Efficiency of Vetiver for the Phytoremediation of Contaminated Land in the "Valle Del Sacco" (Rome, Italy)

Arch. Benito Castorina
Email benito.castorina@fastwebnet.it Site: http://www.vetiverlazio.it

Consultant: Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Technical Unit for Sustainable Development and Innovation of Agro-Industrial System (UTAGRI)

Abstract

The Department of Chemical Engineering, Materials and Environment of the "Sapienza" University of Rome was working on a research project aimed at reclaiming a very large area of land situated close to Rome ("Valle del Sacco"), where the natural soil environment had been altered by agricultural chemicals and improper disposal of industrial waste, causing a series of diseases in people and animals (ART. 199, D.LGS. N. 152/2006). The University's intention was to use Canola to treat the contaminated land, and they contacted the author, a professional in the field of environmental reclamation and a consultant of ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), requesting his collaboration. The author proposed using Vetiver as it is an excellent plant for soil phytoremediation and involving ENEA's Technical Unit for Sustainable Development and Innovation of Agro-Industrial System (UTAGRI). It was decided to investigate both plants and their potential for removing pollutants in the soil. The final objective of the study was therefore to assess the phytoremediation potential of Canola (*Brassica Napus*, L.) and Vetiver (*Vetiveria Zizanioides*, L.) in soils contaminated by toxic elements growing the plants in a laboratory, in collaboration with ENEA (Maniello et al., 2010).

For the experiment, two dozen pots were filled with soil from the contaminated area (the "Valle del Sacco"), and a phosphate fertilizer (containing NPK 19:9:10) was added to half of the pots. Fifteen tillers of vetiver were planted in each of ten pots, five of them fertilized and five unfertilized. In the same way, 15 seeds of canola were sown in each of ten pots, half of which were fertilized and half unfertilized. The remaining pots, fertilized and unfertilized, were set aside as a control experiment to analyze the soil without the plants. Since the pots were placed in a greenhouse, they were irrigated with distilled water to which elements were added to simulate local rainfall. After five months, analyses of plants and soil were carried out at ENEA's Technical Unit for Sustainable Development and Innovation of Agro-Industrial System (UTAGRI) laboratory. To assess the uptake of elements by the plants a total content analysis was done of the soil, followed by an analysis of the extractible fraction in EDTA (ethylene-diaminetetraacetic acid) (Albanese, 2008). The analytical data obtained were used to determine the Translocation Factor (TF) and the Bio-concentration Factor (BF) of each toxic element for the two plants under the two different agricultural conditions.

The EDTA extractable fractions proved in many cases to be higher than 10 % for Mo, Cu and Cd; and 20 % for Pb, Co and Mn. After only a five-month growth period, for many elements (e.g. Al, Cd, Cu, Fe, Pb and Zn) there was a significant decrease in the EDTA

extractable fraction. In some cases (e.g. Ti and V), an increase was noted in the EDTA extractable fraction in the soil after the plants were extracted, and this was true for both canola and vetiver. Moreover, for both plants, soil EC (Electric Conductivity) decreased after harvesting, by 50% for vetiver. For many elements, vetiver showed a higher BF than canola, but the TF was generally lower compared to canola. Phosphate fertilization increased the TF in both canola and vetiver (Rotkittikhun et al.). The BF calculated with regard to the total elemental content are non-significant (very low values), while those calculated with regard to the EDTA extractable fractions are more significant, especially for some elements such as Cr, Ti and Zn.

Key words: soil contamination, phytoremediation, phosphate fertilization, bio-concentration

Premise: Vetiver System, Empowering Sustainable Development

VetiverTechnology (VT) is based on a plant, vetiver (vetiveria zizanioides), the use of which can solve most if not all of the environmental problems due to man-made or natural causes. VT is a low-cost natural technology, and in this sense it is an appropriate solution in the current situation of economic restrictions and a growing trend towards using natural materials. The extensive research and experience of using vetiver, reported in publications appearing mostly on the VetiverNetwork (Greenfield; Truong; Truong et al., 2002), represent the most effective way to convince those with a resistance to innovation who have faith only in traditional techniques of intervention, the latter being certainly more expensive and often invasive or the cause of additional pollution. As Vetiver cannot be used alone for all types of intervention, this author has developed a technique of intervention referred to as "Integrated Environmental Architecture" (IEA), which uses the full potential of VT, where necessary combining it with traditional techniques, so as to provide an effective low-cost intervention which is aesthetically satisfying. For example, even in situations where reinforced concrete is required, VT can be used not only to make the intervention more aesthetically pleasing but also to make slopes more stable (Fig. 1), in addition to allowing for the growth of a protective layer of turf. Consolidation with VT is based on an intelligent technique that exploits the ability of vetiver to form a dense hedge at the base (fig. 2) which is a real filtering barrier, and arranges the plants along the contour lines, forcing water to overflow in a uniform way by reducing the speed and the weight by at least 60%, and in most cases eliminating the need for drains, which are often destroyed by infiltrations of water that in many cases create gullies (fig. 3).

Fig. 1 – Vetiver hedge

Fig. 2 – Slope consolidation with vetiver

Fig. 3 – Drain in dump at Tursi (Italy)

The same reasoning holds for phytoremediation, which makes it possible to avoid complex and energy-consuming installations such as purification plants, which are expensive both to construct and maintain. These were the arguments that convinced the research unit of the University of Rome to include vetiver among the plants to be considered for use in the Valle del Sacco. After an assessment of the advantages and disadvantages in terms of cost and efficiency of a number of plants for soil remediation, Vetiver and Canola were selected for the study. The results of the experiment using these two plants are reported in this paper.

Introduction

The research project

The Department of Chemical Engineering, Materials and Environment of the "Sapienza" University of Rome was working on a research project aimed at reclaiming a very large area of land situated close to Rome ("Valle del Sacco"), where the natural soil environment had been altered by agricultural chemicals and improper disposal of industrial waste, causing a series of diseases in people and animals (ART. 199, D.LGS. N. 152/2006). The University's intention was to use Canola to treat the contaminated land, and they contacted the author, a professional in the field of environmental reclamation and a consultant of

ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), requesting his collaboration. The author proposed using Vetiver as it is an excellent plant for soil phytoremediation. It was decided to investigate both plants and their potential for removing pollutants in the soil. The final objective of the study was therefore to assess the phytoremediation potential of Canola (*Brassica Napus*, L.) and Vetiver (*Vetiveria Zizanioides*, L.) in soils contaminated by toxic elements growing the plants in a laboratory, in collaboration with ENEA (Maniello et al., 2010).

The territory

The territory under study, named after the River Sacco, includes about 22 cities situated along its banks and their hinterland. Pollution in the area has been caused mainly by unplanned exploitation of the territory, where industrial plants and private dwellings have been constructed, sometimes unauthorized and disrespectful of the parameters of environmental safety, aggravating an already critical situation resulting from the use of pesticides and nutrients in agricultural activities. This set of circumstances, in addition to polluting agricultural products, has caused diseases and deformities in the people, animals and plants in the area. Local authorities took note of the situation and decided to prohibit farming and breeding. As a result, many areas were abandoned, leaving them with no controls and subject to improper or illegal dumping, of scraps from industrial processes and wastes of all kinds, many times coming from other areas. The first idea was to reclaim the soil by chemical or mechanical means. But given the difficult economic situation, once the authorities learned about the possibility of using low-cost technologies such as VT, they decided to start experimenting with remediation using plants. A further element of persuasion consists in the proposal that the author is in the process of finalizing, involving the implementation of a pilot project covering an area of 12 hectares to be planted with vetiver. This project would result in a further reduction of costs thanks to the profits to be derived from the use of biomass produced by the vetiver. Vetiver biomass used in a fluid bed reactor of the type already experimented with in Italy would produce for each kg of vetiver more than two cubic meters of syngas, 60% of which is hydrogen. This gas can be used on site for the production of electricity with fuel cells, using vetiver as a permanent reservoir of biomass which produces energy by reducing CO2 in the air considering that each plant absorbs c.3 kg of CO_2 per year without generating tar during the process of transforming biomass into gas (LatiumVetiver 2012).

Materials and Methods

Soil used in the test

After a thorough investigation, Colleferro was identified as a municipality whose soil was representative of the average general conditions of the soils in the entire area under study. In January of 2012 a quantity of soil sufficient for the purposes of the experiment was taken from this site, part of which was brought to the CRA (Research Center for the Study of the Relationship between Plants and Soil) in Rome for a granulometric analysis of the soil.

Fig. 4. CRA: Research Center for the Study of the Relationship between Plants and Soil

Another part of the soil was taken to the author's nursery in Aprilia to be prepared for laboratory testing. Batches of clotted soil were broken up in a container with a drill, and care was taken not to disperse the contents. After that all the soil was massed together and mixed before being distributed in pots with a capacity of 0.08 mc.

Fig. 5. Aprilia: greenhouse where soil and plants were prepared for potting.(http://www.vetiverlazio.it)

Before the soil was distributed in the pots it was crushed and passed through a sieve with a 2 cm mesh, and homogenized in order to have the same physical-chemical conditions of soil in all pots.

Plants used in the test

For this research project the plants used were vetiver (Vetiveria zizanioides) and Canola (Brassica Canola).

Fig. 6 and 7. Vetiver (Vetiveria zizanioides) and Canola (Brassica Canola).

Preparation of irrigation water, pots and planting (UTAGRI)

Since the pots were placed in a greenhouse, they were irrigated with distilled water to which elements were added to simulate local rainfall. As can be seen from Table 1, 0.5 M of a sodium salt of carbonic acid (sodium carbonate Na2CO3) was added and in this way a pH of 5.9 was obtained.

CATIONS			**Used compounds**		**ANIONS**				
								TOTAL	
	Conc.(eq l^{-1}).10^6	**Conc.(mg l^{-1})**		**mg l^{-1} ml l^{-1}**	**Conc.(mg l^{-1})**	**Conc.(eq l^{-1}).10^6**		**Conc. (eq l^{-1}).10^6**	**Conc. (mg l^{-1})**
NH4$^+$	10	0.18	NH_4Cl	0.53	0.35	10	**Cl^-**	10	0.35
Ca^{2+}	5.0	0. 10	CaF_2	0.2	0.09	5.0	**F^-**	5	0.09

Na^+	5.0	0.11	$NaNO_3$	0.41	0.3	4.8	**NO_3**	20	1.25
Mg^{2+}	3.0	0.036	$Mg(NO_3)_2 6H_2O$	0.22	0.18	3.0			
H^+	12	0.012	HNO_3 67%	0.78	0.77	12			
H^+	28	0.028	H_2SO_4 96%	1.36	1.3	28	**SO42-**	30	1.43
Further addition of 0.5 M Na_2CO_3 *in order to reach* **pH = 5.9**									

Table 1. Elements added to distilled water to simulate local rainwater

For the test two dozen pots were filled with soil from the contaminated area (Valle del Sacco), and a phosphate fertilizer (containing NPK in the ratio of 19:9:10) was added to half of the pots. Fifteen tillers of vetiver were planted in each of ten pots, five of them fertilized and five unfertilized. In the same way, 15 seeds of canola were sown in each of ten pots, half of which were fertilized and half unfertilized. The remaining pots, fertilized and unfertilized, were set aside as a control experiment to analyze the soil without the plants.

All the pots were irrigated with the artificial water prepared as described above (Table 1) in such a quantity as to maintain the necessary soil moisture. Photographs were taken periodically to monitor the development of the plants.

Soil and plant sampling

In June, after a 5-month growth period, the plants were extracted from the pots and prepared for analysis. The canola plants were divided into three parts: roots, stems, and leaves. The vetiver plants were separated into roots and leaves. Then samples of each part of the two plants were prepared by washing, mincing, homogenizing, blending and lyophilizating. The soil was dried at a temperature of maximum 30 degrees, the coarser parts were broken up and it was passed through a sieve with a 2 ml mesh. Soil with a granulometry greater than 2 mm (coarse soil) and less than 2 mm were divided into two portions. One portion was analysed to determine the physical-chemical characteristics of the soil (Table 2); the other portion was further refined by milling and samples were used for the spectrometric tests with and without EDTA (Albanese, 2008).

Coarse soil (g/kg)	**8**
Classification for Coarse soil	**Absent [< 10 g/kg]**
Moisture (%)	**5.6**
Bulk Density (g/m3)	**0.92**
pH (H2O)	**8.1**
Classification *for pH (H2O)*	**Moderately Alkaline [7.9 ÷ 8.4]**
pH (CaCl2)	**7.7**
EC (dS/m) - 25°C, 2:1 soultion:soil ratio	**0.40**
CEC (cmol(+)/kg)	**14.4**
Classification *for CEC*	**Medium [10 ÷ 20 cmol(+)/kg]**

Table 2. Soil physical-chemical characteristics before planting

Soil and plant analysis

For analysis both the vetiver and the canola samples thus prepared were hydrolyzed with the addition of ammonia and put into a microwave mineralizer at high pressure for digestion and subsequently analyzed with a plasma spectrometer (ICP-AES). For the spectrometric analysis of the soil samples, one part was treated with an acid solution (HNO_3 + HF + HCL + H_3BO_3), mineralized in a microwave and placed in the spectrometer to determine the elements; the other part was treated with EDTA (0-05 M with pH = 7) and after selective extraction was treated in the plasma spectrometer. Instead the fine soil was treated for physical-chemical characterization to obtain the cation exchange capacity (CEC). The total concentration of analytes in the soil and in the plants was determined by means of inductively coupled plasma atomic emission spectroscopy (ICP-AES) (Mallandrino et al., anno).

The aim was to determine the total input of toxic elements, from the soil, from irrigation waters (simulated rainwater) and from the added fertilizer. The main physical-chemical properties of the soils were determined and the total contents of toxic elements before and after plant growth were compared. For the canola and vetiver plants, the toxic element contents in different plant tissues were determined separately. Moreover, considering that the total content of elements in the soil is not sufficient – with regard to the bioavailable fractions – to explain their translocation from soils to plants, selective extraction procedures were used on the soil to obtain information about the mobile fractions of toxic elements (Soriano-Disla et al. 2008).

In this way, the ENEA team was able to determine the Translocation Factor (TF) of each toxic element in the two plant species under the two different agricultural conditions, and to evaluate the Bio-concentration Factors (BF), with regard not only to the total content of elements in soil, but also to the bioavailable fractions

Note

During all phases of the research attention was paid to factors which could affect the accuracy of the data. So when determining the quantity of toxic elements in the soil, consideration was given to the contribution of irrigation water (simulated rainfall) and the fertilizer that had been added to the soil. Moreover, the values of the elements analyzed were compared with the threshold values indicated in the current legislation in Italy (Table 3).

All.5 D.Lgs 152/2006. - Tab.1: Values of acceptable element concentration limits in the soil and subsoil with reference to the specific destination of use of the sites to reclaim		
Element	**A**	**B**
	Sites for public, private and residential green zones (mg/kg)	**Sites for commercial and industrial use (mg/kg)**
Sb	10	30
As	20	50
Be	2	10
Cd	2	15
Co	20	250
Cr tot	150	800
Cr VI	2	15
Hg	1	5

Ni	120	500
Pb	100	1000
Cu	120	600
Se	3	15
Sn	1	350
Ta	1	10

Tav. 3. Contamination threshold in soil and subsoil by specific destination of use on the basis of current legislation in Italy

Since there is no analogous legislation for agriculture, it was decided to consider the threshold limits both for public, private and residential green zones, and for commercial and industrial purposes.

Results and Discussion

Soil physical-chemical characteristics before planting and after harvesting

Table 3 shows the physical and chemical conditions of the soil before planting and after the extraction of plants. It can be noted that the pH did not change significantly and, based on the classification of soil, it remains "moderately alkaline." The water contained in the soil has a pH = 8.1 so the soil remains "Moderately Alkaline". For the CEC (Cationic Exchange Capacity) the soil is 14.4 cmol per kilogram and thus classified as "Medium". What is greatly changed is the Electric Conductivity (EC) (Hanlon, 1993/2009), which is reduced after harvesting as a result of the effect of both plants, and for the vetiver by as much as 50%.

Soil Physical-Chemical Characteristics	**Before planting**	**After harvesting**	
		Canola	**Vetiver**
Coarse soil (g/kg)	8		
Classification for Coarse soil	Absent [< 10 g/kg]		
Moisture (%)	5.6		
Bulk Density (g/m3)	0.92		
pH (H2O)	8.1	7.8	7.9
Classification for pH (H2O)	Moderately Alkaline [7.9 ÷ 8.4]		
pH (CaCl2)	7.7		
EC (dS/m) - 25°C 2:1 soultion:soil ratio	0.40	0.35	0.20
CEC (cmol(+)/kg)	14.4	14.2	14.1
Classification *for CEC*	Medium [10 ÷ 20 cmol(+)/kg]		

Table 4. Physical-chemical characteristics of the soil before planting and after harvesting

Total content of elements in the soil before planting and after harvesting

Table 5 shows the total content of elements in the soil (both for the elements acceptable in current legislation and for the remaining elements investigated) before planting and after the extraction of the plants from the pots, distinguishing between soil with and without fertilizers for each of the two plants. As can be seen, on the basis of the procedure adopted, overall the differences encountered were not significant.

Soil		Element content of the soil (ppm= mg/kg)																			
		Al	**As**	**Ba**	**Be**	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Mg**	**Mn**	**Mo**	**Ni**	**P**	**Pb**	**S**	**Ti**	**V**	**Zn**	**Zr**
Before planting		44000	28	940	8,8	1,5	< 15	75	65	39000	2600	1120	2,6	47	1400	100	270	4200	170	110	290
After harvesting	**Canola**	39000	27	890	8,1	1,2	< 15	74	55	37000	2100	1070	2,6	43	1300	110	220	3900	150	99	260
	Fertilized Canola	41000	29	930	8,4	1,4	< 15	71	57	37000	2200	1100	2,2	43	1400	98	260	3900	160	100	270
	Vetiver	41000	31	920	8,4	1,5	< 15	72	59	38000	2200	1090	2,1	43	1400	100	270	4000	160	100	270
	Fertilized Vetiver	40000	30	940	8,4	1,3	< 15	68	58	38000	2300	1060	1,7	43	1300	97	280	3900	160	100	270

Table 5. Total content of elements in the soil before and after harvesting

Table 5a shows that the values of all elements are significantly below the acceptable values for commercial and industrial sites. They are also below the values for public, private and residential green zones, except for lead, which is at the threshold limit and this limit is also exceeded (Be and As), in one case considerably (Va) . It should be noted that the content of As in the soil increased slightly after the extraction for both plants, which did not occur in the control pots without plants in the two conditions (fertilized and unfertilized).

Soil		**Element content in the soil (ppm = mg/kg)**								
		As	**Be**	**Cd**	**Co**	**Cr**	**Cu**	**Pb**	**V**	**Zn**
Before planting		28	8,8	1,5	< 15	75	65	100	170	110
After harvesting	**Canola**	27	8,1	1,2	< 15	74	55	110	150	99
	Fertilized Canola	29	8,4	1,4	< 15	71	57	98	160	100
	Vetiver	31	8,4	1,5	< 15	72	59	100	160	100
	Fertilized Vetiver	30	8,4	1,3	< 15	68	58	97	160	100

Sites for public, private and residential green zones (mg/kg)	20	2	2	20	150	120	100	90	150
Sites for commercial and industrial use (mg/kg)	50	10	15	250	800	600	1000	250	1500

Tab.5a - Comparison between relevant soil elements in Table 5 and acceptable element concentration on the basis of current legislation in Italy

Table 6, on the other hand, shows the results obtained with the extractable fractions of the elements in EDTA (ethylene-diaminetetraacetic acid), which were much more significant. Indeed, these values in many cases were higher than 10 % for Mo, Cu and Cd; and 20 % for Pb, Co and Mn. After only a 5-month growth period, for many elements (e.g. Al, Cd, Cu, Fe, Pb and Zn) there was a significant decrease in the EDTA extractable fraction. In some cases (e.g. Ti and V), an increase was noted in the EDTA extractable fraction in the soil after the plants were extracted, and this was true for both canola and vetiver.

Soil		Contenuti di elementi estraibili in EDTA nei suoli (ppm= mg/kg)																			
		Al	**As**	**Ba**	**Be**	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Mg**	**Mn**	**Mo**	**Ni**	**P**	**Pb**	**S**	**Ti**	**V**	**Zn**	**Zr**
Before planting		110	0,70	78	< 0,005	0,25	3,5	0,05	9,9	110	120	263	0,37	1,1	1,7	22	24	0,32	0,26	8,8	3,6
After harvesting	**Canola**	76	0,69	68	< 0,005	0,17	3,2	0,05	7,6	89	99	251	0,29	0,96	1,1	16	10	0,75	0,46	6,7	3,3
	Fertilized Canola	86	0,67	63	< 0,005	0,16	3,3	0,05	7,7	89	100	259	0,30	1,1	1,6	16	28	0,70	0,33	6,6	2,9
	Vetiver	93	0,79	73	< 0,005	0,18	3,3	0,05	8,5	98	110	257	0,32	1,1	1,1	17	13	0,86	0,43	7,4	3,0
	Fertilized Vetiver	90	0,64	70	< 0,005	0,18	3,4	0,05	8,4	96	110	259	0,37	1,0	1,2	18	25	0,98	0,45	7,3	3,4

Table 6. EDTA (ethylene-diaminetetraacetic acid) extractable fraction of elements contained in the soil

Translocation of the element contents from the soil to the plants

Table 7 shows the main elements investigated and the quantities that the plants were able to transfer from the soil to the plant tissues. Canola is divided into three parts (roots, stems and shoots) under the two conditions (fertilized and unfertilized). Vetiver is divided into two parts (roots and aerial parts) under the two conditions.

Plant parts		**Elements in the different plant parts (mg)**																		
		As	**Be**	**Cd**	**Cr**	**Mo**	**Ni**	**Pb**	**V**	**Zr**	**Cu**	**Ba**	**Mn**	**Ti**	**Zn**	**Al**	**Fe**	**Mg**	**P**	**S**
Canola	**Roots** (43.0 g)		0,004	0,008	0,029	0,024	0,037	0,037	0,051	0,061	0,106	0,26	0,504	1,201	0,545	19,425	11,963	16,195	84,004	60,982
	Stem (80.9 g)		0,001	0,009	0,014	0,013	0,046	0,013	0,003	0,006	0,046	0,45	0,268	0,197	0,705	0,220	0,687	9,897	70,210	67,762
	Shoots (82.2 g)		0,002	0,016	0,015	0,051	0,040	0,021	0,020	0,018	0,111	0,57	1,234	0,640	1,264	2,503	4,301	11,026	41,807	101,226
Fertilized canola	**Roots** (36.0 g)	0,05	0,003	0,007	0,03	0,01	0,03	0,03	0,05	0,04	0,08	0,21	0,5	1,3	0,47	17,4	11,9	12,5	66	60
	Stem (100 g)		0,001	0,013	0,01	0,02	0,02	0,02	0,02	0,01	0,11	0,40	1,1	0,6	0,87	2,6	4,1	15,3	63	159
	Shoots (173 g)		0,002	0,019	0,04	0,02	0,09	0,06	0,01	0,02	0,12	0,81	0,7	0,3	1,56	0,4	1,8	30,1	202	230
Vetiver	**Roots** (160 g)	0,17	0,023	0,014	0,17	0,03	0,16	0,21	0,30	0,67	0,82	1,86	3,2	8,2	4,2	131,3	82,2	35,1	56	92
	Aerial part (152 g)		0,002	0,006	0,02	0,02	0,06	0,08	0,02	0,14	0,22	0,24	3,0	3,4	1,47	6,0	5,8	23,3	60	76
Fertilized vetiver	**Roots** (164 g)		0,027	0,015	0,17	0,02	0,15	0,23	0,34	0,69	0,62	2,41	3,0	8,3	2,63	146,6	91,6	31,9	44	83,3
	Aerial part (142 g)		0,003	0,007	0,04	0,02	0,09	0,05	0,03	0,13	0,24	0,40	3,8	3,7	1,14	8,4	7,8	30,2	82	86

Table 7. Total element content of the plants

These data were used to define: the translocation factor (TF) from the soil to the plants (Table 8); the bioconcentration factor (BF) calculated on the basis of the total content of elements (Table 9); and the BF calculated on the basis of the extractable fraction in EDTA (Table 10). These factors make it possible to assess the plant's capacity to absorb the various elements and to detect which parts of the plant contain the greatest concentration of elements.

Plants	**Elements**																	
	Al	**Ba**	**Be**	**Cd**	**Cr**	**Cu**	**Fe**	**Mg**	**Mn**	**Mo**	**Ni**	**P**	**Pb**	**S**	**Ti**	**V**	**Zn**	**Zr**
Canola	0,037	1,05	0,182	0,777	0,267	0,388	0,110	0,340	0,784	0,700	0,611	0,351	0,243	0,730	0,184	0,118	0,951	0,105
Fertilized Canola	41	1,35		1,64	4,11	2,91	13	2,27	1,71	3,28	2,10	2,02	2,99	1,00	9,31	12	1,43	13
Vetiver	0,023	0,756		0,579	0,223	0,361	0,065	0,479	0,473	0,829	0,532	0,528	0,356	0,858	0,085	0,067	0,685	0,097
Fertilized Vetiver	12	3,81	7,53	5,37	4,79	1,65	8,68	2,27	0,734	1,88	2,07	4,65	1,63	3,31	1,57	9,01	1,34	1,20

Translocation Factor (TF) = CAP / CR CAP = element al concentration in the plant aerial part
CR = element concentration in the roots
TF < 1 → the plant accumulates the element in the roots
TF ~ 1 → the element is fairly distributed between the roots and the aerial part
TF > 1 → the plant accumulates the element in the aerial part

Table 8. Translocation factor (TF)

For many elements, vetiver showed a higher bio-concentration factor than canola, but the translocation factor was generally lower compared to canola. Phosphate fertilization increased the TF in both canola and vetiver (Rotkittikhun et al.).

The BF calculated with regard to the total content of elements are non-significant, while those calculated with regard to the EDTA extractable fractions are much more significant, especially for some elements, such as Cr, Ti and Zn.

Plants	**Elements**																		
	Al	**As**	**Ba**	**Be**	**Cd**	**Cr**	**Cu**	**Fe**	**Mg**	**Mn**	**Mo**	**Ni**	**P**	**Pb**	**S**	**Ti**	**V**	**Zn**	**Zr**

	Vetiver	Vetiver	Colza	Colza
	Vetiver		Canola	
	Whole plant	**Aerial part**	**Whole plant**	**Aerial part**
	0,010	0,001	0,002	0,0004
	0,020			
	0,007	0,002	0,007	0,007
	0,009	0,001	0,003	0,002
	0,044	0,026	0,109	0,102
	0,008	0,002	0,004	0,002
	0,051	0,022	0,020	0,015
	0,007	0,001	0,002	0,001
	0,073	0,060	0,071	0,050
	0,018	0,018	0,009	0,008
	0,061	0,042	0,164	0,150
	0,015	0,008	0,013	0,011
	0,268	0,284	0,686	0,495
	0,009	0,005	0,003	0,002
	2,01	1,87	4,18	3,88
	0,009	0,005	0,002	0,001
	0,006	0,001	0,002	0,001
	0,170	0,091	0,114	0,113
	0,009	0,003	0,001	0,001

Bioconcentration Factor **BF = CP / CS**	*CP* = element concentration in plant *CS* = element concentration in soil

Table 9. Bioconcentration factor (BF) with respect to the total element content in soil

Element	**Plants** Vetiver / Vetiver **Whole plant**	Vetiver **Aerial part**	Colza / Canola **Whole plant**	Colza **Aerial part**
Al	3,83	0,340	0,937	0,146
As	0,785			
Ba	0,086	0,020	0,080	0,080
Be				
Cd	0,263	0,155	0,648	0,611
Cr	12,0	2,90	5,35	3,40
Cu	0,335	0,143	0,128	0,097
Fe	2,679	0,363	0,783	0,291
Mg	1,56	1,28	1,51	1,07
Mn	0,075	0,075	0,037	0,035
Mo	0,429	0,294	1,14	1,05
Ni	0,631	0,336	0,538	0,475
P	213	226	547	395
Pb	0,041	0,023	0,016	0,010
S	22,5	21,0	46,8	43,4
Ti	117	70,8	31,1	16,1
V	3,97	0,614	1,37	0,537
Zn	2,06	1,10	1,39	1,37
Zr	0,725	0,258	0,115	0,041

Bioconcentration Factor **BF = CP / CS**	*CP* = element concentration in plant *CS* = element concentration in soil

Table 10. Bioconcentration factor (BF) with respect to the element extracted in EDTA from the soil

Conclusions

The aim of demonstrating the effectiveness of vetiver and canola in removing toxic elements to reduce soil pollution has clearly been achieved, and the results obtained confirm that plants are potential biotechnological tools that can be used massively to re-establish environmental equilibrium. Vetiver has not only proved to be strong enough to remove toxic elements from polluted sites, but has also adapted well to the contaminated soil of the Valle del Sacco. While its qualities did not emerge from the elaboration of the initial data obtained by means of the procedure to calculate the total content of elements in the soil (which showed values of the elements analyzed which were of limited significance), the decision to continue the test using the EDTA (ethylene-diaminetetraacetic acid) procedure produced much more fruitful results. In fact, from the data reported in Tables 8, 9 and 10 it is clear that the values obtained from the extractable fraction of the elements contained in the soil are much more significant for the calculation of the bioconcentration factor (BF) and the translocation factor (TF), as compared to those derived from the total extractable amount. From the same data, it can also be noted that for many elements the BF of vetiver is generally higher than that of canola and the TF is generally lower, in the two soil conditions (fertilized and unfertilized). Taking into account that the plants were in the pots for just five months, this shows that not only is vetiver an excellent bioconcentrator, but also that it concentrates the greatest fraction of the absorbed pollutants in its roots. These assessments are confirmed by table 6, which shows that for many elements (eg., Al, Cd, Cu, Fe, P, Pb, Zn) there has been a substantial reduction in the EDTA extractable fraction for both vetiver and canola. It should also be noted that electrical conductivity (EC) is much reduced, by 50% for vetiver (Table. 4).

An important consideration here is that when analyses of sewage, contaminated water or soil are done, an exhaustive test would be very expensive and it would take a long time to obtain the results. Furthermore, the complexity of assessing the elements contained in the soil is further complicated by the variability of the physical and chemical conditions of the environment in which they are located, since they vary even in adjacent areas. These variations depend on the weather (rain, temperature) and to a considerable extent on the presence and the amount of micro organisms, fungi and lichens, that change the characteristics of the soil and whose existence and proliferation depend on a mutual exchange with plants (Kashern and Singh 2001). Vetiver has a important function in this sense in that, having a much more extensive foliar and root mass than most plants, it can have a more powerful effect, and during the process of photosynthesis it sends a considerable amount of oxygen into the soil through its roots, in this way allowing the proliferation of bacteria that transform, for the benefit of the plant itself, the physical and chemical conditions of the soil, the water and the environment in which it is placed. In addition, vetiver is a perennial plant with roots reaching a depth of up to 5 meters, which thus enable it to carry out a clean-up activity which affects deeper layers. In the research reported here, the data did not reveal a level of pollution that would account for the environmental disaster taking place in the Valle del Sacco, and as a result the vetiver could not realize its full potential. For this reason, following the results of this experiment, it was decided to continue the research by growing plants in a field experiment in an area of the city of Anagni (another town in the Valle del Sacco) where both vetiver and canola have been planted.. The related data are being processed and will be the subject of another publication.

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