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Uptake of Heavy Metals and Other Elements by *Emilia sonchifolia* Grown on an Overburden in Ultramafic Soil from Sorowako, Indonesia

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ABSTRACT

Building a phytomining field on overburden (mining waste material) without a top soil laid on it is the aim of the commercial phytomining. Developing commercial phytomining on this overburden will consequently lower the operational cost of this method of mining. Few compositae species such as *Emilia sonchifolia* have a good adaptation in ultramafic sites in Sorowako and accumulate 190-280 mg kg^{-1} of Ni. Few compositae species such as *Emilia sonchifolia* have a good adaptation in ultramafic sites such as *Emilia sonchifolia* in Sorowako and accumulate 190-280 mg kg^{-1} of Ni. A pot experiment was conducted to test the efficacy of *E.sonchifolia* in acquiring Ni and others elements from top soils and overburden soils (limonitic and saprolitic laterite) derived from of ultramafic rocks treated with and without chicken manure (w/w 1 g kg^{-1}). Total Ni concentration in the topsoil, limonitic and saprolitic laterite were 7.051, 7.884, and 10.524 mg kg^{-1}, respectively. The shoots were collected at 50 days after transplanting and analyzed for their Ni, Cr, Zn, Fe, K and Mg contents. *Emilia* sp produced significantly higher shoot dried biomass and contained higher Zn concentration when grown in topsoil on both treatments. But Ni, Cr and Mg concentrations and contents were higher in saprolitic laterite. Ni concentration in manure treated topsoil, limonitic and saprolitic laterite was 12.5, 30.7 and 254.5 mg kg^{-1} and in the non-treated was 14.7, 29.7 and 210.7 mg kg^{-1}, respectively. Iron was the only element that decreased in concentration when chicken manure was applied. Potassium contents were not different in all soils and treatments. Although *E.sonchifolia* produced 2-5 folds greater shoots in topsoils and limonitic laterites (overburden) than in saprolitic overburden, but the rate of Ni removal was higher in the latter due to much higher concentration of Ni in this soil.

Keywords: *Emilia* sp., Heavy metal, Overburden, Top soil, and Ultrabasic rock.

INTRODUCTION

Ultramafics containing nickel laterites are found mainly in Central and Eastern Sulawesi, with a combined area in excess of 8,000 km^2. The lateritic soils are rich in nickel and commonly strip-mined in Central Sulawesi. Globally, nickel deposits are found in either sulphide (40% of world reserves) or lateritic (ultramafic) deposits (60% of world reserves) with some of the largest reserves in nickel laterites in Indonesia, Cuba, New Caledonia and Australia. The U.S. Geological Survey (2010) estimates the nickel reserves at 7.1 Mt for New Caledonia, 3.2 Mt for Indonesia and 26 Mt for Australia, with 2009 nickel productions of 107,000 t from New Caledonia, and 89,000 t and 167 t from Indonesia and Australia, respectively. High-grade sulphide deposits are depleting, and as a result a higher proportion of future production is expected to come from laterite deposits (Mudd, 2009). Historically, nickel laterites were very difficult to process but with the development of the 'high pressure acid leach' (HPAL) technology lateritic ores have become profitable (Mudd, 2009). Retrieving nickel from laterites is energy intensive and produces large volumes of waste rock. In 2008, a total 86,000 t of nickel was produced from 4.7 Mt of saprolitic ore in New Caledonia (Salazar and McNutt, 2010).

Phytoremediation is an emerging technology that uses specific plants to degrade, extract, or immobilize contaminants from soil and water. This technology has been receiving increasing attention lately as an innovative, cost-effective, and alternative to the more established physical treatment methods used at hazardous waste sites. Phytoremediation approaches generally fall into four categories, one of which is phytoextraction. Phytoextraction is the use of hyperaccumulating plants to remove toxic substances such as heavy metals from the soil and store them in their shoots (Brooks, et.al., 1999). The interest in phytoextraction has grown significantly following the identification of metal hyperaccumulator plant species, which can contain as much as 5% metal on a dry weight basis. (Sangadji, 2002). An ability to predict the efficiency of phytoextration from a particular soil as well as finding super hyperaccumulator plants is crucial to decide upon the commercial application of this technology.

Ultramafic soils differed from the non-ultramafic soils in texture, having a higher proportion of clay and silt. Soils derived from ultramafic bedrock have a number of extreme chemical properties that challenge plants to survive, which include a deficiency in the macronutrients phosphorus, potassium, calcium, and nitrogen, and unusually high concentrations of magnesium and nickel which may act as toxins (Baillie, et.al., 2000; O'Dell and Rajakaruna, 2011). Ultramafic soil profile is made up of a number of layers which include topsoil and overburden layers. In Sorowako, the topsoil layer usually about 0-15 cm thick, contains a large store of seed and nutrients which are vital to mine site rehabilitation. The overburden layer is 30-100 cm of gravely sub-soil material sitting above the caprock. Before mining can begin, the topsoil and overburden are removed separately. The topsoil is directly returned to areas being rehabilitated. The overburden is stockpiled and is returned in the mine pit when mining is completed.

Phytomining for Nickel (Ni) is currently an economically viable possibility, with the additional potential of the exploitation of ore bodies that previously were uneconomical to mine by current methods. Pioneering experiments in the field can further lead to a 'green' alternative to the current environmentally destructive, opencast mining practices. And the efficiency of this green technology depends on many factors: capacity of the root system to take up and transfer metal to above-ground plant parts and the interaction with the soil's physico-chemical characteristics; interction with microbes and other plants; and the ability to control the physical environment to support growth such as wind factor, run off, and particle dispersion on plant surface. This complex interaction is affected by a variety of factors such soil characteristics, climatic conditions, hydrology and geology, and field management. Knowledge on the agronomic and practical requirements of potential plants used for phytomining will be an additional advantage for their successful application. This study aimed to get an initial indication of the efficacy of *E.sonchifolia* to acquire Ni and other elements not only from top soil but also overburden (Limonitic and Saprolitic laterite). Asteraceae species such as *Emilia sonchifolia* from serpentine sites in Sorowako accumulate 190-280 mg kg^{-1} of Ni. Its fast growth rate can be taken adantage as cover crop to reduce soil erosion on phytomining sites.

MATERIALS AND METHODS

Emilia sonchifolia seeds were collected from serpentine -rich areas in Sorowako, Central Sulawesi-Indonesia. Its shoots contain about 190-280 mg kg^{-1} of Ni. Collected seeds were were plnted on ultramafic derived topsoil to produce seeds for experiments. This experiment was carried out in a controlled environment in pots using two types of soils: topsoil and overburden soil (Limonitic and Saprolitic laterite). The soils were tested for their water holding capacities, and thoroughly mixed with basal fertilizers (100 mg kg^{-1} N (NH_4NO_3), 100 mg kg^{-1} P (NaH_2PO_4), 100 mg kg^{-1} K (KCl)) before planting. A half of each soil type was treated with chicken manure (1 g kg^{-1} soil, w/w) and the other half was untreated. *E. sonchifolia* seeds were pre-cultured for 3 weeks and transferred to pots. Prior to planting, pots were first filled with either 0.8 kg top soils or overburden soils (limonitic and saprolitic laterite) which had been treated or untreated with chicken manure. Each is prepared in 3 replicates. In total there were 18 pots. Total Ni concentration (aqua regia extraction) of the topsoil, limonitic and saprolitic laterite (overburden) was 7.051, 7.884, 10.524 mg kg^{-1}, and the pHH_2O was 5.87, 6.52 and 7.01, respectively. The shoots were harvested at 40 days after transplanting. Shoot materials were washed thoroughly with 3% of HCl, and deionized water and dried at 65^{o}C for 48 hours, and their dry weight recorded. Dried samples were ground before analysis. Sub samples of plant material (0.1 g) were digested with a mixture of 5 ml HNO_3 (65%) and 4 ml H_2O_2 (30%), their Ni, Cr, Zn, Fe, K and Mg determined with ICP-OES. Statistical analysis was performed using SigmaStat 4.0. Means and standard deviations are presented for all data. Mean comparisons were calculated using One-Way ANOVA followed by a Duncan-test, and means marked with different letters showed significant differences ($p<0.05$).

RESULTS AND DISCUSSION

A tropical country such as Indonesia, which has many areas with soils derived from of ultramafic parent materials and other metalliferous soils which are studied, is an unexplored source of novel hyperaccumulator plant species. The success of any plant growth on metalliferous soils is significantly affected by prevailing edaphic factors such as chemistry, drought, salinity and physical characteristics of the soils. Sorowako ultramafic soils and other ultramafics have extreme chemical properties as shown in Table 1. The soil has very high heavy metals concentrations but low concentrations of macronutrients. Plant species for phytoremediation (phytomining) therefore need to be selected on the basis of their characteristics, such as uptake efficiency (Clemens, 2006), the translocation of the metals from the root to the shoot, the level of accumulation in the shoots, the growth form, and the metal tolerance of the plant species or ecotype and its associated microbes (Ernst, 1996 and Lasat, 2002), and the ability to adapt to extreme conditions. Most plant species that were discovered for phytomining are slow in growth, have low biomass and has shallow roots. On the other hand, the post mined areas are usually open, no trees left, soils contain high silt and clay which are susceptible to dispersion and surface run-off. Therefore, in phytomining field, non hyperaccumulator but metal tolerance plants which are speedy in growth, are needed as cover crop to avoid soil dispersion and preent soil erosion.

Table 1. Soil chemistry of ultramafic soils from Sorowako, Indonesia.

Parameters	Topsoil	Overburden (Laterite)	
	0-15 cm	Limonitic	Saprolitic
pH[1]	5.75	6.52	7.01
P total[2]	237.00	110.00	83.10
P extractable[3]	3.87	0.23	0.32
K total[2]	5164	4018	4138
K exch.[4]	0.03	0.01	0.02
CEC[4]	42.50	35.10	19.90
Mg exch.[4]	0.52	0.61	4.64
Ca exch.[4]	0.81	0.24	0.45
Mg:Ca	0.64	2.54	10.31
Ni total[2]	7051	7884	10524
Ni extractable[3]	7.54	20.70	30.20
Fe total[2]	131668	436372	240068
Co total[2]	57	294	536
Mn total[2]	1076	3053	4926
Al total[2]	154849	73984	35029
Cr total[2]	17216	11263	8595

Notes: (1) pH in H_2O extract (2) hot HNO_3-HCI soil digestion elemental concentrations in µg/g d.w.
(3) Bray-1 extractant P in µg/g dry weight soil. (4) Extracted with 1M ammonium acetate at pH 7, concentrations in meq/100g dry weight soil. Values are average of two samples, analysed with ICP-OES

E. sonchifolia which is abundantly available at the Sorowako ultramafic sites accumulates 190-280 mg kg^{-1} of Ni. Dry weight and metal and non-metal concentrations of shoots are presented in Table 2. Shoot production was higher when *E. sonchifolia* grown in topsoil and limonitic overburden compared to saprolitic. This strong growth inhibition on saprolitic overburden was accompanied with necrosis, a symptom of toxicity. Ultramafic soils are well known to have low nutrients, high in heavy metals, and high fixing capacity for nutrients like P, K and NH_4. Diffusion is the main pathway for transport to the root surface (Marschner, 1995). As a consequence of this short distance transport, spatial availability is a crucial aspect for delivery of these nutrients to the roots. Spatial availability is affected by root growth, and it is strongly related to soil texture.

Table 2. Shoot biomass and shoot concentrations of Ni, Fe, Cr, Zn, K and Mg of *E.sonchifolia*.

Soil	Shoot	Shoot Concentration					
	D.M.	Ni	Fe	Cr	Zn	K	Mg
	(g)		(mg kg^{-1})			(g kg^{-1})	
T	1.0±0.05^{b*}	14.7±1.1^{c}	406.8±157.4^{b}	9.3±2.0^{b}	28.8±0.3^{b}	41.6±0.5^{a}	5.7±0.5^{b}
T1	3.6±0.28^{a}	12.5.±2.8^{c}	40.0±8.3^{c}	3.6±0.2^{b}	32.2±3.2^{b}	46.9±3.0^{a}	3.1±3.0^{b}
M	0.8±0.04^{b}	29.7±0.8^{c}	215.0±122.8^{c}	10.5±0.9^{b}	43.5±2.3^{a}	42.9±1.6^{a}	5.4±1.6^{b}
M1	3.4±0.06^{a}	30.7±5.2^{c}	134.0±96.8^{c}	5.8±1.5^{b}	39.2±2.0^{a}	44.6±1.0^{a}	3.9±1.0^{b}
Y	0.4±0.04^{d}	210.7±10.1^{b}	633.5±34.2^{a}	28.3±2.7^{a}	26.2±1.4^{c}	44.0±0.7^{a}	13.6±0.7^{a}
Y1	0.7±0.12^{bc}	254.7±51.5^{a}	130.2±49.1^{c}	34.0±10.9^{a}	29.8±4.9^{b}	45.2±0.8^{a}	15.3±6.9^{a}

*Means marked with different letters showed significant differences ($p<0.05$) by Duncan-test
Notes: T, M, Y is standing for topsoil, Limonitic laterite, Saprolitic laterite but untreated while T1, M1, Y1 was treated with chicken manure

Chicken manure application significantly increased shoots productions in all soils (T1, M1 & Y1), but less pronounced in saprolitic laterite (Y). Ultramafic soils are nutrient deficient, thus amendment of organic matter may play positive effect. Addition of organic matters to soil may reduce potential risk of heavy metals in the environment by reducing its mobility. This reduction may be influenced by several factors, among them are degradability of organic matter, salts contents, soil pH, and type of soil and its redox potential (Shuman, 1991). The critical factor in phytomining is to reduce the dispersion and transport of the "crusty" (silty with high Fe) of limonitic and saprolitic laterite during frequent heavy rains resulting to the burying of seedlings and the splashing of silt up on to the surface of the leaves. Such is proven to severely stress the young plants and reduce plant establishment. The highest uptake of Ni and Cr were obtained from saprolitic overburden followed by limonitic and topsoils. The uptake of Fe was strongly influenced by the organic matter amendments. Chicken manure application significantly suppressed the Fe shoot uptake. Organic matter interferes with the formation of stable metal precipitation on one hand, but enhances adsorption on mixed assemblages of fulvic acid and Fe oxide on the other hand (Shumman, 1991). Zinc was not influenced by application of organic matter, and was high in shoot (Table 2) from limonitic overburden. Concentration of K in shoot was very similar for all soils and treatments. The saprolitic laterite has highest Mg:Ca concentration ratio (Table 1), and led to higher uptake of Mg (Table 2). Soil developed from ultramafic parent rocks share chemical peculiarities including high content of specific metals, a high +Mg:Ca concentration ratio and low concentration of macronutrients (Brooks, 1987; Proctor and Nagy, 1992).

CONCLUSION

Significant amounts of Ni and Fe in the shoot E. sonchifolia grown in saprolitic laterite provide sufficient indication that metal extraction is possible with some species of plants. Addition of manure on topsoil and overburden soil seemed to reduce the efficiency of plants to play as mining agents.

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