LAPORAN AKHIR
PENELITIAN UNGGULAN PERGURUAN TINGGI (M)

Judul

Potensi Mikoriza Indigenus untuk Fitomikoremediasi Tanah Tercemar Logam Berat Limbah Tambang Emas Artisanal

Prof.Dr.Ir. Wani Hadi Utomo (NIDN 0004124906)
Dr.Ir. Retno Suntari, MS. (NIDN 0003055806)

Dibiayai oleh

Direktorat Jenderal Pendidikan Tinggi,
Kementerian Pendidikan dan Kebudayaan, Melalui DIPA Universitas Brawijaya nomor : DIPA-023.04.2.414989/2013, tanggal 5 Desember 2012, dan berdasarkan SK Rektor Universitas Brawijaya Nomor : 407/SK/2013, tanggal 2 September 2013

UNIVERSITAS BRAWIJAYA
Desember 2013

HALAMAN PENGESAHAN
PENELITIAN UNGGULAN PERGURUAN TINGGI

Judul Penelitian	:	Potensi Mikoriza Indigenus untuk Fitomikoremediasi Tanah Tercemar Logam Berat Limbah Tambang Emas Artisanal
Kode/Nama Rumpun Ilmu	:	151 / Ilmu Tanah
Bidang Unggulan	:	Agroforestri
Topik Unggulan	:	Manajemen Agrobiodiversitas dalam Pelestarian Lingkungan
Ketua Peneliti		
A. Nama Lengkap	:	Prof.Dr.Ir. Wani Hadi Utomo
B. NIDN	:	0004124906
C. Jabatan Fungsional	:	Guru Besar
D. Program Studi	:	Ilmu Pertanian
E. Nomor HP	:	081259239900
F. Surel (e-mail)	:	hadi_utomo@hotmail.com
Anggota Peneliti (1)		
A. Nama Lengkap	:	Dr.Ir. Retno Suntari, MS.
B. NIDN	:	0003055806
C. Perguruan Tinggi	:	Universitas Brawijaya
Lama Penelitian Keseluruhan	:	1 tahun
Penelitian tahun ke 1	:	Rp. 80.000.000,00
Biaya Penelitian Keseluruhan	:	Rp. 80.000.000,00
Biaya tahun berjalan	:	- diusulkan ke DIKTI Rp. 80.000.000,00 - dana internal PT Rp. 0,00 - dana institusi lain Rp. 0,00 - Inkind tidak ada

Mengetahui,
Dekan

(Prof. Ir. Sumeru Ashari, M.Agr.Sc., PhD.)
NIP/NIK 19530328 198103 1 001

Malang, 23 Desember 2013
Ketua Peneliti,

(Prof.Dr.Ir. Wani Hadi Utomo)
NIP/NIK .19491204 197412 3 001

Menyetujui,
Ketua LPPM

(Prof.Dr.Ir. Siti Chuzaemi, MS)
NIP/NIK 19530514 198002 2 001

ABSTRAK

Proses amalgamasi merkuri dan sianidasi merupakan metode tradisional yang digunakan oleh penambang emas skala kecil di Indonesia untuk mendapatkan emas. Sisa proses tradisional tersebut berupa tailing yang mengandung berbagai logam berat yang mencemari lahan pertanian, karena umumnya dibuang di lahan pertanian. Kadar logam berat pada lahan pertanian tersebut dapat dikurangi dan dinetralisir dengan metode fitoremediasi. Jamur mikoriza arbuskular adalah salah satu endofit penting yang hidup di dalam akar sebagian besar tumbuhan daratan yang menguntungkan pertumbuhan tanaman melalui akuisisi fosfor dan unsur logam dari tanah. Oleh karena itu, upaya peningkatan efisiensi fitoremediasi perlu didahului dengan seleksi isolat yang sesuai dengan strategi fitoremediasi.

Penelitian yang akan dilaksanakan selama dua tahun ini ditujukan untuk (a) seleksi jenis mikoriza indigenus yang bersimbiosis dengan tanaman yang yang potensial untuk akumulator logam berat, dan (b) menentukan jenis mikoriza dan inangnya yang paling sesuai dalam tailing tambang emas,

Eksplorasi secara kualitatif dilakukan dengan metode jelajah pada bulan September-Oktober 2013 pada daerah di sekitar lokasi pembuangan tailing proses sianidasi. Pengamatan diversitas tumbuhan secara kuantitatif dilakukan dengan metode *line intercept*. Parameter yang diamati adalah kerapatan dan kerimbunan setiap takson. Nilai relatif dari kerapatan, kerimbunan dan frekuensi dihitung untuk menentukan indeks nilai penting yang menggambarkan penguasaan suatu takson di habitatnya. Analisis jenis mikoriza dan kondisi substrat dilakukan pada lahan di sekitar lokasi pembuangan tailing sianidasi guna menentukan struktur komunitas, jenis tumbuhan yang dominan/melimpah dan besarnya daya dukung lingkungan. Dari hasil verifikasi potensi tumbuhan dipilih enam jenis tumbuhan yang dominan yang potensial sebagai fitoremediator logam berat yaitu *Duabanga moluccana* Blum., *Erythrina orientalis* L., *Paraserianthes falcataria* (L.) Nielsen., *Paspalum conjugatum* Berg., *Cyperus kyllingia* Endl., dan *Lindernia crustacea* (L.) F..

Hasil penelitian menunjukkan bahwa di lokasi tanah tercemar tailing sianidasi tambang emas skala kecil dijumpai 34 spesies tumbuhan, yang terdiri atas 28 jenis pohon, 3 tumbuhan menjalar dan 2 tumbuhan penutup tanah. Enam spesies diantaranya (*Cyperus kyllingia* Endl., *Duabanga moluccana* Blum., *Erythrina orientalis* L., *Lindernia crustacea* (L.) F., *Paraserianthes falcataria* (L.) Nielsen., *Paspalum conjugatum* Berg.). Jenis mikoriza yang banyak dijumpai di lahan sekitar lokasi penambangan yang tidak tercemar tailing adalah genus *Gigaspora* dan *Glomus*. Semua enam species berasosiasi dengan mikoriza. Pada tanah tercemar tailing, asosiasi mikoriza dengan *P. conjugatum* lebih banyak dijumpai dibandingkan pada spesies tumbuhan lainnya. *D.moluccana*, *E.orientalis*, dan *P.falcataria*, sebagai tanaman kandidat untuk fitostabilisasi, sedangkan *C.kyllingia*, *L.crustacea*, dan *P.conjugatum*, sebagai kandidat untuk fitoekstraksi.

ABSTRACT

Mercury amalgamation and cyanidation process are the traditional methods commonly used by small -scale gold miners in Indonesia to recover gold. The waste of the process is the form of tailings containing heavy metals that contaminate agricultural land. Levels of heavy metals in agricultural land can be reduced and neutralized by the method of phytoremediation. Arbuskular mycorrhizal fungi is one important endophyte that lives in the roots of most land plants that benefit plant growth through the acquisition of phosphorus and metal elements from soil. Therefore, efforts to increase the efficiency of phytoremediation should be preceded by an appropriate selection of isolates with phytoremediation strategy. This study that will be conducted in two years was aimed tor (a) select the type of mycorrhizal symbiosis with indigenous plants that are potential for heavy metal accumulators, and (b) determine the type of mycorrhiza and most suitable host in the gold mine tailings

Qualitative exploration conducted by cruising method was conducted in September- October 2013 in the area of cyanidation tailing diposal. Observation of plant diversity was quantitatively performed by line intercept method. Parameters measured were density and shade of each taxon. Relative value of density and shade were measured to determine the frequency of important value index. Analysis of the type and condition of mycorrhiza substrates was made on land surrounding in the cyanidation tailings disposal to determine the structure of the community, the dominant plant species and magnitude of environmental carrying capacity.

Results of this study showed that on soil contaminated with cyanidation tailings there were 34 plant species. Six species of which (*Duabanga moluccana* Blum., *Erythrina orientalis* L., *Paraserianthes falcataria* (L.) Nielsen, *Paspalum conjugatum* Berg., *Cyperus kyllingia* Endl., and *Lindernia curstacea* (L.) F) were found to be dominant species. Mycorrhizal types found in the area are mostly Gigaspora and Glomus genus. The all six species associated well with mycorrhizae. However, mycorrhizal association with *P. conjugatum* was more prevalent than in other plant species. *D.moluccana*, *E.orientalis*, and *P.falcataria* are potential for phytostabilization strategy, while *C.kyllingia*, *L.crustacea*, and *P.conjugatum* are potential for phytoextraction strategy.

RINGKASAN

Proses amalgamasi merkuri dan sianidasi merupakan metode tradisional yang digunakan oleh penambang emas skala kecil di Indonesia untuk mendapatkan emas. Sisa proses tradisional tersebut berupa tailing yang mengandung berbagai logam berat yang mencemari lahan pertanian, karena umumnya dibuang di lahan pertanian. Kadar logam berat pada lahan pertanian tersebut dapat dikurangi dan dinetralisir dengan metode yang murah, yang dikenal dengan fitoremediasi yang terdiri atas empat jenis teknologi yakni rhizofiltrasi, fitostabilisasi, fitovolatilisasi, dan fitoekstraksi. Diantara empat teknologi fitoremediasi tersebut, fitostraksi merupakan metode yang paling banyak digunakan untuk ekstraksi logam berat pencemar tanah. Namun demikian, fitoremediasi tidak dilakukan sendiri oleh tanaman karena selalu ada interaksi antara mikrooganisme dalam rizosfer dengan tanaman yang menyebabkan peningkatan aktivitas yang terkait dengan remediasi. Jamur mikoriza arbuscular (JMA) adalah salah satu endofit penting yang hidup di dalam akar sebagian besar tumbuhan daratan. Simbiosis ini secara langsung menguntungkan pertumbuhan tanaman melalui akuisisi fosfor dan unsur logam dari tanah. Namun demikian, beberapa penelitian lain menyatakan bahwa penggunaan JMA justru menurunkan konsentrasi unsur logam pada tanaman bermikoriza. Oleh karena itu, upaya peningkatan efisiensi fitoremediasi perlu didahului dengan seleksi isolat yang sesuai dengan strategi fitoremediasi. Penelitian yang dilaksanakan ini ditujukan untuk (a) seleksi jenis mikoriza indigenus yang bersimbiosis dengan tanaman yang yang potensial untuk akumulator logam berat, dan (b) menentukan jenis mikoriza dan inangnya yang paling sesuai dalam tailing tambang emas.

Eksplorasi secara kualitatif dilakukan dengan metode jelajah pada awal pada daerah di sekitar lokasi pembuangan tailing proses sianidasi. Pengamatan diversitas tumbuhan secara kuantitatif dilakukan dengan metode *line intercept*. Tiga buah transek ditarik tegak lurus dam tailing berlawanan arah jarum jam. Jarak antar transek sekitar 40 m. Dalam tiap transek dibuat 5 petak berukuran 1 m x 1 m. Parameter yang diamati adalah kerapatan dan kerimbunan setiap takson. Nilai relatif dari kerapatan, kerimbunan dan frekuensi dihitung untuk menentukan indeks nilai penting yang menggambarkan penguasaan suatu takson di habitatnya. Hasil eksplorasi lapangan dikelompokkan atas dasar jenis tanaman. Dari pengelompokan tersebut kemudian dipilih tumbuhan yang dominan. Biomasa tumbuhan ditentukan dengan metode deskriptif di petak contoh 1 m^2. Biomasa dikeringkan untuk analisis kandungan kalori dan logam berat. Analisis jenis mikoriza dan kondisi substrat dilakukan pada lahan di sekitar lokasi pembuangan tailing sianidasi guna menentukan struktur komunitas, jenis tumbuhan yang dominan/melimpah dan besarnya daya dukung lingkungan. Verifikasi potensi tumbuhan dilakukan pada beberapa plot percobaan skala kecil dengan menanam tumbuhan terseleksi. Percobaan ex situ dilakukan di rumah kaca Laboratorium Fakultas Pertanian, Universitas Brawijaya. Dari hasil inventariasi, dipilih enam jenis tumbuhan yang dominan yang potensial sebagai fitoremediator logam berat yaitu *Duabanga moluccana* Blum., *Erythrina orientalis* L., *Paraserianthes falcataria* (L.) Nielsen., *Paspalum conjugatum* Berg., *Cyperus kyllingia* Endl., dan *Lindernia crustacea* (L.) F. Biji masing-masing species tumbuhan yang diperoleh dari lokasi tailing di kecambahkan selama 5 hari dan kemudian ditanaman pada media tanaman yang berupa campuran tailing dan kompos dengan persentase perbandingan kompos:tailing adalah 20:80.

Hasil penelitian menunjukkan bahwa di lokasi tanah tercemar tailing sianidasi tambang emas skala kecil dijumpai 34 spesies tumbuhan, yang terdiri atas 28 jenis pohon, 3 tumbuhan menjalar dan 2 tumbuhan penutup tanah. Enam spesies diantaranya (*Cyperus kyllingia* Endl., *Duabanga moluccana* Blum., *Erythrina orientalis* L., *Lindernia crustacea* (L.) F., *Paraserianthes falcataria* (L.) Nielsen., *Paspalum conjugatum* Berg.), mempunyai toleransi tinggi terhadap lingkungan marginal di lahan tercemar tailing sehingga tumbuhan ini potensial sebagai fitoremediator logam berat. Jenis mikoriza yang banyak dijumpai di lahan sekitar lokasi penambangan yang tidak tercemar tailing adalah genus *Gigaspora* dan *Glomus*. Semua enam species berasosiasi dengan mikoriza. Pada tanah tercemar tailing, asosiasi mikoriza dengan *P. conjugatum* lebih banyak dijumpai dibandingkan pada spesies tumbuhan lainnya. *Duabanga moluccana* Blum., *Erythrina orientalis* L., dan *Paraserianthes falcataria* (L.) Nielsen, sebagai tanaman yang tahan unsur logam sebagai kandidat untuk strategi fitostabilisasi, sedangkan *Cyperus kyllingia* Endl., *Lindernia crustacea* (L.) F, dan *Paspalum conjugatum* Berg, sebagai kandidat untuk strategi fitoekstraksi.

SUMMARY

Mercury amalgamation and cyanidation process are the traditional methods commonly used by small -scale gold miners in Indonesia to recover gold. The waste of the process is the form of tailings containing heavy metals that contaminate agricultural land as the tailings are commonly discharged to agricultural land nearby. Levels of heavy metals in agricultural land can be reduced and neutralized with an inexpensive method, which is known as phytoremediation that consists of four types of technology i.e. rhizofiltration, pbytostabilization, pnytovolatilisation, and phytoextraction. Among the four phytoremediation technologies, phytoextraction is the most widely used method for the extraction of heavy metal contaminants. However, phytoremediation can not be done alone by plant because there is always an interaction between microorganisms in the rhizosphere. Arbuscular mycorrhizal fungi is one of the important endophyte that lives in the roots of most terrestrial plants. This symbiosis directly benefit plant growth through the acquisition of phosphorus and metal elements from soil. Therefore, efforts to increase the efficiency of phytoremediation should be preceded by an appropriate selection of isolates with phytoremediation strategy. This study that will be conducted in two years was aimed tor (a) select the type of mycorrhizal symbiosis with indigenous plants that are potential for heavy metal accumulators, and (b) determine the type of mycorrhiza and most suitable host in the gold mine tailings.

Qualitative exploration conducted by cruising method was conducted in September- October 2013 in the area of cyanidation tailing diposal. Observation of plant diversity was quantitatively performed by line intercept method. Parameters measured were density and shade of each taxon. Relative value of density and shade were measured to determine the frequency of important value index. Analysis of the type and condition of mycorrhiza substrates was made on land surrounding in the cyanidation tailings disposal to determine the structure of the community, the dominant plant species and magnitude of environmental carrying capacity.

Results of first phase of this study showed that on soil contaminated with cyanidation tailings there were 34 plant species. Six species of which (*Duabanga moluccana* Blum., *Erythrina orientalis* L., *Paraserianthes falcataria* (L.) Nielsen, *Paspalum conjugatum* Berg., *Cyperus kyllingia* Endl., and *Lindernia curstacea* (L.) F) were found to be dominant species. Mycorrhizal types found in the area are mostly Gigaspora and Glomus genus. The all six species associated well with mycorrhizae. However, mycorrhizal association with *P. conjugatum* was more prevalent than in other plant species. *D.moluccana*, *E.orientalis*, and *P.falcataria* are potential for phytostabilization strategy, while *C.kyllingia*, *L.crustacea*, and *P.conjugatum* are potential for phytoextraction strategy.

DAFTAR PUSTAKA

Angle, J.S., Chaney, R.L., Baker, A.J.M, Li, Y., Reeves, R., Volk, V., Roseberg, R., Brewer E., Burke S. and Nelkin J. 2000. Developing commercial phytoextraction technologies: practical considerations. *South African Journal of Science* 97: 619-623.

Auge, R.M., Water relations, drought and vesicular-arbuscular mycorrhizal symbiosis. *Mycorrhiza* 11: 3–42.

Banuelos, G.S. and Dhillon, K.S. 2011. Developing a sustainable phytomanagement strategy for excessive selenium in Western United States and India. *International Journal of Phytoremediation* 13: 208-228.

Barea, J.M., Azco'n-Aguilar, C. and Azcon, R. 1997. Interactions Between Mycorrhizal Fungi and Rhizosphere Microorganism within the Context of Sustainable Soil-Plant Systems, In Multitrophic Interactions in Terrestrial Systems (Eds Gange A.C. and Brown V.K.), Cambridge, United Kingdom, 65-77.

Baya, A.P. and Van Heyst, B. 2010. Assessing the trends and effects of environmental parameters on the behaviour of mercury in the lower atmosphere over cropped land over four seasons. *Atmospheric Chemistry and Physics* 10: 8617-8628.

Berti, W.R. and Cunningham, S.D. 2000. Phytostabilization of metals. In: Phytoremediation of Toxic Metals–Using Plants to Clean Up the Environment.I. Raskin and B.D. (eds), p 71-88. New York:John Wiley & Sons.

Bhargava, A., Carmona, F.F., Bhargava, M., and Srivastava, S. 2012. Approaches for enhanced phytoextraction of heavy metals. *Jurnal of Environmental Management* 105:103-120.

Brundrett, M.C., Ashwath, N. and Jasper, D.A. 1996. Mycorrhizas in the Kakadu region of Tropical Australia I. Propagules of Mycorrhizal Fungi and Soil Properties in Natural Habitats. *Plant and Soil* 184: 159-171.

Chandra Sekhar K., Kamala, C.T., Chary, N.S. Balaram, V. and Garcia, G. 2005. Potential of Hemidesmus indicus for phytoextraction of lead from industrially contaminated soils. *Chemosphere* 58: 507-514

Compant, S., Clément, B. and Sessitsch, A. 2010. Plant growth-promoting bacteria in the rhizo- and endosphere of plants: their role, colonization, mechanisms involved and prospects for utilization. *Soil Biololgy and Biochemistry* 42: 669–678.

Enkhtuya, B., Rydlová, J. and Vosátka, M. 2002. Effectiveness of Indigenous and Non-indigenous Isolates of Arbuscular Mycorrhizal Fungi in Soils from Degraded Ecosystems and Man-made Habitats. *Applied Soil Ecology* 14: 201-211.

Ensley, B. D. 2007. Rationale for use of phytoremediation. In: I. Raskin and B. D. Ensley (Eds.), Phytoremediation of Toxic Metals. Using Plants to Clean up the Environment, J. Wiley & Sons, New York, USA: 3-11.

Ernst, W.H.O. 2000. Evolution of Metal Hyperaccumulation and Phytoremediation Hype, *New Phytology* 146: 357-358.

Evans, L.J. 1989. Chemistry of metal retention by soils. *Environmental Science and Technology* 23:1046-1056.

Feng, G., Song, Y. C., Li, X. L. and Christie, P. 2003. Contribution of arbuscular mycorrhizal fungi to utilization of organic sources of phosphorus by red clover in a calcareous soil. *Applied Soil Ecology* 22: 139–148.

Fitter, A.H. and Hay, R.K.M. 2002. Environmental physiolgy of plants. Academic Press, London, UK, 367 pp.

Glass, D.J. 2000. Economic potential of phytoremediation. In: I. Raskin and B. D. Ensley, (Eds.)., Phytoremediation of Toxic Metals. Using Plants to Clean up the Environment, J. Wiley & Sons, New York, USA: 15-31.

Handayanto, E., Nuraini, Y., Purnomosidi, P., Hanegraaf, M., Agterberg, G., Hassink, J. and van Noordwijk, M. 1992. Decomposition rates of legume residues and N mineralization in an ultisol in Lampung. *Agrivita* 15: 75-86.

Harms, H., Schlosser, D. and Wick, L.Y. 2011. Untapped Potential: Exploiting Fungi in Bioremediation of Hazardous Chemicals. *Nature Reviews Microbiology* 9: 177-192.

Harrier, L.A. and Sawczak, J. 2000. Detection of the 3-phosphoglycerate kinase protein of *Glomus mosseae* (Nicol. & Gerd.) Gerdemann & Trappe. *Mycorrhiza* 10: 81–86

Hidayati, N, Juhaeti, T, dan Syarif, F. 2009. Mercury and Cyanide Contaminations in Gold Mine Environment and Possible Solution of Cleaning Up by Using Phytoextraction. *Hayati Journal of Biosciences* 16: 88-94.

Hildebrandt, U., Regvar, M. and Bothe, H. 2007. Arbuscular mycorrhiza and heavy metal tolerance. *Phytochemistry* 68: 139–146.

Hinton, J. 2002. Earthworms as a Bioindicator of Mercury Pollution in an Artisanal Gold Mining Community, Cachoeira do Pink Brazil. Master Thesis. University of British Columbia, Canada, 140 pp.

Hooda, P.S. 2010. Trace Elements in Soils, Blackwell Publishing Ltd.

Hylander, L.D., Plath, D., Miranda, C.R., Lucke, S., Ohlander, J. and Rivera, A.T.F. 2007. Comparison of different gold recovery methods with regard to pollution control and efficiency. *Clean* 35: 52-61.

Ismawati, Y. 2010. Presentation at the National Mercury Roundtable Forum, Jakarta, 4 August 2010.

Jasper, D.A., Abott, L.K. and Rohson, A.D. 1991. The Effect of Soil Disturbance on Vesicular Arbuscular Mycorrhizal Fungi in Soils from Different Vegetations Types. *New Phytology* 118: 471-476.

Joner, E. J. and Leyval, C. 2001. Time-cpurse of heavy metal uptake in maize and clover as affected by root density and different mycorrhizal inoculation regimes. *Biology and Fertility of Soils* 33: 351–357.

Kabata-Pendias, A. and H. Pendias. 1992. Trace elements in soils and plants. CRC Press, Boca Raton, FL. 365 pp.

Kabir, Z. and Koide, R.T. 2000. The effect of dandelion or a cover crop on mycorrhiza inoculum potential, soil aggregation and yield of maize. *Agriculture, Ecosystem and Environment* 78:167–174.

Khan, A.G., Kuek, C., Chaudhry, T.M., Khoo, C.S. and Hayes, W.J. 2000. Role of plants, mycorrhizae and phytochelators in heavy metal contaminated land remediation. *Chemosphere* 41: 197–207.

Khodaverdiloo, H. and Homaee, M. 2008. Modeling of Cadmium and Lead Phytoextraction from Contaminated Soils. *Soil Science* 41: 149-162.

Khodaverdiloo, H. and Samadi, A. 2011 Batch Equilibrium Study on Sorption, Desorption, and Immobilization of Cadmium in Some Semiaridzone Soils as Affected by Soil Properties. *Soil Research* 49: 45-59.

Koomen, I., McGrath, S.P. and Giller, K. 1990. Mycorrhizal Infection of Clover is Delayed in Soils Contaminated with Heavy Metals from Past Sewage Sludge Applications. *Soil Biology and Biochemistry* 22: 871-873.

Krebs, C.J. 1989. EcologicalMethodology. Harper & Row Publ. New York.

Krisnayanti, B.D., Arifin, Z. Bustan, Sudirman. and Yani, A. 2012. Mercury Concentration on Tailing and Water from One Year of ASGM at Lantung, Sumbawa, Indonesia. In: Environmental, Socio-economic, and Health Impacst of Artisanal and Small-Scale Minings. E. Handayanto, B.D. Krisnayanti and Suhartini (eds). p 61-66. UB Press, Malang, Indonesia

Krzaklewski, W. and Pietrzykowski, M. 2002. Selected physicochemical properties of zinc and lead ore tailings and their biological stabilisation. *Water, Air and Soil Pollution* 141:125–142.

Kumar, P. and Chandra, R. 2004. Detoxification of distillery effluent through Bacillus thuringiensis (MTCC 4714) enhanced phytoremediation potential of *Spriodela polyrrhiza* (L.) Schliden. *Bulletin of Environmental Contamination and Toxicology* 73:903-910.

Lasat, M. M. 2002. Phytoextraction of Toxic Metals: A Review of Biological Mechanisms. *Journal of Environmental Quality* 31: 109-120.

Leyval,C., Turnau,K. and Haselwandter, K. 1997. Effect of heavy metal pollution on mycorrhizal colonization and function: Physiological, ecological and applied aspects. *Mycorrhiza* 7: 139–153.

Li, Y. M., Chaney, R., Brewer, E., Rosenberg, R., Angle, S.J., Baker, A. J. M., Reeves, R. D. and Nelkin, J. 2003. Development of technology for commercial phytoextraction of nickel: economic and technical considerations. *Plant and Soil* 249: 107-115

Liao, S.W. and Chang, W.L. 2004. Heavy metal phytoremediation by Water Hyacinth at constructed wetlands in Taiwan. *Journal of Aquatic Plant Management* 42: 60-68.

Lin, C., Zhu, T., Liu, T. and Wang, D. 2010. Influences of major nutrient elements on Pb accumulation of two crops from a Pb-contaminated soil. *Journal of Hazardeous Materials* 174: 2002-2008

Lomonte, C., Doronila, A.I., Gregory, D., Baker, A.J.M., and Kolev, S.D. 2010. Phytotoxicity of biosolids and screening of selected plant species with potential for mercury phytoextraction. *Journal of Hazardeous Materials* 173: 494-501.

Loth, C. 1996. Abundance of Arbuscular Mycorrhizal Fungi Spores at Different Natives Sites in Dependence of Sludge Applications. *Bodenkultur* 47: 89-96.

Malcova, R., Vosátka, M. and Gryndler, M. 2003. Effects of inoculation with Glomus intraradices on lead uptake by *Zea mays* L. and *Agrostis capillaris* L. *Applied Soil Ecology* 23: 55–67.

Mathur, N., Bohra, J.S.S, Quaizi, A. and Vyas, A. 2007. Arbuscular Mycorrhizal Fungi: A Potential Tool for Phytoremediation. *Journal of Plant Sciences* 2:127-140.

McGonigle, T. P. and Miller, M. H. 1996. Development of Fungi below ground in Association with Plants Growing in Disturbed and Undisturbed Soil. *Soil Biology and Biochemistry* 28: 263-269.

Meagher, R.B., Rugh, C.L., Kandasamy, M.K., Gragson, G. and Wang, N.J. 2000. Engineering phytoremediation of mercury pollution in soil and water using bacterial genes. In: Phytoremediation of Contaminated Soil and Water, N. Terry, and G. Bailuelos. Eds. Lewis Publishers, USA, pp 201-219.

Mohammad, M.J., Pan, W.L. and Kennedy, A.C. 1995. Wheat Responses to Vesicular-Arbuscular Mycorrhizal Fungal Inoculation of Soils from Eroded Toposequence, *Soil Science Society of America Journal* 59:1086-109.

Morel, F.M.M., Kraepiel, A.M.L. and Amyot, M. 1998. The chemical cycle and bioaccumulation of mercury. *Annual Reviews in Ecological Systems* 29:543-566.

Moreno, F.N., Anderson, C.W.N., Robinson, B.H. and Stewart, R.B. 2004. Phytoremediation of mercury-contaminated mine tailings by induced plant-Hg accumulation. *Environmental Practice* 6: 165-175.

NRC (National Research Council). 1980. Mineral tolerance of domestic animals. National Academy of Sciences, Washington, DC. 577 pp.

Pedron, F., Petruzzelli, G., Barbafieri, M., Tassi, E., Ambrosini, P., and Patata, L., 2011. Mercury mobilization in a contaminated industrial soil for phytoremediation. *Communications in Soil Science and Plant Analysis* 42: 2767-2777.

Pielou, E.C. 1975. Ecological Diversity.John Wiley & Sons., New York.

Pilon-Smits, E. 2005. Phytoremediation. *Annual Review of Plant Biology* 56:15-39.

Rahmawati, I. 2011. Pengaruh Kemiskinan Terhadap Maraknya Pertambangan Tanpa Ijin (Studi Kasus Di Kecamatan Sekotong, Kabupaten Lombok Barat). Media Bina Ilmiah, Fakultas Teknik Universitas Muhammadiyah Mataram, Desember 2011: 16-20.

Rillig, M.C. and Steinberg, P.D. 2002. Glomalin production by an arbuscular mycorrhizal fungus: a mechanism of habitat modification. *Soil Biology and Biochemistry* 34: 1371–1374.

Rugh, C.L. 2004. Genetically engineered phytoremediation: one man's trash is another man's transgene. *Trends in Biotechnology* 22: 496-468.

Schippers, A., Jozsa, P.G., Sand, W., Kovacs, Z.M. and Jelea, M. 2000. Microbiological pyrite oxidation in a mine tailings heap and its relevance to the death of vegetation. *Geomicrobiology Journal* 17:151–162.

Schnoor, J.L., Light, L.A., Mccutcheon, S. C., Wolfe, N.L. and Carreira, L.H. 1995. Phytoremediation of organic and nutrient contaminants. *Environmental Science and Technology* 29: 3 18-323.

Schuster, E. 1991. The behaviour of mercury in the soil with special emphasis on the complexation and adsorption processes- a review of the literature. *Water, Air, and Soil Pollution* 56:667-680

Setiawati, T.C. and Handayanto, E. 2000. Role of phosphate solubilising bacteria on availability phosphorus in oxisols and tracer of phosphate in corn by using 32P. Presented at The 19th World Congress of Soil Science, Soil Solutions for a Changing World, 1 – 6 August 2010

Shu,W.S., H.P. Xia, Z.Q. Zhang, C.Y. Lan, and M.H.Wong. 2002. Use of vetiver and three other grasses for revegetation of Pb/Zn mine tailings: Field experiment. *International Journal of Phytoremediation* 4:47–57

Slowey, A.J. 2010. Rate of formation and dissolution of mercury sulfide nanoparticles: The dual role of natural organic matter. *Geochimica et Cosmochimica Acta* 74: 4683-4708.

Stevenson, F.J., and Cole, M.A. 1999. Cycles of soil: Carbon, nitrogen, phosphorus, sulfur, micronutrients. John Wiley & Sons, New York.

Subowo, M., Widodo, S. dan Nugraha, A. 2007. Status dan Penyebaran Pb, Cd, dan Pestisida pada Lahan Sawah Intensifikasi di Pinggir Jalan Raya. Prosiding. Bidang Kimia dan Bioteknologi Tanah, Puslittanak, Bogor.

Taylor, J. and Harrier, L. A. 2001. A comparison of development and mineral nutrition of micropropagated Fragaria × ananassa cv. Elvira (strawberry) when colonized by nine species of arbuscular mycorrhizal fungi. *Applied Soil Ecology* 18: 205–215.

Telmer, K. 2007. Mercury and Small Scale Gold Mining –Magnitude and Challenges Worldwide. GEF/UNDP/UNIDO Global Mercury Project

Thangavel, P. and Subhuram, C. V. 2004. Phytoextraction – Role of hyper accumulators in metal contaminated soils. *Proceedings of the Indian National Science Academy*. Part B 70: 109–130.

Truu, J. Talpsep, E. Vedler, E. Heinaru, E. and Heinaru, A. 2003. Enhanced Biodegradation of Oil Shale Chemical Industry Solid Wastes by Phytoremediation and Bioaugmentation. Estonia Academy Publisher

Vandenkoornhuyse, P. 1998. Effect des metaux sur la diversite des champignons mycorhiziens a arbuscules dans les sols. Ph.D. Thesis. Henri Poincare University, Nancy I.

Wallschlager, D., Desai, V.M.M. and Wilken, R. 1996. The role of humic substances in the aqueous mobilization of mercury from contaminated floodplain soils. *Water, Air, and Soil Pollution* 90:507-520.

Wallschlager, D., Desai, V.M.M., Spengler, M., and Wilken, R. 1998 a. Mercury speciation in floodplain soils and sediments along a contaminated river transect. *Journal of Environmental Quality* 27:1034-1044.

Wallschlager, D., Desai, V.M.M., Spengler, M., Windmiller, C.C. and Wilken R. 1998 b. How humic substances dominate mercury geochemistry in contaminated floodplain soils and sediments. *Journal of Environmental Quality* 27:10441057.

Wolfe, A. K. and Bjornstad, D. J. 2002. Why would anyone object? An exploration of social aspects of phytoremediation acceptability. *Critical Reviews in Plant Science* 21: 429-438

Yang, Z.Y., Yuan, J.G., Xin, G.R., Chang, H.Y. and Wong, M.H. 1997. Germination, growth, and nodulation of Sesbania rostrata grown in Pb/Zn mine tailings. *Environmental Management* 21:617–622.

Yayasan Tambuhak Sinta. 2010. Scoping Study Report of Poboya, Palu ASGM Site.

Ye, Z.H., J.W.C. Wong, and M.H. Wong. 2000. Vegetation response to lime and manure compost amendments on acid lead/zinc mine tailings: A greenhouse study. *Restoration Ecology* 8:289–295.

Ye, Z.H., J.W.C.Wong, M.H.Wong, C.Y. Lan, and A.J.M. Baker. 1999. Lime and pig manure as ameliorants for revegetating lead/zinc mine tailings: A greenhouse study. *Bioresources Technology* 69:35–43.

Ye, Z.H., Z.Y. Yang, G.Y.S. Chan, and M.H. Wong. 2001. Growth response of Sesbania rostrata and S. cannabina to sludge-amended lead/zinc mine tailings- a greenhouse study. *Environmental International* 26:449–455.