Use of phytostabilisation to remediate metal polluted dredged sediment

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Abstract.: Phytostabilisation (combined use of tolerant plants and soil amendments) experiments were conducted at the field scale on dredged sediments polluted with metals. A sediment deposit contaminated with metals and metalloids (Cd, Zn, Pb, Cu and As) was experimentally established in 2002 and monitored until 2004 as part of the European project PHYTODEC (5^{th} Framework Program; EVK1-CT-1999-2004). Six out of nine plots were treated by adding amendments to immobilise metals (Thomas Basic Slags or Hydroxylapatite). Two grass species (*Festuca rubra* and *Deschampsia cespitosa*) were sown on six plots previously treated or not. The three unvegetated plots left were taken as controls. After two years of monitoring, the couple Thomas Basic Slags/*D. cespitosa* was the most efficient additive/plant couple for phytostabilisation purpose.
In this 3 years project, we continue to work on the sediment deposit site previously described and propose to demonstrate the long-term sustainability of phytostabilisation by addressing the following points: (i) sustainability and maintenance of the vegetation cover and amendment action, (ii) reduction of metals mobility and bioavailability, (iii) study of metal mobilization and immobilization mechanisms related to specific bacterial microflora.

Keywords: Phytostabilisation, treatment efficiency, contaminated sediment, metal trace elements, field study, plant diversity, bacterial microflora

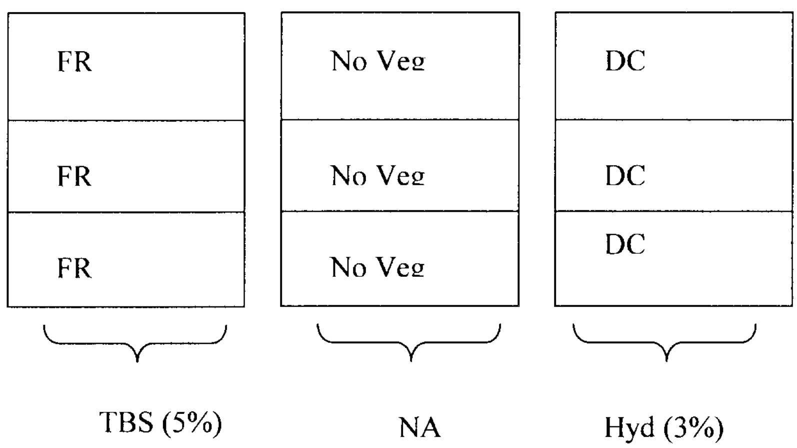
Introduction

In North of France, the maintenance of waterways generates numerous dredged sediment deposits. Due to the local intensive industrial history, sediments are often rich in metal contaminants. Because heavy metals have undesirable effects on ecosystems and human health, the necessity to secure or remediate sediment deposit sites became obvious.
Phytostabilisation (combined use of tolerant plants and soil amendments) aims at reducing the hazards related to the presence of heavy metals in soils and dredged sediment deposits, generally as part of more ample management schemes. Decision makers and the public will accept this technology, only if scientists have proven that the pollution is controlled and thus if potential side effects like increased leaching, toxicity of vegetation and food-chain contamination do not exist or appear over a long period.
This project is performed on a sediment deposit site and aims at demonstrating the long-term sustainability of phytostabilisation by addressing the following points: (i) sustainability and maintenance of the vegetation cover and amendment action, (ii) reduction of mobility and bioavailability of metals, (iii) study of metal mobilization and immobilization mechanisms related to specific bacterial microflora.

Materials and Methods

Experimental field-plot set up: This project uses the experimental field plot designed for the European project PHYTODEC (Fig. 1) [1]. In May 2002, an experimental field plot was set up in an agricultural area in Lallaing (North of France). Three plots of 20 m^2 were dug in an uncontaminated soil. These plots were filled with dredged sediments excavated from the Scarpe canal (Pont de Râches). Concentrations of Zn, Pb, Cd and Cu in sediments were respectively of this area suffer from contamination by non-ferrous metal processing as a consequence of the past and present smelting history of the region.
Two of the plots received different treatments by mixing additives. Thomas Basic slags (TBS) and a synthetic hydroxyapatite (Hyd) were added to the sediment at a rate of 5% and 3% dry weight, respectively. TBS was obtained from Sedest (France) whereas HA was obtained from Brenntag (Germany).The purity of Hyd is certified to 99% by the supplier. Bs is a by-product of the steel industry used for years as a fertiliser by farmers. This additive is phosphorus and lime-rich leading to a significant pH soil increase and a nutritive soil status increase. The possible use of TBS as a soil additive for immobilising metals in a polluted soil was little investigated [2,3]. On the contrary, the application of P amendments, e.g. HA ($Ca_{10}(PO_4)_6(OH)_2$), was extensively studied for this role [4,5,6]. Treated and untreated sediments were mechanically homogenised for two hours. Prior to experimental use, field plots sediments were air dried for two months in order to reduce water content. Field plots were further subdivided in 9 experimental plots as shown in Fig. 1. Seeds of *Festuca rubra* var Marker and *Deschampsia cespitosa* var Caline known to be metal-tolerant and to store metals preferentially in roots than in shoots were sown in July 2002 at a rate of 30 g/m^2 on six plots previously treated or not (Fig. 1). The three unvegetated plots left were taken as controls.

Figure 1. Experimental field-plot set up (FR = *Festuca rubra*; DC = *Deschampsia cespitosa*; No Veg = No vegetation; TBS = Thomas Basic Slags; NA = No amendment; Hyd = Hydroxylapatite)



After 2 years of vegetation monitoring, performances in terms of plant cover, metal tolerance adaptation to climat and sediments trait conditions were very high for both *Festuca rubra* and *Deschampsia cespitosa*. Non vegetated plots were colonized by surrounding species [7].

Sediment sampling:
In June 2007, sediments from all 9 plots were sampled, in triplicate, samples were air-dried and passed though a 2 mm sieve. For metal quantification, aliquots of sediments were dissolved in a microwave oven (NF EN 13346 Standard); element concentrations were measured by inductively coupled plasma atomic emission spectroscopy (ICP-AES) according to EN ISO 11885 Standard. pH

was measured in water according to ISO 10390 Standard. Table 1 shows metal concentrations and pH measured in all plots.

Table 1 : Concentrations of metal trace elements and pH in the sediment related to treatments (average SD ; n=3). DC = *Deschampsia cespitosa* ; FR = *Festuca rubra* ; TBS = Thomas Basic Slags ; Hyd = Hydroxylapatite.

	Hyd			No amendment			TBS		
Plant species	*FR*	–	*FR*	–	–	–	*DC*	–	*DC*
pH	8,7 ±1,6	7,3 ±0,1	7,6 ±0,1	7,2 ±0,3	7,0 ±0,1	7,9 ±0,2	8,4 ±0,1	7,7 ±0,3	8,3 ±0,1
(mg/kg dw) As	45 ± 5	48 ±4	48 ±5	54 ±4	53 ±4	55 ±5	48 ±1	45 ±2	49 ±6
Cd	53 ± 6	67 ±11	65 ±11	86 ±6	84 ±2	84 ±14	86 ±3	86 ±8	85 ±14
Cu	91 ±10	94 ±11	64 ±8	97 ±6	93 ±13	99 ±11	111 ±16	123 ±29	117 ±23
Pb	366 ±66	389 ±96	408 ±54	588 ±245	448 ±82	453 ±66	355 ±30	1111 ±1211	353 ±40
Zn	2703 ±703	2521 ±461	2521 ±304	3275 ±353	3250 ±519	3133 ±464	3171 ±162	3029 ±217	3225 ±271

Microbial analyses: In each sediment sample, enumeration of the total aerobic bacterial and sulphur-oxidising bacterial populations was carried out on sterile microplates, according to a method described by Lors et al. (2004) [8].
Sulphate-reducing bacteria were counted in ready-to use culture tubes containing a solid medium specific to sulphate-reducing bacteria.

Physico-chemical analyses: Metal mobility in sediment samples was assessed using a 0.01 M $Ca(NO_3)_2$ extraction. Twenty grams of air dried sediments were shaken for 48h with 40 ml of 0.01M $Ca(NO_3)_2$ solution. Supernatants were analysed for metal content using ICP-AES.

Vegetation monitoring: The sustainability and maintenance of the vegetation cover was assessed in 2007 on the 6 vegetated plots by regularly monitoring the cover rate of the initial plant species, assessing the plant biodiversity and by the inventory of the new plant species.

Results

Vegetation monitoring:
- Total cover rate of initially sown species:

Initially, sown species are still growing on the plots except *F. rubra* on the plot treated with Thomas basic slags (TBS), which has totally disappeared (Table 2). Cover rates of initially sown species vary from 50% to 90%. In the same treatment conditions, *D. cespitosa* shows a higher cover rate than *F. rubra*.

Table 2 : Total cover rates of initially sown species expressed as % (surface area occupied by individuals of a species in the sampling area, i.e. on the total plot).

	Hydroxylapatite		**No amendment**		**TBS**	
F. rubra	50	-	-	75	0	-
D. cespitosa	-	90	90	-	-	50

- Inventory of colonizing spontaneous plant species:
The result of the inventory clearly shows that some species have spontaneously colonized the plots. These species are usually found in the Nord/ Pas De Calais Region and are not known for their tolerance to metal trace elements or accumulation. No toxicity sign was visible on these plants.
In addition to the herbs, some shrubs at a very early stage were observed. This indicates that, in the near future, a shrub stratus will develop.

- Specific richness:
Species richness is defined by the measure of the biodiversity of all or a part of the ecosystem. The number of species per plot is shown in Table 3. Plots treated with hydroxylapatite present the highest species richness (19 and 16 species) whereas plots treated with TBS present the lowest species richness (8 and 10 species).

Table 3 : Species richness related to plots.

	Hydroxylapatite		**No amendment**		**TBS**	
Species number	19	16	8	10	13	15

Physico-chemical analyses and microbial analyses:
At the time of writing the extended abstract, results from both physical and microbial analyses are not available. The results will be presented and discussed during the conference.

Conclusion

On all plots, spontaneous colonization is in progress. Plants are probably coming from the surroundings of the plots [9,10]. Disappearance of the initially plant species is a function of the colonization intensity. Colonizing plant species compete with initial plant species. In the case of the plot initially vegetated with *F. rubra* and treated with TBS, competition has led to the disappearance of *F. rubra*.
D. cespitosa competes better than *F. rubra* probably due to tussock development and size of the plant.
Initially, sown species were selected on a literature basis for their tolerance to metal trace elements, climatic and soil conditions. New plant species are not known for their tolerance to metal trace elements, that may indicate that neither the sediment characteristics nor the excess of metal trace element in the sediment are restrictive factors for the plant colonization.

From this study, the main result is that the initially vegetation cover is not sustainable and will be probably replaced by colonizing plant species. Consequently, the question that has to be asked is to know if colonizing species are good candidates for phytostabilisation.

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