Environmental restoration with deep roots herbaceous species

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ABSTRACT: The use of deep rooting perennial grasses represents an innovative solution for soil protection and renaturation in severe environmental situations. It allows interventions also in areas where climatic conditions and soil characteristics were until a few years ago considered prohibitive for the development of vegetation. An attractive application would be in abandoned landfills and dumps of mining scraps where the presence of heavy metals (As, Cd, Pb, Zn etc.) usually inhibits the vegetation survival.
Germination tests were conducted on 9 deep roots grass species and 7 highly contaminated soil samples. By monitoring the 63 resulting test pots it was possible to select 4 best performing species that could also demonstrate to develop up to 1,80 m of root system after 1 year in same soil. These results are accompanied by the presentation of 3 full-scale cases (an urban wastes landfill and two abandoned quarries) where similar grasses allowed for a quick environmental recovery and protect the soil from erosion risks. The Authors are therefore confident that in similar situations renaturation may be achieved despite the presence of mentioned phytotoxic agents, thus making this innovative technology a unique and effective approach specifically where time constraints and high costs often prevent the use of traditional remediation procedures.

1 EROSION PHENOMENA AND ENVIRONMENTAL RESTORATION

The erosion on the Italian territory is quite widespread and closely related to weather characteristics of our latitudes, where rain falls represent the more aggressive agent (water erosion).
The severity of erosion action depends on various 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 accelerates 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 stronger 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. These plants behave as pioneer organisms vegetating even on sterile and contaminated soils. The dense vegetation blanket that originates improves the soil structure and it's fertility, preventing erosion very effectively (see Cecconi et al. (2013) and Rettori et al. (2010)). 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 (see Wischmeier & Smith (1965)) empirical equation adopted by United States Department of Agriculture for assessment of hydraulic erosion. Such equation is generally diffused in the following form:

$$A = R \times K \times LS \times C \times P \quad (1)$$

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 expressing the erodibility of the ground [t h/MJ mm];

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

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

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

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.
Their presence helps to reduce the factors P and C 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 (see Cecconi et al. (2012)).
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 flattened 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 (see Richards (1931), Rassam and Cook (2002));

- the soil is mechanically reinforced by the presence of roots (see Waldron (1977)) when their quality and strength match specific criteria (see Bischetti et al. (2001), Bischetti et al. (2009), Bonfanti and Bischetti (2001));

- 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 (see Celi (2010));

- 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 significantly increases its holding capacity of water and nutrients: humus can hold water amounts up to 20 times its own weight and may chemically retain 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 ROOT DEPTH IN CONTAMINATED SITES

To verify the ability of *prati armati* to vegetate in contaminated soils, germination test have been carried out on soil samples taken from landfill mining district of Montevecchio (south-western Sardinia). These sterile materials contain residues from mines tracking and extraction of minerals such as galena (lead sulphide) and blende or sphalerite (zinc sulphide). 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 in Table 1.

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

Pollutants	Analysis date	Unit	Found val.	Ref. val.
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

2.1 *The germination test*

The investigation was conducted on 9 deep root grass species and 7 soil samples taken from different dumps of the same mining district. Each soil sample was used to fill 9 pots of 16 cm diameter, thus allowing the 9 grass species to be tested on every different soil. 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 (see Fig. 1 and 2): 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 volume of the pot.

Figure 1: The test pots after 1 month.

Unfortunately germination is only the first stage of the plant life as phytotoxic substances may kill the sprout or affect its development by roots dwarfing. In order to be acceptable for practical applications the grass sample must therefore be verified against the ability of its root system to develop and to deeply penetrate in the contaminated soil.

Figure 2: Development of the root system within the test pots, after 1 month.

2.2 *The taking root test*

Among the pots of the species that passed the first germination test, 4 were taken, one for each kind. Each pot content was transplanted into a plexiglas tube with a length of 2 m and diameter of 20 cm, filled with the same type of contaminated soil of the pot (see Fig. 3). 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 root growth of the 4 herbaceous species.

About a year after seeding it was clear that the root growth was remarkable in all tested species, exceeding one meter depth in 50% of cases, with one specie exceeding 1,80 m of root 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 (Fig. 4). It was then possible to point out which species are best suitable for the treatment of sites according to the specific phytotoxic agent (arsenic, cadmium, cobalt, chromium, copper, mercury, nickel, lead, antimony, selenium, zinc).

3 APPLICATIONS FOR RENATURALIZATION OF QUARRIES, MINES AND LANDFILLS

The application fields of these technologies, such as the one developed in Italy by Prati Armati srl. (see Napoli (2011)), is quite wide: ridges and embankments of roads and railways, abandoned quarries and mines, sea facing areas, embankments protection of rivers, streams, artificial waterways and landfills, including those for Municipal Solid Waste (MSW).

Figure 3: Plexiglas tube used for roots development testing

In particular, when used in 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. Moreover, rainwater infiltration is highly reduced 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.

Figure 4: Detail of the root system

3.1 *An example of intervention for re-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 5 and 6. 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 time the erosion and reducing leachate production (see Fig. 6).

Figure 5: The MSW landfill Ozieri (Sardinia) in November 2005, before the intervention

Figure 6: The MSW landfill in May 2006, after the intervention of re-naturalization with *prati armati*

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, near Catania, in an area currently used for industrial separation of MSW.
The intervention is shown in Figures 7 and 8. A few months after seeding, planted herbaceous species have completely re-naturalized the slope, blocking erosion (see Fig. 8).

Figure 7: An abandoned quarry near Catania (Sicily), currently used for industrial waste processing: situation in February 2010, before the intervention

Figure 8: The abandoned quarry in April 2011, after the intervention of re-naturalization

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 the Umbria region near Spoleto (see Fig. 9).
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 Figure 10 shows the first visible results of the ongoing re-naturalization.

Figure 9: The abandoned limestone quarry in Spoleto: situation in October 2010, prior to intervention

Figure 10: The limestone quarry in May 2011 showing the first evidence of re-naturalization

4 CONCLUSIONS

An emerging innovative solution based on planting natural herbaceous perennials species with deep rooting system proved to be effective in contrasting soil erosion and favouring renaturation. Careful selection of proper species allows to operate in areas where climatic conditions and soil characteristics 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 and polluted by wastes and hydrocarbons may be successfully treated. Three interesting cases show pictures of wastes landfill and abandoned quarries before and after treatment. This paper illustrates the preliminary investigations in view of extending the application to sites where high levels of phytotoxicity further worsen the possibility of vegetation survival. Laboratory-scale tests were conducted on a number of grass species in order to assess their capability to germinate and take roots in mining scrap samples where heavy metals concentration reaches 10 times the limits admitted by law. The very positive results encourage to proceed with full scale deployment in contaminated sites and old landfills where this innovative technology may represent a unique and effective approach considering that time constraints and high costs often prevent the use of traditional remediation procedures.

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