Assessment of the combined use of MSW and autochthonous tree species for the phytomanagement of mine wastes under semiarid climate.

Evaluación del uso combinado de RSU y especies arbóreas autóctonas para el fitomanejo de residuos mineros en clima semiárido.

D. Martínez-Oró [1*], I. Párraga-Aguado[1], H.M. Conesa[1]

[1]Departamento de Ciencia y Tecnología Agraria. Área de Edafología y Química Agrícola. Universidad Politécnica de Cartagena-UPCT. Paseo Alfonso XIII, 48, Cartagena, 30203 Murcia, España.

*duli.martinez@upct.es

Abstract

Phytomanagement is considered a suitable tool to reduce the environmental risks of abandoned mine tailings. Organic amendments and trees have been successfully used on metal contaminated land. The goal of this work was to assess the effects of Municipal Solid Waste (MSW) addition on plant growth and metal(loid) partitioning in two tree plant species (*P. halepensis* and *T. articulata*) growing on mine tailings. In order to achieve the objective of this work a pot experiment was carried out. The MSW improved soil fertility parameters and thus, plant growth in both plant species but also metal translocation in *P. halepensis.* It was concluded that the positive effects of MSW on plant growth may justify its employment in the phytomanagement of abandoned mine tailings

Keywords: phytostabilisation; heavy metals; stable isotopes; organic amendments.

Resumen

El fitomanejo se considera una técnica adecuada para reducir los riesgos ambientales de depósitos mineros abandonados. Las enmiendas orgánicas y el empleo de árboles se han utilizado con éxito en estos suelos contaminados. El objetivo de este trabajo fue evaluar la adición de un residuos sólido urbano (RSU) en el crecimiento y fraccionamiento de metal(oid)es en dos especies arbóreas (*P. halepensis* y *T. articulata*) creciendo en residuos mineros. Para alcanzar los objetivos de este trabajo se llevó a cabo un experimento en macetas. El RSU mejoró los parámetros de fertilidad de suelo y aumentó la biomasa de ambas especies, aunque favoreció una mayor translocación de metales en *P. halepensis*. Se concluyó que el uso para el fitomanejo de residuos mineros de *P. halepensis* y *T. articulata* puede ser apropiado acompañado del uso de esta enmienda.

Palabras clave: fitoestabilización; metales pesados; isótopos estables; enmiendas orgánicas.

1. INTRODUCTION

Phytomanagement is considered a suitable tool to reduce the environmental risks of abandoned mine tailings [1]. This technology uses plants to immobilize metal(loid)s within the rhizosphere and mitigate the erosion. Organic amendments have been used for improving plant growth on metal contaminated soils [2]. Among the available amendments, municipal solid wastes (MSW) might be an interesting alternative for recycling urban wastes [3]. Trees have been successfully used in phytostabilisation of meta(loid)s contaminated land [1]. Their extensive root system fixes soil particles and immobilizes meta(loid)s.

The main goal of this work was to assess the effects of MSW addition on plant growth and metal(loid) partitioning in two tree plant species growing on mine tailings. For that purpose, a pot experiment was carried out employing two native tree species, Pinus halepensis and Tetraclinis articulata. Our hypothesis was that the MSW amendment might improve tree nutrition, plant growth and, as a result, decrease metal(loid)s uptake by the trees.

2. MATERIALS AND METHODS

A pot experiment was carried out for fifteen months in a greenhouse. The soil treatments tested were: T, unamended neutral pH mine tailings, and TR, neutral pH mine tailings amended with MSW (10% w/w) provided by the local waste treatment plant. A chemical characterisation of T, R and TR was performed. Seedlings of *P. halepensis* and *T. articulata* were transplanted into the pots. The resulting treatments were: PT, *P. halepensis* on unamended tailings; PTR, *P. halepensis* on amended tailings; TT, *T. articulata* on unamended tailings; and TTR, *T. articulata* on amended tailings. Plants were harvested at the end of the experiment and separated into different parts: roots, trunk, branches and leaves. Nutrient and metal(loid) concentrations were measured. Leaf isotopic composition ($\delta^{13}C$, $\delta^{18}O$, $\delta^{15}N$) was also analysed.

3. RESULTS AND DISCUSSION

The tailings samples showed high total metal(loid) concentrations (in mg kg^{-1}: 430 As, 35 Cd, 120 Cu, 10100 Mn, 6200 Pb, 10000 Zn). Amended treatments (TR) showed an improvement of soil fertility parameters (*e.g.* OC, DOC) but also an increase of EC or some water extractable metals concentrations (Mn) (Table 1).

The total dry biomass in the amended treatments, PTR and TTR, was around 4-fold higher than in the not amended ones (Figure 1). Phosphorus was the only nutrient that showed a significant increase (Table 2) in PTR, which could indicate P as a major limiting factor for pines growing in the non amended tailings.

Metal(loid) accumulation was higher in roots of PT than PTR, probably due to a dilution effect caused by higher plant biomass in the amended treatments [4]. This was similar for TT and TTR, except in Cu and Mn which showed higher concentration in TTR roots (Table 3).

Isotope leaf signature has been proposed for the assessment of the ecophysiological status of plants. In order to discern whether these differences on $\delta^{13}C$ are driven by changes in stomatal conductance or by biochemical factors affecting the rubisco activity, Scheidegger [5] proposed a conceptual model. No differences in $\delta^{18}O$ were found in any of the two studied plant species probably due to similar source of water, humidity and limited depth of the soil in each treatment. Therefore, the significant difference found in $\delta^{13}C$ between PT and PTR plants might indicate a higher photosynthetic capacity of the PT pine trees (Table 2). Differences on $\delta^{13}C$ according to the leaf age on pine trees were showed by Parraga-Aguado et al. [6] where young needles from pine trees growing on mine tailings showed higher $\delta^{13}C$ than older needles, and that was also related to a higher photosynthetic capacity of the former. In the case of *T. articulata*, no significant differences were found in $\delta^{13}C$ or $\delta^{18}O$ between treatments, which may indicate that the processes involved in transpiration and photosynthesis are less impacted by the different soil treatments in this plant species. The differences found in $\delta^{15}N$ might be mainly from the different sources of N in each treatment (Table 3). The foliar $\delta^{15}N$ in plant reflects the N source which plants employ: the higher foliar $\delta^{15}N$ in the unamended treatments may indicate that NH_4^+ is the main source for N as it is known that conifer preferentially uptake this ion, which is $\delta^{15}N$ enriched [7]. However, lower foliar $\delta^{15}N$ in the amendment treatments may indicate that NO_3^- has become the main source of N. This may be due to the higher microbial activity promoted by higher DOC in amended treatments which resulted in the ^{15}N enrichment in microbial biomass (microorganism use preferentially NH_4^+) and the generation of water soluble N, depleted in ^{15}N, mainly NO_3^-[8].

4. CONCLUSIONS

P. halepensis and *T. articulata* could be suitable species for phytostabilisation purposes in abandoned mine tailings due to low metal uptake and suitable plant growth, especially, in combination with organic amendments, such as municipal solid wastes.

5. ACKNOWLEDGMENT

This project has been funded by MINECO-FEDER (CGL2014-54029-R, Project ECOMIN) and Seneca Foundation (19248/PI/14). Obdulia Martínez holds a FPI contract (BES-2015-075838) from MINECO.

6. REFERENCES

[1] Parraga-Aguado I, Querejeta JI, González-Alcaraz MN, Jiménez-Cárceles FJ, Conesa HM. 2014. Usefulness of pioneer vegetation for the phytomanagement of metal(loid)s enriched tailings: Grasses vs. shrubs vs. trees. J Environ Manage. 133:51-58.

[2] Mendez M.O., Maier R.M., 2008. Phytostabilization of mine tailings in arid and semiarid environments – An emerging remediation technology. Environ. Health Perspect. 116: 278–283.

[3] He X.-T., Traina S.J., Logan T.J. Chemical properties of municipal solid waste composts. J. Environ. Qual. 21: 318-329.

[4] Jarrell W.M., Beverly R.B. 1981. The Dilution Effect in Plant Nutrition Studies. Adv. Agron. 34: 197–224.

[5] Scheidegger Y.,Saurer M., Bahn M., Siegwolf,R. 2000. Linking Stable Oxygen and Carbon Isotopes with Stomatal Conductance and Photosynthetic Capacity: A Conceptual Model. Oecologia 125, 350–357.

[6] Parraga-Aguado I, Querejeta JI, González-Alcaraz MN, Jiménez-Cárceles FJ, Conesa HM. 2014. Metal(loid) allocation and nutrient retranslocation in Pinus halepensis trees growing on semiarid mine tailings. Sci Total Environ. 485-486: 406-414.

[7] Högberg P. 1997. ^{15}N natural abundance in soil–plant systems. New Phytologist 137: 179–203.

[8] Lerch TZ, Nunan N, Dignac MF, Chenu C, Mariotti A. 2011. Variations in microbial isotopic fractionation during soil organic matter decomposition. Biogeochemistry 106:5–21.

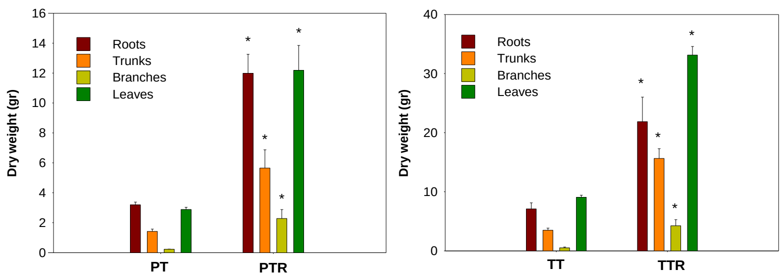

Figure 1. Biomass of each plant organ of *Pinus articulata* and *Tetraclinis articulata*. "*" indicates significant differences ($p < 0.05$). Bars on columns are standard error.

Table 1. Soil characterization at the beginning of the experiment. “*” indicates significant differences ($p < 0.05$) between T and T+R treatments (N=5). Data are average ± standard error.

Soil parameter		Units	Treatments T		Treatments T+R	R
pH (1:5)		-	7.14 ± <0.1		6.95 ± <0.1	5.34 ± 0.12
EC (1:5)		dS m^{-1}	2.41 ± <0.01	*	3.02 ± 0.02	4.06 ± 0.15
OC		g kg^{-1}	1.41 ± 0.1	*	12.6 ± 0.4	160 ± 5
DOC		mg kg^{-1}	29.04 ± 0.7	*	686 ± 40	25220 ± 1032
N total		g kg^{-1}	0.74 ± 0.1		0.94 ± <0.1	12 ± 0.5
Available-P			2.5 ± 0.3	*	4.4 ± 0.3	Not available
Water extractable Ions (1:5)	Cl^-	mg l^{-1}	1.50 ± <0.1	*	103 ± 3	1150 ± 20
	NO_3^-		1.08 ± 0.1		1.04 ± <0.1	10 ± 0.3
	SO_4^{2-}		1472 ± 8	*	1540 ± 11	690 ± 19
	Na^+		1.41 ± <0.1	*	86.9 ± 3	970 ± 18
	NH_4^+		0.41 ± <0.1		0.58 ± <0.1	12 ± 2
	K^+		1.74 ± <0.1	*	45.8 ± 2	640 ± 13
	Ca_2^+		577 ± 3		575 ± 3	315 ± 12
	Mg_2^+		18.5 ± 0.4	*	31.6 ± <0.1	150 ± 6
Water extractable metals (1:5)	As	ug kg^{-1}	7.64 ± 0.7	*	149 ± 9	200 ± 11
	Cd		<10		33.7 ± 1	3040 ± 62
	Cu		<10		816 ± 57	44150 ± 4703
	Mn		106 ± 9	*	11321 ± 721	161700 ± 9255
	Pb		<10		103 ± 6	6600 ± 321
	Zn		430 ± 27		1870 ± 110	196000 ± 5686

Table 2. Nutrients and stable isotopes foliar concentration. “*” indicates significant differences ($p < 0.05$). Data are averages ± standard error (N=4).

Foliar composition	Units	Treatments TP		TPR	TT		TTR
C	g kg^{-1}	491		485	450		444
N		9.5	*	7.4	6		5.5
Na	mg kg^{-1}	1640		1396	744		1082
K		4011		4250	5303		4853
Ca		3774		4096	14617		11793
Mg		2713		3342	1381		1294
P		297	*	525	470		483
δ13C		-29.67	*	-30.64	-28.65		-27.92
δ15N		4.59	*	1.62	5.09	*	2.86
δ18O		30.01		29.95	36.69		36.02

Table 3. Metal(loid)s concentration in root, trunck, branch and leave. “*” indicates significant differences ($p < 0.05$). Data are averages ± standard error (N=4).

Treatments	Organ	Metal(loid)s in plant (mg kg^{-1}) Cd		Cu		Mn		Pb		Zn		As	
PT	Root	1.61		14.41		118.14		289.61		515.27		0.34	
PTR	Root	1.15		10.54		104.08		147.43		309.70		0.26	
PT	Trunck	0.77		2.68		56.72		10.77	*	54.74		0.03	
PTR	Trunck	2.15	*	2.96		56.02		3.21		40.66		0.01	
PT	Branch	0.65		5.12		55.39		25.11	*	56.13		0.03	*
PTR	Branch	2.38	*	4.59		56.11		2.23		48.94		0.01	
PT	Leave	0.08		2.48		153.14		1.75		84.03		0.01	
PTR	Leave	0.37	*	3.51		288.28		5.72		111.65		0.01	
TT	Root	2.39		9.70		143.04		136.03		326.73	*	2.57	
TTR	Root	1.45		23.65	*	146.07		127.80		197.96		0.35	
TT	Trunck	0.79		2.41		8.95		4.30		15.22		0.01	
TTR	Trunck	0.57		2.27		9.03		6.93		11.46		0.00	
TT	Branch	0.79		2.41		8.95		4.30		15.22		0.01	
TTR	Branch	0.46		3.12		17.20	*	2.21		20.62		0.00	
TT	Leave	0.98		2.01		37.16		7.35		30.25		0.01	
TTR	Leave	0.55		1.87		45.90		4.07		29.09		0.01	