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Remediation of toxic metal contaminated soil and mine waste with combined chemical and phytostabilisation

Thesis Book

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1 Introduction and background

My research is connected to the risk management of metal contamination due to mining. The termination of mining in Hungary and all over Europe gives the actuality of the topic. In Europe the assessment and remediation of water and soil contamination from mining, and the complex rehabilitation of mining sites is initiated to be carried out based on a standard management strategy[1]

To reduce the risk of contaminated areas the spreading and uptake of toxic metals has to be hindered on all pathways, therefore efficient, environmental friendly, sustainable and cheap remediation technologies are needed. For the remediation of diffuse pollution phytoremediation is an evolving technology, aiming to reduce risk with plants[2]. To ensure healthy development of plants and acceptable soil moisture and groundwater quality, the solubility and plant uptake of toxic metals shall be reduced, so that the environmental risk posed by toxic metals becomes low. For this reason I combined phytostabilisation with chemical stabilisation of toxic metals in soil.

The combined chemical and phytostabilisation aims at keeping the metals in the soil, not removing them. The chemical stabiliser reduces the mobility of metals, hereby enhances plant growth and the development of healthy vegetation cover. The vegetation decreases the amount of water that gets into the soil, hereby the transport of metals by water, dusting and erosion. The amount of metals that gets into the food chain can be further reduced using plant types that do not transport metals form roots to above ground parts. The combined chemical and phytostabilisation reduces the mobility of metals, therefore the exposure of the receptors (the ecosystem and the humans) in the toxic metal contaminated area. The human and ecological risks that originate from inhalation of dust, consumption of water, dermal contact and consumption of contaminated plants and animals are reduced[345].

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[1] http://viso.ei.jrc.it/pecomines_ext/index.html
[2] Salt, D.E., Smith, R.D., Raskin, I. (1998) Phytoremediation, Annual review of plant physiology and plant molecular biology, 49, 643–668
[3] MOKKA/KÖRINFO lexikon: www.körinfo.hu
[4] Simon L. (2004) Fitoremediáció, BME OMIKK, Budapest, Környezetvédelmi füzetek
[5] Berti, W.R., Cunningham, S.D. (2000) Phytostabilization of metals, In: Raskin, I., Ensley, B.D. (eds.) Phytoremediation of toxic metals: using plants to clean-up the environment, John Wiley and Sons, New York, 71−88

The suitable stabiliser–plant combination has to be chosen based on the properties of the site, the quality of the contaminating metals, the properties of the contaminated soil, the climatic and other site specific conditions, therefore for the development of a new technology pre-experiments and scaled-up technology development is needed. As chemical stabilisers alkaline materials, such as lime and fly ash, clay minerals, elemental iron and iron containing materials, phosphates and organic materials can be applied[6][7]. For phytostabilisation usually grass species are applied as they can produce closed vegetation with their dense root system and enhance the settling of other plant species[8]. Industrial and fodder plants, shrubs and trees can also be applied[9].

In Gyöngyösoroszi, Hungary mining started 150 years ago. Since the 50-s over 40 years intensive zinc and lead mining went on, in 1986 the mining ceased without final closure of the mine leaving acidic and weathering mine wastes behind. Since then the catchment of the Toka-creek has been highly contaminated with toxic metals, mainly cadmium, zinc and lead and occasionally arsenic due to the transport with runoff water and erosion of contaminated solid material from the diffusely polluted areas.[10][11]. Based on the management strategy developed on the basis of the risk assessment and the risk model of the Toka catchment the diffuse pollution that remains after the removal of point sources will be treated by combined chemical and phytostabilisation.

[6] Adriano, D. C., Wenzel, W. W., Vangronsveld, J., Bolan, N.S. (2004) Role of assisted natural remediation in environmental cleanup, Geoderma, 122, 121–142

[7] Kumpiene, J., Lagerkvist, A., Maurice, C. (2008) Stabilization of As, Cr, Cu, Pn and Zn in soil using amendments – A review, Waste Management, 28, 215−225

[8] Berti, W.R., Cunningham, S.D. (2000) Phytostabilization of metals, In: Raskin, I., Ensley, B.D. (eds.) Phytoremediation of toxic metals: using plants to clean-up the environment, John Wiley and Sons, New York, 71−88

[9] Pulford, L.D., Watson, C. (2003) Phytoremediation of heavy metal-contaminated land by trees – a review, Environmental International 29, 529–540,

[10] Gruiz, K., Vaszita, E., Siki, Z. (2006) Quantitative Risk Assessment as part of the GIS based Environmental Risk Management of diffuse pollution of mining origin. In: Conference proceedings of Difpolmine Conference, 12–14 December 2006, Montpellier, France

[11] Gruiz, K.; Vaszita, E.; Zaletnyik, P., Siki, Z. (2008) GIS-based catchment scale modelling of toxic metal transport by erosion in an abandoned mining area – In: Proceedings of the 10th International UFZ-Deltares/TNO Conference on Soil-Water Systems in cooperation with Provincia di Milano, ConSoil 2008 CD, 3–6 June 2008, Milano, Italy, Theme F, 301–310

2 Aims

1. As part of the risk based management concept my main goal was to develop a remediation technology for the mine wastes and the diffusely contaminated agricultural soils due to the spreading of metal containing mine wastes in the area of the Gyöngyösoroszi zinc and lead sulphide ore mine.
2. The basis of the development of the remediation technology is the evaluation and comparison of the available chemical stabilisers in Hungary for the treatment of cadmium, zinc, lead and occasionally arsenic containing soils and mine wastes. I aimed at focusing on amendments considered to be wastes, such as fly ash, drinking water treatment residues and red mud.
3. During the development of the combined chemical and phytostabilisation technology I focused on
    a. investigating the application of the scaled-up technology development,
    b. developing an integrated technology and environmental monitoring for the follow-up of the experiments,
    c. demonstrating the innovative technology, which means performing the first application,
    d. verifying the technology, which means proving its technological, environmental, economical and social efficiency.
4. Development of new, interactive ecotoxicological test methods, that ensure direct contact between the testorganism and the tested soil therefore suitable for effect testing.

3 Materials and methods

I chose three experimental sites in the Gyöngyösoroszi mining area: the agricultural area under the village that is frequently flooded by the sulphidic mine waste containing sediment of the Toka-creek, the waste dump near the main entrance of the mine and a highly acidic, weathered and sulphidic mine waste in the forestry area of the Mátra Mountain. To choose the best stabiliser I performed scaled-up experiments in laboratory microcosms, field lysimeters and field plots (Figure 1).

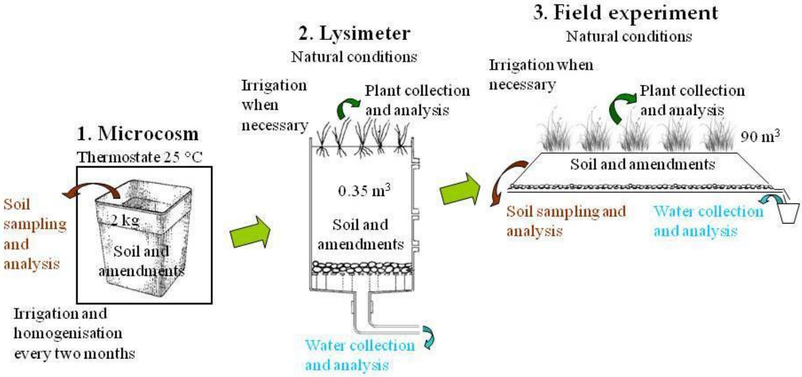

Figure 1: Scaled-up technological experiments

I applied various chemical stabilisers, such as fly ash, lime, iron grit, alginite, raw phosphate, lignite, drinking water treatment residues and red mud in long term (3 years) microcosm experiments. In the field experiments I applied the best stabilisers: fly ashes, mixture of fly ash and lime, and combination of fly ash, lime and iron grit. As plants I chose a grass mixture, *Sorghum* species (sudan grass and broom corn) and maize.

For the monitoring of the experiments I developed an integrated methodology that contains physical, chemical, biological and ecotoxicity methods (Figure 2). For the assessment of the environmental risks, I monitored mainly the mobility and solubility of metals and I applied water, weakly acidic, strongly acidic and alkaline extractions in parallel. For the direct effect measurement of the treated soils I applied interactive ecotoxicity tests. I developed two tests: toxicity testing in soil by microcalorimetry and rapid plant bioaccumulation test.

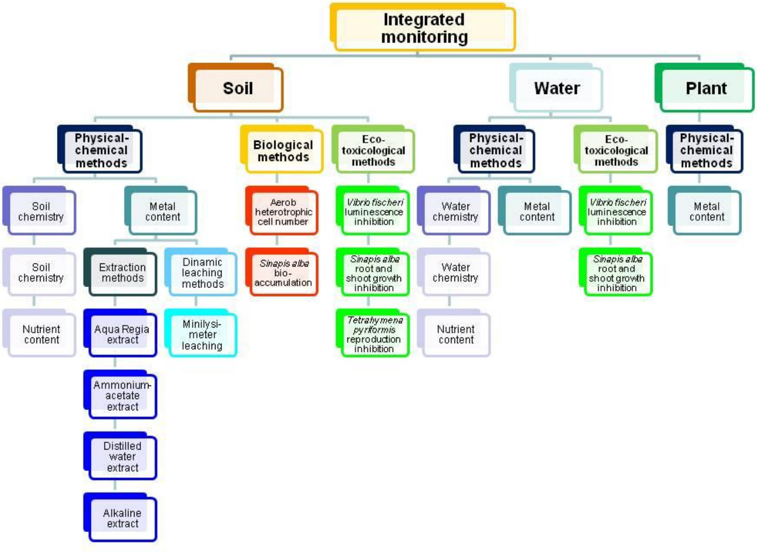

Figure 2: Integrated technology monitoring

4 Results

I proved with the stabilisation experiments that the alkaline fly ash (pH=12.6) is able to reduce the amount of ammonium-acetate extractable Cd and Zn by 45% and 49%, respectively, the distilled water soluble by more than 99% in the Gyöngyösoroszi soils compared to the untreated. The more fly ash added to the soil (1, 2 and 5 weight%) the better was the stabilisation. The effect of fly ash was observed 21 days after addition and the one time addition kept its stabilisation efficiency during 2 years (Figure 3). The stabilisation efficiency of fly ashes is maintained longer than the examined 2–3 years, because metals can be irreversibly absorbed or fixed via crystal growth and metal diffusion into metal-silicate mineral surfaces[12]. Fly ash decreased soil toxicity (bacterial toxicity with 40–50%, plant toxicity with 30–50%) and reduced the amount of Cd and Zn bioaccumulated by plants

[12] Vangronsveld, J., Ruttens, A., Clijsters, H. (1999) The use of cylonic ashes of fluidized bed burning of coal mine refuse for long-term immobilization of metals in soils. In: Sajwan, K.S., Alva, A.K., Keefer, R.F. (eds.) Biogeochemistry of Trace Elements in Coal and Coal Combustion Byproducts pp. 223–233, Plenum, New York.

with 71%. The neutral fly ash applied together with lime showed similar results.

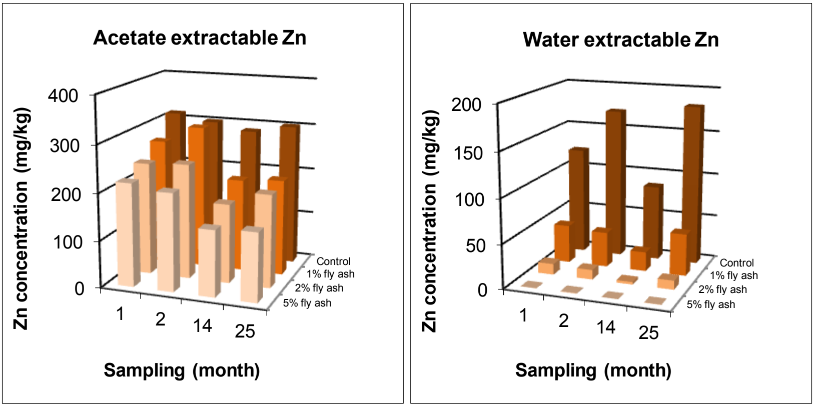

Figure 3: Ammonium-acetate and water extractable Zn-content of 1, 2, 5 weight% fly ash treated contaminated agricultural soil 1, 2, 14 and 25 days after treatment

Fly ashes from various locations and of various times of origin (Oroszlány, Tata, Visonta) differ in efficiency. The most efficient stabilisers considering the decrease in the amount of extractable and plant available Cd and Zn were fly ash “OA” from Oroszlány and fly ashes “TB” from Tata and “V” from Visonta combined with lime. I concluded that it is useful to apply non-alkaline fly ashes with lime to treat acidic soils and mine wastes.

I used elemental iron in arsenic containing mine waste to treat the mobile arsenic fraction found after the pH increase caused by alkaline stabilisers, such as fly ash and lime. Due to the addition of zero valent iron the amount of acetate extractable As decreased by 80%, the water soluble by 50%, the As content in the leachate of minilysimeters by 68% compared to the fly ash + lime treated one without iron. I concluded that the iron should be mixed into the soil deeper than 20 cm, approximately to 40 cm to provide the acceptable As concentration in leachate water.

The traditional amendments that improve soil quality, such as alginite, raw phosphate and lime, which can be regarded as raw materials, decreased the extractable (84–97% decrease in water soluble metal content) and plant available (61–71% decrease) metal content of soil and reduced toxicity (stimulating effect on *Sinapis alba*), but were less efficient compared to fly ashes, which are considered to be wastes. Lime is only efficient on short term[13], so it cannot be recommended to be used on its own, but in case of non-alkaline fly ashes, where the integration of metals into the mineral structures is only performed after a longer time period, lime is an ideal amendment. The advantage of alginite is that it is a rich nutrient source for plants, while raw phosphate is a long term phosphorous source. Lignite mobilised metals in the Gyöngyösoroszi soils, so it cannot be recommended in this case.

Fly ash, drinking water treatment residues and red mud are regarded as wastes. Their deposition generates well-known environmental risks and costs. The deposited harmful and hazardous wastes can be beneficial when applied as chemical stabilisers, because they can reduce the extractable and plant available metal content and toxicity of soils and mine wastes. These wastes can be applied in the necessary amount as cheap amendments that provide long term stabilisation without harmful consequences in soil. The most efficient chemical stabiliser was fly ash among these waste materials. Drinking water treatment residues resulted 60–69%, red mud 85% decrease in the water soluble metal amount. The plant uptake was diminished with up to 18–20% by water treatment residues and with 19–29% by red mud. The amendments did not influence soil toxicity.

In field demonstration I successfully applied fly ash from Tata with *Sorghum* species to treat toxic metal contaminated agricultural soil. The fly ash added at 5 weight% reduced the extractable metal content of the contaminated soil: the ammonium-extractable Cd, Zn and Pb content decreased by 75–77%, the distilled water soluble Cd and Zn by 94%. The amount of Cd and Zn taken up by plants decreased by 70–90%. I recommend broom corn and sudan grass for the combined chemical and phytostabilisation of the agricultural soils in the regularly flooded area of the Toka-creek due to their low metal uptake and possible industrial and energetic utilization.

For the remediation of the highly weathered, acidic and barren mine waste the mixture of fly ash from Tata and from Visonta, lime and elemental iron in combination with grasses and *Sorghum* species was applied successfully. The mixture of fly ash from Tata, fly ash from Visonta, lime and iron grit at 2.5, 2.5, 2.0 and 0.7 weight%, respectively, was the most efficient for the stabilisation of the Bányabárc waste material. As plants I applied grass mixture developed by the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences for phytostabilisation purposes and *Sorghum* species that proved to be suitable phytostabilizing plants for the metal contaminated soil. The Cd, Zn and Pb content of the

[13] Ruttens, A., Adriaensen, K., Meers, E., De Vocht, A., Geebelen, W., Carleer, R., Mench, M., Vangronsveld, J. (2010) Long-term sustainability of metal immobilization by soil amendments: Cyclonic ashes versus lime addition, Environmental Pollution, 158, 1428–1434

leachate water from the treated field plots was under the quality criteria (both the maximum effect based quality criteria suggested for surface waters in the area[14] and the Hungarian quality criteria for subsurface water[15]). Due to the combined chemical and phytostabilisation the pH ~3 leachate water of the acidic mine waste became neutral, the toxicity of the mine waste disappeared, the soil life normalized, the micronutrient content increased, the texture and the water holding capacity improved, healthy and closed vegetation cover developed with metal content under quality criteria for animal fodder [16] (Figure 4).

Figure 4: From the upper left corner: 1. Untreated mine waste from Bányabérc with high mobile metal content and strong toxicity which prevents plant settling, 2. Closed grass cover on the fly ash and lime treated plot, 3. Healthy sudan grass on the fly ash and lime treated plot, 4. View of the treated plots at Bányaudvar

[14] Gruiz, K., Vaszita, E., Siki, Z. (2006) Quantitative Risk Assessment as part of the GIS based Environmental Risk Management of diffuse pollution of mining origin. In: Conference proceedings of Difpolmine Conference, 12–14 December 2006, Montpellier, France.
[15] 6/2009. (IV.14) KvVM-EüM-FVM együttes rendelet a földtani közeg és a felszín alatti víz szennyezéssel szembeni védelméhez szükséges határértékekről és a szennyezések méréséről.
[16] 44/2003. (IV.26.) FVM rendelet a Magyar Takarmánykódex kötelező előírásairól.

I proved the efficiency of the combined chemical and phytostabilisation with technology demonstration. To assess the risk of metals that depends on their mobility I developed an integrated methodology, which means joint evaluation and interpretation of the physical-chemical analytical methods and biological-ecotoxicological tests. I developed a rapid bioaccumulation test with white mustard (*Sinapis alba*) for the estimation of the metal amount taken up by plants. I validated the method by comparison with the metal uptake of field plants. I found the measurement of the heat production of testorganisms to be a new and sensitive endpoint and I developed a soil testing method based on microcalorimetry. With microcalorimetry we can detect very small heat changes (±50 nW, which is $0.5 \cdot 10^{-6}$ °C with Thermal Activity Monitor). I showed that with the measurement of heat production one can detect the effect on *Sinapis alba* of 50 mg/kg Zn in soil , while with the original root- and shoot growth inhibition measurement it can only be observed at more than 500 mg/kg Zn concentration.

I proved that the combined chemical and phytostabilisation as an innovative remediation technology is suitable for the risk reduction of the toxic metal contamination in the diffusely polluted area of the Gyöngyösoroszi mine to a level, where it does not pose any risk to the ecosystem, the water and the humans. The scaled-up technology development proved to be time and cost efficient for the development of the innovative technology. It enabled us to get to the field demonstration of a new technology in three-five years. For the verification of the technology I applied a complex system[17], which evaluates the technological, ecological, socio-economical efficiency of the technology.

5 Thesis statements

Evaluation of the efficiency and the applicability of chemical stabilisers:

1. I confirmed, that the alkaline fly ashes alone and non-alkaline fly ashes together with lime are suitable for the long term stabilisation of mobile cadmium, zinc and lead in contaminated soils and mine wastes (**5**, **9**, **10**, 16).
2. I proved, that the Hungarian fly ashes from different origin have different efficiency for the stabilisation/immobilisation of cadmium and zinc in soils and mine wastes (**5**, 15).

[17] Gruiz, K., Molnár, M., Fenyvesi, É. (2008) Evaluation and Verification of Soil Remediation. In: Kurladze, G.V. (ed.) Environmental Microbiology Research Trends, Nova Science Publishers Inc., New York, 1–57

3. I showed, that elemental iron (in the form of iron grit) is able to reduce the extended arsenic mobility due to the application of alkaline amendments (fly ash, lime) in arsenic containing mine wastes (**2**, 13).
4. I proved that alginite and raw phosphate are suitable stabilisers for toxic metal contaminated soils and that lignite cannot be recommended for the treatment of Gyöngyösoroszi soils (**5**, **9**, 16).
5. I showed, that waste materials, such as water treatment residues and red mud – whose deposition has well-known risks beyond costs – are suitable for the stabilisation of toxic metal contaminated soils and mine wastes (**1**, **5**).

Verification of the efficiency and applicability of the combined chemical and phytostabilisation technology:

6. I proved by field technology demonstration, that the combination of fly ash from Tata with *Sorghum* species is suitable for the combined chemical and phytostabilisation of the diffusely toxic metal contaminated agricultural areas in Gyöngyösoroszi (**4**, 15).
7. I proved by field technology demonstration, that the combination of fly ash from Tata and Visonta, lime and elemental iron with grass mixture or *Sorghum* species is suitable for the combined chemical and phytostabilisation of the highly weathered sulphidic mine waste (**2**, **6**, **7**, 13, 14).

Development of concepts and methods

8. I confirmed the applicability of the scale-up concept for the development of the combined chemical and phytostabilisation technology. (11, 15).
9. I developed an integrated monitoring methodology for the monitoring of combined chemical and phytostabilisation experiments and technology application (**2**, **8**).
10. I developed biological and ecotoxicological test methods: direct contact soil test based on microcalorimetry and rapid bioaccumulation test with *Sinapis alba* (**3**, **9**, 13).

6 Applications

Combined chemical and phytostabilisation is a risk based technology that promotes sustainability. I proved by technology demonstration that it is suitable for the remediation of toxic metal contaminated soils and mine wastes, therefore it can be applied for the rehabilitation of the 11.5 ha diffusely polluted area of the mining site in Gyöngyösoroszi, Hungary. Due to the similarities in metal ore mining sites the general applicability of combined chemical and phytostabilisation was confirmed by the results of the DIFPOLMINE EU-Life project[18].

In Europe the assessment of pollution of mining origin commenced with the PECOMINES project[19]. This technology may be applied in large areas in Poland, Romania and Bulgaria. In Hungary besides the Gyöngyösoroszi mine this technology may be applied in the metal polluted area of the Recsk-Lahoca ore mine. The combined chemical and phytostabilisation can be a remediation solution for all diffusely metal contaminated sites, where the contamination affects large areas. The following areas can be targeted: metal contamination due to industrial activities such as areas near smelters, areas contaminated by traffic for example by lead, contamination of agricultural origin for example due to inappropriate fertilizer or biosolid application, the surface of metal containing and acidifying waste depositions such as coal mining wastes or red mud.

Combined chemical and phytostabilisation can be applied to improve barren and low quality soils. The amendments can provide nutrients, improve soil texture, prevent erosion and raise soil pH. Thus they can be used for the revegetation of waste deposits or as culture media and geotechnical elements (SOILUTIL project[20]).

The combined chemical and phytostabilisation technology and its monitoring methodology suitable for the follow-up of metal mobility and environmental risk were posted to the KÖRINFO/MOKKA database[21]. This database aims at disseminating innovative methods to prevent their disappearance in the „death valley” and meanwhile making them known and accepted by the public.

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[18] http://www.difpolmine.org
[19] http://viso.ei.jrc.it/pecomines_ext/index.html
[20] http://soilutil.hu/
[21] http://www.körinfo.hu/

7 Publications

7.1 Publications on which the thesis is based on

7.1.1 Articles in journals with impact factor

1. **Feigl, V.**, Anton, A., Uzinger, N., Gruiz, K. (2011) Red mud as a chemical stabilizer for soil contaminated with toxic metals, Water, Air & Soil Pollution, online first: 9th September 2011, IF_{2010}: 1.765
2. **Feigl, V.**, Gruiz, K., Anton, A. (2010) Remediation of metal ore mine waste using combined chemical- and phytostabilisation, Periodica Polytechnica, 54 (2), 71–80, IF_{2010}: 0.042
3. Gruiz, K., **Feigl, V.**, Hajdu, Cs., Tolner, M. (2010) Environmental toxicity testing of contaminated soil based on microcalorimetry, Environmental Toxicology, Special Issue: 14th International Symposium on Toxicity Assessment, 25 (5), 479–486, IF_{2010}: 1.932
4. **Feigl, V.**, Uzinger, N., Gruiz, K., Anton, A. (2009) Reduction of abiotic stress in a metal polluted agricultural area by combined chemical and phytostabilisation, Cereal Research Communications, 37, Suppl. 465–468. IF_{2007}: 1.190

7.1.2 Other journal articles

5. **Feigl, V.**, Uzinger, N., Gruiz, K. (2009) Chemical stabilisation of toxic metals in soil microcosms, Land Contamination and Reclamation, 17 (3–4), 483–494.
6. **Feigl, V.**, Anton, A., Gruiz, K. (2009) Combined chemical and phytostabilisation: field application, Land Contamination and Reclamation, 17 (3–4), 577–584.
7. Gruiz, K., Vaszita, E., Siki, Z., **Feigl, V.**, Fekete, F. (2009) Complex environmental risk management of a former mining site, Land Contamination and Reclamation, 17 (3–4), 355–367.
8. Gruiz, K., Molnár, M., **Feigl, V.** (2009) Measuring adverse effect of contaminated soil using interactive and dynamic methods, Land Contamination and Reclamation, 17 (3–4), 443–459.
9. **Feigl, V.**, Atkári, Á., Anton, A., Gruiz, K. (2007) Chemical stabilisation combined with phytostabilisation applied to mine waste contaminated soils in Hungary, Advanced Materials Research, 20–21, 315–318.
10. Gruiz, K., Vaszita, E., Siki, Z., **Feigl, V.** (2007) Environmental risk management of an abandoned mining site in Hungary, Advanced Materials Research, 20–21, 221–225.

7.1.3 Book chapter

11. **Feigl, V.**, Anton, A., Gruiz, K. (2010) An innovative technology for metal polluted soil – combined chemical and phytostabilisation, In: Construction for a sustainable environment (Eds. Sarsby, R. W. and Meggyes, T.), Proceedings of the International Conference of Construction for a Sustainable Environment, Vilnius, Lithuania, 1–4 July, 2008, ISBN 978-0-415-56617-9, Taylor and Francis Group, London, pp. 187–195.
12. Gruiz, K., Vaszita E., **Feigl, V.**, Siki, Z. (2010) Environmental risk management of diffuse pollution of mining origin, In: Construction for a sustainable environment (Eds. Sarsby, R. W. and Meggyes, T.), Proceedings of the International Conference of Construction for a Sustainable Environment, Vilnius, Lithuania, 1–4 July, 2008, ISBN 978-0-415-56617-9, Taylor and Francis Group, London, pp. 219–228.

7.1.4 Other publications

13. **Feigl, V.**, Gruiz, K., Anton, A. (2010c) Combined chemical and phytostabilisation of an acidic mine waste – Long-term field experiment, Conference Proceedings CD of Consoil 2010, 22–24 September 2010, Salzburg, Austria, Consoil 2010 Posters A3-24.
14. **Feigl, V.**, Anton, A., Gruiz, K. (2008a) Kombinált kémiai és fitostabilizácó alkalmazása szabadföldi kísérletben, National Environmental Conference, 16–18 September 2008, Siófok, Hungary, Conference Book, 83–93.
15. **Feigl, V.**, Anton, A., Fekete, F., Gruiz, K. (2008) Combined chemical and phytostabilisation of metal polluted soil – from microcosms to field experiments, Conference Proceedings CD of Consoil 2008, 3–6 June 2008, Milan, Italy, Theme E, 823–830.
16. **Feigl V.**, Atkári Á., Uzinger N., Gruiz K. (2006) Fémmel szennyezett területek integrált kémiai és fitostabilizációja, National Environmental Conference, 19–21 September 2006, Siófok, Hungary, Conference Book, 99–108.

7.1.5 Abstracts in conference proceedings

17. **Feigl, V.**, Gruiz, K., Bagi, A., Hajdu, Cs., Tolner, M. (2009) Microcalorimetry: a sensitive end point in soil toxicity testing, 14th International Symposium on Toxicity Assessment, Program and Abstract Book, 116.
18. **Feigl, V.**, Gruiz, K. (2006) Combined chemical and phytostabilisation of metal polluted soil, International Symposium on Environmental Biotechnology, Book of Abstracts, 312.

7.1.6 Lectures and posters

1. **Feigl, V.,** Gruiz, K., Anton, A.: Combined chemical and phytostabilisation of an acidic mine waste – Long-term field experiment, Consoil 2010, 22–24 September 2010, Salzburg, Austria (poster)
2. Gruiz, K., **Feigl, V.**, Hajdu, Cs., Tolner, M., Bagi, A.: Microcalorimetry: a sensitive test method in soil toxicity testing, 14th International Symposium on Toxicity Assessment, 30 August – 4 September 2009, Metz, France (lecture)
3. Gruiz, K., **Feigl, V.**, Hajdu, Cs., Tolner, M., Bagi, A.: Microcalorimetry: a sensitive test method in soil toxicity testing, 14th International Symposium on Toxicity Assessment, 30 August – 4 September 2009, Metz, France (poster)
4. **Feigl, V.**, Klebercz, O., Uzinger, N., Gruiz, K., Anton, A.: Reduction of abiotic stress in a metal polluted agricultural area by combined chemical and phytostabilisation, 8th Alps-Adria Scientific Workshop, 27 April – 2 May 2009, Neum, Bosnia-Hercegovina (poster)
5. **Feigl, V.**, Anton, A., Gruiz, K.: Kombinált kémiai és fitostabilizácó alkalmazása szabadföldi kísérletben, National Environmental Conference, 16–18 September 2008, Siófok, Hungary (lecture)
6. **Feigl, V.**, Anton, A., Gruiz, K.: An innovative technology for metal polluted soil – combined chemical and phytostabilisation, Green5 – Construction for a sustainable environment, 1–4 July 2008, Vilnius, Lithuania (lecture)
7. **Feigl, V.**, Anton, A., Fekete, F., Gruiz, K.: Combined chemical and phytostabilisation of metal polluted soil – from microcosms to field experiments, Consoil 2008, 3–6 June 2008., Milan, Italy (poster)
8. **Feigl, V.,** Atkári, Á., Anton, A., Gruiz, K. Chemical stabilisation combined with phytostabilisation applied to mine waste contaminated soils in Hungary, 17th International Biohydrometallurgy Symposium, 2–5 September 2007, Frankfurt, Germany (poster)
9. **Feigl, V.**, Atkári, Á., Uzinger, N., Gruiz, K.: Chemical stabilisation combined with phytostabilisation applied to mine waste contaminated soils, Difpolmine Konferencia: What does the future hold for large metal-polluted sites?, 12–14 December 2006, Montpellier, France (poster)

10. **Feigl V.,** Atkári Á., Uzinger N., Gruiz K.: Fémmel szennyezett területek integrált kémiai és fitostabilizációja, National Environmental Conference, 19–21 September 2006, Siófok, Hungary (lecture)
11. **Feigl, V.**, Atkári, Á., Uzinger, N., Gruiz, K.: Combined chemical and phytostabilisation of metal polluted soil, International Symposium on Environmental Biotechnology ISEB ESEB JSEB 2006, 9–13 July 2006, Leipzig, Germany (poster)
12. Gruiz, K., Vaszita, E., **Feigl, V.**, Siki, Z.: Complex risk management of mine waste at the Hungarian model site of the „Difpolmine" project, NICOLE workshop, 11–13 May 2006, Carcassonne, France (poster)

7.2 Other publications which are not connected to the thesis

7.2.1 Article with impact factor

1. Mayes, W.M., Jarvis, A.P., Burke, I.T., Walton, M., **Feigl, V.**, Klebercz, O., Gruiz, K. (2011) Dispersal and Attenuation of Trace Contaminants Downstream of the Ajka Bauxite Residue (Red Mud) Depository Failure, Hungary, Environmental Science & Technology, 45 (12), 5147–5155. IF_{2010}: 4,825

7.2.2 Other publications

2. Gruiz, K., **Feigl, V.**, Vaszita, E., Klebercz, O., Újaczky, É., Atkári, Á. (2010) An integrated approach for the utilization of waste on soil – Innovative manegement and technologies, Conference Proceedings CD of Consoil 2010, 22–24 September 2010, Salzburg, Austria, Consoil 2010 Ths B2
3. Gruiz, K., **Feigl, V.**, Vaszita, E., Klebercz, O., Újaczky, É., Atkári, Á. (2010) An integrated approach for the utilization of waste on soil – Innovative management and technologies, Consoil 2010, Abstract Book of Presentations, 139. (absztrakt)
4. Klebercz, O., Gruiz, K., **Feigl, V.**, Anton, A. (2010) Introducing the project SOILUTIL, Conference Proceedings CD of Consoil 2010, 22–24 September 2010, Salzburg, Austria, Consoil 2010 Posters A3-39
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