



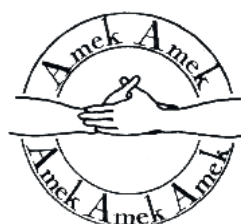
LIFE11 ENV/IT/113 BIOREM

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MANUAL FOR BIOREM INTEGRATED SOIL RESTORATION



CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS



The work has been performed in the framework of the project
"Innovative System for the Biochemical Restoration and
Monitoring of Degraded Soils", co-financed by EU, within the
LIFE+ program.

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1. THE BIOREM PROJECT

The BIOREM project has demonstrated an innovative integrated methodology for the restoration and the biochemical monitoring of degraded soils.

BIOREM has been co-financed by LIFE, the EU's financial instrument supporting environmental and nature conservation projects throughout the EU, as well as in some candidate, acceding and neighbouring countries.

BIOREM provided an integrated system aimed at monitoring the conditions of soil in a dynamic, faster and more effective way, and at restoring degraded soils by combining revegetation and the addition of exogenous organic matter.

In terms of soil remediation, the project objective has been to demonstrate that the BIOREM innovative integrated soil restoration strategy can successfully restore degraded soils, enhancing physical-chemical properties and biochemical activity and increasing fertility up to 25%. This result has been obtained by integrating addition of exogenous organic matter (composted and fresh organic substrates such as biological sewage sludges – a now valueless waste which will be turned into an input) and revegetation with plants conditioned for remediation and adapted to semiarid conditions. The innovative technique has been demonstrated on 10 experimental plots in Italy and Spain, characterized by 10 different types of soil subject to different kinds and degrees of degradation. The effectiveness and flexibility of the proposed system was demonstrated through the success of the remediation process.

In terms of soil monitoring, the project objective was to demonstrate that the BIOREM innovative monitoring system can provide a faster (no lab cultivation of samples is needed), more thorough, dynamic monitoring of soil conditions, extremely



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useful for the development of precisely targeted, far-sighted restoration and development strategies and policies.

Current methods for the assessment of soil conditions can only provide “static” physical/chemical/biological reports about the status of soil in a given moment, upon which only short-term interventions can be based. The project will demonstrate that, starting from a quantitative and qualitative molecular characterization of the biochemical profile of the soil, the BIOREM innovative monitoring system can achieve advanced soil assessment by detecting and evaluating the presence and status of enzymatic processes.

The proposed project activities were fully consistent with the European environmental objectives (as detailed in the Thematic Strategy for Soil Protection) and the four key pillars, and will give a significant contribution to their fulfillment. In particular, the implementation present project will prove crucial for the achievement of:

- Restoration of degraded soils to a level of functionality consistent at least with current and intended use, thus also considering the cost implications of the restoration of soil: BIOREM provided a whole set of strategies and best practices for the cost-effective restoration of degraded soils, using a combined set of state-of-the-art methodologies ranging from addition of organic matter and in situ humification to controlled revegetation. When applied across the EU, the BIOREM methodology will help farmers, as well as land managers in general, to effectively tackle land contamination and depletion, of both recent and old origin.
- Prevention of further soil degradation and preserving its functions: the BIOREM project has a crucial monitoring component, which will provide policy makers and land managers of all sectors



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2. THE CONSORTIUM

ISECNR

The Research Group of ISE-CNR belongs to the Institute for Ecosystem Studies (ISE), of the National Research Council (CNR) of Italy. The CNR-ISE's Group conducts investigations related to chemistry, biochemistry and physics of soil quality with the aim of defining relationships between agriculture and environment. The group has a thorough expertise in many soil and environmental topics. Recently, the group is engaged in many environmental researches and projects, concerning basically soil monitoring, soil protection against desertification, and soil (or other matrixes, such as sediments) reclamation, almost all based on the interactions among soil (or sediments), plants, micro- and macrofauna (earthworm *Eisenia fetida*). A great experience is also on the topic of soil quality conservation and restoration usually carry out through the addition of different sources of organic matter and different types of managements. These multipurpose researches well integrate with the needs to protect soil fertility, biodiversity, desertification, soil pollution mitigation, carbon sequestration in soil, in relation to climate changes and water scarcity.

In the last years, three European projects were developed on the theme of soil desertification and soil recovery, and the reclamation of slightly contaminated sediment.

1. STREP INDEX n. 505450 (2004-2007) – Indicators and Thresholds for Desertification, Soil Quality and Remediation. Page 5 of 113
2. LIFE-ALMOND PROSOIL. 05 ENV/E/000288 (2006-2008). Soil protection in Mediterranean Areas through Cultivation of New Varieties of Almond Tree
3. AGRIPORT-Agricultural Reuse of Polluted dredged Sediments No. ECO/08/239065/S12.532262



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Azienda Pantanello ALSIA

The Farm Experimental Demonstration "Pantanello" is located in the heart of Metaponto, straddling the coast of Puglia and Basilicata, which is characterized by a highly advanced agriculture. The company located in the countryside of Bernalda close to the SS 106 Jonica, was purchased in 1963 by Ente Irrigation and subsequently sold to the Basilicata Region in 1983. Since 1999, is managed by the ALS Pantanello. The cultivated farmland is about 85 ha, with an e-Horticultural-Cereal fruit production. Within the area under a part is intended for experimental and demonstration purposes, the rest is mostly cultivated for production.

In the center stands a corporate conference room, which is a meeting point for the realization of several business conferences and seminars. At the company has deployed a unit of distribution, which includes ten agricultural advisers and specialist advisers.

They are part of the business staff and technical workers fixed, as well as a number of seasonal workers. This organization allows you to carry out business activities predominantly experimental and production links with the world thanks to the action of disclosure. The collaboration with research institutions has allowed us to keep in close touch with the reality that scientific production, in order to provide the most appropriate responses to the needs of industry. Since the 80's dissemination activities has been a key driving force and the action of Pantanello territory.

Over the years the organization has completed a disclosure with the inclusion of specific units for each production sector. This particular technical organization and production has contributed profoundly to bind the Company Pantanello with the territory in which it is located.

The model of integration between Luke and experimental Disclosure Companies, is a meeting between the structure and organization of various public and private entities operating in the area.



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CSIC – CEBAS

The Spanish National Research Council (CSIC) is the largest public institution dedicated to research in Spain and the third largest in Europe. Belonging to the Spanish Ministry of Science and Innovation through the Secretary of State for Research, its main objective is to develop and promote research that will help bring about scientific and technological progress, and it is prepared to collaborate with Spanish and foreign entities in order to achieve this aim. CSIC plays an important role in scientific and technological policy, since it encompasses an area that takes in everything from basic research to the transfer of knowledge to the productive sector. Its research is driven by its centres and institutes, which are spread across all the autonomous regions, and its more than 12,000 staff, of whom more than 3,000 are staff researchers and the same number again are doctors and scientists who are still training. CSIC has 6% of all the staff dedicated to Research and Development in Spain, and they generate approximately 20% of all scientific production in the country. It also manages a range of important facilities; the most complete and extensive network of specialist libraries, and also has joint research units.

CEBAS (Centro de Edafología y Biología Aplicada del Segura) is a CSIC's institute located in Murcia (South East Spain), 50 Km from Mediterranean coast, under semiarid climatic conditions. Created in 1958, with the aim of promoting research in the fields of Agriculture Science, Natural Resource and Environmental Science. Actually, the CEBAS is arranged in five department: Nutrition and plant physiology / Plant breeding and pathology / Food science and technology / Soils and Water Conservation and Organic Refuse Management. Staff: Today, there are 212 persons working at the Centre, among them 51 are scientists, 28 postdocs, 66 postgraduate students, 42 technicians and 25 administrative.

ABONOS ORGÁNICOS PEDRIN

ABONOS ORGÁNICOS PEDRIN is a Spanish company based in Murcia. The company manufactures and commercialises agrochemical products as solid organic manures and products used in the conventional and ecological agriculture. ABONOS



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ORGÁNICOS PEDRIN has increased their initial distribution network as consequence of its huge tradition and experience in the sector.

Nowadays, the company participates in the elaboration of amendments which are friendly-environmental in order to substitute other harmful products as methyl bromide (soils disinfectant). These activities show their preoccupation and obligation for environmental care.

Amek S.c.r.l.

Amek S.c.r.l. since 1989 promotes the development of scientific research and experimentation in the field of biotechnology, particularly enzymes for application in the field of agriculture, zootechny, recovery of biomass and waste and for the remediation of polluted sites.

Since May 2007, Amek S.c.r.l. has been enlisted in Italian National List of Research Enterprises (Anagrafe nazionale delle ricerche).

Amek S.c.r.l. aims to contribute to the promotion and development of scientific research and experimentation in the field of biotechnology to promote their application to agriculture, zootechny, remediation of polluted sites and recovery of biomass and waste.

Starting with a holistic view of nature, AMEK embraces the philosophy of sustainable development: the technological and social progress depends compliance with the earth's chemical-physical and biological equilibrium.

In full compliance with the directions given by European and national environmental legislation, AMEK Scrl studies the application of enzyme preparations to organic wastes treatment for agriculture purposes and polluted soils recover.

In promoting the conservation of agriculture and forestry, developing natural products, using sustainable techniques, the cooperative response to the current needs of saving water and the fight against desertification and soil depauperation.



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3. STATE-OF-THE-ART

Although soil degradation processes in Europe vary considerably from Member State to Member State, with different threats having different degrees of severity, soil degradation is an issue all over the Union:

- An estimated 115 million hectares or 12% of Europe's total land area are subject to water erosion, and 42 million hectares are affected by wind erosion.
- An estimated 45% of European soils have low organic matter content, principally in southern Europe but also in areas of France, the UK and Germany.
- The number of potentially contaminated sites in EU-25 is estimated at approximately 3.5 million. [source: COM (2006) 231, 22.9.2006]



Degraded soil



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Degraded soil

The accumulation of organic matter in soil has taken several hundreds or thousands years. Soil in the world contain approximately 1,500 Gt of carbon (650 Gt in vegetation), and it is the most important compartment of carbon in the terrestrial biosphere (Robert, 2000). Agricultural activities reduce the stock of organic matter of the soil, where the losses in organic matter are often not sufficiently compensated by the additions, leading to an overall decline in the pool of soil organic matter (Lickacz et al., 2001). Tillage usually influences the structure of the soil in a positive way, causing improved aeration and better drainage. However, inappropriate tillage or tillage undertaken when the soil is in and adverse condition – both very common – may provoke the inverse effect: the soil may then be compacted, and the aeration decreased (Lickacz et al., 2001). This process has significant negative consequences on the biologic activity of the soil.



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Below a certain level of soil organic matter, the levels of production fall, either directly, because of a deficiency in nutrients of organic origin, or indirectly, because of a degradation of the structure of the soil. According to Loveland et al. (2003), a threshold of 3,4% of soil organic matter (2 % soil organic carbon) is the level below which potentially serious decline in soil quality may occur. Le Villio et al. (2001) consider a threshold value between 2 or 3 % of soil organic matter in a silty soil. From an environmental and economic point of view, several regions in southern Europe have a critical level of soil organic matter below which the agricultural production could be sharply decreased. In Mediterranean regions, the low levels of soil organic matter of certain densely populated regions are already producing alarming consequences on the levels of production.

Soil depletion and impoverishment cause three main environment-related problems and human level:

- (1) soil erosion of farming areas,
- (2) marginalization and abandonment of agricultural land, and
- (3) soil sealing.

(1) Soil erosion by water is a widespread problem throughout Europe. Physical factors like climate, topography and soil characteristics are important in the process of soil erosion. The Mediterranean region is particularly prone to erosion because it is subject to long dry periods, followed by heavy bursts of erosive rain, falling on steep slopes with fragile soils. With a very slow rate of soil formation, any soil loss of more than 1 t/ha/year can be considered as irreversible within a time span of 50-100 years. The level of soil erosion in the involved regions is between 1 and 10 t/ha/ye (data from IRENA – PESERA project).

(2) The marginalisation of farming areas is driven by a combination of social, economic, political and environmental factors. Marginalisation makes farming less viable over time, leading to the eventual abandonment of agricultural land (within



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farms or as a whole farm). The environmental effects of marginalisation are linked to the abandonment of agricultural land, which may lead to a loss of landscape diversity and related loss in biodiversity, and to an increasing vulnerability to fires, and in some cases, soil erosion. This arises from a regrowth of different shrubs and eventually woodland vegetation on abandoned agricultural land, which suppresses biodiversity-rich grasslands and leads to an increased fire risk in Mediterranean areas.

(3) The conversion of agricultural land to artificial surfaces, which is also known as soil sealing, can impact on soil, water and biodiversity resources. Sealing increases the risks of soil erosion and water pollution, disturbs agricultural habitats, impacts on animal migration patterns and affects the hydrological cycle (increased water runoff and decreased water retention) leading to an increased risk of floods. In addition, it affects the esthetical value of agricultural landscapes, and increases their fragmentation, which can result in more noise and emissions because of increased traffic levels.

From the point of view of policy makers and land managers, whose mission is to try and stop the degradation of soils, the assessment of soil conditions is crucial. Current methods, though, can only provide "static" physicalchemical reports about the status of soil in a given moment, upon which only short-term actions can be based. The BIOREM monitoring technology is based on the fact that one of the effects of the decrease of soil organic matter is a net decline of the biological activity of the soil (see the Soil Biodiversity Report of the Technical Working Group Established under the Thematic Strategy for Soil Protection). Starting from a quantitative and qualitative molecular characterization of the biochemical profile of the soil, the BIOREM method can detect the presence and status of enzymatic processes, demonstrating its ability to provide a more thorough, dynamic picture, extremely useful for the development of precisely targeted, far-sighted restoration and development strategies.



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As a side note, it is important to underline that there is a positive correlation between soil organic carbon and crop yield, so practices that increase soil fertility and crop productivity also mitigate GHG emissions, particularly in areas where soil degradation is a major challenge (Lal 2004). Also, based on Silver et al. (2000), it can be estimated that the restored soil will sequester C at a rate of 130 g/cm²/year for the first 20 yr, and then at an average rate of 41 g/cm²/year for the following 80 years.

All the above issues are strongly connected to European environmental policy and legislation, since soil depletion and its consequences do not only have a biophysical dimension, but at the same time also a socio-economic dimension. Policy makers are expected to make extra efforts at an EU level to bring these two dimensions closer to each other. This is reflected – for instance – in the way that the Common Agricultural Policy has progressively included more environmental requirements. Another example: an appropriate soil management is essential for many Natura 2000 sites, and the limiting impacts of marginalisation will also be relevant in meeting the requirements of the Birds and Habitats Directives, let alone obviously the fulfilment of the Thematic Soil Strategy and the endless connection to other fields of policy relevance.



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4. SOILS TO TREAT

The BIOREM soil restoration methodology can be applied to different types of degraded soils.

- Soil with a clayey-silty structures, with medium or low organic matter and fertility levels. The agronomic qualities are mainly influenced by: high clay content, moderate availability of oxygen, and slope. Despite the fine texture, if the amount of organic substance is low, the structure stability can be moderated; consequently, after heavy rainfall on finely worked soil, crusts of a few cm of thickness are formed in surface. The crusts only partially prevent the water infiltration, but may hinder the plant germination. In the dry period the soil has cracks, with a surface width up to 5 cm, which go deep. During wet period, the soil aggregates swell, exerting a very high pressures on the contact faces, adverse for a normal development of roots, of herbaceous and trees in general. Soil tillage requires special precautions: in dry state, aggregate cohesion and strength cause particular difficulties in work operations, with or without soil overturning, and they need the use of powerful equipment, high strength and toughness. After a heavy rain, the wide range of humidity between the adhesiveness point and the liquid limit involves long waiting times. In these conditions, to carry out cultivation operations, more than 7-9 waiting days may be needed.
- Soil with a silty loam texture and is mildly alkaline and calcareous (results from preliminary soil analysis). This area is characterized by a low content of clay along the profile, that on one hand can increase the risk of crusts formation, especially if there is a low organic matter content, on the other hand the soil tillage could result easier (it can be easily performed with low power equipment). Furthermore, the waiting time decreases because the



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optimum conditions of humidity are restored after prolonged rain: 2-3 days. The active limestone values do not interfere with the choice of crops. The rainfall varies annually, depending on season: from 600 to 800 mm.

- Slightly sloping soil characterized by medium texture with a significant presence of gravel, which ensures a good soil permeability. This soil is situated at about 30 m above sea level and it is originated from marine terraces, which, during the evolutionary processes, such as erosion, have lost their original constitution; however, this soil has a good level of conservation. Its physical characteristics determine a good permeability and its slope makes it susceptible to erosion processes, and, consecutively, to the depletion of fine particles and the decrease in organic matter content.
- Alluvial soil characterized by a high content of clay. In this soil the presence of a shallow aquifer determines a lift of water during the spring period. The soil tends to present phenomena of cracking during dry periods and of bulge in the wet periods. It has low levels of organic matter, and its flora composition is that characteristic of wetlands. The outflow of surface water is ensured by a proper settlement of land, and the water of the aquifer is controlled through a system of channels.
- Poorly developed semi-arid regosol, with loam soil texture with no gravel. It is a flat soil with a good flow of surface water but with a low organic matter content which makes it subjected to desertification. This soil has good structural characteristics which make it suitable for cultivation.
- Soil which shows the top 20 cm to be a humus rich mollic epipedon (4.5% organic carbon), calcareous (49% CaCO₃) with a silt loam texture. The climate of the region is semi-arid Mediterranean with a mean annual rainfall of 300



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mm, about 75% of which falls in April and October. One characteristic of the rainfall is its irregularity; it is infrequent and carries with it a high degree of erosivity. The mean annual temperature is 17°C and mean potential evapotranspiration reaches 800 mm yr⁻¹. The vegetation of the area is the typical of Mediterranean semiarid lowlands: *Pinus halepensis* Mill. and natural shrubs. In this area a soil, three different soils has been sampled: degraded soil (eroded soil), with a 50% of vegetation cover (autochthonous plants).

- Soils submitted to degradation and desertification processes due to the environmental conditions (rainfall, temperature, etc.), and scarce content in organic matter and vegetation. In this area, a bare soil abandoned to the agriculture (degraded soil with 10-15% of autochthonous plants) has been used. The mean annual temperature is 19-20°C, and the evapotranspiration reaches 900-1000 mm year⁻¹. The predominant soil is Xeric Torriortents.
- Soils characterized by not so severe aridity, nevertheless ecosystems have to cope with an important hydric stress. Average yearly rainfall is just under 400 mm, and average temperature is 16.5°C. Intraannual droughts, typical of Mediterranean climate, are severe. In July and most of August there is no virtually rain, but not infrequently more than 5 months with virtually no rain occurs. Maximum rainfall is bimodal with peaks in April and October. Autumn rains can be especially intense, producing severe episodes of soil erosion.. Intensities over 125 mm day⁻¹ are usual. Potential evapotranspiration, measured by Thornthwaite method is close to 900 mm, although empirical measurement with Piché evaporimeter are over 1700 mm. Coldest month is January, with average temperature of 9.5°C and hottest July and August close to 26°C. Frost is relatively uncommon and rarely severe.
- Semiarid Mediterranean climate with an average annual rainfall of 280 mm, which occurs mostly in autumn and spring, and a mean annual temperature of



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19°C; the potential evapotranspiration reaches 900-1000 mm yr⁻¹. One characteristic of the rainfall is its irregularity; it is infrequent and carries with it a high degree of erosivity. The vegetation of the area is the typical of Mediterranean semiarid lowlands: *Pinus halepensis* Mill. and natural shrubs. The canopy cover is 46% and basal cover 70%.

- Terrain is low lying (400 m a.s.l.), but with steep slopes because of its proximity to the coast. The semiarid climate is typically Mediterranean with an annual rainfall around 250–300 mm and concentrated during spring and autumn. The annual average temperature is 18 °C.



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5. ADDITION OF EXOGENOUS ORGANIC MATTER

Effects of organic amendments addition on soil properties

The addition of composts to the soil as organic amendments directly modifies soil physical, chemical, biological and biochemical properties. Therefore, composts may play a key role in the restoration of the fertility of degraded soils and the maintenance or increase of the productivity of agricultural soils

pH. The addition of composts to soil may modify soil pH throughout the following mechanisms: CO₂ emission and subsequent H₂CO₃ formation; Nitrification of the NH₄⁺ present in composts or released from organic N mineralization; Formation of organic compounds of acidic nature during the mineralization of the added organic matter; Exchangeable acidity appeared due to salt effect; Basic cations contained in composts as well as those solved from soil minerals.

The first four effects will produce an increase in soil acidity whereas the latter will contribute to increase soil pH. Consequently, compost addition to soil may decrease soil pH, increase soil pH, or have no effect on pH. In our case soil pH modification will depends on soil buffer capacity. We know that our soils have a good buffer capacity, and for this reason soils not showed any change on pH.

Soil salt content. Composts contains relative high concentrations of salts, exhibiting a saturation extract conductivity in the range of 5-15 dS/m. Compost addition to the soil, particularly at high rates may increase soil salt content producing a deleterious effect on seed germination and on the growth of most crops, particularly when the conductivity of soil saturation extract is higher than 4 dS/m. Therefore, compost salt content may be a limiting factor for their potential use with agricultural purposes. Nevertheless, several authors have observed that although compost addition produce an increase in soil electrical conductivity immediately after the organic amendment, salt content tends to decrease with time due to the salt washing effect produced by



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rainfall events, electrical conductivity values in the amended soils being similar to those of non-amended soils sometime after the organic amendment. In our case, particularly for Spanish soils, no washing effect has been produced ("zero" precipitation in 6 months), and for this reason, more EC is noted in the plots with organic amendment.

Effects on soil chemical properties after six months: macro and microelements; heavy metals

Management of soil organic matter by using stabilized organic wastes is the key for sustainable agriculture. If productivity is to be maintained, an agricultural system able to preserve a satisfactory physical condition in the soil must also be developed.

In our studied soils; a possible fertilizer effect can be indicated observing soluble N and available P. All plots where compost was added showed higher values for these parameters after six months of restoration. Nitrogen (N) and P are key elements in the sustainability of agroecosystems. The efficient use of N and P, as well as its loss and subsequent diffuse pollution, are related through different biological and physical processes in the N and P cycle. There are two main means to improve the efficiency of N and P use, through management practices to reduce loss and by reconciling productivity with environmental considerations. Application of organic materials enhances soil quality and productivity as well as the nutrient status of soil by serving as a source of macro- and micro-elements. The use of treated organic wastes as fertilizer and soil amendments not only results in an economic benefit to the small-scale farmer but it also reduces pollution due to reduced nutrient run-off.

The nature of the organic matter to be added (composted organic matter, fresh organic substrates or biological sewage sludges,) as long as the percentage of organic fraction and the nutrient content (mainly in terms of N, P, K) have been selected following the specifications already developed by the project partners during their previous experiences.



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Within the project implementation, a search for untreated organic wastes and organic wastes treated with technologies, as composting, was carried out; seven different organic wastes have been collected for characterization and evaluation.

Several composts obtained from the mixture of different kind of organic wastes have been included in this study. The wastes collected include aerobically and anaerobically treated sewage sludges, pig slurry and composts from, among others, the organic fraction of domestic organic wastes, sheep and goat manure, and pruning residues.

In order to evaluate from an environmental point of view a wide range of organic wastes and technologies used for organic waste treatment, a search for untreated organic wastes and organic wastes treated with technologies, as composting, was carried out; seven different organic wastes have been collected for characterization and evaluation. Since the co-utilization of various wastes in composting process is a common practice for the obtaining of high added value products (composts) that can be used as soil improvers and fertilizers for crops, several composts obtained from the mixture of different kind of organic wastes have been included in this study.

These organic wastes have been characterized by measuring in them parameters such as pathogens (*Salmonella* and *Escherichia coli*), water content, pH, electrical conductivity, volatile organic matter, ashes content, total C and N, P, K, Ca, Mg, Mn, Na, S, Al, Fe, B, heavy metals and others elements. The potential phytotoxicity of these organic wastes, as well as their possible stimulant effect on plant growth has been also determined by germination tests.

In this preliminary activity, the suitability for an environmental use of the different organic wastes is discussed, as well as the suitability of the technologies used for their treatment.

As it has been observed, the studied organic wastes are suitable product for recycling in soil with environmental purposes. They have an important load of



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organic matter that will contribute to improve soil organic quality and fertility, increasing the pool of organic C in the soil by fixing C in soil colloids, thus avoiding C losses.

Although the main function of organic wastes in soil is to act as soil improvers, they can also act as fertilizers due to the considerable amount of macro and micronutrients they contained. The chemical characterization of the studied wastes has revealed that nutrient content in wastes is more closely related with the nature of the waste than with treatment method used for its stabilization, whereas the rate of waste organic matter mineralization and the risk of phytotoxicity (derived from the use of the end-product) are greatly influenced by treatment technology. In this sense, composting seems to be one of the most promising and used techniques for waste treatment. Treatments such as aerobic or anaerobic digestion also help to stabilize waste organic matter, but the level of organic matter stabilization and product sanitization is lower than that reached with composting.

The use of organic wastes as alternative to mineral fertilizers will help to reduce natural sources consumption and energy costs, as well as the risks of groundwater contamination derived from inorganic fertilization. At the same time these organic wastes will improve the physical and microbiological characteristics of the soils where they are applied. However, due to the fact that organic wastes act as fertilizers at slow nutrient release, it is probably that they cannot cover all crop nutrient demand and organic fertilization has to be complemented with inorganic fertilization, but the reduction of such inorganic fertilization is an important goal. The effects of organic waste addition will be more noticeable after several years of adding the organic amendment to the soil.

The co-utilization of various wastes is a matter of paramount importance in waste treatment since it allow the elimination of several wastes at the same time and to combine wastes with complementary characteristics in order to give a higher added value to the end product.



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After the study carried out, the compost from goat and sheep manure could be considered the most appropriate for the following reasons:

- It is a commercial compost and we can buy it in the market.
- This compost have a stable organic matter
- This compost is free from phytotoxic compounds
- The compost management in field is more easy than fresh organic materials
- The odour is missing in this compost



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6. REVEGETATION STRATEGIES

Controlled revegetation is an effective measure for the integrated restoration of different types of degraded soils.

Controlled revegetation has been performed on 20 of the created sub-plots. For 10 of these sub-plots (one for each soil type) revegetation has been the only remediation solution carried out; on the other 10 (one for each soil type) revegetation has been applied after the addition of exogenous organic matter, in order to demonstrate the superior effectiveness of the BIOREM integrated soil restoration methodology.

Factors affecting plant growth

Many factors influence plant growth, some of them are listed below:

1. **Climate.** The daily and seasonal supply and distribution of moisture, heat, sunlight, wind, and frost provide varieties of regional and local climatic environments. Such environments directly influence the growth, quality, and maturity of crops. Also, indirectly, they may affect the severity of many plant diseases and pest infestations. At present, sufficiently accurate definition and delineation of local specific crop geo-climatic environments is difficult and incomplete. There is, however, much that can be done to take advantage of favourable elements of the climate. Successful farmers can select plant species and varieties within species to suit the local climate. They can partially modify local field and soil climates by protective hedges, land drainage, tillage practices, and the use of crop residues or snow barriers to reduce the severity of winters to biennial and perennial plants. The application of many fertilizer, fungicide, and pesticide treatments can be adjusted to weather conditions.
2. **Soil.** Crop production capacity is greatly influenced by soil quality. Soil quality is determined by physical chemical and biological characteristics, some of which may or may not be economically controlled. Many of the physical properties such as texture, slope, and soil depth, cannot be modified



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economically by the farmer. Yet, these factors determine the suitability of a soil for agricultural production. In general, for the cool moist climate of Atlantic Canada, the most desirable soils are friable, well-drained sandy loam or loams on relatively level to gently rolling topography. Chemical characteristics that affect soil quality are: acidity, organic matter content and supply of essential plant nutrients. In general, if physical properties are satisfactory, the chemical properties can be modified by adequate use of agricultural limestone, manures, commercial fertilizers, green manure plough downs and other organic additives. The biological properties are the expression of microorganism life and activity.

3. Micro-organisms. Soil micro-organisms (bacteria, yeasts, fungi, algae, protozoa, etc.) are present in soils that furnish them with food and water plus a suitable place to live. Their food is the energy material turned over to the soil in the form of plant and animal residues. As soil micro-organisms decompose organic matter, they release nitrogen, phosphorus, and other mineral nutrients in forms available to crops. In addition, the decomposing organic matter improves soil tilth, increases the moisture holding capacity, and lessens the soil loss.

4. Crop Management. In addition to the foregoing, a successful crop production program is influenced by soil preparation, seeding date, tillage, weed and pest control, time and placement of fertilizer applications, grazing practices, harvesting dates, etc.

Plant cover

Revegetation is an essential part of every rehabilitation process. Bare soil will erode, recompact (if it has been recently tilled), lose soil structure, lose nutrients and undergo invasion by weed species. Traditional approaches have usually involved seeding a mixture of agronomic grasses and legumes with erosion control as the primary objective. On the other hand, modern rehabilitation projects have more demanding objectives, however, such as re-establishing a commercial forest.



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Sometimes, techniques required for one objective (such as developing complete ground cover to prevent erosion) may conflict with others (establishing a free growing crop of trees).

The guidelines below, and the discussion of various revegetation strategies, show how different techniques might be used to achieve a variety of rehabilitation objectives.

- To control surface erosion, use of grass and legume seed mixtures as your first choice, then shrubs and hardwood species, then conifers. However, keep in mind that grass, particularly sod-forming species, may interfere with conifer establishment on some sites.
- Use vegetation with ecological characteristics that are compatible with your long-term objectives. Gain familiarity with the potential of native grasses and legumes by experimenting on sites with low erosion potential. Keep in mind that experience with native grasses and legumes is limited, and they may be more risky than agronomic seed mixtures where immediate erosion control is required. Consult with an agronomist in your area for help in selecting native plants for use in rehabilitation prescriptions.
- Use grasses and legumes to restore and maintain soil structure, especially in medium- and fine-textured soils.
- To enhance development of soil with a distinct forest floor, consider the use of native shrubs and hardwood species. They may be successfully interplanted with conifers. Keep in mind, however, that native shrubs and hardwood trees are less effective than grasses and legumes for short-term erosion control and rapid improvement in soil structure.
- Develop or have an expert of site-specific requirements for seeding rates, planting densities and species mixtures. More intensive approaches are often required in rehabilitation work than in agriculture.
- Consider using bioengineering techniques in situations of high sensitivity or risk.



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- When developing strategies for revegetation, consider other uses of the site and their possible effects on your prescription. For example, where deer populations are large, plan to control browsing by creating barriers to deer access, delaying planting until other food sources are available, or by using other techniques. Also, in areas with cattle grazing, plan and implement measures to prevent cattle from congregating on the rehabilitated area, minimize grazing use until the tree seedlings become established, or try other techniques such as obstacle planting to protect seedlings. Local experience will often be the best source of innovative solutions to problems associated with shared use of rehabilitated areas by wildlife or cattle.
- Remain flexible. There are an unlimited number of possible approaches. Be guided by the ecological considerations of the site, an analysis of the risk and your ultimate objectives.

Planting shrubs

Revegetation with native shrubs can be a valuable rehabilitation tool (Figure), particularly in highly sensitive areas such as recreational areas, alpine tundra and grasslands. Native shrubs have not received a great deal of attention for rehabilitation of forest lands in the past, but the infrastructure necessary to allow routine use of shrubs has been rapidly developing in recent years.

Various methods can be used to establish native shrubs. Container stock can be hardy and, although it may be browsed in some areas, it can be planted in areas where seed retention and survival are difficult. Many species such as alder, rose, soopolallie and juniper may be planted by direct seeding if a source of seed can be found. As well, several species can be established as rooted cuttings – and willow can be established as unrooted cuttings of stems – but mortality rates are high. Species such as saskatoon and wolf willow can be easily established as cuttings from roots.



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Pistacia lentiscus used for Soil Revegetation in semiarid zones

Advantages of planting shrubs for rehabilitation

- Shrubs have deep, woody root systems that give mechanical support to slopes. When planted with grass, they can help to prevent sloughing of the shallow sod layer. The woody top growth also helps to stabilize rehabilitated areas by reducing surface wind velocity.
- Shrubs establish more quickly and easily than trees, and often grow on sites not suitable for conifers.
- Available shrub species tend to be indigenous and better adapted than introduced grasses and legumes.
- Some species will fix nitrogen even in areas where legume success is unlikely.



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- Shrubs may serve as nurse trees to a conifer crop, providing a source of browse to draw animals away from seedlings and protecting seedlings from frost.
- Shrubs improve soil and forest floors by drying them out, adding organic matter, and some species fix nitrogen. Compared to grasses and legumes, these objectives may be achieved with fewer negative effects on conifers.
- Shrubs provide a good source of food and protective cover for wildlife.
- In forested areas, shrubs may improve visual quality by screening disturbed areas from view, and by softening the harsh lines of disturbed areas.

Disadvantages of planting shrubs for rehabilitation

- Ground cover is discontinuous and it may take many years to develop a forest floor and continuous root mat. Planting shrubs is not the best choice for short-term erosion control.
- There is no direct return on the cost of planting, though there may be indirect returns.
- Shrubs will compete with conifers, but in well-designed plantings there may actually be a net growth benefit to conifers.
- Some shrub species may be severely checked by heavy browsing.

Planting conifers

Planting conifers for rehabilitation requires more flexibility and perhaps more stringent planting practices than would be used in planting most cutover areas (Figure). For example, planting at higher than maximum stocking densities where soil conservation or risk of increased seedling mortality have to be taken into consideration; in rutted areas, take more care to select good microsites for planting; consider larger than normal stock where the need for more robust seedlings is indicated, and species requirements may change as a result of disturbance.



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Pinus spp for Soil Rehabilitation

Advantages of planting conifers for rehabilitation

- Planting conifers offers the most direct route to a forest of anticipated commercial value.
- Stock and seed are readily available.
- Seed-rich debris may serve as both seed source and mulch.
- Rapid growth of conifers mitigates visual impacts associated with soil disturbances.
- Conifers have greater root strength for slope stabilization than grasses or legumes.

Disadvantages of planting conifers for rehabilitation



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- Above- and below-ground growth is slow compared to that of some other types of vegetation.
- Forest floors and site-nutrient pools are restored more slowly than with other vegetation types.
- Root systems are coarse compared to those of some other types of vegetation and are therefore not the best for controlling erosion or restoring soil structure.
- Commercial planting densities are often too low to provide optimum rehabilitation effects such as erosion control or nutrient capture.

The plants chosen for the revegetation were *Pinus halepensis* and *Pistacia lentiscus*; these species have been selected on the basis of a preliminary selection between different suitable species.

Plant Selected for the trial:

- *Pinus halepensis* Mill,
- *Olea europaea* var. *sylvestris*,
- *Nerium oleander* L.
- *Pistacia lentiscus* L.
- *Halimus Atriplex* L.

The experimentation was conducted in a greenhouse for two months. The soil used was a typical soil from semiarid zones. The experiment was carried out in extreme conditions, without addition of water. Although all the species used in this study were well adapted to arid climates, it has been shown a higher survival rate in *Pinus halepensis* and *Pistacia lentiscus* L., which have been selected as the most adaptable ones. In the following, their descriptions:

Pinus halepensis (Aleppo pine Common name, family Pinaceae). The Aleppo pine grows from sea level to 1,200 meters in the Iberian Peninsula, it is fully extended



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throughout the Region of Murcia. It is a drought tolerant species, usually growing in areas with rainfall of around 500 mm, although it is known that at some points it can be developed with only 200-250 mm. On the ground, it can grow in any type of terrain (except in soils with high salt content).

***Pistacia lentiscus* L.** (Common Name Lentisco, family Anacardiaceae). Mastic is a fairly abundant specie in the region of Murcia, growing in semiarid areas. It grows in all types of soils, from sea level to over 1,000 meters.



Pinus halepensis and *Pistacia lentiscus*



Planted sites



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7. CONCLUDING REMARKS AND EXPERIMENTAL PROTOCOL

The BIOREM methodology is fully in line with the European Commission's objectives in terms of

- a) erosion, organic matter decline, salinisation, compaction and landslides, and
- b) management of contamination.

Soil degradation process put at risk their conservation and protection, constituting a serious problem in Mediterranean countries. The climate change could increase this risk. New technologies which can help to soil protection and their biodiversity are needed. The loses of organic matter is one of the main threats for soil degradation, pointing to the exogenous organic matter (that can be added to the soil as amendment such as organic wastes) as an invaluable source of organic matter, contributing not only to soil rehabilitation but to fixing C in such soil. To avoid the degradation of the C proceeding from the organic amendment (mineralization) it is necessary to stabilize such C by mean of mechanisms that allow elongating its live in the soil.

The BIOREM methodology is able to obviate these problems, through two connected actions:

- 1. Addition of exogenous organic matter (compost) (12-25 kg/m² on the basis of compost and initial soil characteristics) to the soil**
- 2. Revegetation action, by planting the most adaptable plants.**

1) Organic matter plays a key role in development and functioning of terrestrial ecosystems, determining potential productivity of natural and agricultural systems. Soil organic matter addition notoriously improves soil physical, chemical, and biological properties as well as soil water efficiency. Therefore, to improve soil quality



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and restore or increase its fertility and productivity it became necessary to provide to the soil the suitable level of organic matter to improve their physical properties and to reactivate nutrient biogeochemical cycles and microbial activity.

Up to now peats and manures have been the traditional sources of organic matter. However, these materials are increasingly scarce and expensive, which has led to the search of new sources of organic matter based on organic wastes. Among them urban wastes (domestic wastes and sewage sludges) have been proposed due to their high organic matter content and the fact that they are abundant, cheap, and are produced in a continuous and punctual way. The use of urban wastes as organic amendment will allow solving two problems at the same time: On the one hand the scarcity of organic matter of many soils such as those of the Mediterranean regions, and on the other, the problem derived from the increasingly production and accumulation of organic wastes.

2) Vegetation. A key factor in degradation of soils in the Mediterranean areas is the loss of plant cover, allowing increased erosion and salinization processes to occur. The presence of vegetation in these areas is important, since it provides physical protection to soil and contributes organic matter that enhances soil moisture and soil fertility characteristics. The rhizosphere can be considered as a "microbial nucleus", because plants excrete 10-20% of their photosynthates as root exudates, which can serve as substrates for the microbial community, thus increasing the number of microorganisms and their activity in the rhizosphere. The high microbial biomass and microbial diversity in plant rhizosphere open up a great range of metabolic possibilities (e.g. xenobiotic degradation). The microorganism species making up the rhizosphere depends on the species and age of plant, and on the type of soil.

The results obtained during the BIOREM project proved that semi-arid degraded soils can be reclaimed, immediately after the application of remediation strategies, through the chemical property improvement and the reactivation of the microbial metabolism of soil.



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The treatment with plant alone, ensuring a regular nutrient cycle, has been able to stimulate soil functionality.

In the Italian sites, the organic matter application seems more able in successfully maintaining these processes.

As it has been observed the studied organic wastes are suitable product for recycling in soil with environmental purposes. They have an important load of organic matter that will contribute to improve soil organic quality and fertility, increasing the pool of organic C in the soil by fixing C in soil colloids, thus avoiding C losses.

Although the main function of organic wastes in soil is to act as soil improvers, they can also act as fertilizers due to the considerable amount of macro and micronutrients they contained. The chemical characterization of the studied wastes has revealed that nutrient content in wastes is more closely related with the nature of the waste than with treatment method used for its stabilization, whereas the rate of waste organic matter mineralization and the risk of phytotoxicity (derived from the use of the end-product) are greatly influenced by treatment technology. In this sense, composting seems to be one of the most promising and used techniques for waste treatment. Treatments such as aerobic or anaerobic digestion also help to stabilize waste organic matter, but the level of organic matter stabilization and product sanitization is lower than that reached with composting.

The use of organic wastes as alternative to mineral fertilizers will help to reduce natural sources consumption and energy costs, as well as the risks of groundwater contamination derived from inorganic fertilization. At the same time these organic wastes will improve the physical and microbiological characteristics of the soils where they are applied. However, due to the fact that organic wastes act as fertilizers at slow nutrient release, it is probably that they cannot cover all crop nutrient demand and organic fertilization has to be complemented with inorganic fertilization, but the reduction of such inorganic fertilization is an important goal. The effects of organic



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waste addition will be more noticeable after several years of adding the organic amendment to the soil.

The diffusion of the present methodology will prove crucial for the achievement of:

- (1) Restoration of degraded soils to a level of functionality consistent at least with current and intended use, thus also considering the cost implications of the restoration of soil. When applied across the EU, the BIOREM methodology will help farmers, as well as land managers in general, to effectively tackle land contamination and depletion, of both recent and old origin.
- (2) Prevention of further soil degradation and preserving its functions.

Moreover, it can contribute to the following aspects:

- Sustainable use and management of organic amendments: A significant reduction in the volume of organic wastes which can end up in landfills is expected, thanks to the alternative offered for recycling these organic wastes in degraded soils with adequate management.
- Soil Protection. Our proposal implies a strategy that combines organic amendments and covers vegetation that will permit the restoration of degraded soils, and therefore, will protect an important natural resource, the Soil.
- Nature and biodiversity: The promotion of sustainable soil use, with particular attention to preventing deterioration and contamination, will be made when promoting a new soil status with high quality. It implies benefits to soil biodiversity and functionality.
- Climate change: BIOREM methodology will consider the Kyoto Protocol, and emissions will be reduced as much as possible if the valorization of organic wastes as an organic amendment increases C fixation in soils, thereby avoiding the greenhouse effect



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8. PHOTO GALLERY

Here, some pictures from the project implementation are reported.





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Revegetation



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Pistachia and Pinus plants





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Revegetation



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Revegetation



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Revegetation



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Biorem methodology in greenhouse





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Biorem methodology in greenhouse



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