Session: E.3 - Sustainable use of the subsurface

SCALE-UP EXPERIMENTS FOR COMPOSING CULTIVATION MEDIA FROM DEGRADED SOILS AND WASTE AMENDMENTS

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Abstract

The possibility of using industrial or municipal waste materials to improve the texture, nutrient content and productivity of bad quality soils is getting more and more attention recently, as the problems generated by soil loss are getting worse, and the costs of waste deposition reaches higher levels. Waste utilization for soil improvement offers possible solution for several soil problems, meanwhile gives an alternative for waste landfill. Even so, successful researches and industrial solutions focusing on this topic are still individual attempts without an overall concept or clear guidelines to take into consideration for safe and effective application. When managing the risk of waste utilisation on soil we have to understand that the hazard associated with the waste differs from the land-use specific risk of waste utilisation on soil. Even if there is some risk it can be fully controlled and, the value-based benefits may overcompensate the risks. Smart, risk-based compromise may lead to the acceptance of a low-risk utilisation of waste on soil compared to a high risk or very high cost waste disposal or other physico-chemical waste treatments.

The experiments presented in this paper demonstrate the usefulness of these principles in technology development, proving that several waste materials with substantial hazard might have a positive effect on soil properties without considerable risk when mixing with soil in the proper ratio. Scaled up experiments were performed in laboratory microcosms and filed plots with the aim of in-situ production of fertile cultivation media from the waste soil of the temporary cover of the landfill slope by mixing it with organic and inorganic waste materials. (**Figure 1.**) Prior to mixing the components, values and hazards of the all utilized wastes were assessed by physical-chemical and biological-ecotoxicological methods. As a preliminary experiment, 3 types of municipal sewage sludge, and 2 types of combustion ashes (fly ash and wooden ash) were mixed in 4 different waste soils originated from the slope of the same landfill block, in altogether 24 soil microcosms. Based on the results of this experiment, 16 blocks of small field plots were constructed and monitored for 1.5 years. The changes in soil nutrient content, texture and toxicity were followed by integrated physical-chemical and biological-ecotoxicological monitoring methodology.

Our results show that the application of composted sewage sludge and coal combustion fly ash successfully enhanced soil organic content (Humus%) and the quantity of plant available Nitrogen, Phosphorus and Potassium-content. After 1.5 years of field application 300% growth in soil microbial activity and 700% growth in biomass production was recorded compared to control treated with only artificial fertilizers, by using only waste-origin amendment, without any adverse effects observed.

Figure 1. Grass grew on Site II and III 14 months after amendment

1. Introduction

The possibility of using industrial or municipal waste materials to improve the texture, nutrient content and productivity of bad quality soils is getting more and more attention recently, as the problems generated by soil loss are getting worse, and the costs of waste deposition are reaching higher levels. Waste utilization for soil improvement offers possible solution for several soil problems, meanwhile gives an alternative for waste landfilling. Even so, successful researches and industrial solutions focusing on this topic are still individual attempts without an overall concept or clear guidelines to be taken into consideration for safe and effective application. When managing the risk of waste utilisation on soil we have to understand that the hazard associated with the waste differs from the land-use specific risk of waste utilisation on soil. Even if there is some risk it can be fully controlled and the value-based benefits may overcompensate the risks. Smart, risk-based compromise may lead to the acceptance of a low-risk utilisation of waste on soil compared to a high risk or very high cost waste disposal or other physico-chemical waste treatments. Gruiz et al. (2010) proposed a comprehensive, risk-based management concept of waste utilization for soil improvement based on successful applications from literature and their own observations. The steps of the management scheme (information collection on the concerning waste materials and soils; creating the risk scenario for risk calculation; hazard, benefit and exposure assessment; risk characterisation; risk and value-based decision and communication of the results) ensure that the benefits of the technology would overwhelm its potential adverse effects.

A special area of soil protection is the substitution of soil by materials composed from wastes and bad quality soils. Great amount of fertile soil growing media is needed every year as covering material for land revitalization (e.g. landfills, brownfields, road construction sites, urban green surfaces), and for growing media in horticultural and agricultural uses. Usually fertile and good quality topsoil or peat-based artificial soil is used for this purpose, but recently a growing number of articles deal with the possibility of substitution of soil with mixture of wastes. In Spain (Abad et al., 2001) and the United Kingdom (Cull, 1981) detailed lists of possible peat substitutes are available already to facilitate choosing the best material for each purpose. Most frequently used materials are composted sewage sludge and compost: Stabnikova et al. (2004) used infertile subsoil, co-composted sewage sludge and horticultural waste to create artificial soil, Sparke et al. (2011) added compost to subsoil and sand/silt mixture, Ostos et al. (2008) examined compost and pine barks as peat substitute in nursery growing media. Several studies have shown also the soil improving effect of fly ashes. Fly ash provides both macro- and micronutrient source, improves porosity and water holding capacity, and by its high pH, raises the availability of most nutrients (Basu et al., 2009). Also many studies prove the advantages of using sewage sludge and fly ash together (Sajwan et al., 2003). Fly ash added to sewage sludge compensates the mostly acidic pH of sewage sludges, provides additional nutrients, and repels sewage-origin pathogens (Xu et al., 2010).

The present study examines the possibility to create soil substitute for land revitalization by in-situ mixing of bad quality subsoil managed as inert waste and different kinds of sewage sludges and fly ashes in a scale-up experiment.

2. Materials and methods

2.1. Experimental site

Our demonstration site is located at the communal waste landfill of .A.S.A. Hungary Ltd. in Gyál, near Budapest. Communal waste deponies, raised gradually along with the incoming amount of waste, use large quantities of low quality soil and inert waste originating from construction and demolition sites. The material used at .A.S.A. is very heterogeneous, typically low in organic matter and nutrients and constitutes the surface layer of depony from the start of landfilling till the final recultivation in the next 10 or more years. Therefore temporary vegetation is needed to protect the steep ringwall from erosion and improve the esthetical view of the deposit close to the residential area. The goal was to develop a 30–40 cm deep layer of fertile growing media at affordable price, utilising the actual, yet barren ringwall material mixed with organic and inorganic wastes, which can sustain continuous vegetation on the surface of the landfill during its continuous process of construction.

2.2. Soils and amendments

The revegetation of the whole landfill surface requires a universal amendment technology which works indifferently on the very heterogeneous ringwall material. Therefore four experimental sites were chosen, built from different materials, to examine the effectiveness of the chosen amendment technologies. The following five waste-origin amendments were tested alone and in combinations:

Raw sewage sludge (RSS) from a small town near Budapest (Telki), originating from Living Machine Technology (Organica Water Inc.)
Digested sewage sludge (DSS) from Budapest, emerging from mechanical and biological treatment technology (South-Pest Wastewater Treatment Plant)
Composted sewage sludge (CSS) from Hódmezővásárhely (.A.S.A. Hungary)
Biomass filter ash (BFA) from biomass power plant at Szakoly (DBM Zrt.)
Coal combustion fly ash (CFA) originated from North-East Hungary (Mátrai Power Plant)

All soils and wastes were tested by an integrated methodology using physical-chemical and ecotoxicological methods summarized in **Figure 2.** Results are summarized in **Table 1-3.** Values lower/higher than suggested by literature are highlighted.

Table 1. Texture, pH and nutrients of soils and waste amendments

Soil/waste	$pH(H_2O)$	K_A	Total salt (m/m%)	$CaCO_3$ (m/m%)	H% (m/m%)	Al-K_2O (mg/kg)	Al-P_2O_5 (mg/kg)	Total N (m/m%)
Soil, site I	7.8	63	0.08	38.08	1.53	138.89	9.42	0.14
Soil, site II	8.4	64	0.17	15.03	1.71	283.89	29.08	0.07
Soil, site III	7.4	49	0.19	15.44	2.85	390.14	55.43	0.09
Suggested value in this type of soil*	**5.5–7.9[1]**	**15–40[1]**	**<0.15[1]**	**5<[1]**	**1.71<[1]**	**161<[1]**	**81<[1]**	**0.1<[2]**
Biomass filter ash			4.00			13790.00	2782.00	0.01
Coal fly ash						3950.00	2386.00	0.01
Raw sewage sludge	5.7		6.08	1.44	24.90	7092.00	22432.00	5.21
Composted sewage sludge	6.6		2.23	1.20	63.30	6120.00	14300.00	1.92
Digested sewage sludge	7.9		0		19.80	5610.00	8356.00	2.38

*Suggested values are taken from Kalocsay et al. (2012) (1) and Marx et al. (1999) (2)

Table 2. Total toxic metal content of soils and waste amendments in ppm (mg/kg)

Soil/waste	As	Cd	Co	Cr	Cu	Hg	Ni	Pb	Se	Zn
Soil, site I	10.66	0.19	13.79	39.39	25.51	*	52.99	11.65	2.78	58.07
Soil, site II	18.44	0.13	14.27	36.93	19.95	*	34.54	18.70	*	86.62
Soil, site III	15.39	0.66	13.82	39.85	23.80	*	46.70	20.46	1.61	75.58
Biomass filter ash	6.26	2.18	4.85	13.27	34.37	*	11.53	14.55	*	239.73
Coal fly ash	1.55	0.12	3.47	10.52	17.93	*	7.82	2.93	*	47.39
Raw sewage sludge	5.17	0.68	4.02	26.42	219.60	0.43	19.18	17.99	1.67	633.18
Composted sewage sludge	3.27	0.17	2.38	10.60	76.90	*	11.10	11.40	1.20	
Digested sewage sludge	18.63	2.31	10.40	268.52	650.71	2.50	78.23	103.30	1.43	1027.02
Maximum value in soil*	**15.00**	**1.00**	**30.00**	**75.00**	**75.00**	**0.50**	**40.00**	**100.00**	**1.00**	**200.00**
Maximum value in sewage sludge for agricultural use*	**75.00**	**10.00**	**50.00**	**1000.00**	**1000.00**	**10.00**	**200.00**	**750.00**	**100.00**	**2500.00**

*Maximum values are from Hungarian Governmental Regulation number 10/2000 (2000)

The clayey structure and lack of essential nutrients is apparent in the case of all the three chosen soils. Waste amendments have the potential to mend the deficit, but they may also pose a risk to the soil and the environment. Sewage sludge and fly ash, depending on their origin may contain a wild range of toxic metals in high concentration, and in concentrated form they might have massive toxic effects on bacteria, plant or animals, as it is shown in **Table 3**. The goal of the present experiment is to test whether toxic effect ceases with dilution and could be overwhelmed by advantages of nutrient resupply and texture amelioration.

Table 3. Ecotoxicity of waste amendments

Waste	*Vibrio fischeri* luminescence		*Sinapis alba* root&shoot inhibition test			
			Root		Shoot	
	EC20 (g/ml)	EC50 (g/ml)	ED20 (g)	ED50 (g)	ED20 (g)	ED50 (g)
Biomass filter ash	0.391	>1.00	0.06	0.82	0.37	4.48
Coal fly ash	0.121	0.67	0.55	3.46	0.03	0.36
Raw sewage sludge	>1.000	>1.00	>5.00	>5.00	>5.00	>5.00
Composted sewage sludge	0.224	0.593	>5.00	>5.00	>5.00	>5.00
Digested sewage sludge	>1.000	>1.00	1.06	1.13	0.97	1.1

2.3. Experimental design of scale-up experiments

2.3.1. Preliminary pot experiment

10 pieces of 4 kg pots were filled with the combination of one type of degraded soil from the experimental site and the five amendments according to **Table 4.** An untreated microcosm and one treated with artificial fertilizers ($Ca(H_2PO_4)_2xH_2O+CaSO_4$; NH_4NO_3; and K_2O, amount counted according to soil requisite (Buzás et al., 1979)) served as control. After one month of adaptation the microcosms were planted with grass (mixture described by **Feigl, 2010**), and were incubated in a climate room, with 12 hours dark (15 °C) and 12 hours illuminated (21 °C) cycles in the first two weeks (germination), and 15 hours dark (16 °C) and 9 hours illuminated (22 °C) cycles in the remaining 6 weeks (illuminance: 25000 lux). After 8 weeks plant biomass and element content were measured. Soil sampling and analysis was carried out after 0, 1, 2 and 3 months.

Table 4 Treatments of the ASA landfill ringwall material in soil microcosms

Amendment added to soil from Site I (m/m%)	Abbreviation
Untreated control	CON
Artificial fertilizer only	FER
3% fly ash	CFA
3% biomass filter ash	BFA
10% raw sewage sludge	RSS
10% digested sewage sludge	DSS
10% composted sewage sludge	CSS
10% sewage sludge mix (1:1:1 mixture of the three sludges)	MSS
10% sewage sludge mix + 3% fly ash	MSS+CFA
10% sewage sludge mix + 3% wood ash	MSS+BFA

2.3.2. Small field plot experiment

At each experimental site 3x9 m^2 field plots were dug up and amended with the combination of the best performing waste amendments according to the results of microcosm experiment (Table 5). Soil sampling and analysis was carried out after 0, 3, 14, 17, 25 and 32 months.

Table 5 Treatments of the ASA landfill ringwall material in field experiments

Treatment	site 1	site 3	site 4
Artificial fertilizer only	x	x	x
3% fly ash	x	x	x
10% composted sewage sludge	x		
10% composted sewage sludge +3% wood ash	x		
10% raw sewage sludge		x	x
10% raw sewage sludge + 3% fly ash		x	x

2.4. Monitoring methodology

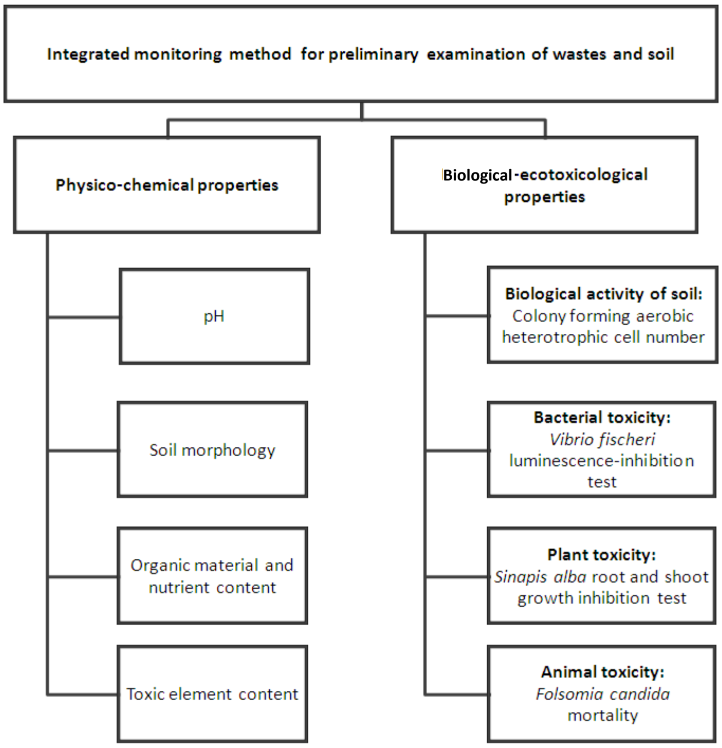


Figure 2. Methods for preliminary examination of wastes and soil

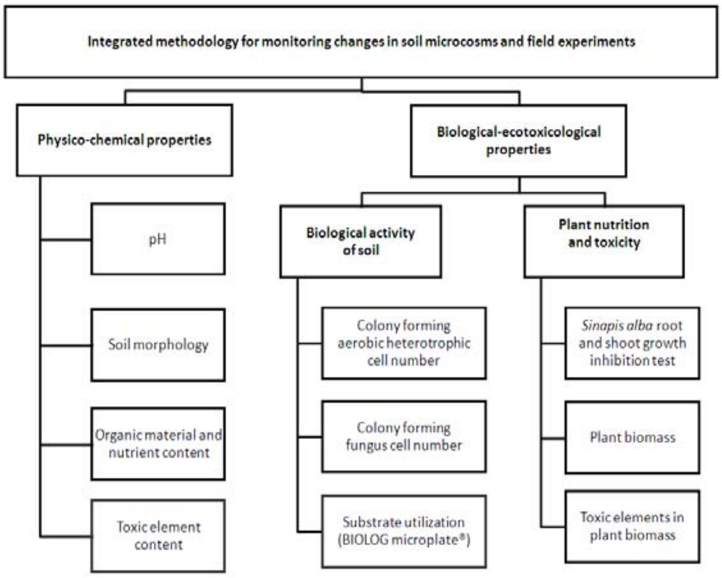


Figure 3. Monitoring methods for pot and field experiments

2.4.1. Integrated monitoring methodology

The integrated monitoring methodology used for the follow-up of the experiments consists of the determination of the physico-chemical properties of the soil and waste mixtures and the measurement of their biological activity and ecotoxicity. After an overall testing of both soil and waste samples (**Figure 2**), we followed the experiments with a methodology focused on important key factors: soil nutrition, biological activity and plant growth (**Figure 3**).

2.4.2. Sampling and physico-chemical analyses

500 g of soil samples were taken from each pot, or collected from the plots from 8–10 points in 0–15 cm depth. The samples were homogenized, air-dried, disaggregated and sieved (2 mm aperture) in the laboratory, and physico-chemical properties were measured according to Hungarian Standards (detailed in references)

Aerobic heterotrophic colony forming units

For the measurement of microbial activity (living cell concentration) 1 g wet soil was placed into 10 ml tap water (sterilized in an autoclave, 10 min at 121°C) and was shaken for 30 minutes at 400 rpm (3 replicates). A 10 fold dilution series was prepared and 100 µL of the 10^4, 10^5 and 10^6 dilutions were measured into Petri-dishes. 10 mL of meat agar (cooled to 45°C, composition: 3 g meat extract, 5 g glucose, 5 g peptone, 0.5 g NaCl, 17 g agar, 1 L distilled water, sterilized for 10 min at 121°C) was poured in each Petri-dish and was incubated at 30°C for 48 hours. The number of colonies was counted (Gruiz et al., 2001).

2.4.3. *Vibrio fischeri* luminescence inhibition test

Two grams of dry soil/waste was suspended in 2 mL 2% NaCl solution and a five-step dilution series was prepared. After the measurement of the reference luminescence intensity, 50 µL of the dilution series was added to the test medium. The luminescence intensity was repeatedly measured after 30 min exposure time with a luminometer (Lumac Biocounter M 1500 1). The toxicity was characterised by the inhibition rate (%) of the samples and the copper-equivalent E_sD50_{CuEq} (mg/kg) (Cu equivalent concentration of an unknown contaminant or mixture of contaminants in the sample causing 50% inhibition) (Gruiz et al., 2001).

2.4.4. *Sinapis alba* root and shoot growth inhibition test

For the *Sinapis alba* (white mustard) test, the method of Gruiz et al. (2001) was adopted. 5 g of air dried grained, sieved (2-mm sieve) soil/waste was measured into a Petri-dish, wetted with 3.5 mL water and 20 seeds were placed on top. The samples were incubated at 25 °C for three days. The length of roots and shoots were measured manually. Root and shoot growth inhibition was calculated: I(%) = (C–P)/C×100, where I: inhibition %; C: length of roots/shoots on uncontaminated control, (tap water on a filter paper); P: length of roots/shoots on polluted sample.

2.4.5. *Folsomia candida* (Collembola) mortality test

Twenty grams of air dry, grained, sieved (2-mm sieve) soil/waste was measured into a 370 cm^3 glass jar, wetted with 5 cm^3 water and 2 mg yeast was added as nutrient. Ten animals from 14 days old synchronized culture were placed into the jars and were incubated at 25°C for seven days. The amount of surviving animals was counted: water was added into the jar, stirred, and the living animals swam to the surface of the water, where they were counted. Inhibition of survival was calculated: I(%) 5 (C–P)/C 3x100, where I, inhibition %; C, number of animals survived on uncontaminated control; P, number of animals survived on polluted sample. EC20 and EC50 values can be calculated from the dose-response curve (Gruiz et al., 2001).

3. Results and discussion

3.1.1. Preliminary pot experiment

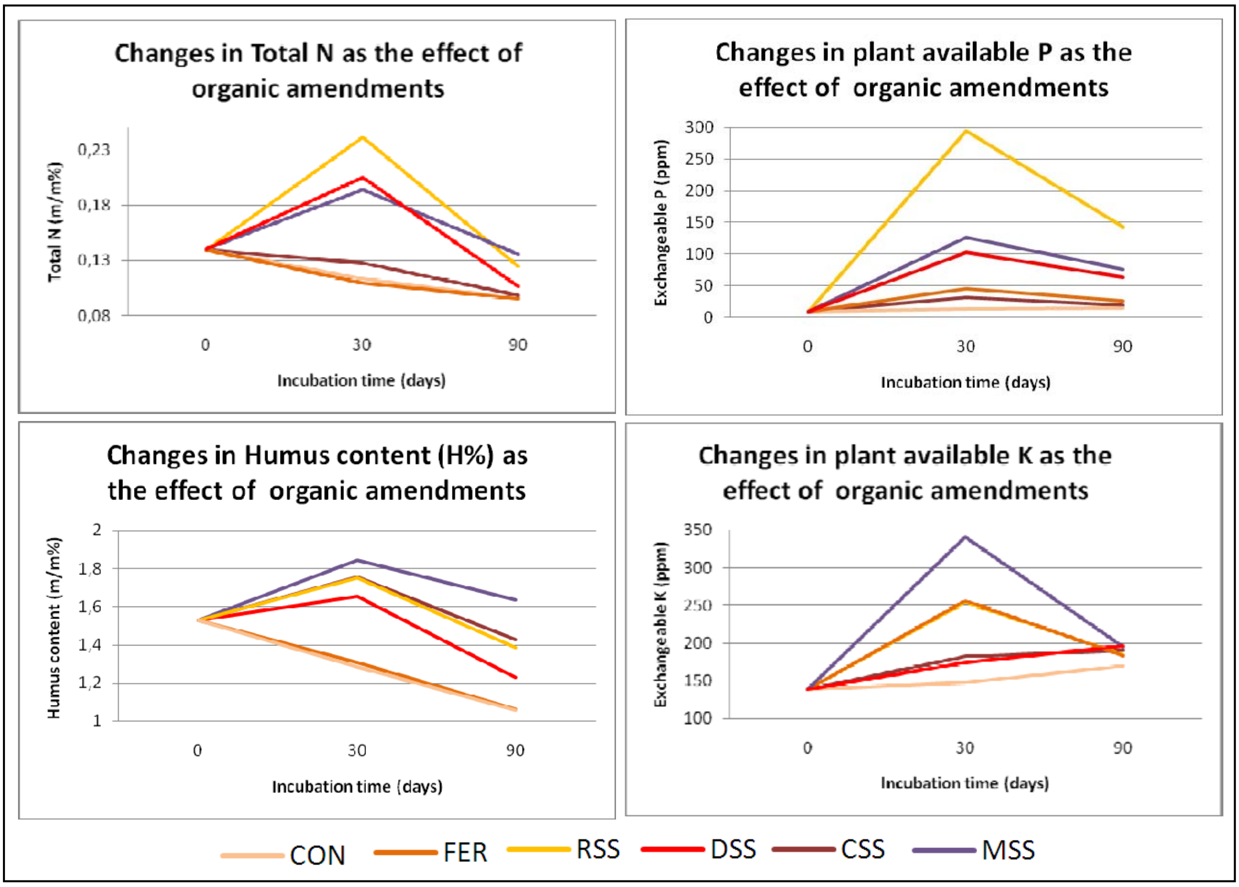
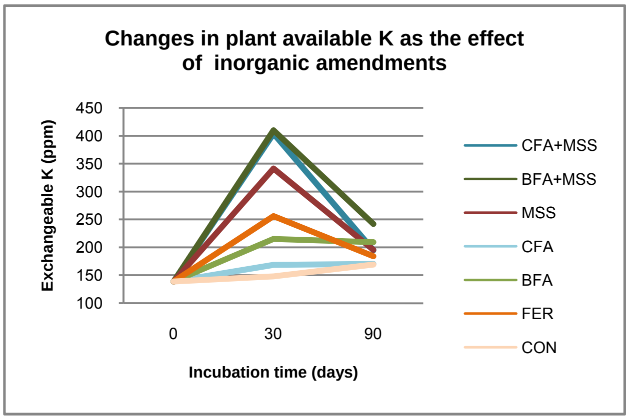


Figure 4. Effect of organic amendments on the quantity of humus and macronutrient content in preliminary pot experiment

3.1.2. Effect of organic amendments on soil nutritive potential

As **Figure 4.** illustrates, all organic amendments caused higher values of plant-available nutrients compared to untreated control. As it could be expected, as the consequence of plant uptake, a decrease of nutrient content was observed in every microcosm, with the notable exception of plant available K, which showed a slight increase during the 90-day period of incubation. This might be caused by the addition of nitrogen, which facilitates the availability of potassium bound to the bedrock (Ángyán et al., 2010), that could serve as an additional source of potassium for plants. Altogether significant increase was observed both in Humus content and available plant nutrients during the whole incubation period. The most effective treatments were MSS and RSS, best-performing treatments for all four parameters, and producing the best results for H%, K and N (MSS) and P (RSS).



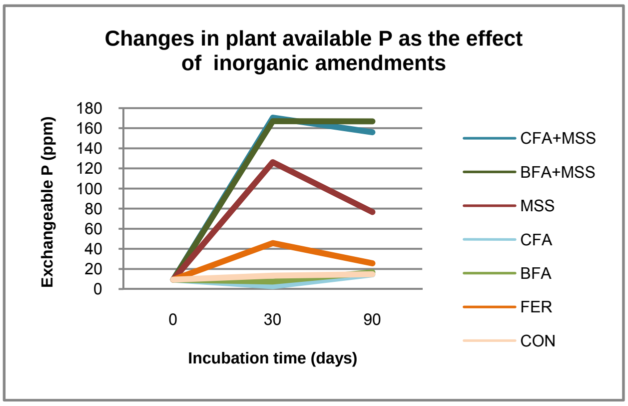


Figure 5. Effect of all waste amendments on plant growth in oreliminary pot experiment

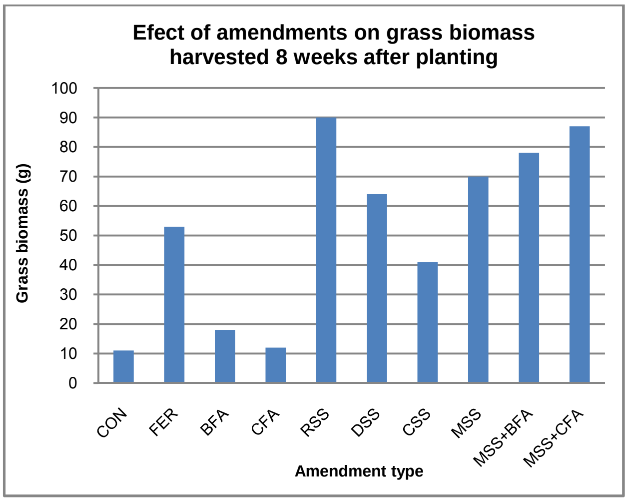


Figure 6. Effect of inorganic wastes on the quantity of humus and macronutrient content in preliminary pot experiment

3.1.3. Effect of inorganic amendments

As **Figure 5.** shows, inorganic amendments alone were scarcely able to raise the levels of available K and P content more than artificial fertilizing, but both BFA and CFA shows remarkable improvement when applied together with organic amendment (MSS). The effect is most spectacular in P-content: combined treatment could not only grant additional nutrient source to the soil, but produced a long lasting effect compared to organic amendment only.

Figure 6. illustrates the notable effect of additional nutrients by depicting the biomass of grass planted in the pots on the 30th day of the experiment and harvested on the 90th day. Results show that organic amendments (except CSS) caused 500–800% growth in plant biomass, while artificial fertilizing could achieve only 400% improvement compared to the control. The positive effect of applying sewage sludge and fly ashes together can be observed here as well: BFA and CFA improved the effect of MSS by 10% and 25%, respectively.

Although data is not presented here due to the lack of space no ecotoxicological effects were observed for neither of the amended soils.

According to plant biomass the most effective amendment was raw sewage sludge (RSS). This indicates that N and P amendment were the bottleneck factors of plant growth in the soil of Site I. This assumption is supported by the fact that although BFA proved to be significantly better source of potassium than CFA, altogether MSS+CFA treatment caused higher grass yield than MSS+BFA.

Taken these results we chose raw sewage sludge (RSS), composted sewage sludge (CSS) and coal combustion fly ash (CFA) to conduct field plot experiments with. We excluded DSS because of lower nutritive potential (**Figure 5.**) and the risk caused by its high toxic element content (**Table 2.**). CFA were chosen to BFA considering higher plant yield achieved by CFA treatment (Chart 3.).

3.2. Field experiment

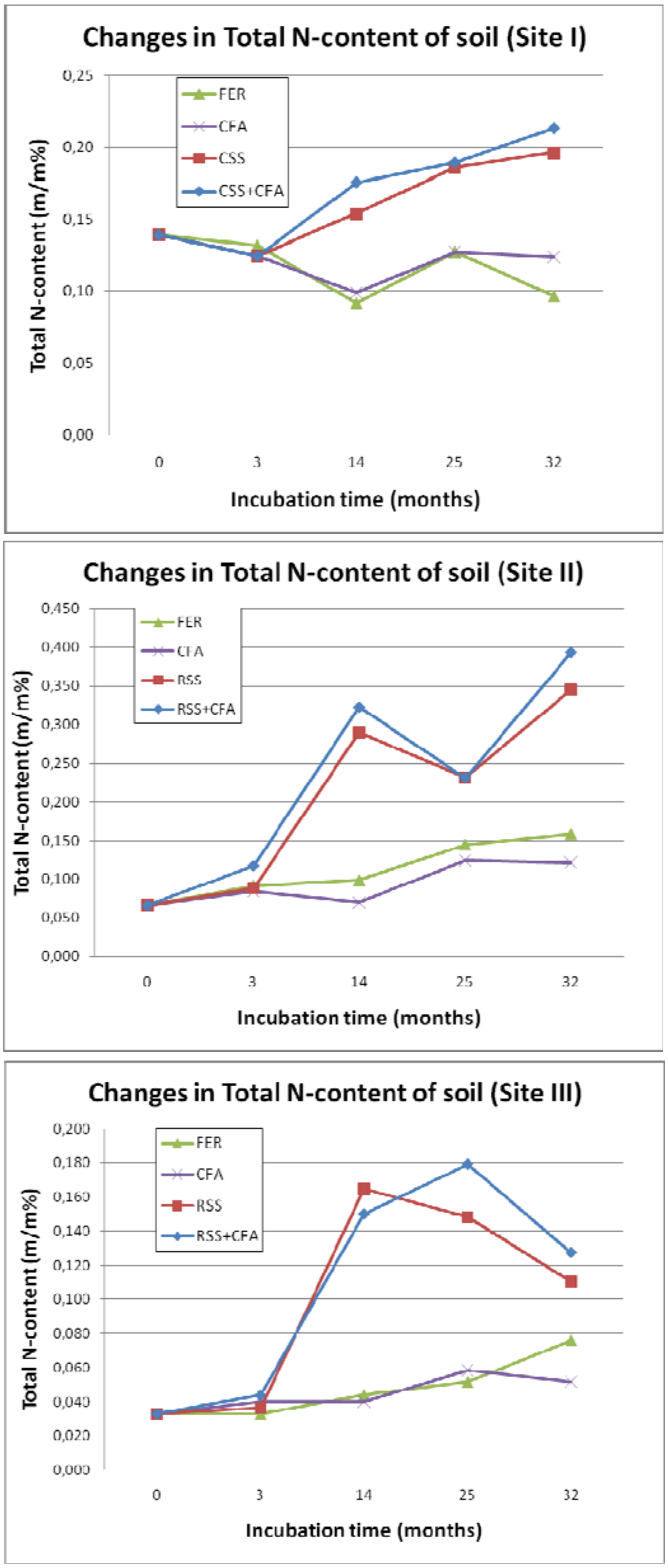


Figure 7. Changes in Total N-content of the soil of the three field plots before and after the addition of waste amendments

3.2.1. Effect on soil nutrient content

Treatments were able to provide satisfactory source of all main nutrients (Humus content, Total N, available P and K content). Due to the lack of space, we only present here the charts for total N, since nitrogen is the main factor influencing plant yield for grasses (Ángyán et al, 2010.)

Looking at **Figure 7.** we can see that CSS amendment caused a stabile growth of 30–300% in Total N. RSS also raised Total N, but this effect didn't prove as stabile as in the case of CSS: at Site 3, 60% of the additional nitrogen was already gone by the 32th month after application. As we can see in all three cases, CFA alone didn't raise N-content significantly, but it amplifies the effect of organic amendments.

Similar tendencies could be observed in the case of Humus content: CSS raised humus content from 1% or less to 3–5%, and preserved this value, while the effect of RSS started to lessen significantly about one year after treatment. The addition of CFA protracted this decrease.

For P and K both CSS and RSS could provide nutrients for the soil in excess. From initial values of 9–50 ppm phosphorus, the highest values reached were 200 to 2000 ppm (considered excessive from 160 according to Marx et al., 1999). In the case of K, the highest values were 500–1600 ppm (excessive from 850 ppm) as an effect of organic nutrient, CFA alone also proved to be satisfactory K-source (treatment caused K content from 250 to 1600 ppm).

Altogether, although effect of the amendment varies on a wide scale, sewage sludges proved to increase effectively all of the main nutrient contents. CFA alone isn't enough as nutrient source for all macronutrients, but added together with organic amendments it can support and elongate their positive effect.

Since all nutrients in the amended soils were present in excess, we can even consider lowering application rates form 10% to 5% or less, taking into account the bottleneck factor of our nutrient stock (nitrogen). By this we are reducing not only the necessary amount of soil amendments, but also the risk of the leaching of nutrient into surface or subsurface waters. On the insulated surface of a waste landfill, excess nutrient doesn't pose a risk to the environment, but when applying within different circumstances (e.g. roadside revegetation etc), application rates must be chosen carefully to avoid eutrophication of natural waters.

3.2.2. Effect on soil biological activity and plant growth

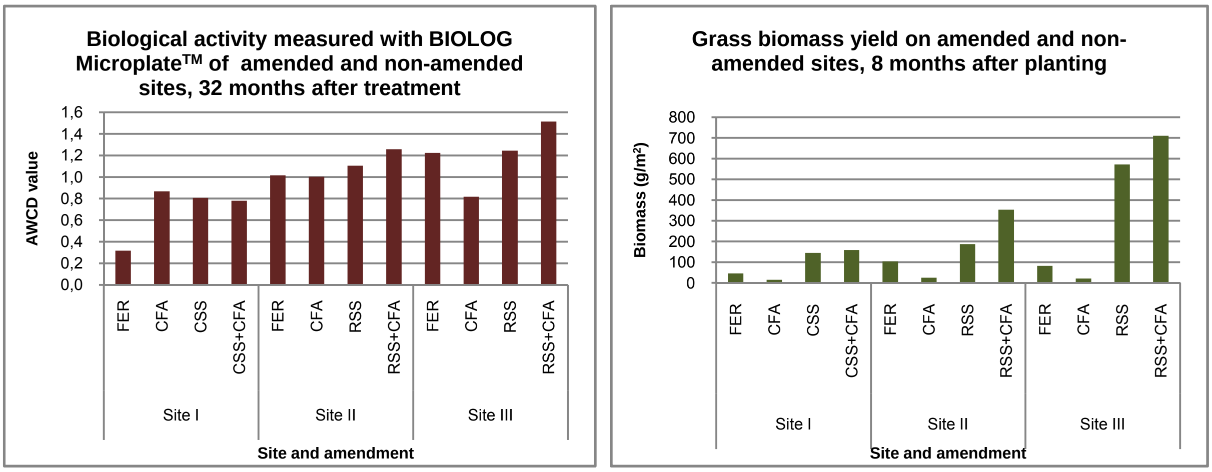


Figure 8. Changes in biological activity and grass yields on the field plots before and after the addition of waste amendments

Figure 8. illustrates the positive effect of additional soil nutrient provided by wastes on the ecosystem of the experimental site. With one exception (CFA) discussed later, all amendments in all soil types could increase biological activity compared to artificial fertilizing (FER). The effect is even more eye-catching observing grass yields: more than tenfold increase was achieved compared to control (FER). Grass yield data point out a salient and curious trend. While clear toxic effect of applying CFA alone can be observed in all three sites (on Site **III** also visible in AWCD data). RSS+CFA amendment produced the best yields in the case of all soil types.

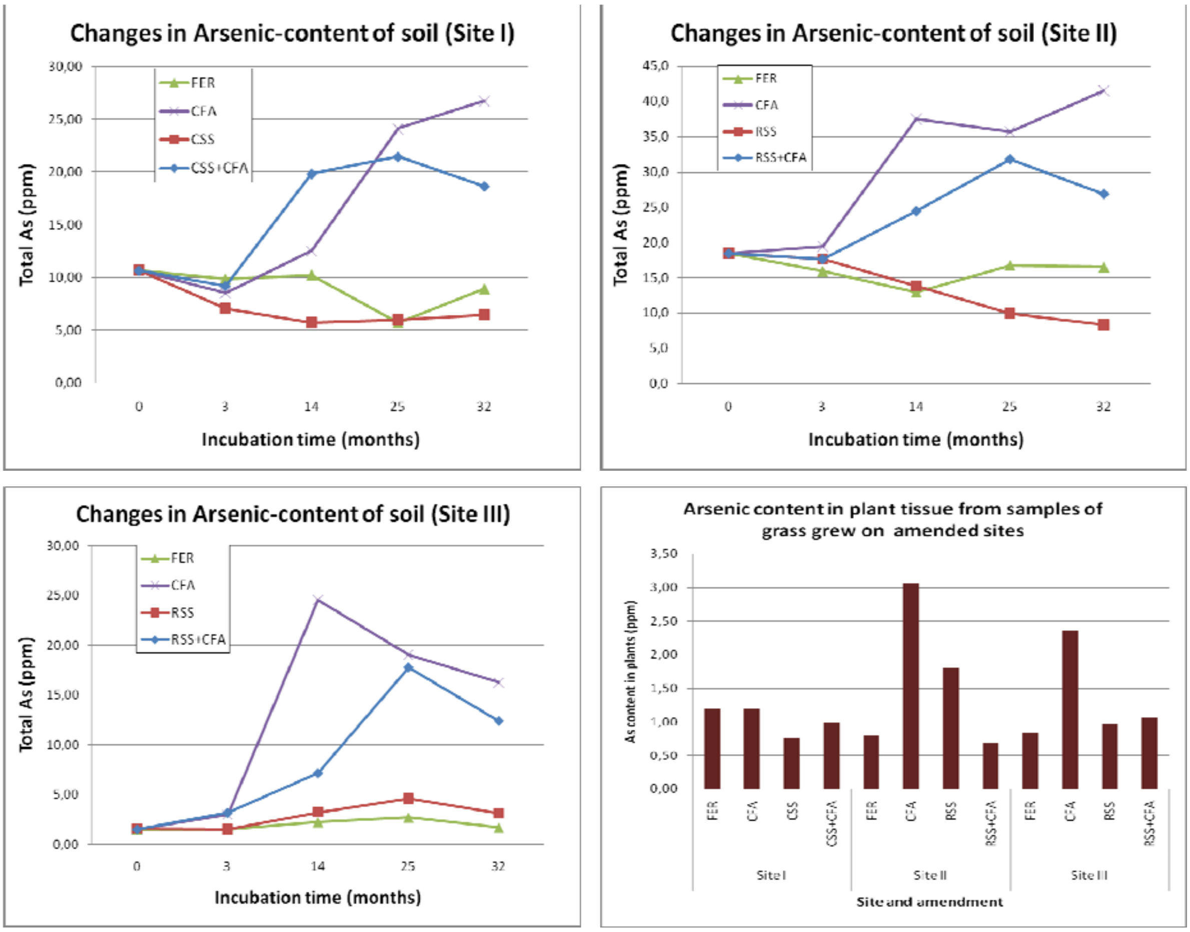


Figure 9. Changes in Arsenic content of soil and grass biomass after the addition of waste amendments to field plots

Toxicity of CFA is assumedly caused by the arsenic content of CFA. This can be supported by depicting the total arsenic content of the soils after the addition of the amendments **(Figure 9.).** Although the preliminary examination of wastes didn't show alerting quantity of toxic metals, increased arsenic content is clearly visible in all sites, both in CFA and SS+CFA treated soils. This fact points out the importance of major inhomogenities in waste amendments, which makes it difficult to ensure their safe application. Nevertheless our results implicate that although total As in CFA amended soils is higher than acceptable (10 ppm according to Hungarian regulations), the plant uptake of arsenic might be greatly restricted by the addition of sewage sludge: despite the high As content of grass grown on CFA-treated soil of Site II and Site III, no increase compared to control is observed in grass grown on RSS+CFA-amended soils. This point is important since environmental risk is determined by plant available metal content, and the connection of total As and plant available As is rather complicated and not well described yet (Martínez-Sánchez, 2011). Our results show that sewage sludge might be able to bind arsenic permanently, and our observation is confirmed by others as well (e.g. Karczewska et al., 2012). Finally we should note, that only CFA-treatment alone caused As content higher than 2 ppm (limit allowable in human food according to 17/1999. (VI. 16.) Hungarian Governmental regulation.

4. Conclusion

Barren or semi-barren areas with degraded soil pose a constant risk to the ecosystem and lead to further contamination and deterioration. Removal, exchange and disposal of these soils are expansive and not sustainable. *In situ* amendment or remediation with wastes has a double benefit: landscaping of these areas and utilization of agricultural and industrial wastes. The usable wastes can also have their own risks, but this can be decreased and compensated by the benefits produced in improving soil properties. Trying two kinds of fly ashes and three types of sewage sludges we found that 2% of coal fly ash combined with 10% of sewage sludge mixed to low quality waste soils can make an artificial soil sufficiently serving as growing media for grass and other plants. Trying the amendment technique in three different kinds of waste/degraded soil at field conditions we can state that this combination is suitable for supporting plant life, despite of heterogeneous stock materials and the possible environmental risk posed by the toxic metal content of coal fly ash. When using sewage sludge combined with coal fly ash, during the monitored two years continuous vegetation was sustained in the amended plots, no toxic effect was observed on plants, and arsenic content in plant tissues didn't surpass the limits for human food.

Acknowledgements

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