INTRODUCING THE PROJECT SOILUTIL

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Abstract

The technological research program named SOILUTIL aims to develop technologies for soil remediation and amelioration using waste materials as soil additive. The poster reviews some of the possible uses of several types of wastes for soil (e.g. fly ash, red mud, Fe-Mn oxid-hydroxid precipitates and iron forges), based on examples from literature and project results so far. It also introduce the reader to on-going research fields: stabilization of toxic mining waste, reducing global environmental risks of soil carbon enrichment methods, amelioration of sandy soils, developing geotechnical elements and cultivation memiums, and creating the technical and informatical background for meeting soil needs and values available in wastes, by the develpoment of a database and a waste-mixing software.

Keywords: soil remediation; soil degradation; waste utilization; global carbon circulation

Introduction

Only 3% of the Earth is covered by fertile soil and even this is subjected to various soil degradation processes starting from organic matter decline and pollution through acidification to erosion. Management and disposal of various waste materials produced as a result of human activity is one of the actual problems to be solved worldwide. The ideal solution gives an efficient waste utilisation alternative. The world SOILUTIL is a mosaic world which combines the worlds Soil and Utilization, being the project's goal is to imrpove soil qualities by waste utilization. The comprehensive aim of the Soilutil project is to ameliorate degraded/contaminated soil, improve the stability of swampy, instable soil and sustain on long term soil quality developing non-hazardous wastes utilisation technologies with the help of a modern engineering toolbox.

The project achieves its aims simultaneously with the following objectives:

1. Mitigation of environmental risk, re-use of wastes, generation of benefits instead of costs.
2. Amendment of degraded soils (deteriorated, non-permeable, eroded, non-fertile, contaminated, geotechnically problematic soils) by in situ treatment, stabilisation, remediation or restoration targeting long-term preservation or improvement of soil quality according to land-use.
3. Preparation of the adequately selected waste composites/compositions as cultivation medium, the optimum from physical, chemical, biological and cost point of view.
4. Production of geotechnical elements and constructions from wastes: permeable wrapping, permeable cover, draining layer, vertical and horizontal filter layer, underground reactive barrier and reactive soil zone filling.
5. Field demonstration and verification of 4 of the developed technologies.
6. Introduction of a risk-based approach into the waste management, waste exploitation and utilization practice.
7. Setting up of a database including the inventory of industrial wastes, waste utilisation technologies and opportunities.
8. Development of waste mixing/combining software improving soil quality criteria. Examination of the broader applicability of the software ex. waste mix solid fuel, construction material, etc..
9. Legal background provided with navigation on the WEB interface and decision support for the use of the database.
10. Contribution to the amendment of environmental regulations to comply with the sustainable environmental quality requirements for waste management.

Proven and potential use of wastes as soil amendments

Several kinds of wastes can possibly be used for solving soil problems. Some of these are widely used, and some are in different phases of experimental verification. Hereby we introduce the most promising wastes for our goals, showing their main features and examples of their applications publicated. Since one of the main problems when trying to use wastes as secondary product is its inhomogenity due to differences in raw materials and waste production processes, in this part of our study we make emphasis on Hungarian applications if they exist.

Fly ash

Fly ashes from different combustion processes have been used for several purposes as soil additives. Due to its silica content it can be used as stabilising agent for trace elements Vangronsveld et al. (1996-) has demonstrated the effectiveness of a kind of coal fly ash (beringit) in immobilization of zinc and cadmium at long scale field application. Ruttens et al. (2006) has used cyclonic ashes for immobilizing Zn, Cd and Pb. Solla-Gullon et al. (2008) applied wood ash for fertilizing soil for forest plantation, and observed increase in P, Ca, Mg and K-content. There are many other uses of fly ash as a K and Ca-fertilizer (Rautaray 2003, Mittra 2005, Moutsatsou 2006). Alan et al. (1996) used pressurized fluidized bed combustion for an acidic and sodic soil, and observed increase in water conductivity, and in plant production as well.

Since fly ashes somtimes contain toxic trace elements above limit, they are often considered hazardous wastes. The management of great quantites of this kind of waste means additional expences for the energy plants, meanwhile at least part of it could be re-used as soil additive. The potential use of fly ash from different energy plants of Hungary is verified by long time field experiments on the metal contaminated mining site of Gyöngyösoroszi. (Feigl, 2007, 2008, 2009)

Red mud

Red mud is the by-product of alumina extraction from bauxite using caustic soda. It is an alkaline, sludge-like material with high iron and aluminium content. Red mud is proven to be efficient soil amendment by international and Hungarian experimental results. It is used for the stabilization of toxic metals in soil: Cd, Pb, Zn, Cu, Ni (Lombi, 2001). Field application has also proved that red mud, combined with lime (Gray, 2006) or other waste materials (Friesl, 2005) can decrease metal availibilty and toxicity for plants. According to Lombi (2001), red mud causes more durable reduction in metal mobility than sole liming, and the risk of metal re-mobilization is also smaller. That can be explained by the difference in the stabilization mechanism of lime and red mud: while lime decreases mobility by only shifting the pH from acid to basic region, red mud works also by co-precipitation of toxic metals with its unoxidized components. Red mud has also been successfully used for phosphorus fixation in soil: Summers (1997) has achieved more than 30–75% decrease in phosphorus concentration in soil drainage water after red mud treatment in field experiences over a period of four years.

Deposits of red mud, the residue from bauxite processing are also a serious problem in Hungary, since large amounts of residues have remained from the once-prosperous aluminum industry. In many cases, the metal content of red mud is not critical, the toxic metal content is generally below the limiting value, therefore their application as a stabilizer provides a double benefit.

In the period 2006–2008, long-time microcosm experiments were conducted by our group, to examine the stabilizing effect of red mud produced in Hungary, which is available in great quantity from deponies of a former alumina plant. The waste was used as stabilizing amendment for mine waste and agricultural soil contaminated with toxic metals. According to the results of the 17 months experiments, 5% red mud has lowered water extractable Cd, Zn-content by 60%, As-content by 70%. According to tests with *Sinapis alba*, red mud treatment could decrease growth inhibition of the examined soil, and effected lower bioaccumulation rates in plants for Zn (30% decrease compared to control), Pb (50% decrease) and As (80% decrease) (Feigl et al., 2008). Further research aims to verify the use of red mud as stabilizing amendment in field experiments.

Fe-Mn-oxide-hydroxide precipitates

This kind of waste originates from drinking water pre-treatment plants, wherethe Fe- and Mn-content of the water from the bank-filtration wells is oxidized by ozone and filtered by sand filters. The precipitate is removed from the sand filter by washing and concentrated by settling. The resulted 30% dry material content waste is then transferred to waste deposit in variable quantities since no other possible use is yet known in industry.

Due to its Fe (II)-hydroxid content, this kind of waste can also be an effecitve amendment for immobilizing trace elements in paralel to its further oxidation. Müller and Pluquet (1998) used Fe-Mn-precipitates for immobilizing Zn and Cd in sea sediment after dredging. Hungarian microcosm experiments (Feigl, 2008) examined Fe-Mn precipitate wastes from two different treatment plants in Hungary, working with very similar technology. From the two types, one (R) prowed to be successfull in immobilizing metals (e.g. 20 to 70% decrease in acetat-soluble Cd and Zn content), while the other (Cs) has shown greater variability in stabilizing potencial. This points out that the inner values of the same type of waste material can differ greatly according to the generating process, and even to time, space and other factors.

Iron forges

The efficiency of (elemental iron (also called ZVI=Zero Valent Iron) in remediation is widely proven in publications, as reviewed by Cundy et al. (2008). Iron can be used for remediating soil or ground water, in situ or ex situ, used as soil amendment or as charge of a permeable reactive barrier. The mechanism of its effect is either coprecipitation or reductive reactions. The experiments made with arsenic and other metals containing acidic mine waste have also shown that iron grit can increase the immobilizing effect of other treatments such as fly ash and lime addition (Feigl et al., 2010).

Olive mill waste

Many studies mention olive-mill waste or wastewater as a potential soil fertilizer, (Roiz, 2005; López-Pinero, 2008; Mekki, 2009). López-Pinero and his co-workers observed significant increases in total organic carbon (TOC), water soluble organic carbon (WSOC), humic and fulvic acids, and aggregate stability after four consecutive annual additions of different forms of olive-mill wastes. Oil facturation is a prospering industry in Hungary as well, only using sunflower seed as feedstock instead of olive. Accordingly it can be an important goal to examine the possibilities of using sunflower oil facturing wastes in soil remediation. Presently we are studying one kind of waste: an alcaline wastewater from vegetable-oil processing, containing phospholipids and triglyceride residues. Preliminary studies show that this kind of waste can increase soil activity without any harmful effect observed.

Alcaline wastes against soil acidification

The spreading problem of soil acidification called to life the long-used method of treating acid soils with lime. Several forms of lime are commonly used for this purpouse (limestone powder, hydrated lime, lime containing tuff, etc). However there are many types of lime-containg wastes, what could be used against acidification. These include sugar beet lime, building materials like crushed concrete and bricks, wastes of cement production, magnesite production, tan-yards, etc. Lime-containing wastes can have other additional benefits in soil amelioration/remediaton. The efficiency of metal stabilisation can also be increased by lifting soil pH, and lime addition may positively influence the role of soil in the global C-circulation, as explained below.

Case-studies of applications

Introduction of on-going researches of the SOILUTIL project

Remediation of metal contaminated sites

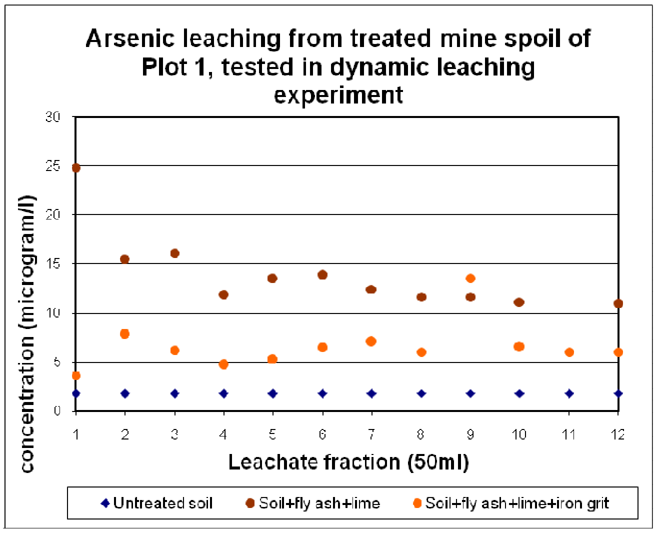

Chart 1: Decrease in leachable As-content effected by fly ash, lime and iron grit treatment

Toxic metal contamination from former mining activity is a serious problem of certain regions of Hungary. Our group continues remediation experiments on the former mining site of Gyöngyösoroszi, Hungary since 2003. During that period we developed and verified a combined treatment for immobilizing the toxic metal cotent of mining wastesand contaminated agricultural soils with fly ash, lime and steel shots, from small-scale lab experiments to field experiments. Our results show that this treatment combined with phyitostabilization can effectively decrease the leachable metal content, toxicity, and plant metal concentration.

Three small-scale field experiments were carried out, two for three different types of mine waste, and one for agricultrual land. All have been followed by an integrated chemical and ecotoxicological monitoring. These were: extraction with solvents of growing acidity for the follow up the mobility of toxic metals, static and dynamic leaching tests for controlling drainage water, bacterial and plan toxicity testing for measuring the effect and bioaccumulation of the soil contaminants. (Feigl, 2009). **Charts 1–2.** show the monitoring-results of one of the three the field experiments (Klebercz, 2009).

Two plots have been formed from two different kinds of acid mine waste: one freshly opened, and one from the surface, half-way to humification. Both plots have been treated with 5% fly ash and 2% slack lime, and after one year, 0,5% iron grit have been added to stabilize arsenic, which became mobilized due to the increased pH. Results seen on **Chart 2** show that the leachable metal contents have been reduced lastingly to 1/10–1/100 part of the initialvalues for Zn, Cd, Pb and Cu. Dynamic leaching tests with artificial rainwater were made to test the potential of iron grit in stablilizing arsenic. The results seen on Chart 1 support the observations of field experiments that the fly ash + lime treatment mobilizes the As-content of soil, and confirm that iron addition can mitigate this mobilizing effect significantly. Toxicity levels for bacteria and plants have also dropped significantly (30–70%) and testing bioaccumulation showed that final metal content of the plants is acceptable (compared to Hungarian law).

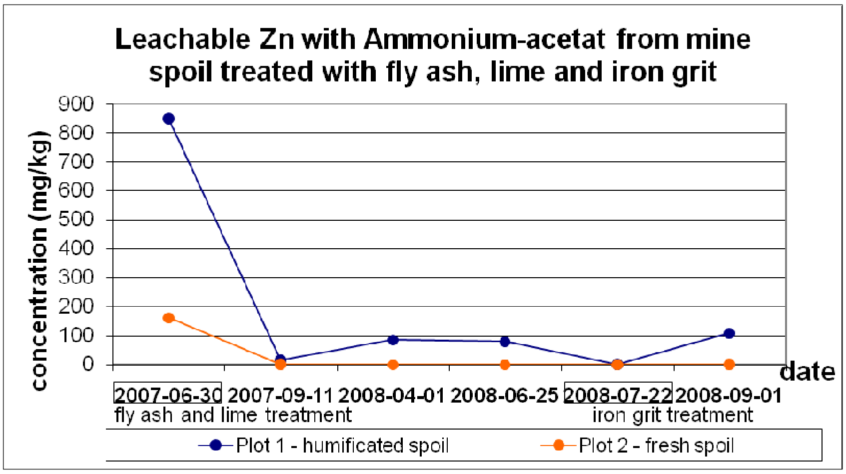

Chart 2.: Decrease in leachable Zn-content effected by fly ash, lime and iron grit treatment in long-scale field verification

The method of combined chemical and phytostabilization proved to beefficient for reducing ecological risk of metal contaminated wastes. The aim of further research is to solve this complex stabilization problem solely with waste materials. Theoretically slack lime could be substituted with any lime-containing waste mentioned before, and its potential has been shown in other studies as well, for example the use of sugar beet lime combined with sewage sludge for metal stabilization published by Madejón in 2005. Other lime-containing industrial wastes can also come to calculation (Garrido, 2004). Evaluation and field verification of these possibilities is one of the further goals of SOILUTIL.

Reducing CO_2-emission of soils ameliorated by organic wastes

When developing an environmental risk reduction technology, one must take into consideration the eco-efficiency of the technology. Efficien risk reduction, or eco-efficiency conists of three factor:

1. The potential to decrease the environmental risk the technology has been orignally designed for (e.g. land contamination or soil degradation processes).
2. The additional environmental risks caused by the technology itself in local or regional scale (e.g. different emissions to soil or to surface or subterrean water, especially for in-situ technologies)
3. The eco-efficiency of the technology on global scale (e.g. effects on global climate or ozonic layer), often examined using the tool of Lifecycle Assessment (LCA).

The latter, namely the effect of soil technologies on global climate due to greenhouse gas emission or sequestration has been the topic of several recent studies, here only to mention the article of Chapin and Ruess in Nature (2001). Soil microbial activity plays a importantt role in the global C-circulation. Soil CO_2-emission can vary between 10–100 kgCO_2/ha/day according to soil properties and vegetation type (Rastogi, 2002). As a comparison, at the lowest rate, each ha of soil emits every day a CO_2 amount equivalent to a 100 kilometers long journey with car, taken in account CEC goals (2007) on car emissions.

A widely used waste management method for organic wastes (particulary sewage sludge) is it application on soil as fertilizer and structure-developing material. It is not only one of the cheapest ways of deposing wastes arising in great quantity, but if doing the correct way, it can result in sustainable soil quality and land use. One important disadvantage of this solution from the global point of view is that easily biodegradable compounds are degraded fastly by soil microbes, and instead of remaining in soil, cause an abrupt increase in soil CO_2-emission.

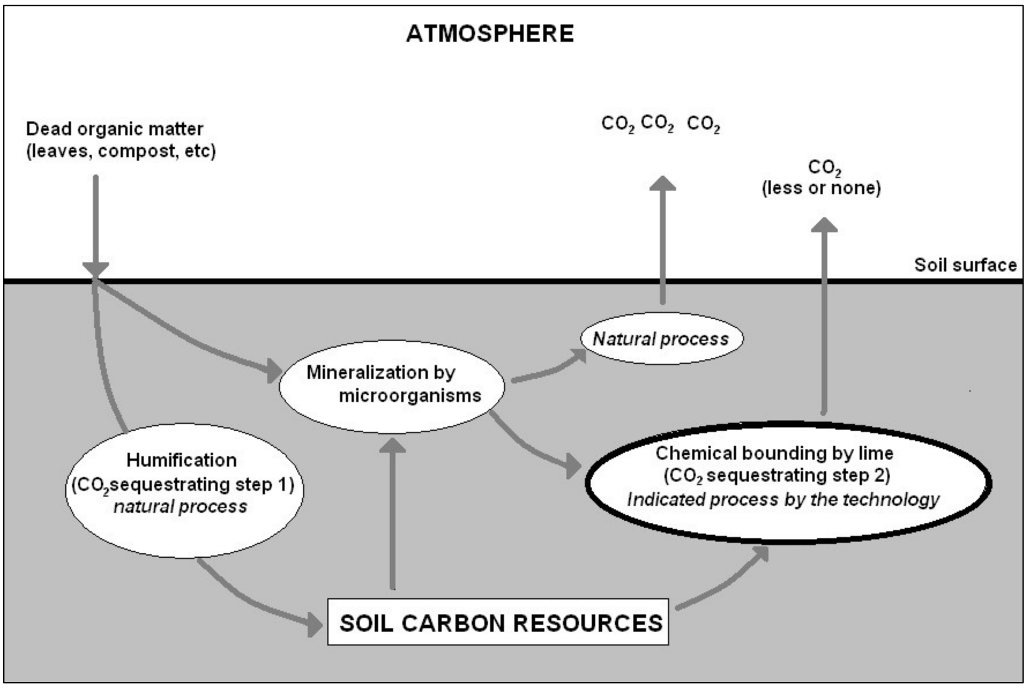

Figure 1.: Possible way for reducing the global risk of soil amelioration technology

Our research's intent is to reduce this carbon loss by by using additional amendments – if possible of waste origin – that can sequestrate CO_2 in soil as an organic or inorganic compound. That way we could not only decrease CO_2 emission of the landfilled surface, but at the same time increase the C-content of soil as well. The theory of the research is shown on **Figure 1.** In the preliminary laboratory experiences we tested lime as a promising sequestrator agent, to continue later with other alcaline wastes (e.g. sugar beet lime). As reference material we use glucose. The tested waste was a sludge from sunflower oil processing. The experimental apparatus is a flow tghrough reactor of 1 l, filled with 500 gram of soil, We areated with CO_2 free air for 5x6 hours during 5 days, and captured the emitted CO_2 in 1n NaOH solution. After measuring the quantity of captured CO_2 by titrimetry for each period of aeration, we could determine an emission trend according to the used treatments. The results are shown on **Chart 3-4**.. On **Chart 3.** we show the intense increasing effect of glucose, on the CO_2 emission of soil, and the effect of lime in fixing CO2 and as a result decreasing its measured flux. The difference between lime-containing and control is even more evident if we consider that the living cell number/g soil is much higher in lime-treated soils, than in untreated ones. The difference is smaller, but still significant for the oily waste shown on **Chart 4.**

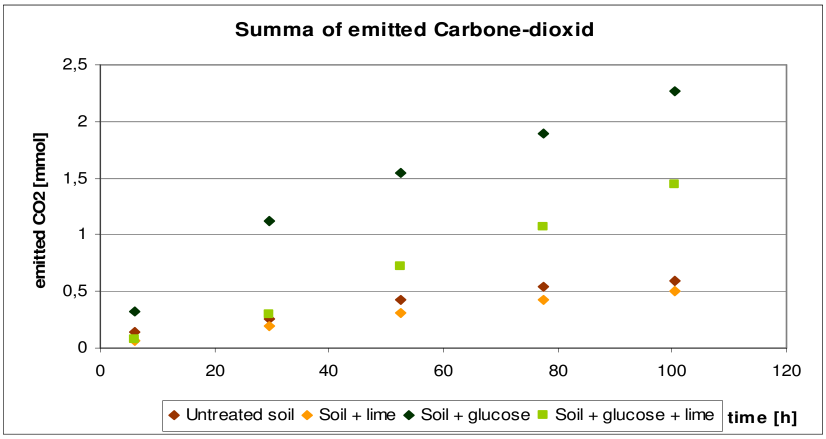

Chart 3. : Total carbon emission in 5-day dynamic respiration test for different treatments with glucose and lime

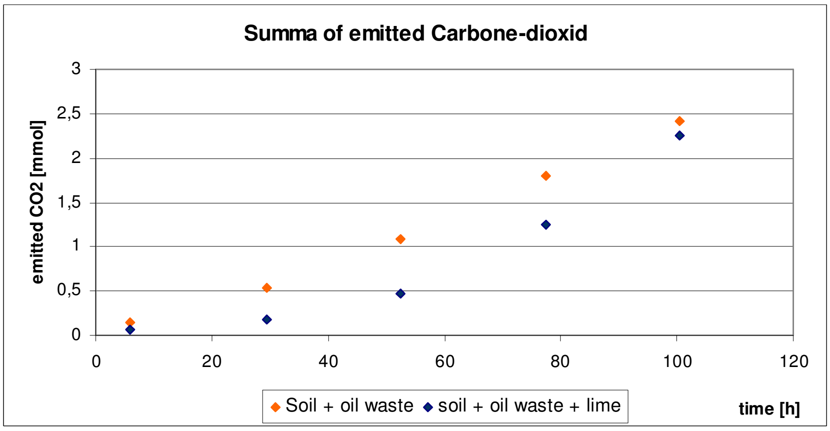

Chart 4.: Total carbon emission in 5-day dynamic respiration test for soils treated by oil waste and lime

If we want to examine the CO_2-sequestrating effect of lime, we must take into consideration the number of living cells in the examined soil. When examinig this we found that somtimes lime addition stimulates cell growht (this is probably caused by other microbes at higher pH), and it results higher living cell numbers. Even so, the CO_2 emission to air remains at a lower level, than without lime addition. **Chart 5.** shows That confirms our presumption that lime has the potential of sequestrating CO_2 in living soil. Further researches will raise the question wether this change is lasting, in what forms of soil components does it results, and what is the top limit of this kind of CO_2 capturing. We also plan to try other kinds of organic wastes as nutrient, and substitute pure lime powder with lime containing wastes.

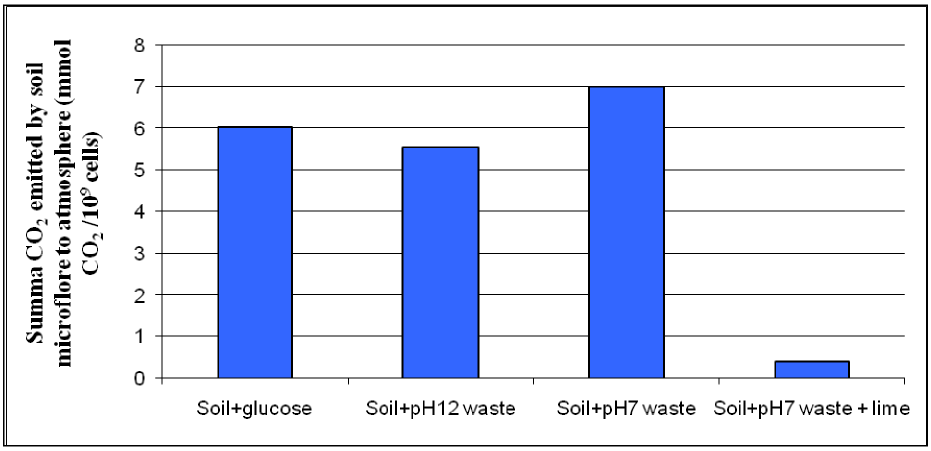

Chart 5.: Effect of soil CO_2 emission per living cell in amended soils with different carbon sources and lime

Amelioration of sandy soils

The main problems of sandy soils are the lack of organic and inorganic colloids; small natural nutrient supply; high water transparency and low water holding capacity, small useable water storage. These features make sandy soils very sensible to drought and deflation. Sandy soils without lime content can also suffer from low pH and small buffer capacity. For agricultural use it is necessary to ensure the water and nutrient supply needed for plants, to enrich soils in organic and inorganic colloids and build up efficient defence against deflation.

Our demonstration site in Őrbottyán, Hungary is a plough-land that has been used as an experimental site for various agricultural experiments in the last 15 years. It is a calcareous sandy soil with low fertility and water holding capacity. Selected waste amendments are several kinds of organic wastes, dolomite powder, and clayee wastes (e.g. waste bentonit from wine industry, which serves as nutrient source at the same time). Laboratory experiment are going on.

Development of a cultivation medium

Artifical cultivation media play an important role as substitute to natural soil in the the restoration of mines, waste deponies, stabilization and covering of railway slopes, industrial sites, industrial parks, remediation, recultivation of abandoned industrial premises, etc. These establishments need a largequantity of fertile cover material, Organic and inorganic wastes pre-treated and mixed with basic rock or low quality soils, according to a proven recipe can have double advantage: gives solution for the utilization of largequantities of wastes, and resolves the covering media needs without using good quality agricultural soils for this purpouse.

Successful small-scale field experiments has been conducted by our group in Almásfüzitő, Hungary, for covering a red mud deposit. The purpouse of the covering layer is to prevent the strongly alcaline and toxic metal-containing waste from leachate, and this way to reduce environmental risk. During the experiments, a combination of waste covering materials and revitalizing methods have been tested in a multiple-phase revitalization technology. The covering layer structure has been from the surface: 0-30 cm compost, 30-80 cm sewage sludge and 20% compost, 80-100 cm 50-50% mixture of compost and fly ash from coal combustion plant. The multiple-phase revitalization method consisted of treatment with special inoculum of microrhiza mixture developed for this case in laboratory, and phytostabilization by two types of grass mixture, maize, *Myscanthus sinensis* Gracillimus, and *Eleagnus angustifolia* L. Results showed that the vitalization was successful: the biomass production increased considerably, for the grass mixture from 1,27 t/h to 2,49 t/ha (MOKKA Final Report, 2008).

Our other demonstration site is a communal wastelandfill of A.S.A. Hungary near to Budapest, and the goal is the temporary vegetation of the actually bare top layer of the slope of the deposit. The covering material used is a very heterogeneuous clay soil, with very low nutrient levels, Since this layer would be a temporary coverage, which is going to be covered at the final recultivation/rehabilitataion??, our goal is to develop a fertile covering layer at affordable price, utilisingthe actualcovering material mixed with organic wastes, and to choose the most fitting, fast growing grass type which can rapidly cover the slopes of the deposit during its continuous process of construction, to protect the slopes from erosion and improve the esthetical view of the deposit close to the residential area.

Geotechnical constructions and elements

In the first year of the SOILUTIL Project the development of capillary barrier systems to cover the surface of waste deposits and to normalize the water permeability of the cover is planned to be developed. The model site is one of the red mud deponies in Hungary). Based on the work of Harder and Martin (2001) a capillary barrier system has been designed. The capillary system will have two parts: a capillary layer, that contains porous fine material and is able to hold to keep the infiltrating water and supply it for plants, and a capillary barrier layer, that contains non-porous ourse material without capillary forces. hindering the transport of toxic substances up into the capillary layer and the cover. In case of red mud reservoirs it stopsthe transport of the highly alkaline (pH=12) leachate to the cover. The capillary barrier also aims to drain the excess water amount that cannot be retained by the waterholding capacity of the capillary layer.

Usually fine to coarse sand is used as capillary layers and coarse sand to fine gravel is used as capillary block layers. In our project we plan to use waste materials, such as crushed brick and tiles as capillary layers, and crushed concrete as capillary block layers. In laboratory experiments the usability of various materials with different particle size will be tested. The interface of the two layers is also constructed from wastes, such as wastes from agriculture or forestry, or textile wastes. The promising combinations is tested first in laboraty, lateronin field lysimeters and in field experiments.

Use of research data in a Database for a future waste mixing software

All the data of the examined waste is going to be entered in a database, which for one hand contains data sheets for wastes, including risks and potencial values of wastes for soil amending utilization. The database also contains verified thechnologies of soil remediation and amelioration by utilizing wastes. The third part of the database provided by RISSAC contains map data on soil degradation and contamination. By the comparative evaluation of the three part of the database it will make possible to meet the needs of soils with the values of waste, giving a basis for further research and industrial techology application. The planned final product is a waste mixing software able to list technological possibilities for solving a specific soil degradation problem by the use of wastes.

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