Assessing Performance of Organic Amendments in Soil Regeneration Strategies for Semi-Arid Regions: a case study in Lagos do Sabor, NE Portugal

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RESUMO

A degradação do solo é um grande problema mundial, particularmente acentuado em regiões semi-áridas como Lagos do Sabor, no nordeste de Portugal. Estas zonas caracterizam-se por uma erosão intensa, perda de matéria orgânica e degradação da estrutura do solo. A regeneração do solo é o fator chave para a recuperação de ecossistemas degradados e para a manutenção da biodiversidade. Para além disso, é uma estratégia de desenvolvimento sustentável que pode reduzir a pressão sobre as florestas naturais e possivelmente conservá-las, reduzir a escassez de produtos de madeira e combater a erosão e a desertificação do solo. Neste sentido, o nosso estudo centrou-se na avaliação do desempenho de diferentes substratos para a regeneração do solo e suporte do crescimento das plantas nas condições semi-áridas de Lagos do Sabor, no nordeste de Portugal, com vista à reflorestação com árvores autóctones. Os substratos testados incluíram areia, composto e um substrato comercial. O principal objetivo do estudo é avaliar a influência destes substratos na retenção de água, no crescimento das plantas e na redução da erosão do solo.

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O estudo inclui várias experiências em estufa para medir a capacidade de retenção de água dos substratos e observar o crescimento de quatro espécies de árvores autóctones: ***Quercus suber*** (sobreiro), ***Quercus rotundifolia*** (azinheira), ***Juniperus oxycedrus***(zimbro) e ***Arbutus unedo*** (medronheiro). Foram também instalados no campo dispositivos de controlo da erosão para medir a erosão do solo em diferentes condições experimentais.

Os resultados mostram que o substrato comercial tem a melhor capacidade de retenção de água, seguido do composto, enquanto a areia tem a capacidade mais baixa. Esta maior retenção de água tem um impacto positivo direto no crescimento das plantas, com as plantas do substrato e do composto a apresentarem um melhor crescimento vegetativo e uma maior resistência ao stress hídrico. Em termos de erosão, a perda de solo foi maior na zona da azeitona do que na zona do composto, devido aos ventos fortes.

Em conclusão, a utilização de substratos ricos em matéria orgânica é fortemente recomendada para a regeneração do solo em regiões semi-áridas. São também fornecidas recomendações práticas para a aplicação destes resultados a outras regiões semi-áridas, incluindo a utilização regular de composto e de substratos orgânicos, a seleção de espécies vegetais nativas e a instalação de dispositivos anti-erosão.

palavras-chave: degradação do solo, erosão do solo, USLE, alteração orgânica, retenção de água, regeneração

ABSTRACT

Soil degradation is a major global problem, particularly acute in semi-arid regions such as Lagos do Sabor in north-eastern Portugal. These areas are characterised by intense erosion, loss of organic matter and degradation of soil structure. Soil regeneration is the key to recovering degraded ecosystems and maintaining biodiversity. It is also a sustainable development strategy that can reduce pressure on natural forests and possibly conserve them, reduce the scarcity of wood products and combat soil erosion and desertification. With this in mind, our study focused on evaluating the performance of different substrates for regenerating soil and supporting plant growth in the semi-arid conditions of Lagos do Sabor, in north-eastern Portugal, with a view to reforestation with native trees. The substrates tested included sand, compost and a commercial substrate. The main aim of the study was to assess the influence of these substrates on water retention, plant growth and the reduction of soil erosion.

The main objective of the study is to evaluate the influence of these substrates on water retention, plant growth and the reduction of soil erosion.

The study includes various greenhouse experiments to measure the water-holding capacity of substrates and to observe the growth of four native tree species: ***Quercus suber, Quercus rotundifolia, Juniperus oxycedrus and Arbutus unedo***. Erosion control devices were also installed in the field to measure soil erosion under different experimental conditions.

The results show that the commercial substrate has the best water retention capacity, followed by compost, while sand has the lowest capacity. This improved water retention has a direct positive impact on plant growth, with substrate and compost plants showing better vegetative growth and greater resistance to water stress. In terms of erosion, soil loss was greater in the olive zone than in the shrub zone, due to the steep slopes.

In conclusion, the use of substrates rich in organic matter is strongly recommended for soil regeneration in semi-arid regions. Practical recommendations are also provided for applying these results to other semi-arid regions, including the regular use of compost and organic substrates, the selection of native plant species and the installation of erosion control devices.

keywords: soil degradation, soil erosion, USLE, organic amendment, water retention, regeneration

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1 INTRODUCTION

1.1 Context and importance of the study

Soil, like air and water, is a very important natural element that provides ecosystem services essential to survival. Soil is fundamental to plant growth and plays a crucial role in global food security by supporting food production. In addition, billions of organisms live in soil, supporting biodiversity and biogeochemical cycles. According to Mol and Keesstra (2012), it is essential to improve communication between soil scientists, society and governments in order to solve soil-related problems, such as water management, biodiversity conservation and climate change adaptation. The United Nations has also recognised the importance of soils in achieving the Sustainable Development Goals (SDGs), highlighting their key role in the sustainability of ecosystems (FAO, 2017). Soil degradation is a major global challenge, particularly prevalent in semi-arid areas such as Lagos do Sabor, in north-east Portugal. These regions are characterised by severe erosion and a reduction in organic matter and soil quality. Soil restoration is essential to restore damaged ecosystems and preserve biological diversity. It is also a sustainable approach that reduces pressure on natural forests, promotes their preservation, compensates for the lack of wood products and combats soil erosion and desertification. Healthy soils improve water retention, promote plant growth and reduce erosion. According to FAO (2017), the rehabilitation of damaged soils is also crucial to ensuring food security and the resilience of ecosystems to the effects of climate change. Moreover, organic amendments help to improve soil structure, increase the quantity of nutrients and promote the activity of micro-organisms. Tejada et al (2006) have shown that the use of compost, sand and substrate can considerably improve soil quality, promote plant growth and reduce erosion. In addition, they encourage the growth of micro-organisms, which help to break down organic matter and form humic substances, improving soil fertility.

1.2 Research objectives

The goal of this research is to evaluate the effectiveness of various substrates for soil regeneration and plant growth in the semi-arid conditions of Lagos do Sabor. The main aim is to study the response of native species such as ***Quercus suber, Quercus rotundifolia, Juniperus oxycedrus and Arbutus unedo*** to various substrates (sand, compost, loam) and to assess their potential for soil regeneration. We will also use the USLE model to assess soil losses in these areas. By examining these relationships, we aim to devise effective methods for

increasing fertility of degraded soils and minimizing erosion, thereby enabling sustainable soil management in semi-arid areas.

To achieve this, field equipment was set up to assess erosion, and greenhouse tests were carried out to examine the maximum water retention capacity of various substrates. These measurements help to assess the effectiveness of substrates under conditions of water stress and high temperatures, common in semi-arid regions. The findings of this research offer practical advice for developing more robust and sustainable soil regeneration strategies, designed to meet current and future climate challenges.

2 LITERATURE REVIEW

2.1 Soil degradation and semi-arid region

- **Causes and consequences**

According to Roose et al. (2010), soil degradation is described as a significant reduction in the natural capacities of soils, such as retaining water and nutrients, supporting roots and plants, preserving biological diversity, filtering pollutants and storing carbon. Various processes, such as salinization, carbonate dissolution, waterlogging, compaction, overgrazing, leaching, mineralization of organic matter and erosion, can cause this degradation. Lal (2001) points out that the geomorphological and climatic characteristics of semi-arid regions accentuate soil degradation processes. Soil degradation in these regions is mainly due to erosion caused by water and wind. According to Oldeman (1992), soil degradation affects around 1,100 million hectares worldwide, or around 56% of the earth's surface, through water erosion, and around 28% of degraded land is affected by wind erosion. These forms of erosion pose major problems in semi-arid regions, due to the variability of water withdrawals and the intense winds that dislodge soil particles.

Intense but variable rainfall leads to runoff, which also exacerbates soil degradation in semi-arid regions. The topography of the land is an essential element in this process. The presence of slopes increases the impact of run-off by increasing the speed and quantity of water flow, leading to significant erosion of the soil's fertile layer. Lal (2001) explains that the reduction in the nutrient-rich top layer of soil reduces soil fertility and has a negative impact on agricultural productivity. At the same time, soil degradation is being exacerbated by the effects of climate change, particularly in semi-arid areas such as Lagos do Sabor. According to climate model predictions, drought episodes are set to become more frequent and intense, further exacerbating soil degradation through erosion (IPCC, 2014). Rising temperatures lead to an increase in the rate of evapotranspiration, which reduces the water available to plants and makes soils more susceptible to wind and water erosion (FAO, 2017).

Climate change is accentuating the reduction in the natural capacity of soils to regenerate due to water stress. Reduced rainfall and rising temperatures disrupt water cycles, in particular the ability of soils to retain water, making them more susceptible to degradation. Lack of water delays the decomposition of organic matter and limits the activity of micro-organisms, reducing soil fertility (Tejada et al., 2006).

More frequent and longer droughts, combined with unsustainable farming methods, exacerbate soil degradation. The decrease in vegetation cover due to climate change increases the vulnerability of soils to degradation, which increases the risk of erosion (Mol and Keesstra, 2012). To reduce these effects, it is important to implement soil management methods adapted to the changes, using organic amendments to strengthen soil resistance and encourage water conservation.

Declining soil fertility results from the loss of topsoil, rich in essential nutrients, which has a direct impact on agricultural productivity. Reduced fertility leads to lower crop yields, jeopardizing food security in affected areas. The frequent compactness of the degraded soil structure reduces its water retention capacity. Reduced water retention capacity exacerbates drought in semi-arid regions, impacting plant growth and water supply for agriculture and other uses. Soil rock fragments increase is due to the selective erosion of fine particles, leaving coarse materials that are less able to retain water and nutrients. This constant erosion is turning farmland into barren deserts. The capacity of damaged soils to support a wide variety of species diminishes. The reduction in organic matter and water retention capacity has an impact on soil micro-fauna and flora, leading to a decline in biodiversity as a whole.

- **Soil regeneration strategies**

Various strategies have been implemented to combat soil degradation. One promising method for restoring the soils of Lagos do Sabor is to plant native species that adapt to local climatic conditions. ***Quercus suber, Quercus rotundifolia, Juniperus oxycedrus*** and ***Arbutus unedo*** are well adapted to the semi-arid conditions of Lagos do Sabor. These plants can survive stressful situations due to lack of water and high temperatures, making them ideal for soil regeneration initiatives. According to Morgan (2005), it is recommended to choose native plant species adapted to local conditions in order to maintain the balance of the ecosystem. It is important to take into account the availability of seeds and plants, selecting species with a low risk of fire and with suitable technical characteristics to prevent erosion. As well as checking the environmental compatibility and resistance to trampling of the species used for replanting, the choice of plants can also take into account aesthetic aspects to improve the landscape, as well as the creation of diversified and homogeneous wildlife habitats. Trees help to maintain soil fertility by fertilizing it with organic matter and fixing nitrogen. They improve soil composition by encouraging high infiltration rates and a capacity to retain accumulated water. As a result, there is less run-off and erosion are more effectively controlled.

Dense, uniform plant cover is the best way to prevent erosion. The use of native plants such as grasses, trees and shrubs are strongly recommended to revitalize gullies, landslide scars, roadsides, pipelines, abandoned mine sites and eroded land in recreational areas. Soil conservation methods, such as hedges and terraces, can reduce run-off and erosion. These techniques slow down the flow of water, encouraging infiltration and reducing soil erosion. Living hedges, formed by lines of trees or shrubs, act as a physical protection against erosion, while terraces provide flat areas that slow down the rapid flow of water.

The use of organic amendments is an effective method of improving soil quality and fertility. Tejada et al (2006) show that the use of compost considerably improves soil fertility while reducing erosion. Natural additions such as compost, manure and plant residues increase the level of organic matter in soils, improving their structure, water-holding capacity and fertility. Mol and Keesstra (2012) highlight the importance of collaboration between scientists, farmers and policymakers in implementing large-scale sustainable soil management practices. This cooperation is needed to promote and share sustainable farming methods that can be adopted by local farmers to restore soils and increase agricultural production. Natural modifications, in particular, are essential in this plan as they improve plant growth by optimising soil characteristics.

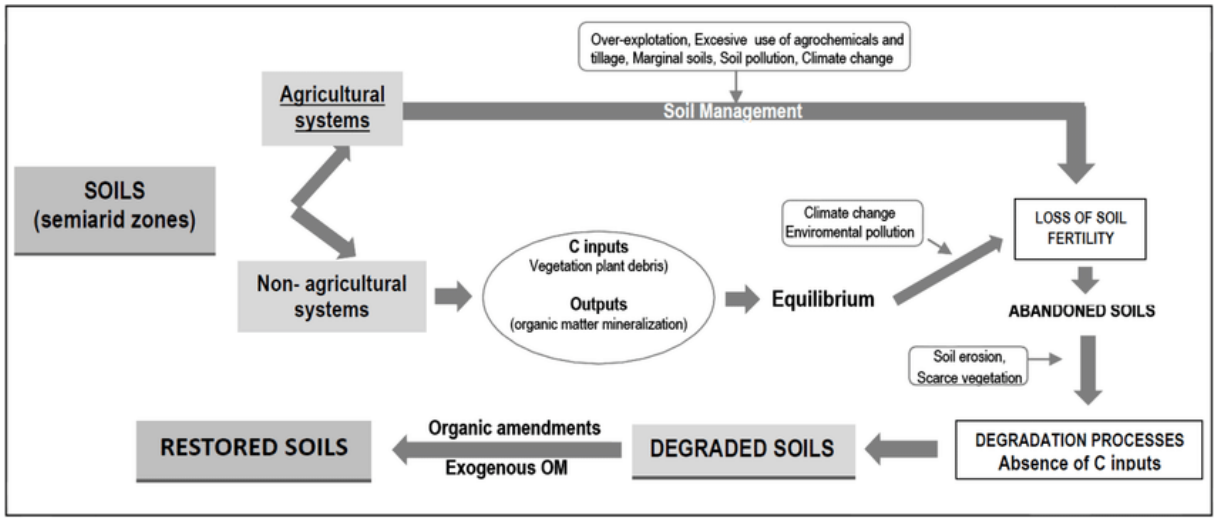

Figure1: Soil degradation and restoration in semi-arid-arid zones (source: García et al. (2017))

2.2 Organic amendments and soil restoration

- **Types of organic amendments**

Different types of materials such as compost, manure, crop waste and sewage sludge are used as organic amendments to improve soil quality. The amendments used in this research are sand, compost and substrate. Sand is frequently present in soils in semi-arid regions and it is also

used to improve water infiltration of plant substrates. However, due to its low water retention capacity, it is often mixed with organic soil improvers to increase the overall efficiency of the soil. Research by Blanco and Lal (2008) has shown that introducing sand into degraded soils can enhance water penetration, but that it is essential to combine organic amendments to maintain appropriate levels of water and nutrient retention. Compost improves soil structure by encouraging the aggregation of soil particles and providing the nutrients necessary for plant growth. Substrates provide plants with ideal growing conditions. They ensure healthy plant growth even when there is a lack of water, by effectively retaining water and nutrients. Research by Raviv and Lieth (2008) has shown that mixtures of peat and compost retain much more water than soils containing no soil improvers or only sand, which is essential for crops in semi-arid zones.

- **Mechanisms of soil improvement**

Organic amendment such as compost, sand and substrate are essential for restoring degraded soils, particularly in semi-arid areas such as Lagos do Sabor. These changes improve the physical-chemical and biological characteristics of the soil, promising optimal, sustainable plant growth.

Compost:

Compost is organic matter enriched with essential nutrients. It strengthens soil composition, increases water retention and provides essential nutrients for plant development. Tejada et al (2006) have shown that the use of compost improves the resistance of soil aggregates, particularly to erosion, and increases the water retention capacity of soils. This is essential for semi-arid soils, which are often affected by compaction and insufficient porosity.

Nutrient enrichment: Compost provides the soil with nitrogen, phosphorus and potassium, nutrients that are necessary for plant growth. According to Carlos Garcia and other researchers (2017), the incorporation of organic soil improvers such as compost improves soil quality and enhances its ability to withstand difficult climatic conditions.

Increased micro-organism activity: Compost stimulates microbial activity by providing a source of organic carbon. This encourages the decomposition of organic matter and the creation of humus, which improves soil fertility in the long term, according to Manna et al. in 2007.

Sand:

Sand is often used to improve the structure and texture of soils, particularly those that are heavy and clayey. However, because of its limited capacity to retain water, it is generally combined with other organic soil improvers.

Improved drainage and infiltration: Sand increases the soil's absorption capacity, promoting the flow and penetration of water. Blanco and Lal (2008) have shown that incorporating sand into degraded soils can increase water infiltration, thereby reducing run-off and erosion.

Reduced compression: By improving soil quality, sand reduces compression, which increases the interstitial space available for plant roots and soil organisms.

Substrate:

The substrate, which generally consists of a mixture of compost, peat and other organic matter, creates ideal growing conditions for plants. It combines the benefits of natural and synthetic soil improvers to increase the water retention and nutrient qualities of the soil. The water retention capacity of the soil is considerably improved by the substrate. A study by Reubens et al (2011) showed that mixtures of compost and peat retained more water than soils containing only sand.

Nutrient supply and growth promotion: Substrates provide a nourishing organic environment, stimulating healthy, robust plant growth. They also help to improve soil composition by increasing permeability and reducing compactness.

Increased soil biodiversity: Like compost, substrates encourage microbial activity and soil biodiversity, which helps to break down organic matter and form humic substances (Garcia et al., 2017).

2.3 Cases studies and precedents

- **Comparison with similar studies**

Organic amendments such as compost, manure and crop residues have been shown to improve soil structure by promoting aggregation of soil particles. Tejada et al (2006) have shown that the use of compost in semi-arid soils promotes the stability of aggregates, thereby reducing erosion and promoting water retention. These improvements are essential for soils in semi-arid regions, which often have low water retention capacities and accumulated erosion due to

irregular and intense runoff. Reubens et al (2011) studied the impact of different organic amendments on soil properties and crop yields in a semi-arid Mediterranean region. They found that compost significantly improved water retention and soil porosity compared with other amendments such as crop residues. Other research, such as that carried out by Larney et al. (2012), confirms these results, noting an increase in aggregate cohesion and a decrease in soil density with the use of compost and manure. Organic amendments have a positive effect on the chemical properties of soils, allowing efficient retention of water and nutrients, which contributes to plant growth in water-scarce situations. Research by Raviv and Lieth (2008) showed that substrates containing peat and compost retained much more water than bare soils or soils amended only with sand, which is essential for crops in semi-arid zones.

Natural additives improve the nutritional quality of soils, particularly with regard to essential nutrients such as nitrogen, phosphorus and potassium. According to Lal (2001), increasing organic matter content through soil improvers increases the cation exchange capacity of soils, which in turn enhances nutrient retention in the root zone and improves soil fertility. This is crucial in semi-arid soils, which often lack nutrients due to low organic matter content and leaching. Research by Mokolobate and Haynes (2001) showed that the use of municipal waste compost in acid soils increased the pH, the amount of organic matter and the levels of available nutrients, thereby favoring plant development. Similar positive results were observed with the use of organic soil improvers such as biochar. The study by Glaser et al (2002) showed that biochar increases soil fertility by improving nutrient retention and in particular leaching, which is beneficial for degraded soils in semi-arid regions. Organic amendments are important for influencing the biological characteristics of soils by promoting microbial activity and soil biological diversity. According to published research, the addition of organic matter promotes an increase in microbial biomass and enzymatic activity, which stimulates the decomposition of organic matter and the creation of humus, thereby improving soil fertility in the long term (García-Gil et al., 2004). Tejada et al (2006) also found a significant increase in microbial activity and soil enzymes after compost application, indicating an overall improvement in soil health.

In some cases, organic amendments encourage the development of beneficial micro-organisms such as arbuscular mycorrhizae, which improve nutrient uptake by plants and their resistance to abiotic stresses (Borie and Rubio, 2003). Soils in semi-arid regions are highly dependent on these biological interactions, as microbial biodiversity is generally limited by extreme climatic conditions and low levels of organic matter. Several case studies demonstrate the effectiveness

of organic amendments in restoring degraded soils in semi-arid zones. For example, research by Barzegar et al (2002) in a semi-arid region of Iran showed that the use of compost and manure increased the strength of soil aggregates, the amount of organic matter and crop yields. A study by Pascual et al (1998) in Andalusia, Spain, showed that the use of sewage sludge improved the physical-chemical and biological characteristics of soils, thereby increasing agricultural productivity and soil health.

In Australia, Chan et al (2007) studied how soil properties in a semi-arid zone are affected by organic amendments. They observed a significant increase in water retention, cation exchange capacity and soil microbial activity following the application of green waste compost and poultry manure, demonstrating the potential of organic amendments to restore degraded soils.

- **The specific case of Logos do Sabor**

Lagos do Sabor, located in north-east Portugal, presents a distinct set of soil restoration challenges. It is imperative to refine soil regeneration techniques in this region to make the most of organic amendments such as substrate, compost and sand. Native plants such as ***Quercus Suber, Quercus rotundifolia, Juniperus oxycedrus***, ***Arbutus Unedo*** adapt perfectly to the region's climatic conditions. These plants have deep roots that contribute to soil stability and better water retention. Their ability to withstand drought makes them ideal for soil regeneration projects in this region. Compost and organic matter are essential for improving soil structure and increasing the level of organic matter. In a study conducted, Tejada et al (2006) showed that the use of compost significantly improved the cohesion of soil aggregates and water retention. These improvements help to reduce soil erosion and stimulate plant growth. A study carried out in southern Spain by Pascual et al (1998) showed that the use of sewage sludge and urban compost improved the physical-chemical characteristics of soils, increasing their water retention and fertility. These strategies can be successfully adapted and implemented in Lagos do Sabor.

Comparative research and case studies clearly demonstrate that the use of organic amendments, combined with erosion management measures and the use of native plants, can greatly improve soil quality. By improving aggregate stability, water retention and soil fertility, these approaches offer a sustainable solution for soil restoration in Lagos do Sabor and similar areas.

2.4 Study site : Logos Do Sabor, NE Portugal

- **Site Description**

Logos do Sobor study site is located in north-east Portugal, known for its semi-arid climate. Lagos do Sabor extends over more than 200 km and covers the territories of four municipalities in the Braganza district: Alfândega da Fé, Macedo de Cavaleiros, Mogadouro and Torre de Moncorvo. (vagamundos.pt)

Figure 1 :District of Braganza and its municipalities (source: interior, (2020))

- **Climatic and soil conditions**

Climate conditions:

The north-eastern region of Portugal, including Lagos do Sabor, presents a diversity of climatic conditions. The main climatic domains in this area are primarily determined by temperature and precipitation, as illustrated in the referenced figures (Royer et al., 2021).

Terra Quente:

This domain is characterized by a semi-arid climate with average annual temperatures exceeding 14° C and average annual precipitation below 600 mm. It encompasses lower altitudes and more interior areas, often subject to high evapotranspiration rates, contributing to drier conditions (Royer et al., 2021).

Terra Fria:

This domain includes higher altitudes with average annual temperatures ranging from 9 to 12.5° C. Precipitation is typically higher than in Terra Quente, but exact values vary depending on specific microclimates and altitudes (Royer et al., 2021).

Specific Climatic Data for Lagos do Sabor

Lagos do Sabor is located in the Terra Quente climatic domain, with an average annual temperature of about 14° C and average annual precipitation of about 600 mm, corresponding to a semi-arid climate (Royer et al., 2021).

Soil type:

The distribution of the main soil groups in the olive-growing region in the northeast of Portugal, specifically in Lagos do Sabor, is drawn from the report (Figueiredo, 2013). Here are the main soil groups, their characteristics, and their geographical distribution, based primarily on figures 3 and 4.

Main Soil Groups

Leptosols

- Characteristics: Shallow soils with a hard rock layer at less than 50 cm depth, often very stony. The typical profile is A R, A C R, or A B C R.
- Distribution: Predominantly cover the region, accounting for 71.6% of the total area.
- Secondary Types:
    - Lithics: Very shallow with hard rock at less than 10 cm.
    - Umbrics : Contain a medium to high amount of organic matter, with a dark A horizon.
    - Distasteful: Ocric A horizon, very acidic.
    - Eutric: Ocric A horizon, slightly acidic to neutral.

Cambisols

- Characteristics: Soils with a cambic B horizon, not limited by hard rock at less than 50 cm. Few stones, soil thickness less than 1 m.
- Distribution: Cover 13.4% of the region.

- Secondary Types: Not specified in the available details but generally found on slopes and various types of rocks (schists, granites, quartzites, basic rocks).

Other Soil Types

- Luvisols: 0.5% of the region.
- Alisols: 1.2% of the region.
- Podzols: 0.1% of the region.
- Fluvisols: 0.9% of the region.
- Pararegossols (Regosols): 4.7% of the region.
- Anthrosols: 6.9% of the region.

Geographical Distribution in the Municipalities of Lagos do Sabor

The four municipalities of Lagos do Sabor and the geographical distribution of the main soil groups are detailed by (Figueiredo, 2013):

- Municipality A: Leptosols are predominantly dominant, followed by Cambisols.
- Municipality B: Leptosols and Cambisols cover most of the area, with some zones of Luvisolos and Alisoles.
- Municipality C: Predominantly Leptosols, with a notable presence of Cambisols and small areas of Fluvisols.
- Municipality D: Leptosols are also dominant, with scattered areas of Anthrosols and Regosols.

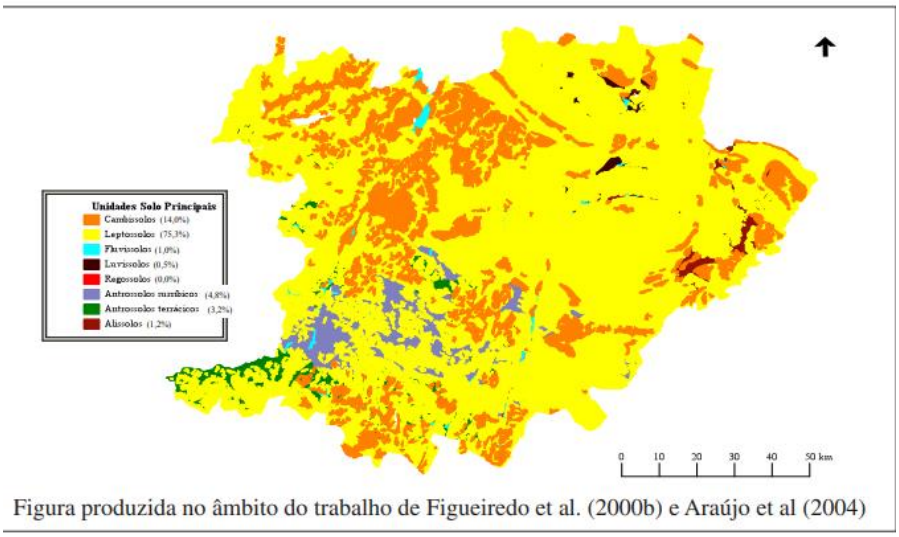

Figure 2 : Main Soil Units dominant in the Soil Cartographic Units of North-Eastern Portugal (source: Figueiredo, (2013))

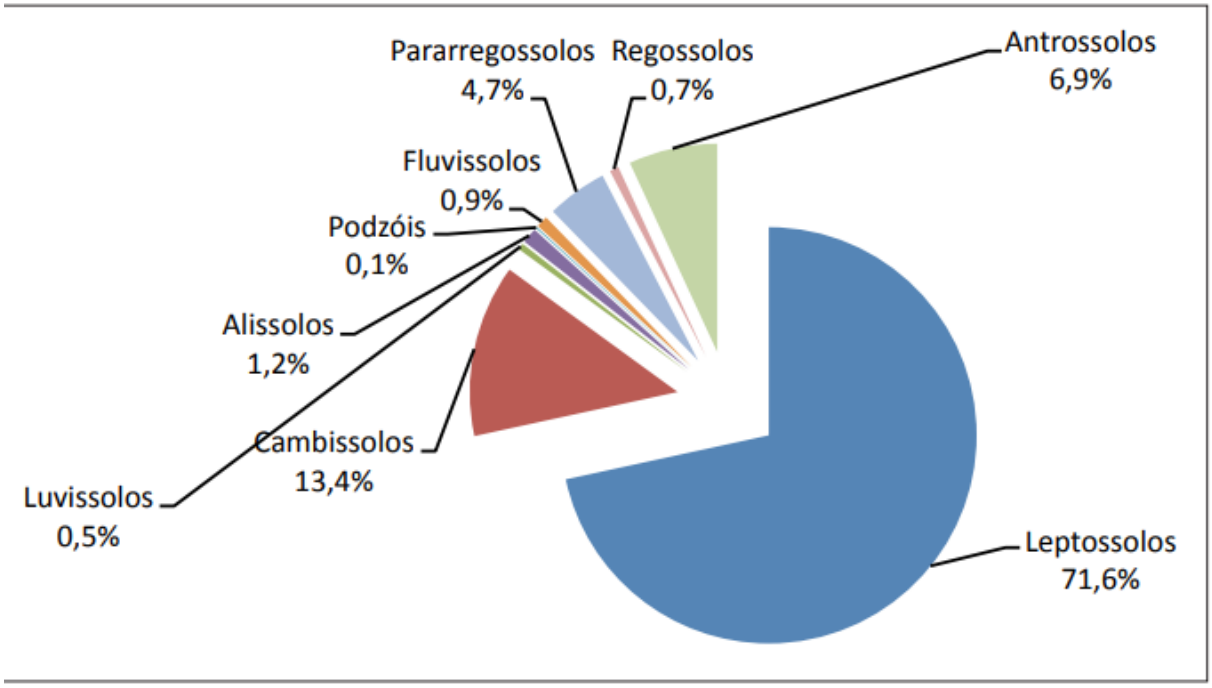

Figure 3 :Main Soil Units of North-East Portugal (source: Figueiredo, (2013))

2.5 Materials and methods

- **Task completed**

This section summarises the various activities carried out to assess the performance of different substrates in regenerating soils and supporting plant growth in semi-arid environments with a view to reforestation. The activities have been grouped into four main categories: Greenhouse seedling experiment, greenhouse substrate dissemination, installation of erosion control fences in the field, and use of erosion models. Each category meets specific study objectives.

Greenhouse seedling experiment:

- **Experimental Plan**

The aim of the greenhouse experiment was to examine how the substrates (sand, compost and substrate) maintain the water retention and growth of four native tree species: ***Quercus Suber, Quercus rotundifolia, Juniperus oxycedrus, Arbutus Unedo***. The seeds were planted in 120 containers filled with sand, compost and substrate. The plants were assessed at regular intervals to evaluate their vegetative growth and their ability to withstand water stress. Experiments to measure the water retention capacity of each substrate were carried out simultaneously.

- **Seed collection and preparation**.

A total of 8,000 seeds of the four types of trees were collected locally, including 1,200 ***Quercus suber*** seeds, 1,200 ***Quercus rotundifolia*** seeds, 2,400 ***Arbutus Unedo*** seeds and 1,200 ***Juniperus oxycedrus*** seeds. They were then treated in the laboratory, sieved to remove impurities and cleaned to ensure successful germination. ***Quercus suber*** and ***Quercus rotundifolia*** seeds were pre-germinated, while the ***Juniperus oxycedrus*** and ***Arbutus Unedo*** seeds were pre-germinated in the laboratory.

- **Description of the substrate**

The physical and chemical properties of the three types of substrates (sand, compost and substrate) were analyzed and listed in Table 1.

Table 1: Test materials - Physical-chemical analysis (n = 3) (Hernández et al., 2024))

Parameter	Units	Sand – T		Compost – SC		Commercial substrate - SS	
		Mean	*Stdev*	*Mean*	*Stdev*	*Mean*	*Stdev*
Bulk density	g/cm3	1,05	0,03	0,50	0,01	0,11	0,00
Particle density	g/cm3	2,49	0,12	1,39	0,10	0,42	0,05
Porosity	%	57,9	0,1	63,7	3,7	74,7	2,8
C total	%	33,2	0,6	34,8	1,5	51,0	0,1
N total	%	1,3	0,2	2,5	0,1	1,2	0,0
P-PO4	mg/Kg	0,6	_	1,2	0,2	45,9	3,2
K2O	mg/Kg	10,1	_	>400	> 400	331,0	287,2

- **Monitoring plan**

The plants were monitored regularly to measure their development and check their physical condition. Measurements were taken on the biomass of the above-ground and below-ground parts of the plants. Experimental conditions were monitored by recording greenhouse temperature and relative humidity.

Substrate dissemination in the greenhouse:

The substrates underwent water retention tests for 360 hours, with and without a plastic cover, in order to reproduce natural drought and evaporation conditions. The aim was to assess the

water retention capacity of three different substrates in order to analyse their impact on plant health and development.

Installation of erosion control barriers in the field

To assess soil erosion, specific fabric devices have been installed in the field. These devices capture and measure the quantity of soil eroded under different experimental conditions. Here is a detailed description of these devices and their installation:

Description of the devices

- **Dimensions and materials:**
  - Length: 1 meter
  - Width: 0,5 meter
  - Material: Durable fabric capable of retaining eroded soil particles while allowing water to run off.
- **Structure:**

The devices consist of rigid wooden frames that hold the material in place.

The material is securely fastened to the frames to prevent any movement or sagging during water run-off.

Installation of the devices

- **Orientation et location:**

The devices are installed along the slope to simulate natural water flow conditions. Two devices were placed in the olive grove area and two in the sparse shrub area on slopes where erosion is likely to be most intense.

- **Soil preparation:**

Before installation, it is necessary to prepare the ground surface by removing debris and ensuring that the surface is uniform. The ground is lightly compacted in order to reproduce the natural conditions of the land while facilitating the installation of the devices.

- **Fixing the devices:**

The frames of the devices are sunk deep into the ground to ensure their stability during water run-off. The fabric is placed over the frame and secured firmly with hooks, ensuring tension and stability.

Application of erosion models:

Application of the USLE to estimate soil erosion, taking into account the influences of climate, soil, relief and vegetation. This involves calculating the R, K and LS factors, as well as the C factor. The results obtained will be used to assess possible soil degradation and to measure the effectiveness of soil management practices. This type of task is essential to achieving the objectives of the study, which are to examine the impact of substrates on water retention, plant growth and the reduction of erosion in semi-arid conditions.

- **Description of the sand, compost and substrate**

Three types of substrates were used in the greenhouse: sand, compost and substrate. These elements provide ideal development conditions for the seeds.

The sand chosen for this research is a medium-sized silica sand. The medium size of the sand grains allows water to run off, preventing the soil from becoming saturated and compacted. Sand plays an important role in reducing soil compaction, which is essential for promoting a structure favourable to root growth (Hopmans et al., 2002). In terms of porosity, sand has a total porosity 57% and a density of 2,49g/cm³ (Hernández et al., 2024). High permeability allows good circulation of air and water in the soil, which is advantageous for plants in terms of ventilation and drainage.

Figure 4 :Sand used in greenhouse

The compost used in this project contains a lot of organic matter, with a percentage of organic carbon of 34.8%. It also contains important nutrients such as nitrogen (2.5%), phosphorus (1.2mg/Kg) and potassium (10372mg/Kg) (Hernández et al., 2024), which are essential for plant development (Tejada et al., 2006). Compost has a particle density of 1.39 g/cm³. By improving soil quality and increasing the amount of organic matter, compost helps to retain more water

and improve soil fertility (Manna et al., 2007). Compost is essential for improving the capacity of soils to retain water, thereby mitigating the effects of drought and improving the resilience of ecosystems in the face of climate change (IPCC, 2021).

Figure 5 :Compost used in greenhouse

The substrate used in this research is a special substrate for germinating all types of seeds. Its fine, low-salt texture gives it an appropriate water-holding capacity, ensuring a constant level of humidity that favours a high germination rate and perfect development of the seedlings. This substrate is balanced and enriched with organic fertiliser, which promotes its nutritional component in the plant's initial development phase. It is made up of blond sphagnum peat moss, Siro Agro 1 (pine bark humus - RAL certified), coco peat and organic fertiliser of animal origin (source, siro.pt). The organic matter content is over 60%. The substrate has a porosity of 74.7% (Hernández et al., 2024), which ensures good air circulation and ideal water retention (Reubens et al., 2011). The lightness of the substrate is due to its low bulk density of 0.1 g/cm³ (Hernández et al., 2024), making it easy to handle. The substrate provides a growing environment rich in nutrients and organic matter, which promotes vigorous plant growth (Tejada et al., 2006). In times of climate change, soil is very useful for retaining moisture, helping to control periods of water scarcity and ensure a constant supply of water for plants (IPCC, 2021).

Figure 6 :Substrate used in greenhouse

- **Greenhouse planting process for the four species**

The seeds of four tree species (***Quercus Suber, Quercus rotundifolia, Juniperus oxycedrus, Arbutus Unedo***) are sown in the greenhouse in containers filled with three types of substrates: sand, compost and potting compost. The following steps are followed to ensure optimum preparation and planting.

Preparing the seeds

The laboratory work involves several essential steps to prepare the seeds before sowing. Firstly, there is **sieving**, which involves passing the seeds through sieves to separate out unwanted impurities such as dust, plant debris or small stones. This stage is designed to ensure that only high-quality seeds are used for sowing, thereby ensuring the uniformity of the sowing process. Next, a **cleaning** operation is carried out to remove stones and any remaining impurities. A careful inspection of the seeds is carried out to avoid any hindrance to germination and seedling growth. The final stage involves **crushing** the larger elements to create an environment conducive to germination and initial growth of the young plants. Shredding prepares a fine, uniform seedbed, offering optimum conditions for seed germination.

Pre-germinated acorns:

Acorns, cork oak and holm oak seeds are pre-germinated to break their dormancy and ensure uniform germination. This special treatment improves the germination process of these species.

Figure 7 :*Seeds of Quercus suber and rotundifolia* pregerminated

Germination before planting in the laboratory for *Juniperus* and *Arbutus unedo*:

Juniper and arbutus seeds undergo pregermination in the laboratory to increase their germination rate and initial growth.

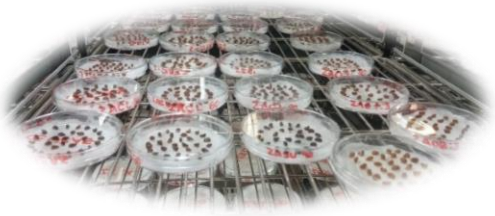

Figure 8 :photo of Juniperus oxycedrus *in the laboratory*

Figure 9: Photo of arbutus unedo seed

Sowing and germination:

In the greenhouse, seedlings are sown in honeycomb containers fitted with guides and holes for the roots, to facilitate aeration and prevent the roots from sticking.

Filling the containers: The containers are placed close to the substrates and filled using a shovel. They are shaken to ensure that the substrate is evenly distributed, then filled completely a second time. The containers are then placed on supports raised off the ground before seeding.

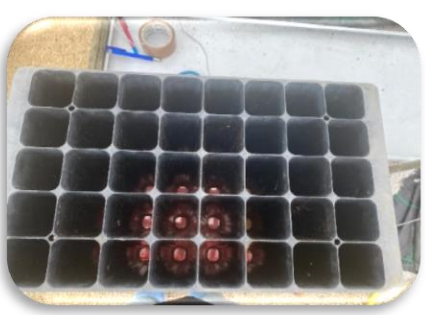

Figure 10 : photo of contours filled with substrate

Sowing: The seeds are placed superficially in the trays. Two ***Arbutus Unedo*** seeds are placed per tray, while a single ***Quercus Suber*** and ***Quercus rotundifolia*** seed is planted per tray. ***Juniperus oxycedrus*** seeds are sown about a month after the other species to take account of their specific germination cycle.

Maintenance and monitoring:

The progress of the plants since the seeds were sown was monitored twice a week, by filling in monitoring sheets containing the following data:

- Plant number
- Germinated plants per tray
- Germination date

To study the morphological criteria of the seedlings in the nursery, it was necessary to take dendrometric measurements, i.e. height and diameter, using the following equipment:

- Graduated ruler
- Vernier calipers
- Measuring sheet

Figure 11 :Plant development in the greenhouse

2.6 Water Retention Capacity Measurement

The importance of the water-holding capacity of substrates is fundamental to managing water stress. Organic amendments such as compost and potting soil can help reduce the consequences of prolonged periods of drought by improving the water retention capacity of soils. These amendments allow soils to increase their water retention capacity, which is crucial for plants during periods of low rainfall. Improving soil composition also improves water absorption, thereby reducing runoff and erosion (Tejada et al., 2006; Manna et al., 2007). It is preferable to

sample mixed substrates to study soil hydraulic properties at the wet end of the water retention curve, as the use of compacted samples is generally not recommended due to the influence of soil structure on water retention in this range (Hopmans et al., 2002).

- **Description of the two measurement methods**

Evaporation method:

The test was carried out on trays placed on a 10 m long metal table, 1 m above the soil surface, at the IPB's EFASTUS facility. The evaporation method was applied with three repetitions for sand, compost and substrate. The trays were filled with air-dried substrates, roughening the surface to avoid stratification effects.

- Tray installation:

  The substrates were spread evenly and the surface roughened to avoid the formation of distinct layers.

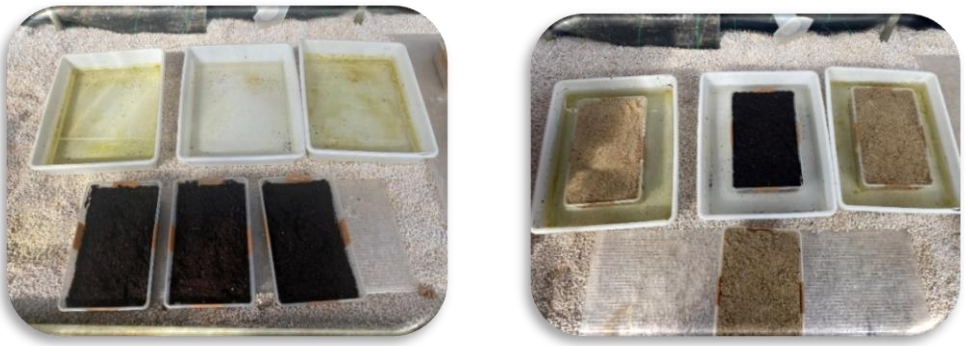

Figure 12 :Photo showing substrate trays

- Measurement and weighing:
  - The samples were first weighed to determine their dry weight.
  - The samples were then saturated with tap water until they could absorb no more water, indicating complete saturation.
  - Samples were left to evaporate naturally and weighed at specific time intervals: 15 minutes, 30 minutes, 1 hour, 3 hours, 8 hours, 24 hours, 72 hours, 1 week and finally 15 days.
  - Temperatures were recorded before each weighing in order to control the experimental conditions.

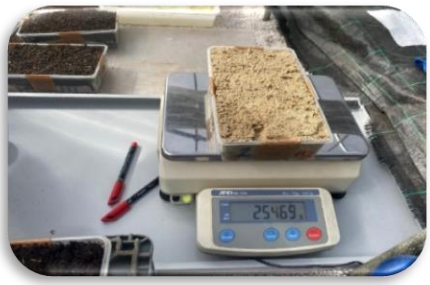

Figure 13: Photo showing the measuring balance

Method without evaporation (covered with a cloth)

This method was carried out in the same place and under the same conditions, except that the samples were covered with a cloth to prevent evaporation.

- Setting up the trays:
  - The same trays were used.
  - The substrates were spread evenly and the surface was roughened.

- Measurement and weighing:
  - Samples were initially weighed to determine their dry weight.
  - Samples were saturated with tap water until fully saturated.
  - After each weighing, the trays were covered with a cloth to prevent evaporation.
  - Weighings were carried out at the same time intervals: 15 minutes, 30 minutes, 1 hour, 3 hours, 8 hours, 24 hours, 72 hours, 1 week and finally 15 days.
  - Temperatures were recorded before each weighing.

Figure 14: photo Method without evaporation

❖ **Experimental protocols and instruments used**

Instruments used

- Precision balance:
  - Used to measure the initial and subsequent weight of samples with a high degree of accuracy.
  - Electronic laboratory balance.
- Plastic trays:
  - Used as containers for sand, compost and substrate samples.
  - Dimensions: 0.03 m^2 per tray.
- Waterproof cloth:
  - Used to cover samples in the non-evaporative method to minimize water loss through evaporation.
- Thermometer:
  - Used to record temperature before each weighing to monitor environmental conditions.

2.7 Field Measurement Setups

- **Setup for measuring erosion**

The erosion measurement devices described in the tasks completed section were installed on slopes representative of the study site in order to collect and assess runoff and soil loss after sampling.

Figure 15: Measuring devices

- **Calculation methodology using the USLE (Universal Soil Loss Equation)**

Soil loss due to erosion can be assessed by field work or laboratory simulations. The choice of method depends on the objective of the study, which will determine the soil erosion data and control factors to be used (Morgan, 2005). The Universal Soil Loss Equation (USLE) is an essential tool for estimating soil loss due to water erosion. In this study, the USLE will be used to quantify soil erosion at Lagos do Sabor by applying region-specific parameters. The USLE is represented by the following formula:

$$A=R\times K\times LS\times C\times P$$

where:

- A is soil loss (tons/ha/yr.),
- R is the rain erosion factor (MJ mm/ha/h/yr.),
- K is the soil erodibility factor (tons/ha/MJ/mm),
- LS is the slope length and slope factor (unitless),
- C is soil cover and management factor (unitless),
- P is the conservation practice factor (unitless).

Figure 16 : Map showing the location of the first device

R factor:

Measuring the erosivity of rainfall is essential for understanding and assessing soil erosion. In this research, we will apply the method developed by Tomás de Figueiredo to assess the erosive intensity of rainfall in north-east Portugal. This process is based on the EI30 index, which merges the amount of kinetic energy and the removal force.

Calculating the erosivity index

Data from the Pinhão / Quinta de Santa Bárbara meteorological station (Figueiredo, 2001), combined with research by Figueiredo and Gonçalves (1990), have made it possible to formulate the following equation for calculating the erosivity index of withdrawals (Figueiredo, 2015):

$$R=3{,}0292\ P^{0{,}852}$$

Where:

- R: Erosivity index (MJ/ha.mm/h)
- P : Annual precipitation (mm)

Rainfall data collection

To determine mean annual precipitation (P), we will use the historical precipitation data available on Portugal's SNIRH (Sistema Nacional de Informação de Recursos Hídricos) website, recorded at the Alfândega da Fé meteorological station from 1913 to 2021.

K factor

The value of the erodibility factor (K) is taken from (Edson, 2016), which is based on the original equation by Wischmeier & Smith (1978). methodology of (Edson, 2016):

$$100K = [2.1M\ 1.14 \times 10^{-4} \times (12-a) + 3.25(b-2) + 2.5(c-3)]\ 0.1316$$

Where:

$$M = (\%\ \text{silt} + \%\ \text{fine sand}) \times (100 - \%\ \text{clay})$$

- a is the percentage of organic matter (maximum 4%).
- b is the soil structure code.

- c is the soil permeability code.

Classification of soil structures (by Figueiredo, 1990):

- 1: Very fine and lumpy granular aggregations.
- 2: Fine granulometry and lumpy aggregates.
- 3: Medium and coarse granular and lumpy aggregates.
- 4: laminoform, prismoform, anisoform and very coarse elements.

Permeability classes (Figueiredo, 1990): :

- 1: Fast and very fast.
- 2: Moderately fast.
- 3: Moderate.
- 4: Moderately slow.
- 5: Slow.
- 6: Very slow.

Correction for Rough Elements:

$$\mathbf{Keg = K_{tf} \times e^{-0.035 \times \%EG}}$$

C factor

The cover and management index (C) are essential for assessing soil losses caused by water erosion. The rigorous approach to determining this factor in semi-arid regions, such as Lagos do Sabor in north-east Portugal, is described by Fernanda Zanella Alves in her study.

We will apply Fernanda Alves' method to calculate the C factor for the shrublands and Olivier lands in Lagos do Sabor, in north-east Portugal.

Fernanda Alves uses both field measurement techniques and simulations in her study to evaluate the C-factor (Alves, 2019).

- The C factor on plant density and cover in shrublands and Olivier plots.
- Record soil management methods, such as crop rotation and the use of mulch, in the documentation of management practices.

Calculation of sub-factors C1, C2 and C3 (Alves, 2019).

C1 - Vegetation Cover and Height

$$C1 = (1 - FC \times e^{-0.34H})$$

Where:

- FC = Crop coverage fraction (values from 0 to 1)
- H = Height of vegetation (m)

C2 - Residue cover

$$C2 = e^{-2,5.RC}$$

Where:

- RC = Residue cover fraction (values from 0 to 1)

C - Combined Factor

$$C = (1 - FC \times e^{-0.34H}) \times e^{-2.5.RC}$$

C3 - Root Density

$$C3 = a \times e^{-b \times \%\text{Superficial Root Density}}$$

Where:

- a = 0,45
- b = 1.5664 for grasses

Use of Fernanda Alves parameters

Fernanda Alves has developed specific values for the C factor depending on the type of plant cover and vegetation density. In our case, our devices were placed under olive trees and shrublands.

L factor:

The effect of slope length on erosion can be evaluated by the expression (Figueiredo, 2015),

$$L = 0.213\ \lambda^{0.5}$$

Where:

- L - Slope length factor:
- λ - Length of the slope, in meters, from the origin to the final point of flow.

The length λ is determined on google earth by identifying the point,

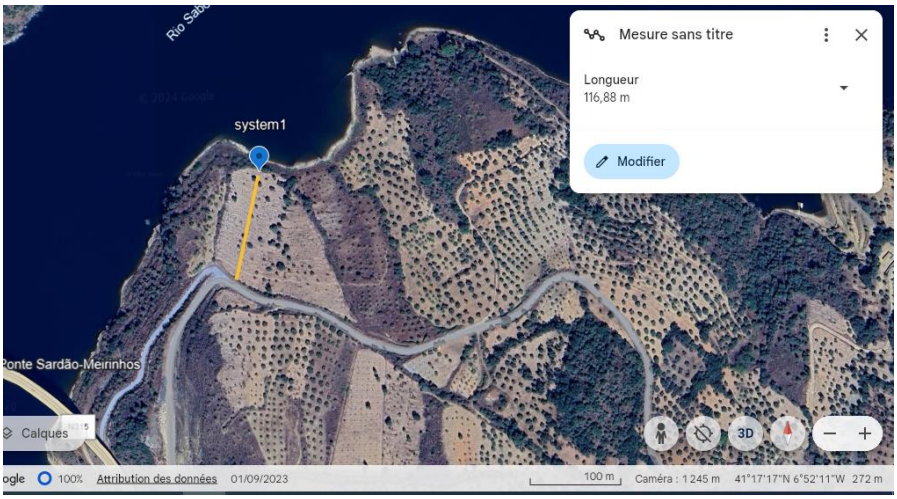

Figure 17:Map showing the length of the olive area

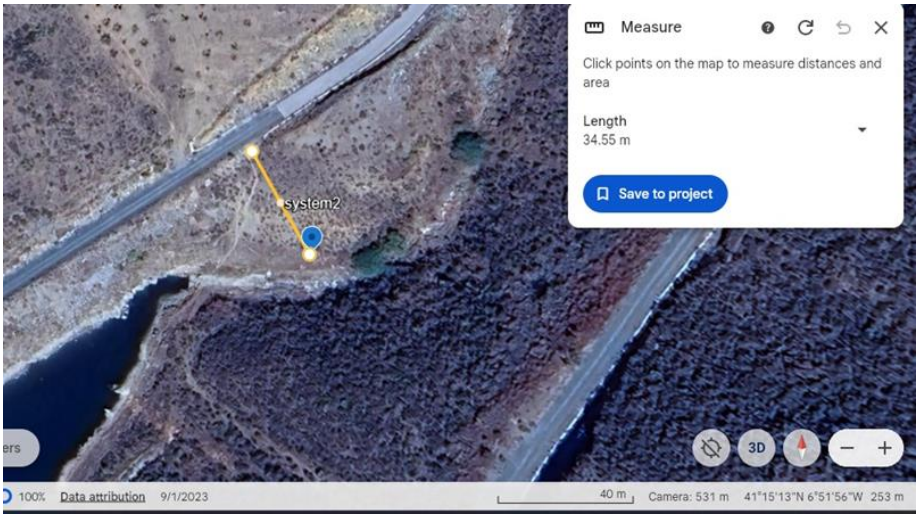

Figure 18: Map showing the length of the shrublands area

S factor:

The influence of slope on an erosion process can be estimated by the following expression (Figueiredo, 2015):

$$S = 16.8 \sin\theta - 0.50 \quad \text{with} \quad \mathbf{Sin\theta = \Delta h \backslash \lambda}$$

Where:

- S - slope factor,
- θ - angle of the slope (degrees).
- Δh= difference in altitude

In our case study, the angle of the slope will be deduced from the difference in altitude, i.e. from the furthest point upstream to the furthest point downstream, and from the length.

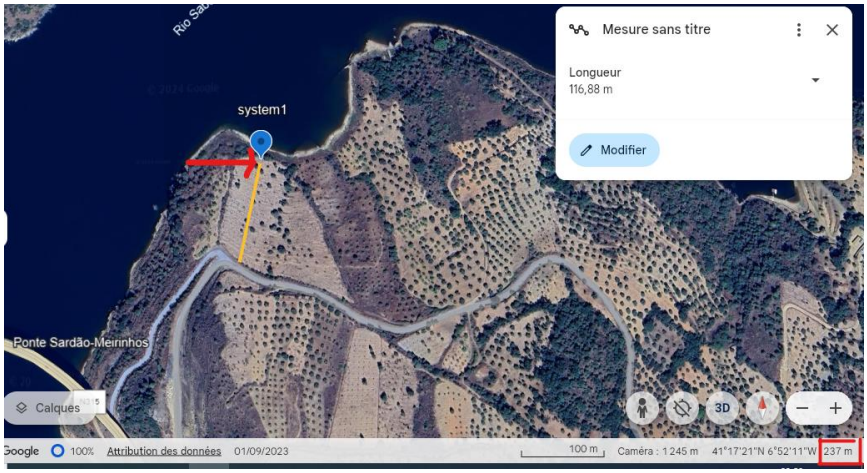

Figure 19:altitude downstream of system1

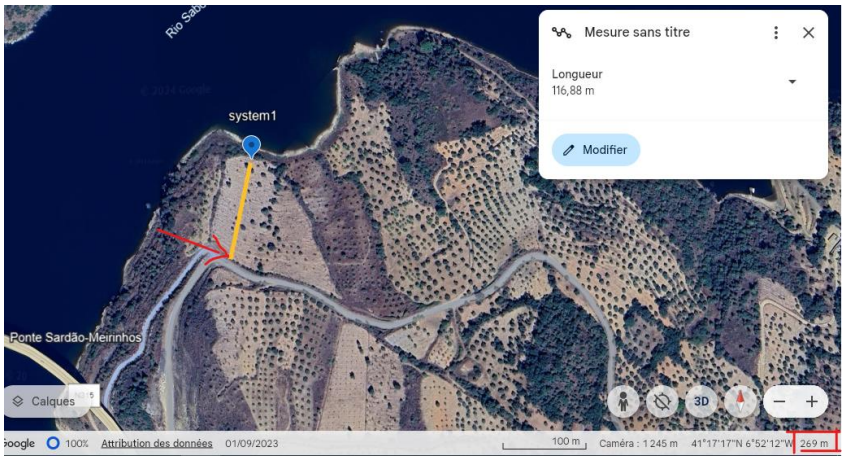

Figure 20: altitude upstream of system 1

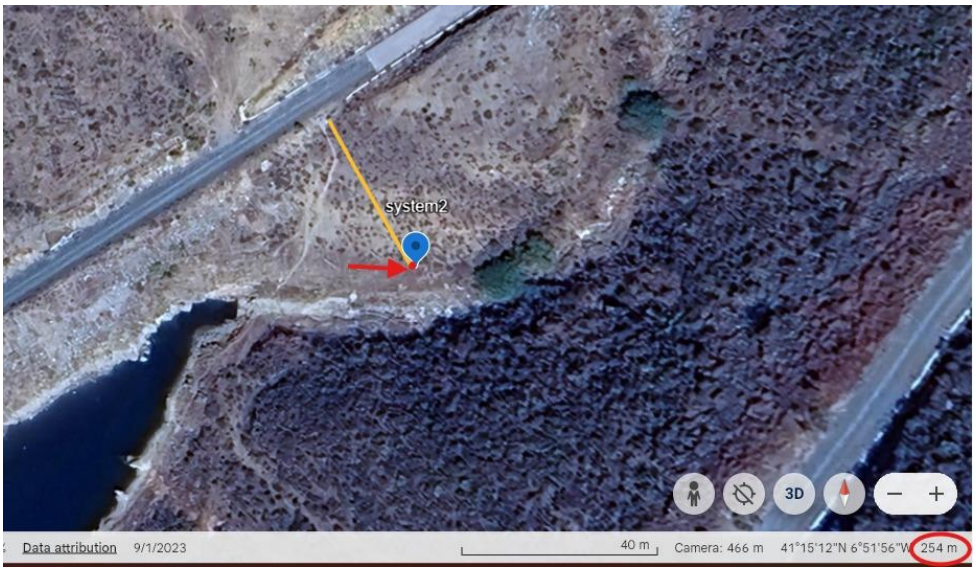

Figure 21: altitude downstream of system2

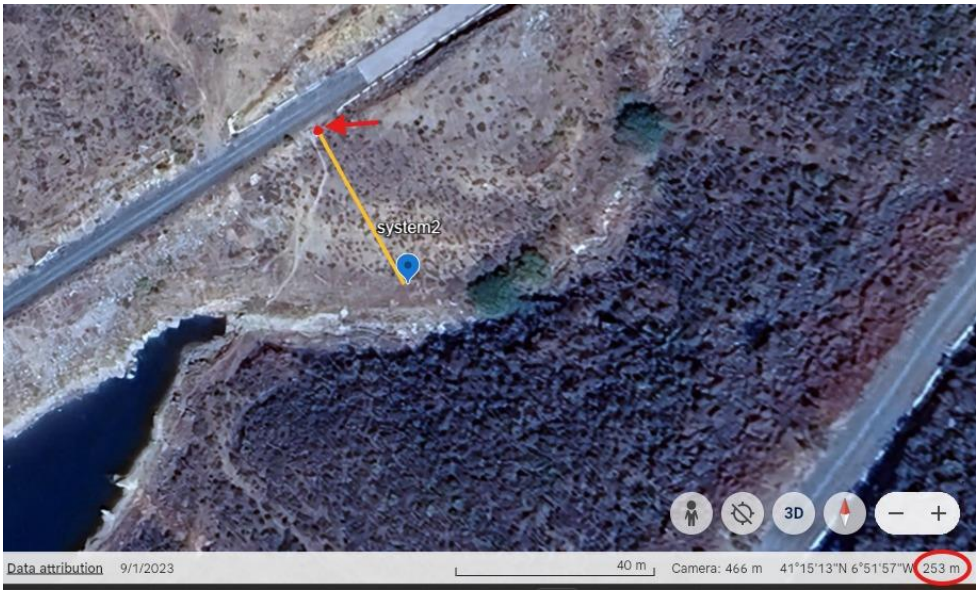

Figure 22: altitude upstream of system 2

P factor

For the value of the conservation practice factor, a fixed value of 1 was adopted in order to neutralize the effect of the factor on soil loss estimates, given that the conservation practice factor was not used in the areas studied in this work.

3 RESULTS

3.1 Performance of substrates

Plant growth and overall health

***Quercus suber* and *Quercus rotundifolia*:**

Oak seedlings grown in substrate and compost showed rapid growth with a significant increase in above-ground and root biomass. Leaves were bright green, indicating good overall health. The high organic matter content of the substrate favored the development of deep, extensive roots with better structured rootballs. This improved root structure increased the seedlings' durability after transplanting and their survival rate. In comparison, seedlings experienced only limited growth in sand. The sand's low water retention potential resulted in low water availability, limiting root development and overall growth. These observations confirm the studies of Tejada et al (2006), who showed that soils rich in organic matter promote better plant growth. The germination rates of ***Quercus suber*** in the greenhouse after 20, 28 and 40 days are shown in the table

Figure 23: image of the formation of the compost clod

Table 2:Germination trials in greenhouse (n = 3) - Quercus suber (Hernández, 2024)

Parameter	Units	Sand – T		Compost - SC		Commercial substrate - SS	
		Mean	*Stdev*	*Mean*	*Stdev*	*Mean*	*Stdev*
Germination rate 20 d	%	4,5	2,7	7,5	4,7	40,0	10,6
Germination rate 28 d	%	34,0	2,9	32,5	7,7	74,5	4,1
Germination rate 40 d	%	70,0	5,3	60,0	9,8	86,0	4,2

Juniperus oxycedrus :

Juniper oxycedrus showed uniform growth and good general health in both substrate and compost. The ability of these substrates to retain water optimally promoted strong root development, which is fundamental for survival in semi-arid conditions. In contrast, juniper seedlings planted in sand showed slow growth and poor health. Their development was hampered by water stress caused by the sand's low water retention capacity.

Arbutus unedo:

Arbutus unedo plants grew very rapidly, with a marked increase in biomass in both substrate and compost. These substrates encouraged deep root development and improved nutrient availability. In the sand, on the other hand, *Arbutus unedo* showed limited growth and dead leaves. Their development was considerably limited by the small amount of water present in the sand, confirming the importance of using substrates with high water retention capacity for these species in semi-arid conditions.

Comparison among the three substrates

- Substrate:

Substrate showed the best performance of the three substrates tested. It offers optimal plant growth thanks to its highwater retention capacity and high organic matter content. The substrate enabled vigorous plant growth, deep root development and improved resilience to water stress. The observations of this study are in line with the research of Tejada et al (2006), who demonstrated the importance of soils rich in organic matter for plant growth.

- Compost

Plant growth was also enhanced by compost, although slightly less than with substrate. Thanks to its ability to retain water and its nutrient-rich composition, plants were able to maintain good health and optimal root development. According to research by Manna and colleagues (2007), the use of compost improves soil structure and increases its capacity to retain water, which is essential for promoting plant growth

- Sand

Sand gave the poorest results in terms of plant development. Plants had limited water availability due to its low water-holding capacity and high porosity, which limited root development and overall plant growth. Early symptoms of water stress were observed in plants grown in sand, confirming that sand is not suitable for growing these species under semi-arid conditions. These results are in line with the findings of FAO (2017), which stresses that sandy soils have limited water-holding capacity due to their low organic matter content.

Figure 24: comparison of the three substrates

3.2 Water retention capacity

Water retention test results

The tables below show the results of the water retention tests (Uncovered) for the three substrates (sand, compost and substrate). The values in Table 3(page 41) indicate the masses measured (in grams) at different times after saturation. These results were used to calculate the relative cumulative water loss in % presented in Table 4(page 41)

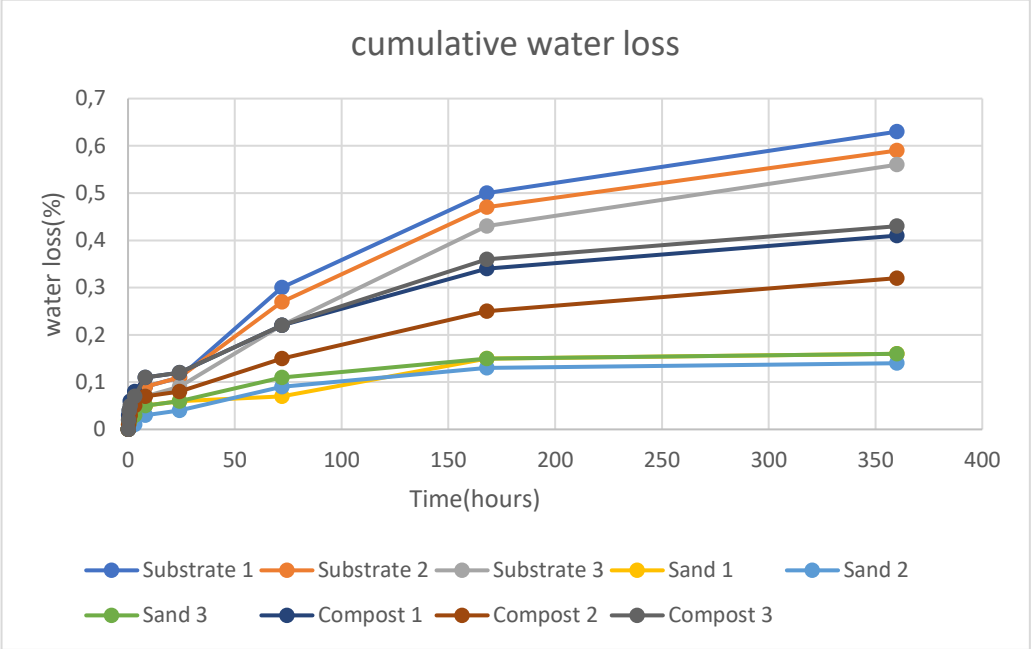

Figure 25: cumulative loss of water from substrates as a function of time

The results of cumulative water loss for the different substrates studied are illustrated by the curve presented over a period of 360 hours. The results clearly show that substrate and compost lose more water than sand. In fact, the maximum cumulative loss for substrate is 63% over 360 hours, compared with 14% for sand.

To better understand the results for water loss, we calculated the density of the different substrates. Here is an in-depth analysis based on substrate density information.

Table 5: Bulk density of substrates

	Initial weight	Areas (cm^2)	Height (cm)	Bulk Density
Substrate 1	471,5	264	5	0,357
Substrate 2	447,7	264	5	0,339
Substrate 3	494,3	264	5	0,374
Sand 1	2188,1	264	5	1,658
Sand 2	2546,9	264	5	1,929
Sand 3	2327	264	5	1,763
Compost 1	902,2	264	5	0,683
Compost 2	902,1	264	5	0,683
Compost 3	823	264	5	0,623

To obtain the dry weight, 10 g samples of compost, substrate and sand were dried at 105°C for 48 hours. The following results are the moisture percentage obtained:

Table 6: the moisture content of substrates

Treatment	Hours of dissecation									
	0h	0,25h	0,5h	1h	3h	8h	24h	72h	168h	360h
Substrate 1	204%	198%	197%	196%	190%	177%	171%	112%	51%	12%
Substrate 2	173%	167%	165%	164%	159%	148%	143%	98%	45%	11%
Substrate 3	155%	152%	151%	150%	146%	136%	132%	99%	46%	12%
Sand 1	19%	18%	16%	16%	15%	13%	12%	11%	1%	0%
Sand 2	16%	16%	16%	16%	15%	13%	12%	6%	1%	0%
Sand 3	19%	18%	17%	17%	16%	13%	12%	7%	1%	0%
Compost 1	71%	66%	64%	60%	58%	52%	50%	34%	12%	2%
Compost 2	51%	49%	48%	46%	44%	40%	39%	29%	13%	2%
Compost 3	80%	76%	73%	71%	67%	61%	59%	40%	15%	2%

Table 7: Moisture content during the experiment uncover

	Substrate weight	Dry substrate weight	%H
Substrate	10	8,625	15,94
Sand	10	9,931	0,69
Compost	10	8,906	12,28

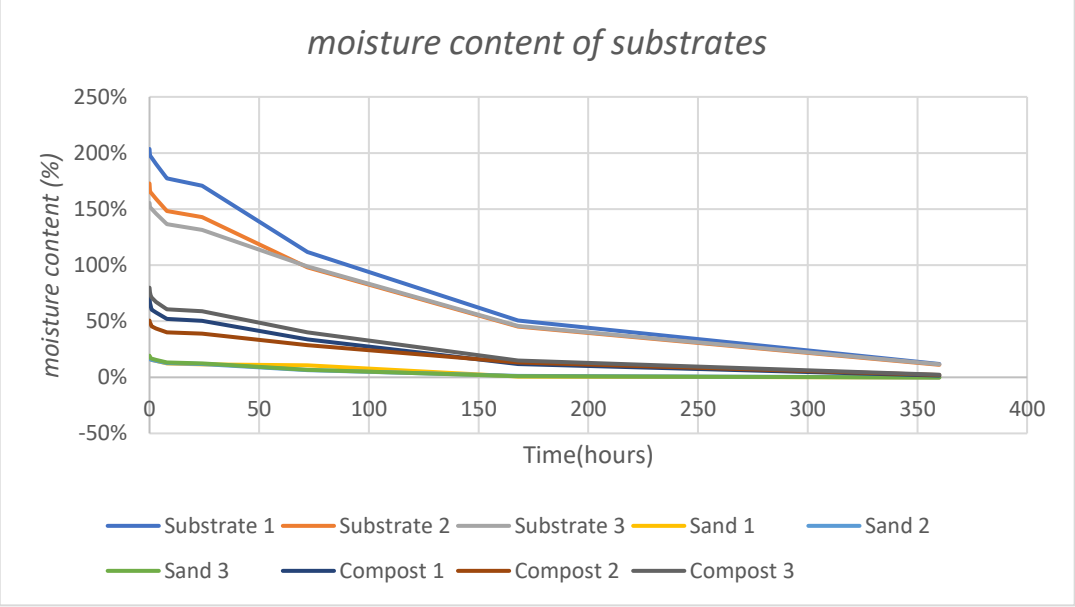

Figure 26: Moisture content of substrates as a function of time

According to the results, the substrates showed very high initial water retention (204% to 155%) which progressively decreased to 12% after 360 hours, the composts had intermediate retention (80% to 51%) which decreased to 2%, while the sands had low initial water retention (19% to 16%) which rapidly decreased to 0%, demonstrating the superiority of the substrates and composts in their ability to retain water under prolonged drying conditions.

Analyse of the effects of plastic cover

The table below shows the results of the initial weight measurements and those taken throughout the experiment (table 8 and 9, page 42).

In the same way as for the experiment without cover, the water content was determined for the experiment with cover. This approach makes it easier to assess the effectiveness of the substrate and identify its maximum water retention capacity.

Table10: Moisture content during the experiment with cover

Treatment	Hours of dissecation									
	0	0,25	0,5	1	3	8	24	72	168	360
Substrate 1	260%	260%	259%	257%	257%	253%	251%	235%	205%	170%
Substrate 2	179%	179%	178%	178%	177%	174%	172%	156%	124%	92%
Substrate 3	141%	141%	141%	141%	140%	136%	134%	115%	84%	56%
Sand 1	37%	37%	37%	37%	37%	36%	35%	33%	28%	23%
Sand 2	31%	29%	31%	31%	31%	30%	29%	27%	21%	20%
Sand 3	37%	37%	36%	36%	36%	35%	35%	31%	23%	19%
Compost 1	68%	68%	68%	68%	67%	66%	65%	57%	46%	37%
Compost 2	90%	88%	88%	87%	86%	85%	83%	75%	58%	43%
Compost 3	104%	102%	101%	101%	100%	98%	96%	85%	68%	50%

From the table above, the average percentage of moisture has been calculated and represented in the graph below

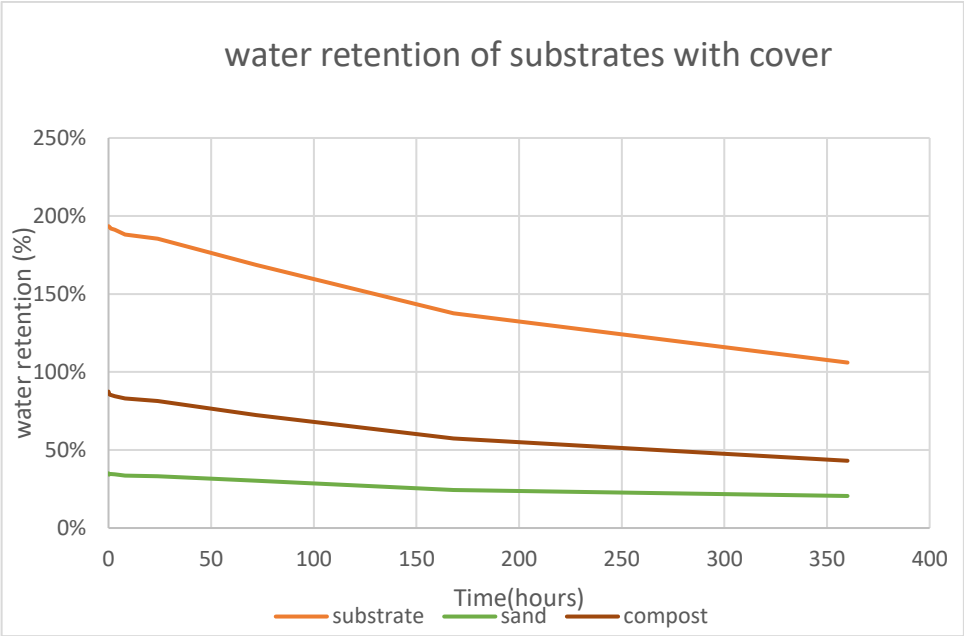

Figure 27: water retention of substrates with cover as a function of time

This graph represents the average percentage of water retention for the different substrates over the duration of the experiment with a plastic cover over a period of 360 hours.

It can be seen that the graph for the commercial substrate shows a very high initial water retention of around 200%, which gradually halves to around 100% after 360 hours, meaning that the commercial substrate has a very high initial water retention capacity and slow moisture loss due to the plastic sheeting. This highwater retention capacity is attributed to its high organic matter content and its structure, which improves water absorption and retention. Similarly, the compost's initial water retention capacity gradually decreases to around 45% after 360 hours.

Compost also has a good water retention capacity, although lower than that of commercial substrate. Its water loss curve is faster than that of commercial substrate, but slower than that of sand, demonstrating its moderate water retention efficiency. In contrast, the graph for sand starts at around 50% water retention and gradually decreases to around 25% after 360 hours. Sand has the lowest water retention capacity of the three substrates. Its graph shows rapid water loss despite the plastic cover.

Table 3: Measuring weight without cover

	Initial weight	Weight after saturation and initial drainage	0,25hours	0,5hours	1hours	3hours	8hours	24hours	72hours	168hours	360h
Temperatre		28C					26C		25C	27C	
Substrate 1	471,5	941,3	923,3	921	917,2	899,9	860,4	839,9	656,9	467,4	347
Substrate 2	447,7	984	961,5	955,2	951,9	934,5	895,3	875,7	713,9	523,9	400,9
Substrate 3	494,3	1084,9	1068,9	1066,9	1062,9	1044,6	1004,2	983,3	845,2	618,7	473,9
Sand 1	2188,1	2506,9	2484,2	2449,5	2440,9	2421,9	2375,2	2355,3	2334,3	2129	2108,5
Sand 2	2546,9	2798,5	2791,5	2783,3	2775,3	2756,6	2706,5	2686,5	2558	2435,5	2400,8
Sand 3	2327	2631,7	2603,8	2588,7	2572,1	2552,5	2501,1	2481,7	2354,6	2227,8	2203,8
Compost 1	902,2	1486,7	1448	1428,9	1395,7	1373,9	1324,2	1309,8	1165,7	974,2	884,4
Compost 2	902,1	1395,5	1378	1368,8	1348,8	1331,1	1297,5	1287,6	1192,2	1050,1	945,8
Compost 3	823	1457,9	1423,4	1403,8	1386,4	1355	1301,6	1287,2	1134,5	931,6	828,9

Table 4: Cumulative water loss in % without cover

cumulative water loss%	0h	0,25h	0,5h	1h	3h	8h	24h	72h	168h	360h
Substrate 1	0	2%	2%	3%	4%	9%	11%	30%	50%	63%
Substrate 2	0	2%	3%	3%	5%	9%	11%	27%	47%	59%
Substrate 3	0	1%	2%	2%	4%	7%	9%	22%	43%	56%
Sand 1	0	1%	2%	3%	3%	5%	6%	7%	15%	16%
Sand 2	0	0%	1%	1%	1%	3%	4%	9%	13%	14%
Sand 3	0	1%	2%	2%	3%	5%	6%	11%	15%	16%
Compost 1	0	3%	4%	6%	8%	11%	12%	22%	34%	41%
Compost 2	0	1%	2%	3%	5%	7%	8%	15%	25%	32%
Compost 3	0	2%	4%	5%	7%	11%	12%	22%	36%	43%

Table 8: Measuring weight with cover

	Initial weight	Weight after saturation and initial drainage	0,25hours	0,5hours	1hours	3hours	8hours	24hours	72hours	168hours	360h
Substrat 1	310,1	937,9	937,4	935,7	931,2	929,9	921,4	914	874	794,9	704
Substrat 2	360,7	845,9	844,9	843,9	843,3	841,1	831,8	823,8	775,3	680,5	582,6
Substrat 3	424,7	862,1	861,5	860,7	859,5	855,5	843,1	834,5	766,8	655,4	556,5
Sand 1	2111,2	2436,5	2430,8	2427,3	2426,3	2422,9	2413,3	2404,3	2364,5	2272,2	2175,3
Sand 2	2402,5	2642,6	2612,1	2641,6	2641	2636,9	2621,6	2610,7	2559,6	2450,8	2416,9
Sand 3	2206,6	2541,9	2533,9	2530	2526,5	2521	2506,1	2495,6	2431	2290	2213,8
Compost 1	870,9	1232,6	1232,1	1231,3	1230,5	1225,1	1215,8	1205,3	1151,3	1068	1000,7
Compost 2	926,7	1480,1	1464,4	1461,4	1460,4	1450,1	1439,9	1427,2	1360,4	1233,4	1113,1
Compost 3	810,3	1389	1377,7	1366,5	1365,8	1360,8	1349	1338,3	1261,9	1142,2	1019,8

Table 9: Cumulative water loss in % with cover

Cumulative water loss %	**0**	**0,25**	**0,5**	**1**	**3**	**8**	**24**		**72**	**168**	**360**
Substrate 1	0	0%	0%	1%	1%	2%	3%		7%	15%	25%
Substrate 2	0	0%	0%	0%	1%	2%	3%		8%	20%	31%
Substrate 3	0	0%	0%	0%	1%	2%	3%		11%	24%	35%
Sand 1	0	0%	0%	0%	1%	1%	1%		3%	7%	11%
Sand 2	0	1%	0%	0%	0%	1%	1%		3%	7%	9%
Sand 3	0	0%	0%	1%	1%	1%	2%		4%	10%	13%
Compost 1	0	0%	0%	0%	1%	1%	2%		7%	13%	19%
Compost 2	0	1%	1%	1%	2%	3%	4%		8%	17%	25%
Compost 3	0	1%	2%	2%	2%	3%	4%		9%	18%	27%

3.3 SOIL EROSION

Collected data and analysis of results

R factor

Climatic conditions in the semi-arid region of Lagos do Sabor are illustrated by the R value of **671 MJ/ha.mm/h**. Precipitation erosivity is directly influenced by average annual rainfall ((Lima, 2016).). According to Morgan (2005), a high R value indicates a high kinetic energy of precipitation, which increases the risk of water erosion.

K factor

After correcting for the presence of coarse elements, the soil erodibility factor K of 0.014 ton/ha per unit R classifies this soil as low erodibility (Lima, 2016). It is essential to correct these estimates in soils consisting of shale and other similar rocks, such as Ieox, which predominates in the study area (Lima, 2016).

S factor

The values of the S factor are very different for the different slopes of the devices installed:

- The S value is 4.6 in the olive tree zones (with an average slope of 27.37%).
- The S value is 0.342. In shrublands areas (with an average slope of 2.9%).

The slope of the land is directly associated with these variations, where a higher slope translates into a higher S factor, increasing erosion potential (Alves, 2019).

RK and RKS products

According to the RK product, which represents the potential for soil loss by focusing exclusively on climatic and pedological factors, the value of Ieox soil units is 9,394 tonnes/ha/year. According to (Figueiredo, 2015), this figure highlights the region's risk of natural erosion without human intervention.

The RKS, taking topography into account, reveals potentially significant soil losses:

- Olive-growing area: 43.21tonnes per hectare per year. -
- Shrublands areas: 3,21tonnes per hectare per year.

These values are very worrying in steeply sloping areas, exceeding the tolerable erosion limits established by Morgan (2005), who estimates that a loss of more than 10 tonnes/ha/year is considered critical.

C factor and RKLSC product

With C-factor values of 0.24 in the olive zone and 0.051 in the shrublands zone (Alves, 2019) and for a slope with lengths of 167.88 and 34.55 respectively, we obtain RKLSC values that correspond to the estimated soil loss under the conditions defined for the different sectors. For the first system, the olive grove zone, we obtain a value of **24.88** tonnes/ha.yr, and for the second system, the shrublands zone, we obtain a value of **0.20** tonnes/ha.yr.

These results show that soil loss in the olive grove zone far exceeds the soil loss tolerance of 10 tonnes/ha.year, a tolerance threshold often taken as a reference as proposed by Arnoldus (1977). This tolerance actually applies to thick soils with a renewable substrate, which is not the case in this region. According to Arnoldus (1977), the tolerance for fine soils with a non-renewable substrate is of the order of 2 tonnes/ha.year. Soil loss in olive groves areas is accentuated by their steep slope of **27,37%**, while soil loss in shrublands areas is well below tolerance because of their gentle slope (**2.9%**). Soil conservation measures in these areas need to be more rigorous.

4 DISCUSSION

4.1 Interpretation of results

Significance of observed differences between substrates

Germination tests on ***Quercus suber*** showed that the commercial substrate favoured significantly better early germination, with a germination rate at 20 days of 40.0%, compared with 4.5% for sand (T) and 7.5% for compost (SC). At 28 days, the commercial substrate maintained its superiority with a germination rate of 74.5%, compared with 34.0% for sand and 32.5% for compost. At 40 days, the commercial substrate continued to have the best germination rate at 86.0%, outperforming sand at 70.0% and compost at 60.0%. To sum up, the commercial substrate (SS) stood out for its excellent physical and chemical properties, favouring better germination of Quercus suber than sand (T) and compost (SC). Its low bulk density, high porosity and high nutrient content (C, N, P, K) appear to be very beneficial for seedling growth.

According to the results, the substrate and compost have higher water retention capacities than sand, which is vitally important for plant growth in semi-arid conditions. The substrate retains water better, with a cumulative retention of 12% after 360 hours without cover. In other words, it is 12 times more stable than sand, which has a cumulative retention of just 0% at the end of the experiment. Compost, on the other hand, has a water retention capacity of 2%. The difference between the substrates is due to their physical characteristics and composition. The substrate with a porosity of 74.7% is the best performing of the three, which can be seen in the greenhouse as the plants grow faster in the substrate and compost than in the sand.

Similarly, in the cover experiment, which evaluated water loss through evaporation and internal drainage, the substrate had a retention capacity of 170%, followed by compost with 50% and finally sand with 20%. The retention capacity of the substrate is therefore higher in the case of internal drainage. In this experiment, the substrate performed 6 times better than the substrate without cover, as did the compost. Sand also performed 100% better. These results show that substrates are much more effective at retaining water in the presence of a cover, which reduces evaporation and improves internal drainage.

The substrate is rich in organic matter (51%), which reinforces the soil structure and improves its hygroscopic properties. According to Tejada et al (2006), soils rich in organic matter are known to retain more water. This is due to the increased formation of aggregates in the soil, creating pores that retain water and facilitate its infiltration. Better soil structure means better availability of nutrients for plants, which is crucial for their development, particularly in water-stressed conditions such as those found in semi-arid regions. Despite being slightly less effective than substrate, compost has nevertheless demonstrated significant water retention. The nutrients and organic matter (34,8%) present in the soil promote the formation of stable aggregates, increasing its porosity and capacity to retain water. According to Manna and colleagues (2007), the use of compost can not only increase the water concentration of soils, but also improve their overall structure, thus promoting plant growth by improving the availability of water and nutrients.

Sand, on the other hand, has a low water-holding capacity, dries out quickly and is less suited to growing conditions in semi-arid environments. The composition of sand is essentially made up of coarse particles and is devoid of organic matter, which limits its ability to retain water and nutrients. Highly porous, sandy soils allow water to penetrate rapidly, which is advantageous for drainage but problematic for water retention. Sandy soils have limited water retention capacity due to their low organic matter content and high porosity, as highlighted by FAO (2017).

Furthermore, data on substrate densities show that sand has a significantly higher density (on average 1.783 g/cm3) than compost (0.663 g/cm3) and substrate (0.357 g/cm3). Sand's low water-holding capacity is partly due to its high density, as it doesn't have enough pores to retain moisture. This observation is also confirmed by the moisture content measured after drying, with sand having the lowest moisture content (0.69%), followed by compost (12.28%) and substrate (15.94%). Variations in density and water content clearly demonstrate the increased effectiveness of substrate and compost in retaining water. Substrate performs best in terms of water retention, with low density and highwater content, followed closely by compost. The properties of substrate and compost make them relevant choices for improving the water-holding capacity of soils in semi-arid conditions, promoting optimal plant growth and sustainable management of water resources.

In summary, these results suggest that the use of substrates containing high levels of organic matter, such as compost and substrate, can significantly improve the water-holding capacity of

soils, which is vital for agriculture in semi-arid zones. The physical characteristics of these substrates improve not only water absorption, but also soil structure and nutrient availability, promoting healthy plant growth and sustainable soil management.

4.2 Implications for Forest Resource Management

Recommendations for soil regeneration practices

The importance of using substrates rich in organic matter for soil regeneration in semi-arid regions is highlighted by the results of this study. The measures taken may also have beneficial consequences for the preservation of Lake Sabor, which is an essential water resource for the region. Here are a few recommendations drawn from the results of the study:

Use of substrate rich in organic matter

Improvement of water retention: Substrates rich in organic matter, such as compost and specially designed substrates, are recommended to improve water retention and soil regeneration. They improve water retention, soil structure and nutrient availability, encouraging dynamic vegetative growth and better resistance to waterlogging.

Regular application: These organic amendments should be used frequently to maintain and improve soil characteristics. Annual or biennial applications may be necessary to compensate for organic matter losses and maintain soil fertility. According to Ouédraogo et al (2004), it has been shown that the use of compost can reduce soil erosion by 20-30% and promote crop growth by increasing the amount of organic matter present in the soil.

Selection of plant species

Native species: Plant native plant species such as cork oak (Quercus suber), holm oak (Quercus ilex), juniper (Juniperus) and arbutus (Arbutus unedo), which are effective in substrates rich in organic matter and are adapted to local conditions.

Plan diversity: Encourage plant variety to improve ecosystem resilience and soil stability. A greater variety of plants can help prevent disease and pest infestations, while improving soil structure and fertility.

Water conservation and erosion control techniques

Install terraces and hedges to reduce run-off and soil degradation. These infrastructures help to slow down the flow of water and encourage its penetration, which improves water retention and

soil quality. Terraces and hedges play a similar role as physical barriers that prevent erosion by retaining sediment and stabilising the soil.

Maintaining dense, constant vegetation on the ground helps to limit erosion. Plant roots contribute to soil stability and prevent erosion caused by water and wind. Intact plant cover can attenuate the effects of raindrops on the soil, reducing the risk of crusting and surface run-off.

Application of results to other semi-arid regions

The results of this research, adapted to Lagos do Sabor, could be applied to other semi-arid areas with comparable soil and climate conditions. For example, Morocco, which is largely located in a semi-arid zone, provides an interesting example of the application of soil regeneration methods adapted to conditions similar to those in Lagos do Sabor. The problems of water resource management, soil erosion and land degradation are very present and require strong and appropriate measures. The following implications can be envisaged for wider use:

Local adaptation

Assess local conditions: adapt recommendations to take account of local specificities such as soil, rainfall and relief. It is essential to carry out a prior assessment of soil and climatic conditions in order to best adapt soil regeneration practices.

Training and extension

Implement training programmes to raise awareness among farmers and land managers of the importance of organic substrates and water conservation methods. It is essential to pass on scientific knowledge to local practitioners so that they adopt sustainable practices.

Cooperation: Promote cooperation between research institutes, public bodies and local populations in order to design and apply soil management strategies adapted to local situations. By integrating traditional and scientific knowledge, sustainable solutions can be created through a collaborative approach.

Monitoring and evaluation

Set up monitoring programmes to assess the effectiveness of soil regeneration practices over the long term. Regular monitoring allows methods to be adapted in line with results and changes in the environment. Encourage the participation of local communities in research and monitoring programmes to ensure ownership and sustainability of soil regeneration practices.

Community involvement is crucial to ensure that the methods adopted meet local needs and respect local culture.

Rio sabor conservation

The maintenance of local ecosystems and water resources depends on the preservation of Lake Sabor. The proposed soil management and regeneration methods could improve the quality and quantity of the lake's water. By reducing soil wear and improving water retention, these methods can reduce sedimentation in the lake, thereby improving its storage capacity and water quality.

In summary, the results of this research provide a sound basis for the formulation of practical advice on forest resource management and soil restoration. The use of substrates rich in organic matter, the implementation of water conservation and erosion control techniques, and the selection of appropriate plant species can greatly improve soil health and ecosystem resilience in semi-arid regions. To ensure the long-term success and sustainability of these practices, it is essential to adapt them to specific local conditions and to support them with training, cooperation and ongoing monitoring programmes

4.3 Study limitation

Methodological and experimental constraints

Controlled greenhouse conditions

The research was carried out in a greenhouse under controlled conditions, which do not fully reproduce natural outdoor conditions. Conditions such as temperature, humidity and light were more stable than in nature, which can affect plant growth and water retention in the soil.

The incomplete reproduction of climatic variability and natural abiotic stresses limits the generalisation of results to real field conditions.

Duration of the experiment:

The time required for experimentation can be an obstacle. The long-term effects of different substrates on water retention and plant performance may not be clearly visible after just 15 days. Seasonal and annual fluctuations were not taken into account.

Scale of research:

The research was conducted on a small scale, using samples grown in greenhouses. The impact on large areas such as agricultural fields or forests was not studied. The complex relationships between different plants, underground life and meteorological conditions on a large scale were not taken into account.

Uniformity of substrates:

The substrates used in the experiment were uniform and standardised. In nature, soils show significant spatial diversity in terms of their texture, structure and organic composition, which can have an impact on the results.

Damage to field devices

The erosion measurement equipment installed on site has been damaged by extreme weather conditions and human activity. Strong samples, gusts of wind and the presence of animals or people may have damaged the equipment. These events highlight the challenge of keeping measuring instruments in good condition in difficult natural environments.

5 CONCLUSION AND FINAL CONSIDERATION

5.1 Summary of results

The aim of this research was to examine the performance of different substrates such as sand, compost and a commercial substrate in soil restoration for reforestation with native plants and plant growth in semi-arid conditions, particularly at Lagos do Sabor in north-east Portugal. The main results of the study are as follows:

Growth and germination: Plants grown in the substrate showed early germination, such as Quercus suber with a germination rate at 20 days of 40% compared with 4.5% for sand (T) and 7.5% for compost (SC), as well as better general health. These native plants, such as Quercus suber, Quercus ilex, Juniperus and Arbutus unedo, showed a considerable increase in biomass and root development in the commercial substrate, with compost and sand proving a less effective growth medium for the plants.

Water retention: The substrate showed its performance by retaining 12% after 360 hours, compared with 2% for compost and 0% for sand. However, in the covered soil experiment, sand was able to retain 23% water after 360 hours. This suggests that soils rich in organic matter considerably improve water retention capacity, which is essential for plant growth in semi-arid environments.

Soil erosion control: Evaluation of the RKLSC product has shown that areas in olive have soil loss well above tolerance. However, the areas in the shrublands had erosion below tolerance. It can therefore be concluded that higher levels of organic matter in the soil lead to a reduction in soil erosion, underlining the importance of substrate selection in soil conservation initiatives.

5.2 PRACTICAL RECOMMENDATION

Based on the results, the following practical recommendations are proposed for soil regeneration in semi-arid regions:

Use of organic substrates: The use of substrates rich in organic matter, such as commercial substrates and compost, can improve water retention in the soil and promote robust plant growth. Regular application of these amendments can help maintain soil fertility and structure.

Plant species selection: Planting native species that are well adapted to local conditions, such as Quercus suber, Quercus ilex, Juniperus and Arbutus unedo, can improve ecosystem

resilience and soil stability. These species have shown better growth performance in substrates rich in organic matter.

Water conservation and erosion control techniques: The use of soil conservation techniques, such as creating terraces, planting hedges and maintaining dense vegetation cover, can reduce run-off and soil erosion. The use of organic mulch can also help retain soil moisture and protect against erosion.

5.3 FUTURS PROSPECTS

In order to deepen this analysis, future studies and long-term projects should focus on the following points.

Extension to other regions: applying the results to other semi-arid regions with similar conditions in order to validate the results and adapt the recommendations to different environmental contexts.

Use of technological advances: examine the exploitation of advanced technologies, such as remote detection and GIS, to monitor soil health and erosion in real time in order to develop more accurate and adaptable soil management strategies.

Community involvement: involve local communities in the research and implementation phases to ensure acceptance of sustainable soil management methods that meet local needs and are culturally appropriate.

5.4 SUGGESTION FOR FUTURE RESEARCH

Long-term study under real condition:

Studies over several growing seasons and under real field conditions are essential to better understand the long-term influence of organic substrates on water retention and plant success. It is recommended that these studies include a variety of sites with different climatic and topographical conditions in order to assess the reliability of the results (Lal, 2001).

Large-scale evaluation:

Larger-scale studies, including entire agricultural or forest plots, could explore the impacts of substrates in more complex environments. In particular, this involves examining the relationships between various plant species and underground life, as well as the influence of management methods on water conservation and soil quality (Aguiar et al., 2017).

Integration of climatic factors:

It is recommended that climate simulations be included in future studies to analyse the response of substrates and soil management practices to climate change. This would provide a better understanding of the adaptability of soil regeneration techniques to future climate scenarios (Morgan, 2005).

Soil biodiversity analysis

Given that organic substrates have an impact on soil biodiversity, it would be useful to take a close look at the response of different soil microbial and faunal communities to the addition of these substrates. Studying microscopic and subterranean life could provide essential data on the overall well-being of the ecosystem (Borja et al., 2021**)**

Comparative regional studies:

Comparing the results of this research with those of other semi-arid regions such as Morocco could provide valuable information on the effectiveness of soil regeneration methods in different pedoclimatic contexts. Comparative regional studies would make it possible to formulate recommendations adapted to different local situations.

Participatory approaches:

Involve local people and land managers in future studies to test and improve soil restoration methods. Participatory methods can facilitate the fusion of traditional knowledge and new technologies, leading to wider and sustainable adoption of recommended practices (Morgan, 2005).

Ultimately, despite the information provided by this study on the importance of organic substrates in soil regeneration in semi-arid conditions, further research is crucial to validate and extend these findings. Long-term studies under real conditions and on a large scale, while taking climatic and biological factors into account, are essential to better understand and manage soils in semi-arid environments.

Finally, we hope that this study will serve as a basis for other work and/or lead to future work in the field of soil conservation. By adopting these approaches, it is possible to improve soil health, increase agricultural productivity and guarantee the sustainability of ecosystems in semi-arid regions. These practices need to be adapted to specific local conditions and supported by training, collaboration and ongoing monitoring programmes to ensure their long-term success and sustainability**.**

6 Bibliographie

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