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Multi-functional role of grassland systems in the ecological restoration of mines, landfills, roadside slopes and agroecosystems

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SUMMARY – Grassland sites of the Mediterranean region of central Spain were analysed as reference systems for restoring several scenarios: (i) abandoned mines with polluted soils; (ii) old urban waste landfills; (iii) roadside slopes; and (iv) degraded agroecosystems with eroded soils. At all the sites, we found pasture plants with multiple functions such as providing soil cover and adapting to water, salt and heavy-metal stresses, as well as acting as a reservoir for native Mediterranean grassland flora. Species growing in the mine soils were mainly Graminaceae, and this plant family was found to accumulate substantial quantities of Zn and other heavy metals. Pasture species capable of stabilizing soils on roadside slopes were: *Dactylis glomerata, Cynodon dactylon, Medicago sativa* and *Plantago albicans.* Plant covers containing several legumes, installed to combat soil erosion and increase N in olive and vine crop systems, achieved good cover and did not compete for the water available to the crops.

Keywords: Degraded soil systems, heavy metals, plant covers, ecological restoration.

RESUME *– "Rôle multifonctionnel des systèmes herbacés pour la restauration des mines, dépôts d'ordures, talus des routes et agroécosystèmes". Des pâturages méditerranéens d'Espagne ont été analysés comme systèmes de référence pour restaurer : (i) les sols pollués à cause des mines abandonnées ; (ii) de vieux dépôts d'ordures urbaines ; (iii) des talus des bords des routes ; et (iv) des sols dégradés des agroécosystèmes de céréales, oliviers et vignoble. Dans tous les endroits, nous avons trouvé des plantes avec de multiples fonctions telles qu'assurer la couverture végétale du sol et aussi s'adapter à des conditions de stress par manque d'eau, par sel et par métaux lourds, et agir comme réservoir pour la flore des pâturages. Les espèces qui se développent dans les sols des mines abandonnées sont principalement des graminées et elles accumulent d'importantes quantités de Zn et d'autres métaux. Des espèces capables de retenir le sol des talus sont :* Dactylis glomerata*,* Cynodon dactylon*,* Ononis spinosa*,* Medicago sativa*,* Plantago albicans *et* Centaurea paniculata*. Des couvertures d'herbacées, qui contiennent des légumineuses aptes et qui n'opposent pas de concurrence aux cultures quant à la disponibilité en eau, sont installées dans l'oliveraie et le vignoble, afin de combattre l'érosion du sol et d'en augmenter le N.*

Mots-clés : *Sol dégradés, métaux lourds, couvertures d'herbacées, restauration écologique.*

Introduction

Spain has many sites in which old abandoned mines have given rise to landfills and soils polluted with heavy metals. The plant communities that grow at these sites form grasslands that are grazed by cows, sheep and wild animals.

In addition, the revegetation of old disused solid waste landfills capped years ago with soils taken from surrounding pastures, show mixed community species, some corresponding to the initial stages of ecological succession and others representing more advanced stages emerging from the capping soil's seed bank.

This last situation is similar to that arising after cereal crop systems have been abandoned, after woody crops are grown in degraded soils, or after the colonisation of roadside slopes.

Given their similarity (Hernández and Pastor, 2007; Pastor and Hernández, 2007), we set out to analyse these disturbed systems and their inherent processes to try to minimize soil degradation in relation to adjacent ecosystems with a view to their use as reference systems for ecological restoration measures. In this report, we summarize our 20 years work on this topic.

Materials and methods

Ten abandoned mine sites in central mainland Spain were analysed in terms of characterising their plant communities and determining the heavy metal contents of the topsoil layer by stratified sampling of the different morphological features and plant communities of the terrain (landfills, slopes and grasslands of areas affected or not by pollution).

In addition, floristic relieves were recorded for 20 waste landfills –capped with soil and overlying different substrates (granite, gneiss, arkoses, gypsum, limestone, marl, clay, silt, conglomerates) – and in surrounding grassland reference ecosystems of the central Iberian Peninsula.

We also examined several hectares of abandoned cereal crops, and of olive and vine agrosystems at the experimental farm "La Higueruela" (Santa Olalla, Toledo, Spain). The climate of this area is semiarid, with irregular rainfall, sometimes torrential, that has for centuries provoked runoff and soil loss processes.

The experimental designs and details of the methods used can be found in Hernández and Pastor (2007) and Pastor and Hernández (2007). In a further in depth study, we applied a conceptual slope model to the analysis of 62 roadside slopes in the central Peninsula as landscape structures, essentially in terms of features related to erosion and vegetation.

The slopes were typified according to their geomorphology (10 physiographic variables), to their substrate (limestone or siliceous materials), and the properties of the top 10 cm of soil (18 granulometry variables among other soil factors), as well as to characteristics related to other vegetation factors (species determining physiognomy, species providing soil cover, or stabilizing and landscape covering species, etc.). At each slope, floristic relevés were recorded in areas measuring 10 m x 4 m.

Results and discussion

The grassland systems of the different scenarios we have examined over the years contain soils degraded both by erosion and by heavy metal pollution. Thus, most of the abandoned mine sites have soils that exhibit more than three of the metals determined: Cr, Co, Ni, Cu, Zn, Pb, Ba, As, Cd and Al; 62 of the topsoil samples showing contaminating levels. The species growing in these contaminated soils are listed in Table 1. The next table (Table 2) shows an example of the above-ground heavy metal contents attained by species of the main plant families of these grassland pastures.

Table 1. Grassland species growing in the soils of abandoned mines containing more than one heavy metal

Agrostis castellana	*Crepis capillaris*	*Lolium rigidum*	*Sonchus asper*
Andryala integrifolia	*Crepis vesicaria*	*Plantago afra*	*Spergularia purpurea*
Avena barbata	*Dactylis glomerata*	*Plantago coronopus*	*Stipa lagascae*
Bromus hordaceus	*Diplotaxis catholica*	*Plantago lagopus*	*Trifolium striatum*
Bromus madritensis	*Echium vulgare*	*Plantago lanceolata*	*Trisetum paniceum*
Bromus rubens	*Jasione montana*	*Pulicaria paludosa*	*Vulpia ciliata*
Bromus tectorum	*Leontodon taraxacoides*	*Sanguisorba minor*	*Vulpia myuros*

Table 2. Heavy metal contents (ppm) of grassland species (grouped as families), which show at least three heavy metals in their above-ground mass, growing in the soils of an old Cu mine

Plant family	Cu	Zn	Cd	Cr	Ni	Pb
Graminaceae	566±1568	223±244	6±0.9	7±11	2±4	3±4
Leguminosae	28±26	87±22	3±5	1±1.4	1.3±1.8	0±0
Others	37±50	153±175	6±8	0.04±0.09	0.9±1.1	0.7±1.5

We also examined the specialization of the landfill flora to the different levels of disturbance (Hernández *et al*., 1998 and 1999; Adarve *et al*., 1998), along with the adaptive strategies of the colonising species of these settings, as manifested by several biological attributes (Hernández *et al*. 2002). Our findings indicate that salinity is the main factor conditioning the presence and growth of grass species both at the landfill site and in the discharge areas of surface leachates. Moreover, Zn was the only metal detected in large quantities in their capping soils. Table 3 shows an example of the response shown by grassland species growing in soils containing higher than the permitted levels of this oligoelement.

Table 3. Concentrations of Zn (mg kg^{-1}) recorded in the above-ground mass of different species of the grassland community grown in soils treated with increasing amounts

Species	Control	300	500	700
Vulpia myuros	74.6	228	765	1157
Polypogon maritimus	75.0	278	-	957
Juncus buffonius	75.3	120.5	149	893
Echium vulgare	259	811	-	-
Trisetum paniceum	63	373	-	-
Lolium rigidum	-	255	-	-
Gaudinia fragilis	-	251	-	-

We tested the installation of grass covers containing a large proportion of pasture legumes to combat the erosion of soils that had been kept bare for over 50 years in olive and vine crop systems. These vegetation covers rendered good results in terms of the cover achieved (Table 4) and of their management to avoid competition for the water available for the crops (Hernández *et al.* 2005). We could say, for example, that the mixture of three subclover cultivars sown at the start of the first year of the experiment was very satisfactory, since the species invaded the plots of the remaining treatments. The persistence of subclover, although highly affected yearly by the rainfall regimen, determines that its demise one year does not necessarily mean its loss, provided the appropriate amount of rainfall is received the following year. Other legumes with beneficial effects on the soil (Table 5) emerged from the soil's own seed bank.

Table 4. Mean cover estimates (%) recorded for the vineyard soil in spring

Plant cover	1997	1998	1999	2000	2001	2002	2003	2007
T. subterraneum plus weeds	86	95	95	91	85	86	52	86.4
Leguminosae plus weeds	48	49	53	87	86	90	31	81.4

Table 5. Species richness (mean of total number) of legume covers (mean %) in olive plots in which the growth of weeds was promoted

Leguminosae / year	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Richness (total no. spp.)	7	8	8	9	10	10	12	10	8	10
Ornithopus compressus	+	6	16	61	32	55	35	43	12	25
Biserrula pelecinus	+	4	14	32	10	37	23	22	9	18
Trifolium arvense	+	5	4	5	2	3	2	1	1	4
Lupinus angustifolium	+	1	1	3	+	2	2	1	+	1
Other leguminosae *	2	7	16	10	3	9	13	5	2	3

* *T. angustifolium, T. hirtum, Trigonella polyceratia, Vicia lutea, V. sativa.* + indicates presence only

Species richness was high in the communities growing on mature roadside slopes and these were

comprised of species belonging to the three families most frequently occurring in pastures worldwide (Leguminosae, Graminaceae and Compositae).

The systems are a reservoir and showcase for the grassland flora of the territory, sometimes lost through intense human disturbances. They also act as corridors connecting natural areas with the consequent benefits for herbivores.

Composites and legumes, with their tap roots, were examined in terms of their capacity to stabilize slopes (Table 6); and grasses, with their rhizomes and creeping mode of growth yet covering a good part of the slope surface, were similarly considered to protect the slope's topsoil layer.

Table 6. Pasture species most capable of stabilizing soil commonly occurring on roadside slopes overlying arkosic and limestone substrates

Species	Export zone	Transport zone	Sedimentation zone
Dactylis glomerata	+	+	+
Cynodon dactylon	+	+	+
Ononis spinosa		+	
Medicago sativa			+
Eryngium campestre	+	+	+
Plantago albicans	+		
Centaurea paniculata		+	+

The grass communities of the pastures examined in these systems containing degraded and or polluted soils are linked to oligotrophic, nitrophilic and ruderalization processes. This last process is often also related to "phosphorophilia" (Pastor and Hernández, 2001).

Box 1 outlines the results obtained in soil chemical and plant mineral uptake analyses.

Box 1. Pastures that could be used as references for the ecological restoration of systems with impoverished, polluted and degraded soils.

- Pastures poor in nutrients: found on acid soils. Plant communities exhibit successful strategies: mainly the conservation of nutrients and hardening of structures (roots and rhizomes)... OLIGOTROPHY.
- Pastures with altered nutrient levels: mainly found on basic soils. The loss of nutrients is due to several causes: overgrazing by sheep, excess fertilizers, dumped waste, poor land use... NITROPHILIA + PHOSPHOROPHILIA.
- Degraded pastures: found on any type of eroded soil polluted with heavy metals. The loss of nutrients or their lack of availability is due to interactions with toxic metal levels or an excess salt load.

Conclusions

At all the sites examined corresponding to abandoned mines, solid urban waste landfills, roadside slopes, soils used to cultivate cereals in the past and bare soils in olive groves and vineyards, we today find pasture communities with multiple functions: they provide soil cover, adapt to water, salt and heavy-metal stresses, and act as a reservoir for native Mediterranean grassland flora. This makes them ideal references for the ecological restoration of similar degraded soil systems, both at the species level and at the level of plant covers, in which a single community may offer the system more than one function.

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