Evolution of the Soil and Vegetation Cover on Road Embankments after the Application of Sewage Sludge

By: Andrés Ferrer, Ignacio Mochón, Juan de Oña and Francisco Osorio

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Ferrer, A. [2]; Mochón, I. [1]; Oña, J. [2] and Osorio, F. [2, 3,]*

[1] *GIASA, Gestión de Infraestructuras de Andalucía, Andalusia Regional Public Works and Transport Ministry, SPAIN*

[2] *Department of Civil Engineering; University of Granada, SPAIN*

[3] *MITA Research Group; Institute of Water; University of Granada, SPAIN*

**Corresponding author address.- Departamento de Ingeniería Civil; Universidad de Granada; Campus de Fuentenueva, s/n; 18071; Granada – SPAIN; Telephone.- 34958242931; Fax.- 34958242931; e-mail.- fosorio@ugr.es*

ABSTRACT

This research study used sewage sludge from urban wastewater treatment plants to restore road embankments. The results have been used to propose a series of basic principles for the application of sludge in this context. In the study, six experimental plots (each composed on one cut slope and one fill slope) were set up on a highway located in the province of Jaen (Spain). The soil and vegetation in the plots were restored by a conventional hydroseeding process, with each plot receiving a different sludge dosage. A control plot did not receive any treatment at all, whereas another plot was hydroseeded, but without any sludge added to the slurry mix.

In the plots, soil evolution was controlled from the moment that the embankment was created and hydroseeded until the present. As part of the soil monitoring process, agronomic parameters and the heavy metal content of the soil were analyzed in the laboratory. Another parameter of analysis was the vegetation cover, which was studied on the basis of on-site visual inspections and the rasterization of images with a view to calculate the percentage of vegetation cover on each plot.

Results showed the effectiveness of sewage sludge as an organic complement in the restoration of road embankments. Its viability is enhanced by the fact that the sludge can be applied with the same methods used in public highway construction. The results also showed the optimal sludge dosage to be used in the slurry mix during the hydroseeding process.

KEYWORDS: road slope; sludge; landscape restoration; waste management

1. INTRODUCTION

Sewage sludge is a by-product obtained from urban wastewater treatment processes (Singh and Agarwal 2008). Currently, there has been a spectacular increase in the amount of sewage sludge, probably because of the construction of new treatment plants and increase of wastewater. Solutions should be found for the problem generated by these growing sludge quantities. This evidently involves the effective management and reuse of this biosolids. In today's world, the elimination of sewage sludge is an expensive process that could lead to environmental pollution because of its potentially harmful components (Elliott 1986; Wang and Jones 1994; Zhou and Gao, 1994; Singh and Agarwal, 2008).

Sewage sludge characteristically contains high levels of the principal plant nutrients, N and P, and is enriched with organic material. For this reason, the application of sewage sludge to soil is a common practice throughout the world (Gerhardt et al. 1997). However, there are now strict regulations to guarantee the safe recycling of sludge because of the potentially harmful substances that it may contain, such as heavy metals (Council Directive 86/278/EEC of 12 June 1986, on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture; *Ministerio de Agricultura, Pesca y Alimentación* [Ministry of Agriculture, Fishing, and Food], Order of 28 May 1998 regulating fertilizers and similar products, Madrid, 1998, transposed from European Legislation) (McGrath et al. 1994).

In this sense, the use of sludge to restore road embankments causes fewer problems from the perspective of health and waste management since such embankments are land surfaces that are not used for any other purpose. The plants that grow on embankments protect the highway since they help reduce pollution, reduce visual impact, and protect the embankments from soil erosion (Blunt and Doken 1994). Consequently, planting a cover crop on road embankments is of great importance to highway management. However, the soil in newly constructed road embankments is generally not very fertile, poorly structured, and low in nutrients (De Oña et al 2009). This limits the growth and development of vegetation on embankments, and substantially reduces the protection that it can offer against erosion (Blunt and Doken 1994). This can lead to road embankment instability. Consequently, measures should be taken to improve the soil characteristics of road embankments, especially newly constructed ones.

In order to achieve the maximum growth and development of the plant species planted on the embankments, dosages of sewage sludge could be added to the hydroseeding slurry mix. The sludge provides the embankment soil with the nutrients (De Lira et al. 2008), texture (Junfeng et al. 2008), and structure necessary for vegetation to grow and flourish, and also improves the water retention coefficient in the soil (Sort and Alcañiz 1999).

The objectives of this study were to analyze the following: (i) the effects of sewage sludge on the physical-chemical properties of the road embankment soil (Gao et al. 2008); (ii) the use of sludge as part of the hydroseeding slurry mix on embankments; (iii) the growth and development of hydroseeded plant species on embankments, and their evolution over time.

2. MATERIALS AND METHODS

During the research study (from April 2007 to April 2009), various analyses were simultaneously carried out to demonstrate the advantages of applying sewage sludge to road embankments (De Oña and Osorio 2006a, 2006b); how this influenced the physical and chemical properties of the soil (Morel and Guckert 1981); and how it enhanced vegetation growth (Thomann 1984).

2.1. LOCATION OF THE AREA OF THE STUDY

For the purposes of this study, a series of six experimental plots were laid out on road embankments, both on cut and fill slopes. The plots were located on the highway connecting the towns of Arjona and Porcuna in the province of Jaen (Andalusia, Spain). The approximate altitude was 317 meters above sea level. All plots had a southeast orientation and a slope of 2H:1V.

The latitude and longitude reference for the plots is the following:

Cut slopes (D1, D2, D3, D4, D5 and D6):

Latitude: 37º 54’ 46,16” N

Longitude: 4º 6’ 16,31” O

Fill slopes (T1, T2, T3, T4, T5 and T6):

Latitude: 37º 55’ 32,94” N

Longitude: 4º 5’ 55,00” O

2.2. CLIMATE DATA

Arjona has a seasonal-rainfall oceanic bioclimate with a meso-Mediterranean thermotype, characterized by a dry subhumid ombrotype and a mild warm thermal type (Rivas 1988). It has a mean annual temperature of 17.31 ºC and a mean annual rainfall of 415.80 mm (Data source: *Agencia Estatal de Meteorología*, Spain), occurring mainly during the autumn and winter months.

Before evaluating the data, it was necessary to study climate parameters related to the mean annual, and monthly precipitation as well as the mean, minimum, and maximum temperature per year and per month. These important climate parameters were taken into account because of their influence on vegetation growth and the soil improvement process. Although the previous paragraph gives the mean annual data obtained from historical precipitation and temperature records, the following paragraphs focuse on the data pertaining to 2007—2009, since these were the specific time periods of the research.

These data were obtained from the *Agencia Estatal de Meteorología* in Spain, more specifically at weather stations at the following locations:

- *Arjona-Santo Tomas* with UTM coordinates (X: 398566 and Y: 4202815) at an altitude of 340 meters above sea level.
- *La Higuera de Arjona* with UTM coordinates (X: 411601 and Y: 4200814), at an altitude of 260 meters above sea level.

The temperature values obtained are shown in table 1.

(TABLE 1)

The precipitation values obtained are shown in table 2.

(TABLE 2)

2.3. CONTRIBUTION OF SLUDGE TO ROAD EMBANKMENTS AND HYDROSEEDING

Sewage sludge was applied to the experimental plots in order to verify its possible benefits and effectiveness as an organic complement for the soil and vegetation. The sludge dosages applied were 50 gr/m^2, 200 gr/m^2, and 400 gr/m^2 of dry material. The sludge itself had a content of 7.41% dry material.

These dosages were applied to the experimental plots, cut slopes as well as the fill slopes. For the purposes of the study, the sludge was sprayed on four plots, whereas the other two were used as control plots (see table 3). One of the control plots was conventionally hydroseeded without sludge, and the other plot received no treatment whatsoever.

(TABLE 3)

The application of the hydroseeding slurry mixture with the sludge dosages was performed in three stages:

- In the first stage the hydroseeder deposit was filled with sludge, which was sprayed onto the embankments. Because of its liquid state, it was necessary to spray the embankments several times in order to reach the desired sludge dosages of dry material.

- In the second stage, the plots were hydroseeded in the conventional way. They were sprayed with a slurry mix for a surface area of 2000 m^2, composed of the following ingredients:
  - Seeds: 70 Kg
  - Water: 5,000 liters
  - Mulch: 160 Kg
  - Fertilizer: 100 Kg
  - Stabilizer: 1.5 Kg (approximately 1% of the mulch weight)

  The types of seed used in the hydroseeding slurry for the 6 plots, both cut slopes and fill slopes are shown in table 4.

(TABLE 4)

- In the third stage, the embankments were sprayed with mulch so that the fine material in the sludge would not lump together in the soil and form a thin crust that did not allow water to penetrate beneath the ground surface. In this phase, 3000 liters of water and 320 Kg of mulch were applied to a surface of 2000 m^2.

The procedure and sludge quantities applied were the same for both the cut slope and fill slope of each plot. However, in plot number 6 (cut slope and fill slope), a modification was made. This plot was not conventionally hydroseeded with sludge. It only received the maximum dosage of sludge (400 g/m^2), with seeds (35 g/m^2). Subsequently, in the same way as the other plots, it was sprayed with water and mulch.

2.4. INITIAL CHARACTERISTICS OF SOIL AND SLUDGE

Before describing the characteristics of the soil and sludge, it should be pointed out that before being hydroseeded, the cut slopes had no topsoil in contrast to the fill slopes, which did have this type of soil, since topsoil is generally added after the construction of embankments. Consequently, the fill slopes possessed better agronomic properties than the cut slopes since the soil of both without the addition of topsoil was very compact, impermeable, and rich in clay and lime.

In order to have a better idea of the agronomic parameters of soil and sludge before the hydroseeding process, various laboratory analyses were performed: (i) three analyses of the soil on the cut slopes (plots D2, D5 and D6); (ii) three analyses of the soil on the fill slopes (plots T2, T5 and T6); (iii) one analysis of the sludge. Table 5 shows the heavy metal content of the sludge and soils. Table 6 gives the values of the various agronomic parameters analyzed.

(TABLE 5)

(TABLE 6)

As can be observed in the results for soil and sludge (Table 6), the agronomic parameters obtained from the sludge analysis are better than those obtained for the soil on the embankments because of sludge's high content in organic material, nitrogen, and fulvic acids.

According to Table 6, embankment soils had a fulvic acid content of less than 1%, whereas the sludge had a fulvic acid content of 7%. This is important since fulvic acid is decomposed organic material available for vegetation (Eyheraguibel et al. 2008).

The total humic extract in the soils was also less than 1% in contrast to the sludge, which had a total of 8.4%. This extract is the sum of all the humic acids (fulvic and humic), which represents the organic fraction of the soluble soil in the alkaline medium necessary for the formation of an evolved soil and vegetation (Eyheraguibel et al. 2008).

Another important parameter was the carbon/nitrogen ratio, which indicates the proportion of nitrogen in the soil. This ratio should not be very high since a high ratio means that there is less nitrogen in the soil, and nitrogen is a necessary nutrient for plant growth. In most cases, the absence of nitrogen is a limiting factor for plant growth. As reflected in Table 6, this ratio was lower for sludge than for the soil. This meant that adding sludge to the soil would increase its nitrogen content, and thus, this nutrient would not be limiting (Dorgelo and Leonards 2001).

Another indicator of the presence of nitrogen is Kjeldahl nitrogen, which in the case of the different soils was insignificant (lower than 1%), whereas in the sludge, it was 5.5%. The impact of this parameter is the same as that of the carbon/nitrogen ratio.

Also crucial in the comparison of soil and sludge agronomic parameters is the percentage of organic material, which was much greater in the sludge than in the soil. Organic material is a necessary source of soil nutrients. It provides support for vegetation, as well as a base for the formation of a structured soil with texture. It is also a means of protecting the soil against water erosion (Veum et al. 2009).

In contrast, the sludge was found to have a greater quantity of heavy metals (see Table 5) although the amount was lower than the limit established in the European Union regulations concerning the use of sewage sludge in farming (Council Directive 86/278/EEC of 12 June 1986).

2.5. MONITORING AND CONTROL

2.5.1. Vegetation cover

The vegetation cover was calculated with the following methodology:

- Firstly, an on-site visual inspection was made of the plots in order to obtain a preliminary assessment of the vegetation cover.
- Next, photographs were taken of each plot. These images had to be carefully centered in order to capture the entire plot.
- The photos were then rasterized with the software application ARCMAP, made by ESRI.
- Once the images were rasterized, a polygonal layer was created for each of the images. This layer contained a polygon of the same size as the plot in the photograph.
- After creating the polygon, the image was clipped. In this way a new raster of the image was obtained which only showed what was inside the plot.

- The different colors in the images were then detected in the raster. During this process, certain colors, difficult to detect or confused by the program, were intensified. This resulted in a slight error, though it had the advantage of making the process more precise.
- After the colors of the raster had been detected, a software application was used to count the number of pixels occupying each color. The sum of the figures thus obtained was the total number of pixels in the image. The percentages of pixels of each color were then calculated.
- Once the color percentages were obtained, it was necessary to identify what each color represented. In this case, percentages were identified that represented the vegetation in each plot, and thus, the total vegetation cover in each plot was obtained.

The methodology used has certain limitations because of the slope of the embankments and the height of the vegetation cover. Since the photograph was taken from the highway, no image of the surface plane was obtained. To obtain such a photo, it would have been necessary take it from the air. The other limitation is in the way the program interprets the pixel colors. The program often interprets pixels corresponding to dry plants (and whose color is thus less intense) as though they were soil. In any case, these results were compared to on-site visual observations.

2.5.2. Soil

After the embankments were laid out, the soil was monitored on the cut slopes as well as on the fill slopes. A series of analyses were performed, prior to the hydroseeding process. The results obtained are presented in section 2.4.

After two years of study, various soil samples were analyzed on the cut slopes as well as the fill slopes. The plots analyzed were the same as those initially analyzed (i.e. plots D2, D5, D6, T2, T5 and T6).

Table 7 lists the analysis methods used for each soil parameter.

(TABLE 7)

3. RESULTS AND DISCUSSION

3.1. ESTIMATE OF THE REAL AMOUNT OF SLUDGE APPLIED TO THE SOIL

As previously mentioned, the sludge dosages applied to the embankments were 50 gr/m^2, 200 gr/m^2 and 400 gr/m^2 of dry material for sludge with 7.41% of dry material. The sludge applied was in a liquid state and was sprayed on the embankments with a hydroseeder. This made it difficult to accurately control the amount of sludge applied at each stage. In order to overcome this obstacle and be able to measure the real sludge dosages applied to the embankments, control textile squares of the same dimensions and density were placed on each plot. After the hydroseeding, the textiles were removed, and then analyzed in the laboratory to identify the quantity of dry sludge material applied to each plot. The results obtained are shown in Tables 8 and 9.

(TABLE 8)

The dosages obtained after the hydroseeding were found to correspond approximately to the originally specified application dosages in the experiment. Consequently, the real sludge dosages applied were the following:

(TABLE 9)

3.2. SOIL EVOLUTION OVER A TWO-YEAR PERIOD

After a two-year period, various soil samples were analyzed on the cut slopes as well as the fill slopes. As previously mentioned, the plots analyzed were the same as those initially analyzed (i.e. plots D2, D5, D6, T2, T5 and T6). The tables 10 and 11 show the heavy metal content in the soil samples as well as their agronomic properties two years after the dosages application.

(TABLE 10)

(TABLE 11)

As shown in Table 10, the copper and chrome content decreased in all of the soil samples, if compared with the contents of the same sample in table 5. For all the other parameters the results are not significant: some of them decrease and other increase. This fall in the content of copper and chrome was probably produced due to absorption by plants and the mobilization of metals produced by the water. In all cases, however, the final values were much below the levels permitted in European regulations (Council Directive 86/278/EEC of 12 June 1986).

The agronomic parameters are listed in Table 11. The values show that the soil samples that received sludge dosages (cut and fill slopes of plots 5 and 6) have higher levels of humic extract, organic carbon, and organic material. This naturally means that they have a greater percentage of nutrients for plant growth. Furthermore, the results show how the pH decreased in all of the soil samples, though the decrease was greater in the soil samples with sludge.

3.3. MONITORING OF VEGETATION COVER AND PLANT GROWTH

Regarding plant growth, curiously enough, 90% of the existing vegetation cover was different from the crop planted. The most abundant species in that 90% quantity was Jaramago (*Sinapis alba*). Although in a lesser percentage than the Jaramago, the hydroseeded cover crop also flourished. In fact, it was protected by the invading species, which acted as a kind of shelter. The Jaramago was not included in the hydroseeding. So it is considered invasive, however it is a specie native of the area.

Figures 1 and 2 illustrate the results obtained for the vegetation cover. These graphs show how the percentages of vegetation cover were higher in the plots that received sludge dosages than in the plot that was conventionally hydroseeded and in the plot that received no treatment at all. Generally speaking, the fill slopes showed better results than the cut slopes. This confirms that in embankments with topsoil, the restoration of vegetation cover is more successful than on embankments without topsoil.

The following graphs show that higher sludge dosages led to an optimal evolution of the vegetation cover on the embankments. This is clear evidence that sludge enriches the soil, as shown in Table 11, which reflects the embankment soil evolution over the two years of the study. Moreover, it can be observed how in cold, dry, and climatically unfavorable periods, the vegetation cover exceeded 20% on the embankments that received sludge dosages and was equal to 20% in those that did not receive any treatment.

(FIGURE 1)

(FIGURE 2)

4. CONCLUSIONS AND RECOMMENDATIONS

The outcome of this study led to the following two conclusions. The first conclusion is related to the viability of sludge application in the restoration of road embankments, and the second refers to the results obtained in the enhancement of soil quality and plant growth.

Regarding sludge application, we found hydroseeding to be a viable method that could be used to spray sludge on the embankment without increasing restoration costs or the time of application. The equipments used to apply sludge have been similar to those used in a conventional hydroseeding.

The results obtained pertaining to the evolution of the soil and the enhancement of plant growth show how the agronomic parameters of the soil were dramatically improved when sludge was added to the hydroseeding slurry mix. After two years, quantities of fulvic and humic acids, organic carbon and humic extract decreased. This decline is due to organisms decay and the effects of plant roots that absorb nutrients. This is demonstrated due to increased organic matter content in soil indicating that there are decaying plant debris. In contrast, this did not occur in plots which did not receive any sludge when they were hydroseeded (plots D1, D2, T1 and T2).

The vegetation cover on the road embankments was significantly improved by the sludge addition. Sludge-treated plots withstand dry summer periods better than non-treated plots, as shown in Figures 1 and 2. The decrease of vegetation coverage for parcels D1, D2, T1 and T2 is more important compared to the parcels treated with sludge.

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5. REFERENCE LIST

Blunt, S.M., Doken, T.C. (1994). Erosion of Highway Slopes in Upland Walse: problems and solutions. Vegetation and Slopes: Establishment. Protection and Ecology. In: D.H. Barker (Ed.), Proceedings of Conference (pp. 95–107). Oxford.

Council Directive of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (86/278/EEC).

De Oña, J., Osorio, F. (2006a). Application of sludge from urban wastewater treatment plants in roads´ embankments, Journal of Hazardous Materials, 131(1-3), 37-45.

De Oña, J., Osorio, F. (2006b). Using waste to reduce slope erosion on road embankments. Transport, 159(Issue TR1), 15-24.

De Oña, J., Osorio, F., Garcia, P.A. (2009). Assessing the effects of using compost–sludge mixtures to reduce erosion in road embankments. Journal of Hazardous Materials, 164 (2-3), 1257-1265.

Dorgelo, J., Leonards, P.E.G. (2001). Relationship between C/N ration of food types and growth rate in the snail Potamopyrgus jenkinsi (E.A. Smith). J. N. Am. Bethol. Soc., 20(1), 60-67.

Elliott, H.A. (1986). Land application of municipal sewage sludge. Journal Soil Water Conservation, 41, 5–10.

Eyheraguibel, B., Silvestre, J., Morard, P. (2008). Effects of humic substances derived from organic waste enhancement on the growth and mineral nutrition of maize. Bioresource Technology, 99 (10), 4206-4212.

Gao Pengcheng, Tang Xinbao, Tong Yanan, Chen Yingxu. (2008). Application of sewage sludge compost on highway embankments. Waste Management, 28, 1630-1636.

Gerhardt, T., Spliethoff, H., Hein, K. (1997). Thermische Nutzung vonKlärschlä mmen in Kraftwerksfeuer ungsanlagen. J. Entsorgungspraxis, 3, 50–58.

Junfeng Shen, Xuewu Zhou, Daisheng Sun, Jianguo Fang, Zhijun Liu and Zhongmin Li. (2008) Soil improvement with coal ash and sewage sludge: a field experiment. Environ Geol, 53, 1777 – 1785.

Lira De, A.C.S., Guedes, M.C., Schalch, V. (2008). Sewage sludge recycling in eucalypt plantation: Carbon and nitrogen [Reciclagem de lodo de esgoto em plantação de eucalipto: Carbono e nitrogênio]. Engenharia Sanitaria e Ambiental, 13 (2), 207-216.

McGrath, S.P., Chang, A.C., Page, A.L., Witter E., E. (1994). Land application of sewage sludge: scientific perspectives of heavy metal loading limits in Europe and the United States. Environ. Rev. 2, 108–118.

Morel, J. L. and Guckert, A. (1981). The influence of sewage sludge application on physical and biological properties of soils. In G. Catroux, P. L'Hermite and E. Suess (eds) Proceedings of a Seminar Organized Jointly by the Commission of the European Communities, Directorate-General for Science, Research and Development and the Bayerische Landdesanstalt für Bodenkutur und Pflanzènbau (pp. 25-42), Munich.

Rivas, S. (1988). Bioclimatología, Biogeografía, y Series de Vegetación de Andalucía Occidental. Lagascalia 15, 91-119.

Singh, R.P., Agarwal M., M. (2008). Potential benefits and risks of land application of sewage sludge. Waste Management, 28 (2), 347-358.

Sort, X., and Alcañiz, J. M. (1999). Land Degradation and Development, 10, 3-12.

Thomann, Ch. (1984). Experimental study on the use of urban sewage sludge on Mediterranean forests. In: Utilization of sewage sludge on land (eds: S. Berglund. R.D. Davis and P. L'Hermite) (pp. 61-78), D. Reidel, Lancaster.

Veum, K.S., Goyne, K.W., Motavalli P.P. and Udawatta, R.P. (2009). Runoff and dissolved organic carbon loss from a paired-watershed study of three adjacent agricultural Watersheds. Agriculture, Ecosystems & Environment, 130 (3-4), 115-122.

Wang, M.J., Jones, K.C. (1994). Uptake of chlorobenzenes by carrots from spiked and sewage sludge-amended soil. Environmental Science and Technology, 28, 1260–1267.

Zhou, Q., Gao, Z. (1994). Compounds contamination and secondary ecological effects of Cd and As in soil alfalfa ecosystems. Journal of Environmental Sciences, 6, 330–336.

Table 1: Temperatures for April 2007 — March 2009

YEAR	MONTH	MAX T. ºC	MIN T. ºC	MEAN T. ºC
2007	APRIL	19.27	8.86	14.07
2007	MAY	24.84	11.45	18.15
2007	JUNE	30.10	14.93	22.52
2007	JULY	36.35	17.38	26.87
2007	AUGUST	35.00	16.90	25.95
2007	SEPTEMBER	29.93	15.03	22.48
2007	OCTOBER	23.93	8.84	16.39
2007	NOVEMBER	18.00	2.06	10.03
2007	DECEMBER	14.22	1.55	7.89
2008	JANUARY	14.68	2.97	8.83
2008	FEBRUARY	17.55	5.27	11.41
2008	MARCH	19.38	4.64	12.01
2008	APRIL	21.70	7.83	14.77
2008	MAY	23.09	11.71	17.40
2008	JUNE	32.60	14.73	23.67
2008	JULY	35.29	16.51	25.90
2008	AUGUST	36.09	16.87	26.48
2008	SEPTEMBER	27.73	14.03	20.88
2008	OCTOBER	22.77	10.35	16.56
2008	NOVEMBER	14.86	3.46	9.16
2008	DECEMBER	13.23	1.38	7.31
2009	JANUARY	11.00	2.71	6.86
2009	FEBRUARY	15.25	3.00	9.13
2009	MARCH	19.93	6.35	13.14

Table 2: Precipitation for April 2007 - March 2008 and April 2008 - March 2009

YEAR	MONTH	PRECIPITATION (mm)	YEAR	MONTH	PRECIPITATION (mm)
2007	APRIL	79.6	2008	APRIL	156.9
2007	MAY	109.9	2008	MAY	66.0
2007	JUNE	4.1	2008	JUNE	0.0
2007	JULY	0.0	2008	JULY	2.1
2007	AUGUST	5.3	2008	AUGUST	0.0
2007	SEPTEMBER	40.6	2008	SEPTEMBER	52.5
2007	OCTOBER	35.7	2008	OCTOBER	58.4
2007	NOVEMBER	87.2	2008	NOVEMBER	68.1
2007	DECEMBER	9.6	2008	DECEMBER	43.0
2008	JANUARY	76.0	2009	JANUARY	77.9
2008	FEBRUARY	77.3	2009	FEBRUARY	63.2
2008	MARCH	21.4	2009	MARCH	83.0
ANNUAL TOTAL		**546.7**	**ANNUAL TOTAL**		**671.1**

Table 3: Dosages for each one of the plots

PLOTS	DOSAGES
D1 & T1	No treatment
D2 & T2	Conventionally hydroseed
D3 & T3	Conventionally hydroseed + Sludge (50 gr/m^2)
D4 & T4	Conventionally hydroseed + Sludge (200 gr/m^2)
D5 & T5	Conventionally hydroseed + Sludge (400 gr/m^2)
D6 & T6	Sludge (400 gr/m^2) + Seeds + Mulch

Table 4: Seeds in the hyroseeding slurry mixture

Mixture%	Species	Purity%	Germination%
20	Festuca Arundinacea	97.30	89
15	Dactylis Glomerata	98.10	95
15	Bromus Snermis	97.50	90
15	Onobrychis Sativa	99.70	78
10	Agropyrum Cristatum	98.45	86
10	Lolium Perenne	99.90	93
10	Melilotus Officinalis	99.50	75
5	Retama Sphaerocarpa	95.00	76

Table 5: Heavy metal content in the soil and sludge samples (April 2007). Mercury analysis method, PE-D/0005 Atomic fluorescence, for the rest of the parameters PE-D/0025 ICP-OES

Heavy Metals	D2 mg/kg m.s.	D5 mg/kg m.s.	D6 mg/kg m.s.	T2 mg/kg m.s.	T5 mg/kg m.s.	T6 mg/kg m.s.	SLUDGES mg/kg m.s.	EUROPEAN UNION LIMIT
Cadmium	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	2.00	40.00
Copper	21.00	17.00	18.00	18.00	19.00	18.00	185.00	1750.00
Chrome	39.00	39.00	37.00	36.00	37.00	36.00	156.00	150.00
Mercury	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	1.76	25.00
Nickel	12.00	13.00	13.00	12.00	13.00	12.00	69.00	400.00
Lead	5.00	5.00	5.00	8.00	10.00	9.00	76.00	1200.00
Zinc	30.00	31.00	30.00	27.00	29.00	27.00	669.00	4000.00

Table 6: Agronomic parameters of soil and sludge (April 2007)

Agronomic parameters	D2	D5	D6	T2	T5	T6	SLUDGE
Fulvic acids %	0.30	0.40	0.50	0.80	0.60	0.60	7.00
Humic acids %	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Total humic extract %	0.10	0.20	0.30	0.40	0.40	0.30	8.40
Carbon/nitrogen % ratio	8.70	10.80	13.00	7.50	7.70	8.00	3.40
Organic carbon %	0.30	0.40	0.30	0.50	0.50	0.50	18.80
Organic material %	0.60	0.80	0.70	1.10	1.20	1.20	41.90
Kjeldahl nitrogen g/Kg m.s.	<0.50	<0.50	<0.50	<0.70	<0.70	<0.70	5.50
pH	8.4	8.2	8.4	8.3	8.3	8.3	7.3

Table 7: Soil analysis methods

Parameter	Analysis method
Cadmium	PE-D/0025 ICP-OES
Copper	PE-D/0025 ICP-OES
Chrome	PE-D/0025 ICP-OES
Mercury	PE-D/0005 Atomic fluorescence
Nickel	PE-D/0025 ICP-OES
Lead	PE-D/0025 ICP-OES
Zinc	PE-D/0025 ICP-OES
Fulvic acid %	PE-F/0061; Volumetric extraction
Humic acid %	PE-F/0061; Volumetric extraction
Total humic extract %	Volumetric extraction
Carbon/nitrogen % ratio	C/N Ratio
Organic carbon %	Volumetry PE-F/0011
Organic material %	Volumetry PE-F/0011
Kjeldahl nitrogen g/Kg m.s.	Kjeldahl PE-F/0007
pH	Electrometry PE-F/0012

Table 8: Real sludge amount (g/m^2) applied to each plot in Arjona, obtained from the control textile.

PLOTS								Textile density g/m^2 = 312.5
	Receiving weight (g)	**Final dry weight (g)**	**Textile weight + amount (g)**	**Surface(m^2)**	**Textile weight (g)**	**Real weight amount (g)**	**Amount per surface unit (g/m2)**	**Real sludge amount (g/m2)**
T2	400.00	687.00	287.00	0.55	171.88	115.13	209.32	0
T3	404.00	732.00	328.00	0.57	178.13	149.88	262.94	53.62
T4	396.00	804.00	408.00	0.56	175.00	233.00	416.07	206.75
T5	397.00	913.00	516.00	0.55	171.88	344.13	625.68	416.36
T6	400.00	851.00	451.00	0.57	178.13	272.88	478.73	426.23*
D2	397.00	648.00	251.00	0.55	171.88	79.13	143.86	0
D3	404.00	694.00	290.00	0.57	178.13	111.88	196.27	52.41
D4	404.00	775.00	371.00	0.56	175.00	196.00	350.00	206.14
D5	396.00	873.00	477.00	0.55	171.88	305.13	554.77	410.91
D6	397.00	836.00	439.00	0.56	175.00	264.00	471.43	418.23*

Table 9: Real amount of sludge received by the experimental plots

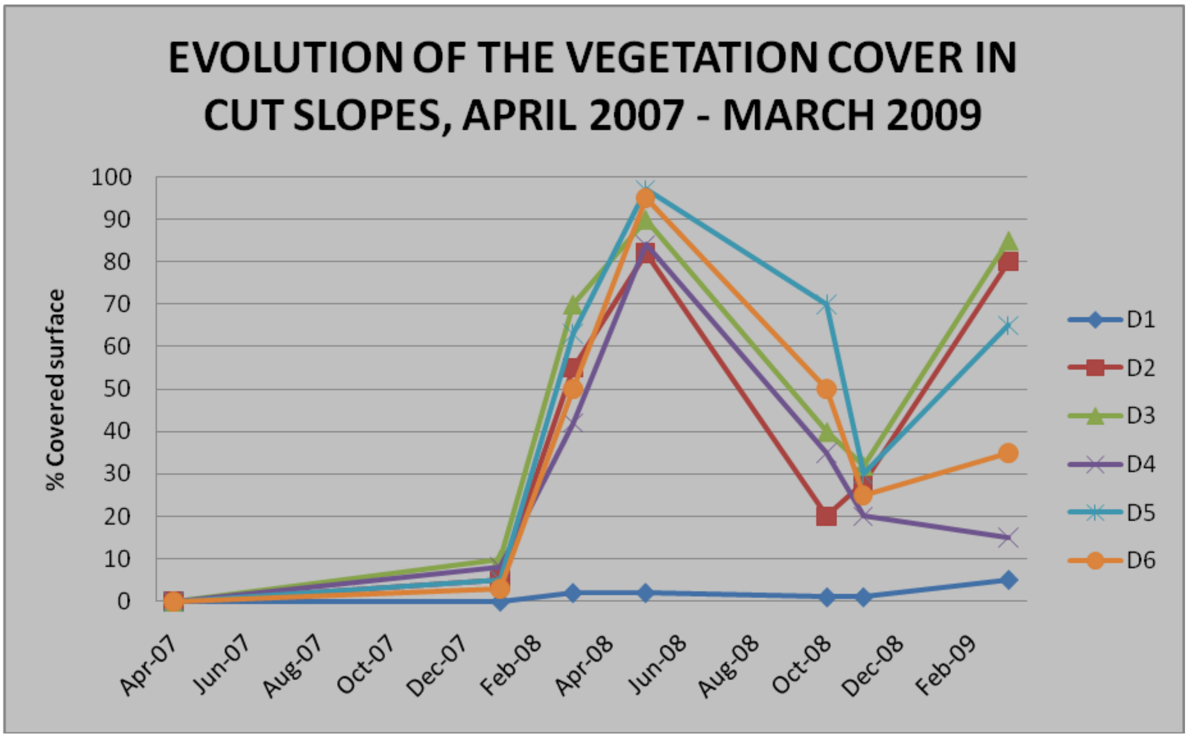
PILOT PLOTS	SLUDGE DOSAGE (g/m2)
T2	0
T3	53.62
T4	206.75
T5	416.36
T6	426.23
D2	0
D3	52.41
D4	206.14
D5	410.91
D6	418.23

Table 10: Heavy metal content in soil samples (April 2009). Mercury analysis method, PE-D/0005 Atomic fluorescence; for the other parameters PE-D/0025 ICP-OES.

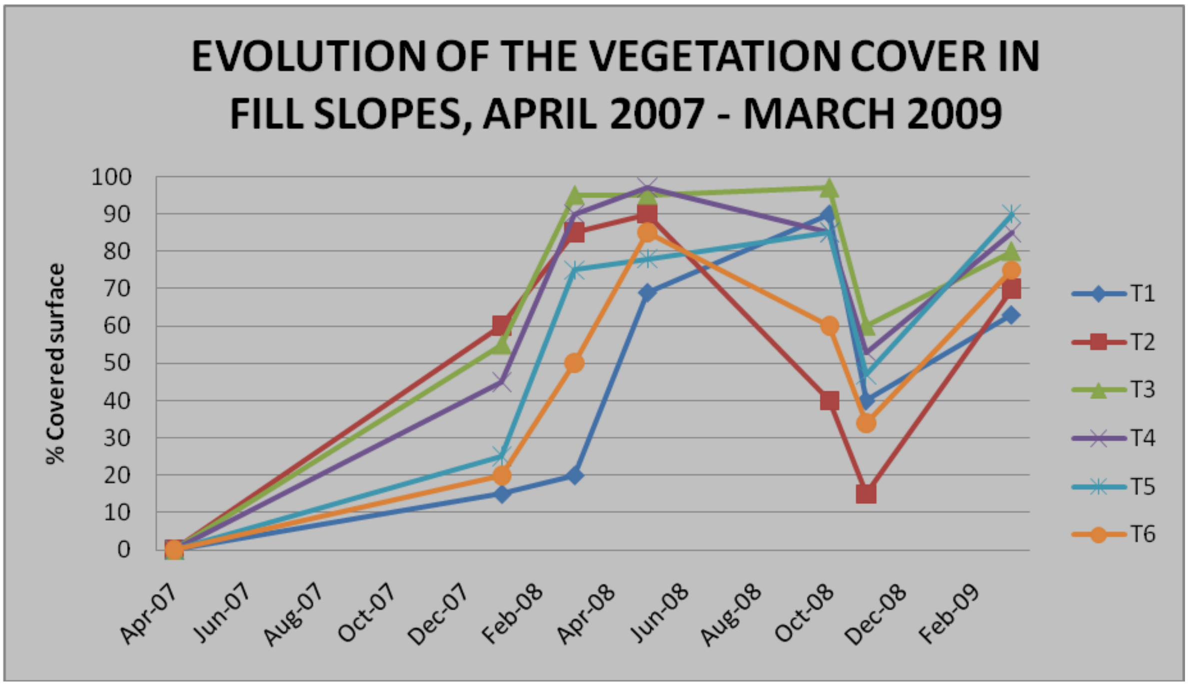
Heavy metals	D2 mg/kg m.s.	D5 mg/kg m.s.	D6 mg/kg m.s.	T2 mg/kg m.s.	T5 mg/kg m.s.	T6 mg/kg m.s.	EUROPEAN UNION LIMIT
Cadmium	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	40.00
Copper	10.00	13.00	9.00	13.00	15.00	13.00	1750.00
Chrome	31.00	31.00	29.00	34.00	29.00	27.00	150.00
Mercury	<0.10	<0.10	<0.10	<0.10	<0.10	0.19	25.00
Nickel	12.00	13.00	11.00	14.00	13.00	12.00	400.00
Lead	4.00	5.00	5.00	8.00	10.00	9.00	1200.00
Zinc	25.00	33.00	27.00	32.00	33.00	71.00	4000.00

Table 11: Agronomic soil parameters (April 2009)

Agronomic soil parameters	D2	D5	D6	T2	T5	T6
Fulvic acids %	<0.10	<0.10	<0.10	<0.10	0.30	<0.10
Humic acids %	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Total humic extract %	0.10	0.20	0.20	0.20	0.50	0.20
Carbon/nitrogen % ratio	6.40	5.50	5.90	4.80	8.50	6.20
Organic carbon %	0.20	0.50	0.30	0.40	1.00	0.60
Organic material %	0.50	1.20	0.70	0.80	2.20	1.30
Kjeldahl nitrogen g/Kg m.s.	<1.00	<1.00	<1.00	<1.00	1.10	<1.00
pH	8.2	8.1	8.1	8.0	7.9	8.0


EVOLUTION OF THE VEGETATION COVER IN CUT SLOPES, APRIL 2007 - MARCH 2009
% Covered surface
100
90
80
70
60
50
40
30
20
10
0
Apr-07
Jun-07
Aug-07
Oct-07
Dec-07
Feb-08
Apr-08
Jun-08
Aug-08
Oct-08
Dec-08
Feb-09
D1
D2
D3
D4
D5
D6

(FIGURE 1)


EVOLUTION OF THE VEGETATION COVER IN FILL SLOPES, APRIL 2007 - MARCH 2009
% Covered surface
100
90
80
70
60
50
40
30
20
10
0
Apr-07
Jun-07
Aug-07
Oct-07
Dec-07
Feb-08
Apr-08
Jun-08
Aug-08
Oct-08
Dec-08
Feb-09
T1
T2
T3
T4
T5
T6

(FIGURE 2)

FIGURE CAPTION LIST

Figure 1: Evolution of the vegetation cover in cut slopes during April 2007 — March 2009

Figure 2: Evolution of the vegetation cover in fill slopes during April 2007 — March 2009