic origin lies in a bed of sedimentary rocks, composed mainly of limestone and Jurassic conglomerates. The mineral concentration is 1.8%, mostly chalcopyrites and bornite, leading to a daily production of 3,300 tons of waste material.

The climate of the zone is typically mediterranean, with cold and rainy winters and hot and dry summers. Average annual rainfall is 300 mm (Di Castri & Hajek 1976). General physiognomy of the vegetation in adjacent hills is that of matorral with a high degree of disturbance by goat grazing and wood cutting.

Two plots of 50 x 50 m were set up on a 120 ha tailing disposal area that was abandoned in 1965. Plot 1 was located on a flat area in the center of the tailing and Plot 2 was located on a flat near the edge of the retaining wall of the tailing. The substrate of the plots consisted of waste material only and were bare of plants except for isolated individuals of *Polygonum aviculare, Senecio adenotrichium*, and *Erodium cicutarium* growing on cow and horse manure.

Chemical analyses of tailing material

Four samples of surface material of the tailings were randomly collected for chemical analysis from each plot. As tolerance of plants to copper toxicity does not merely depend on concentration of copper (Morishima & Oka 1977), other metals were also determined. The presence and concentration of copper, magnesium, sodium, iron, calcium, nickel, zinc, molybdenum and lead were determined by atomic adsorption spectrophotometry (with a PERKIN-ELMER Model 305) and *via* humid calcination with a nitropercloric mixture. Sulphates were determined by gravimetric precipitation with $BaSO_4$. Soil pH was determined in a 1/2.5 (W/V) suspension of tailing material in water. Organic matter was calculated from organic carbon estimated by oxidization with di-cromate in presence of H_2SO_4, without addition of external heat (Black 1965). Electric conductivity, as a measure of the soil salt content, was determined by a saturated-paste method (Richards 1954). Values are expressed in mmhos/cm at 25°C. Mineral nitrogen (ammonium, nitrite and nitrate) was extracted with 2N KCl. Phosporus was extracted with a 5M $NaHCO_3$ solution at pH 8.5 (Olsen's method, Saavedra 1975). Potasium was extracted with 2N ammonium acetate at pH 7.0. Texture of tailing material was estimated by tactile means.

Field experiments

Field experiments were initiated in late winter (August 1978). Seeds of native and introduced species were broadcast or sown individually, on quadrats of 1 x 1 m of tailing, under two conditions: on pure tailing material or on tailing material plus fertilizers (45 g/m² N, 45 g/m² P, 200 g/m² seabird mulch). Each treatment was replicated four times. Table 1 provides details about species, families, number of seeds sown in both plots.

Ten greenhouse-cultured plants of each of the following species were planted in both plots: *Acacia caven, Prosopis chilensis, Cassia closiana* (native shrubs), *Atriplex nummularia* (introduced shrub), and *Cassuarina equisetifolia* (introduced tree). In addition, in Plot 2 the native tree *Schinus molle* was planted. Each plant received 100 g leaf litter, 20 g N, 20 g P and 100 g seabird mulch. Distances between plants was 3 m.

In Plot 1, two groups of ten greenhouse-cultured plants of each of the following species were planted: *Atriplex nummularia, Galenia secunda* (introduced prostrate perennial herb) and *Muelenbeckia hastulata.* One group of plants received 100 g of leaf litter only, while a second group received 20 g N, 20 g P, and 100 g seabird mulch in addition to the leaf litter. Distances between plants was 3 m.

RESULTS AND DISCUSSION

Chemical analysis

Concentrations of Fe, Ni, Cd, Zn, Mo, and Pb in the tailing material are not different from those found in adjacent soils (Table 2). pH values vary between 7 and 8, probably resulting from the high Ca concentrations found in the tailings. Hence, the tailing material could be classified as mildly alkaline (USDA-SCS 1974). Copper concentration in crop soils varies between 5 and 100 ppm (Ludeke 1977). In the tailing, copper values averaged 1,200 and 2,100 ppm in Plot 1 and Plot 2, respectively. In both plots we found high concentrations of SO_4 (between 2,300 and 3,300 ppm) and Ca (7,100 and 8,300 ppm) (Table 2). These ions are important because of their interactions with copper, either decreasing its mobility (SO_4), or compet-

TABLE 1

Species, families, and number of seeds sown in 1-m^2 quadrats in Plots 1 and 2 set up on a tailing disposal located in El Soldado copper mine. *Species only in Plot 1.

Especies, familias y número de semillas sembradas en cuadrantes de 1 m^2 en las Parcelas 1 y 2 ubicadas en un depósito de relave en la mina de cobre El Soldado. *Especies presentes sólo en la Parcela 1.

Species	Family	Number of seeds sown
Acacia caven (Mol.) Mol.	Mimosaceae	50
Baccharis sp. plus *Proustia cuneifolia* D. Don	Compositae Compositae	hand-broadcasted
Cassia closiana Phil.	Caesalpiniaceae	50
Medicago sativa L. plus *Rizhobium* sp.	Papilionaceae	hand-broadcasted
Muehlenbeckia hastulata (J.E. Sm.) Johnst.	Polygonaceae	50
Ricinus communis L.	Euphorbiaceae	50
*Senecio adenotrichius** DC.	Compositae	hand-broadcasted
*Solanum tomatillo** Remy	Solanaceae	50

TABLE 2

Chemical analysis of tailing material taken in Plots 1 and 2 at the El Soldado copper mine. Values are given in ppm, except for pH, organic matter (O.M.) in %, and E.C. expressed in mmhos/cm. Number of samples in all cases is four.

Análisis químico de material de relave colectado en las Parcelas 1 y 2 en la mina de cobre El Soldado. Los valores están en ppm, excepto para el pH, la materia orgánica (O.M.) en %, y la E.C. expresada en mmhos/cm. Número de muestras en todos los casos es cuatro.

Location		SO_4	Cu	Ca	Mg	Na	N	p	K	pH	O.M.	E.C.
Plot 1	$\bar{x}$	3,300	1,200	8,300	50	145	3.0	1.0	112	7.8	1.1	2.58
	SD	1,400	900	1,100	31	62	2.1	0.0	37	0.2	0.3	0.88
Plot 2	$\bar{x}$	2,300	2,100	7,100	18	61	2.6	1.0	48	7.8	0.9	2.09
	SD	1,600	500	1,800	8	15	1.5	0.0	16	0.2	0.3	0.09
Soil*	$\bar{x}$	50	875	5,300	48	36	10.3	13.5	179	8.1	1.8	1.70
	SD	100	741	616	25	5	7.3	17.9	103	0.5	0.8	0.81

Fe, Ni, Cd, Zn, Mo, and Pb $<$ 10 ppm in all samples.

*: Soil samples were collected from areas close to the tailings.

ing with it in the diffusion into the plants (Ca).

Due to the absence of organic material in the tailing, these spoil materials lack the natural buffer capacity of normal soils. Furthermore, organic matter when present may decrease the concentration of free Cu ions in the soil, thus decreasing its availability to plants (Ernst 1975, Jacintho *et al.*, 1976). Comparing the chemical composition of Plots 1 and 2 (Mann-Whitney U test) it was found that Plot 1 was more alkaline and contained higher concentrations of Mg and Na than Plot 2,

but lower concentrations of Ca (Table 2). The plots did not differ in regard to the other elements.

Texture of the Plot 1 was clay, whereas Plot 2 was sandy; the latter, therefore, having a better drainage. The tailing samples from both plots were nonsaline (values lower than 4 mmhos/cm) (Table 2).

Field experiments

No seeds of any of the species germinated under the fertilizer treatment. This may be due to the absence of organic matter and/or to an excess of fertilizer. The organic matter tends to absorb the excess of anions and cations up to the saturation point. In this way, the organic matter act as a buffer in normal soils avoiding the shock effect produced by chemical products like fertilizers (Ludeke 1977). In addition, the high reactiveness of Cu ions allows the formation of very stable complexes with organic matter, making them less available to plants (Ernst 1975, Jacintho *et al.*, 1976). In Plot 1, in the assays without fertilizers (Table 3), the best results were obtained with the shrubs *Acacia caven* and *Cassia closiana*. The annual herb *Medicago sativa* exhibited high germination, but survivorship was low. A similar situation was observed for the perennial herb *Senecio*

TABLE 3

Results of the seed experiments in Plots 1 and 2. Seeds were sown in August 1978 and observations reported here were done in March 1979, except where indicated. Since no seedlings were observed in the 1 m^2 quadrats with fertilizer, we report only the results obtained in the unfertilized quadrats. Species as in Table 1.

Resultados de los experimentos con semillas en las Parcelas 1 y 2. Las semillas fueron sembradas en agosto de 1978 y las observaciones señaladas aquí se hicieron en marzo de 1979, excepto donde está indicado. Debido a que no se observaron plántulas en los cuadrantes de 1 m^2 fertilizados, mostramos sólo los resultados obtenidos en los cuadrantes no fertilizados. Nombre de especies como en la Tabla 1.

Species	Plot 1	Plot 2
Acacia caven	15% seeds emerged as seedlings reaching heights of 12 cm.	75% seeds emerged as seedlings reaching heights of 15 cm.
Baccharis sp. plus *Proustia cuneifolia*	20 seedlings 1 cm in height in September 1978. They died afterwards.	5 seedlings 1 cm in height in october 1978. They died afterwards.
Cassia closiana	50% seeds emerged as seedlings reaching heights of 5 cm.	40% seeds emerged as seedlings reaching heights of 4 cm.
Medicago sativa	Numerous seeds germinated from which about 50% reached the seedling stage. Height of seedlings was 8 cm. In February 1979, the plants were eaten by the rodent *Octodon degus.*	The same as Plot 1, but the heighth reached by seedlings was 15 cm. Seedlings were not consumed by rodents.
Muehlenbeckia hastulata	No seedling emergence.	20% seeds reached the seedling stage. Height of seedings was 10 cm.
Ricinus communis	No seedling emergence.	30% seeds reached the seedling stage. Maximum height was 5 cm.
Senecio adenotrichius	35 seedlings 1-2 cm in height in September 1978. They died afterwards.	--------
Solanum tomatillo	No seedling emergence.	--------

adenotrichius, and the shrub *Proustia cuneifolia.* The perenial herbs *Solanum tomatillo, Ricinus communis* and *Muehlenbeckia hastulata* did not germinate under any treatment.

Growth rates of seedlings of *A. caven* and *M. sativa,* were higher in the unfertilized quadrats of Plot 2 compared to Plot 1 (Table 3). Moreover, seed germination of *R. communis* and *M. hastulata* was likewise noted in the unfertilized quadrats of Plot 2.

After pooling the data for all species of trees and shrubs for both plots, there was a significant increase in plant size between September 1978 and March 1979 ($F(1, 20) = 9.47$; $p < 0.01$). The species which exhibited the greater increments were *C. closiana, A. nummularia* and *Cassuarina equisetifolia* (Table 4).

In Plot 1, average height of fertilized *A. nummularia* plants (Fig. 1) was 50% higher than that of the unfertilized plants at the

TABLE 4

Average height (in cm) of shrubs or trees planted in Plots 1 and 2 in the tailing disposal of El Soldado copper mine. Plants were measured in September 1978 (S) and March 1979 (M). All plants were fertilized as described in methods.

Altura promedio (en cm) de arbustos y árboles plantados en las Parcelas 1 y 2 en un depósito de relaves de la mina de cobre El Soldado. Las plantas se midieron en septiembre de 1978 (S) y marzo de 1979 (M). Todas las plantas se fertilizaron como se describe en los métodos.

Species	Plot 1		Plot 2	
	S	M	S	M
Acacia caven	60	60	60	60
Atriplex nummularia	40	90	40	90
Cassia closiana	35	80	35	85
Cassuarina equisetifolia	80	170	30	150
Prosopis chilensis	80	90	100	100
Schinus molle	*	*	40	60

*: No data.

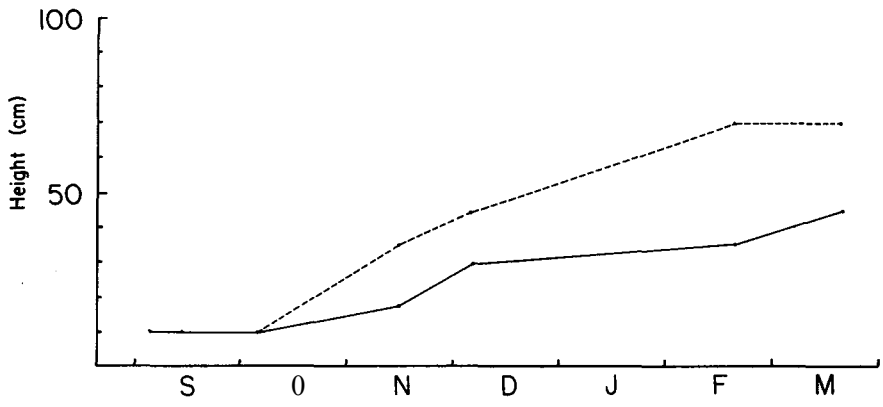

Fig. 1: Average height of fertilized (---) and unfertilized (——) *Atriplex nummularia* plants from September 1978 through March 1979.

Altura promedio de plantas de *Atriplex nummularia* fertilizadas (---) y no fertilizadas (——) desde septiembre de 1978 hasta marzo de 1979.

end of the growing season ($F(1, 19) = 10.56$; $p < 0.005$). Average diameter of fertilized *Galenia secunda* plants (Fig. 2) was four times higher than that of unfertilized plants at the end of the growing season ($F(1,9) = 14.78$; $p < 0.005$). Fertilized and unfertilized *M. hastulata* plants were not significantly different, however, leaves of non-fertilized plants were more yellowish and shed more frequently (personal observation). The growth of plants and leaf shedding produced an increase of the organic material under the canopies. These areas were colonized by herbaceous weeds of fast growth and insects such as *Eriopsis conexa.*

Although some introduced species showed higher growth rates in the tailings (e.g., *A. nummularia, Cassuarina equisetifolia*) than native species, it is not advisable to reclaim these spoil materials with these species. Introduction of non-native species would alter the structure of the regional plant communities and cause additional problems. Native species such the leguminous *Acacia caven* and *Prosopis chilensis* are particularly convenient since these species have associated N-fixing *Rizhobium* nodules in their roots, improving soil condition for further colonization.

Although our results show that several species can survive and grow under the tailing conditions, long-term observations are needed to determine the feasibility of providing a long-lasting plant cover on the tailing.

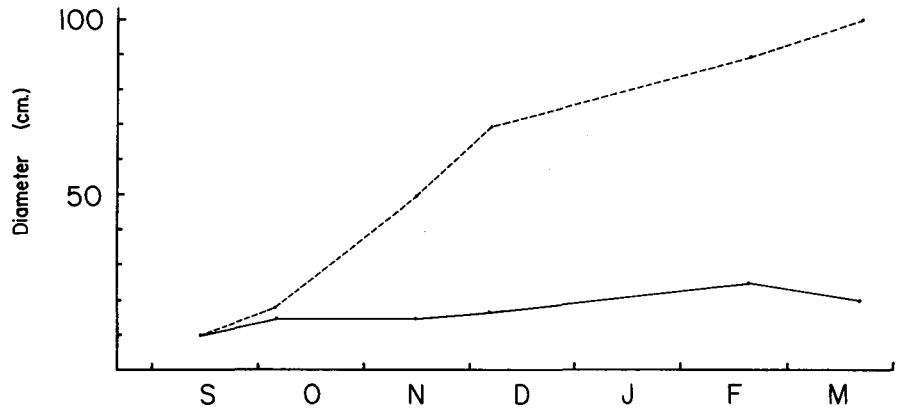

Fig. 2: Average diameter of fertilized (– – –) and unfertilized (——) *Galenia secunda* plants from September 1978 through March 1979.

Diámetro promedio de plantas de *Galenia secunda* fertilizadas (– – –) y no fertilizadas (——) desde septiembre de 1978 hasta marzo de 1979.

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