ENVIRONMENTAL RESTORATION OF CONTAMINATED SITES, QUARRIES, MINES AND LANDFILL WITH DEEP ROOTS HERBACEOUS SPECIES

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SUMMARY

The environmental restoration of contaminated sites and old landfills often turn out to be very difficult, mainly because plant species used for the renaturation of sterile and/or contaminated soils don't take roots easily. Over the years several techniques have been developed for soil protection and renaturation. Among these there is an emerging innovative technology that uses only natural herbaceous perennials plants with deep rooting system, and allows to operate in areas where climatic conditions were until a few years ago considered prohibitive for the development of vegetation: barren lands, altered or fractured rocks, soils treated with addition of lime up to 5% by weight, soil polluted by waste, hydrocarbons and heavy metals in concentrations up to 10 times higher than the upper limits admitted by law. In addition, these herbaceous plants show the ability to withstand high temperatures produced by the fermentation of organic waste in landfills.

Keywords: erosion, planting roots, mechanical and hydraulic effects, surface protection of slopes, tolerance to polluted soil

1 EROSION PHENOMENA AND ENVIRONMENTAL RESTORATION

The erosion on the Italian territory are quite widespread and closely related to weather characteristics of our latitudes, where rain falls represent the more aggressive agent (water erosion).

The intensity of erosion action depends on several factors, such as intensity and duration of rainfall, length and angle of slope, soil permeability and degree of saturation, presence of vegetation, intrinsic soil erodibility.

The intense erosion prevents the formation of *humus* in the soil and accelerate the leaching of nutrients making very difficult the growth of vegetation. Some pioneer species, particularly frugal, sometimes succeed in taking root on bare eroded slopes, but often a meteoric event more intense than usual is sufficient to eradicate them.

Nevertheless, recent studies have highlighted the ability of some deep rooting herbaceous species (*prati armati*) to vegetate in prohibitive climatic conditions where plant species typically used for greening interventions cannot grow, thus being able to very effectively prevent the erosion. These plants would behave as pioneer organisms vegetating even on sterile and contaminated soils where they develop a dense vegetation cover, improving soil structure and fertility. The soil would therefore become more suitable to colonization by most demanding plant species (such as shrubs and trees) accelerating the process of naturalization and environmental restoration.

Several approaches for quantitative evaluation of erosion (soil loss) have been proposed, like those based on theoretical models, physical models at reduced scale and empiric models. Among the last ones is evidenced the Universal Soil Loss Equation - USLE (Wischmeier and Smith, 1965; 1978), empirical equation adopted by United States Department of Agriculture for assessment of hydraulic erosion. Such equation generally is diffused in the following form::

$$\mathbf{A = R \times K \times LS \times C \times P} \qquad \textbf{(1)}$$

where:

A: specific soil loss [t/ha year], associated to phenomena of *rill* and *interill* erosion;

R: *Rainfall-Runoff Erosivity Factor*: climatic factor relevant to the intensity and duration of precipitations [MJ mm/ha h year];

K: *Soil Erodibility Factor*: pedologic factor that expresses the erodibility of the ground [t h/MJ mm];

LS: Geometrical factor function of the steepness and length of the slope;

P: *Supporting Practices Factor*: reduction factor taking into account possible interventions of protection, control and conservation;

C: *Cover-Management Factor*: reduction factor depending on the vegetation.

The anti-erosion techniques today's most popular date from 1950-60. All involve the use of synthetic products such as geocells, geomats, geonet, or biomats, fascinate, wicker, etc.. which, however, in difficult climatic conditions, may not completely solve the problem of erosion and do not allow rapid renaturation.
In recent years, considerable interest is attributed to anti-erosion interventions that use natural systems, such as certain types of herbaceous species which combine high resistance to phytotoxic conditions with good geotechnical properties, thereby helping to reduce the factors P and C that appear in the reported USLE equation with the result of reducing the specific soil loss. The role of vegetation in protecting slopes from erosion has long been studied and documented by experimental research.
To reduce water erosion phenomena, and thus the soil loss due to water run-off, the use of deep rooting herbaceous plants looks promising for the following reasons:

- grass leaves dissipate most of raindrops kinetic energy, thus mitigating their erosive effects (*splash erosion*);
- in case of heavy rainfall, a major fraction of meteoric water streams above the flatten vegetation layer, even when the leaves are dried, waterproofing the slope and substantially reducing the infiltration of water;
- the presence of vegetation may reduce the speed of runoff water on the ground and therefore the intensity of erosion;
- there will be a delay in meeting the conditions of complete saturation of the soil due to the mechanism of plant transpiration, as liquid water is absorbed from the soil through the roots and transferred to the atmosphere as vapour;
- the soil is mechanically reinforced by the presence of roots;
- the vegetal blanket retains the soil particles, resulting in containment actions, filter and contrast of grains sweeping away phenomena;
- the content of organic matter in the soil increases, which in turn leads to a reduction of the intrinsic soil erodibility thanks to the formation, in the soil itself, of more stable structural aggregates;
- the increase in soil organic matter results in a significant increase of its water retention capacity;
- the retention of nutrients is also increased by both the biological uptake by the vegetation and the chemical withholding operated by the *humus*.

1.1 Improvement of fertility, structure and water holding capacity of the soil due to the presence of vegetation

The presence of vegetation causes a significant increase in soil organic matter and this in turn improves the soil structure, fertility and water retention. Soil organic matter may be considered as a mixture of compounds derived from plants and micro-organisms at different stages of degradation, starting from fresh organic scraps up to products almost transformed into *humus*. *Humus* is the fraction of organic matter most active in terms of chemistry and physics and is derived from its decomposition and elaboration. Its content of organic matter varies from less than 1% in desert soils to 1 -15% in forest soils and to more than 90% in the peat.
The presence of organic matter in the soil causes a significant increase of its water holding capacity and nutrient holding capacity: *humus* is able to hold quantities of water up to 20 times its own weight and to make a chemical retention of nutrients such as potassium, calcium, magnesium, phosphorus. It also determines a slowing-down of the process of phosphorus retrogradation, the protection of trace elements from insolubilization and the increase of buffering capacity.

The presence of organic matter in soil also reduces its susceptibility to erosion because it leads to the formation, in the soil itself, of more stable structural aggregates. It also favours the development of soil fauna and microorganisms, since these will use it as foodstuff substrate.
The organic matter also plays an important role in inactivating, by adsorption, various organic compounds bearing biotoxic action, both from biological origin (polyphenols) and synthetic (herbicides and pesticides in general). The soils rich in organic matter are therefore important systems to dispose of organic compounds bearing biotoxic properties, thus are capable to reduce pollution of groundwater.

2 TESTING GERMINATION AND ROOTS DEPTH IN CONTAMINATED SITES

To test the ability of *prati armati* to vegetate in contaminated soils, germination tests have been carried out on materials similar to those of landfill mining district of Montevecchio in south-western Sardinia, where dumps of sterile materials from mines tracking and residues from extraction of minerals such as galena (lead sulphide) and blende or sphalerite (zinc sulphide) are present.
Quantitative analysis of pollutants in different soil samples were conducted using optical emission plasma spectrometry ICP-OES (Inductively Coupled Plasma - Optical Emission Spectrometer).
The principal pollutants detected were: arsenic, cadmium, cobalt, chromium, copper, mercury, nickel, lead, antimony, selenium and zinc, in concentrations sometimes over ten times higher than the upper limits admitted by law. As an example the concentrations detected in soil sample N° 14 are reported

Pollutant	Analysis date	Unit	Found values	Reference values
As	01 June 2010	mg/kg	544,4	50
Cd	01 June 2010	mg/kg	140,3	15
Pb	01 June 2010	mg/kg	9263,0	1000
Zn	01 June 2010	mg/kg	20216,5	1500

Figure 1. Content of pollutants in contaminated soil samples used in germination tests of *prati armati*

2.1 The germination tests

To test the germination of several deep roots grass species, 7 soil samples were used having features comparable to 7 different dumps of the same mining district. 9 different species of deep roots herbaceous plants were tested for capability of germination: 9 pots of 16 cm diameter (one for each grass species) were therefore filled with each soil sample.
A total of 63 pots were therefore monitored. The pots were subjected to watering cycles simulating rainfall.
One month after sowing the following results were obtained: out of the 9 herbaceous species tested, at least 4 were able to germinate in all soil samples, developing at the same time a root system that embraced the entire soil volume contained in each pot.

b) The test pots

b) Development of the root system within the test pot

Figure 2. Results one month after seeding

The same experiment revealed which of the tested herbaceous species could demonstrate to adapt to critical conditions, and therefore suitable to be used for treatment of sites contaminated by arsenic, cadmium, cobalt, chromium, copper, mercury, nickel, lead, antimony, selenium, zinc. After this first phase of germination tests, a second test was conducted to verify the ability of the root system of the different grass species to deeply penetrate in the contaminated soil.

2.2 The taking root tests

Among the pots of the species that were able to germinate on contaminated soil, 4 were taken, one for each species. Each pot content was transplanted into a plexiglas tube with a length of 2m and diameter of 20cm, filled with the same type of contaminated soil of the pot. The test tubes were equipped with drip irrigation system. Thanks to the transparency of the tube walls, it was possible to monitor over time the roots growth of the 4 herbaceous species.
About a year after seeding it was clear that the roots growth was remarkable in all tested species, exceeding one meter depth in 50% of cases, with one specie exceeding 1,80m of roots length.
The study demonstrated therefore that the tested grass species are not only capable to germinate on contaminated soils, but may vegetate and increase the depth of their root system.
The experiment revealed which of the tested herbaceous species were able to grow in contaminated soil. It was then possible to select grass species useful for the treatment of sites contaminated by arsenic, cadmium, cobalt, chromium, copper, mercury, nickel, lead, antimony, selenium, zinc.

a)

b)

Figure 3: a) Plexiglas tube used for roots development testing b) Detail of the roots system

3 APPLICATIONS OF DEEP ROOTS HERBACEOUS PLANTS FOR THE RENATURALIZATION OF QUARRIES - MINES - LANDFILLS

The application fields of these technologies, such as the one developed in Italy by **Prati Armati srl**., is quite wide: ridges and banks of roads and railways, embankments, quarries, mines, landfills, sea facing areas, banks protection of rivers, streams, artificial waterways. .
In particular, in the case of contaminated sites and old landfills:

- coverage and water erosion protection of slopes is obtained in a short time;
- wind erosion, generating polluting clouds of dust, is reduced;
- the plants isolate the waste material from the environment and improve the visual impact of the treated area.
- leachate generation in landfills is strongly reduced, thanks to the intense transpiration capacity of these plants and to the high reduction of rainwater infiltration as the slope waterproofing brings the major fraction of meteoric waters to stream above the flatten grassy layer;
- downstream dragging of emerging waste is reduced, as they will be wrapped within the vegetation cover.

The treatment of contaminated soil areas with deep rooting herbaceous plants does not replace the remediation, but may provide a fast, affordable solution for the emergency securing of landfills slopes. In addition, these interventions (see Italian Decree DM 471/99) fall within the category of "*in situ*" techniques that do not foresee handling or removal of polluted soil and waste.

3.1 An example of intervention for naturalization of a MSW landfill

A typical example of installation of deep rooting herbaceous plants, aimed at the re-naturalization of a MSW landfill, was carried out in Sardinia and represented in Figures 4 a) and 4 b). A few months after intervention, the sown herbaceous species could completely re-naturalize the site despite the unfavourable climatic conditions. The deep root system could moreover protect the superficial portion of the slope, contrasting at the same the erosion and reducing leachate production (see Fig.4b).

a)

b)

Figure 4: The MSW landfill Ozieri (SS): a) Situation in November 2005, before the intervention b) After the intervention of re-naturalization with *prati armati* (May 2006)

3.2 An example of intervention for the re-naturalization of an abandoned quarry

An example of re-naturalization intervention on an abandoned quarry through the use of deep rooting herbaceous species was carried out in Sicily, nearby Catania, in an area currently used for industrial separation of MSW. The intervention is shown in Figure 5 a) and 5 b).
A few months after seeding, planted herbaceous species have completely re-naturalized the slope, blocking erosion (see Fig.5b).

a) b)

Figure 5. The abandoned quarry nearby Catania, currently used for industrial waste processing. a) Situation in February 2010, before the intervention b) After the intervention of re-naturalization (April 2011)

3.3 Another example of intervention for re-naturalization of a quarry

Another example of a re-naturalization of an abandoned limestone quarry through the use of deep rooting herbaceous species, is the one carried out in Umbria region nearby Spoleto.
After about 7 months from intervention, despite the prohibitive climatic conditions, the sown herbaceous species began to colonize the slope, triggering the process of re-naturalization. This process is still active and picture 6b) shows the first visible results of the ongoing re-naturalization.

a) b)

Figure 6. The abandoned limestone quarry in Spoleto. a) Situation in October 2010, prior to intervention. b) The first evidence of re-naturalization (May 2011)

4 CONCLUSIONS

The use of deep rooting perennial grasses allows to contrast erosion and to re-naturalize areas where climatic conditions were until a few years ago considered prohibitive for the development of vegetation: barren lands, altered or fractured rocks, soils treated with lime up to 5% by weight, soils polluted by waste, hydrocarbons and metals. The use of these plants thus appears promising for environmental restoration of contaminated sites and abandoned landfills. Over the years the application of deep rooting herbaceous plants in this type of sites has been successfully tested, as shown in the examples described above. Rapid re-naturalization was actually achieved also in quarries and landfills, where typically the taking root of vegetation appears particularly difficult. With this type of interventions it is also possible to drastically reduce leachate generation in landfills and perform the emergency securing of landfills slopes, specifically where time constraints and high costs often prevent the use of traditional remediation procedures.

5 REFERENCES

Bischetti G.B., Bonfanti F., Greppi M., 2001. *Misura della resistenza a trazione delle radici: apparato sperimentale e metodologia d'analisi*. Quaderni di Idronomia Montana, 21/1, 349-360.
Bischetti G.B., Chiaradia E. A., Epis T., 2009. *Prove di trazione su radici di esemplari di piante PRATI ARMATI®. Rapporto conclusivo*. Dipartimento di Ingegneria Agraria, Università degli Studi di Milano.
Bonfanti F., Bischetti G., 2001. *Resistenza a trazione delle radici e modello di interazione terreno – radici*. Istituto di Idraulica Agraria, Milano – Rapporto interno.
Celi L., *La sostanza organica del suolo.* Environment, Ambiente e Territorio in Valle d'Aosta.
Prati Armati srl, archivio fotografico e banca dati.
Rassam D.W., Cook F., 2002. *Predicting the shear strength envelope of unsaturated soils*. Geotechnical Testing Journal, Technical Note, 25: 215-220.
Rettori A., Cecconi M., Pane V., Zarotti C. 2010. *Stabilizzazione superficiale di versanti con la tecnologia Prati Armati®: implementazione di un modello di calcolo per la valutazione del coefficiente di sicurezza*. Accademia Nazionale dei Lincei – X Giornata Mondiale dell'Acqua, Convegno: Frane e Dissesto Idrogeologico, marzo 2010.
Richards, L.A., 1931. *Capillary conduction of liquids through porous medium*. Physics, Vol. 1.
Waldron LJ, 1977. *The shear stress resistance of root-permeated homogeneous and stratified soil*.
W.H. Wishmeier, D.D. Smith, 1965. Predicting rainfall erosion losses from cropland east of the RockyMountain. Agr. Handbook, n. 282, U.S. Dept. of Agr.