Moroccan pilot project:

Carbon farming and afforestation in arid zones

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Project duration: 2018–2022
Partners: St1, Mohammed VI Polytechnic University (UM6P), OCP Group and the Natural Resource Institute Finland (LUKE)
Location: Benguerir, Morocco
Funder: Business Finland

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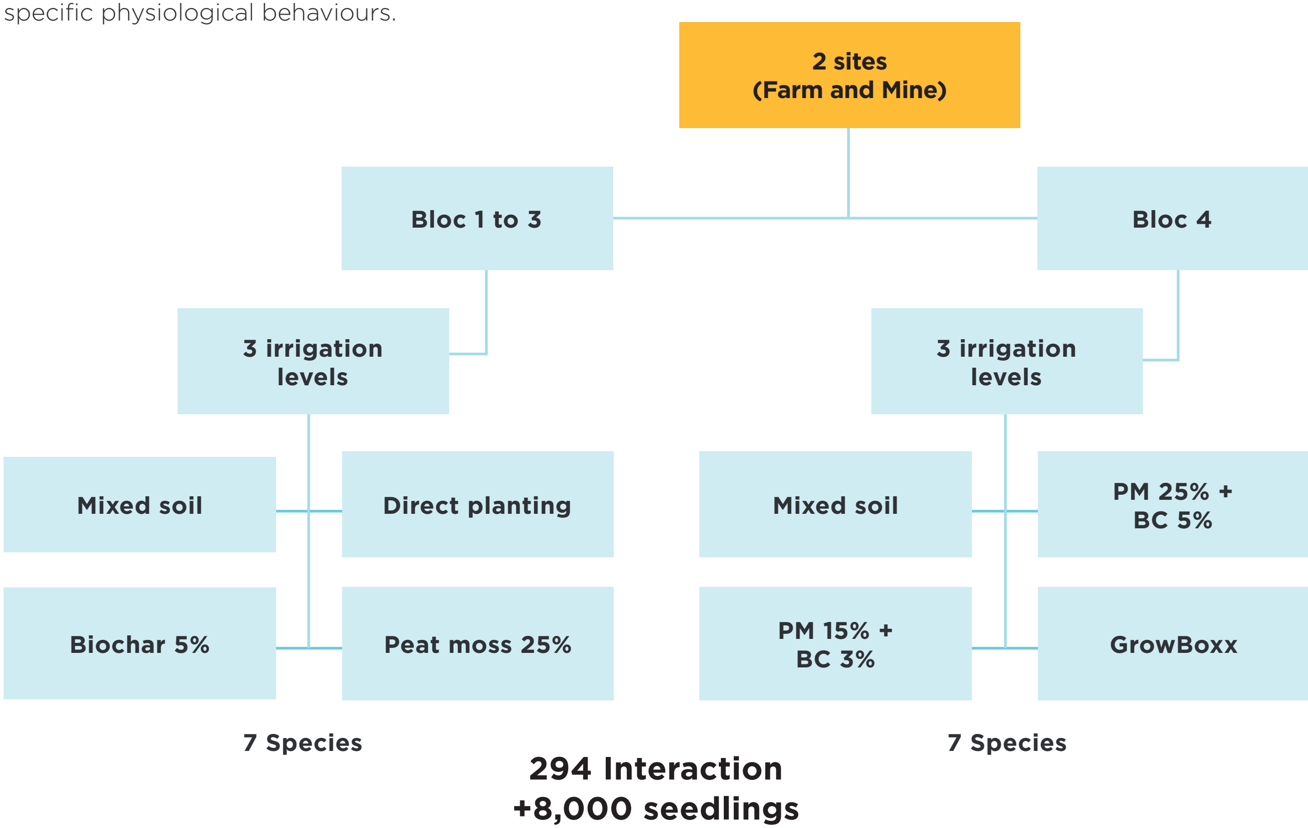
The aim of the pilot project "Carbon farming and afforestation in arid zones" was to identify the potential of seven fast-growing tree species to form a significant carbon sink in dry areas. As a broader objective, the project aimed to create a nature-based climate change mitigation solution by rehabilitating marginal drylands and mined lands through carbon sequestration.

St1, Mohammed VI Polytechnic University, and OCP Group, collaborated in the project's implementation. Field testing was carried out by the Mohammed VI Polytechnic University and directed and monitored by the Natural Resource Institute of Finland.

Governments and organizations worldwide have widely recognized the importance of carbon sequestration in addressing climate change. Without significant emission reductions and carbon sequestration, the world will fail to meet the target of limiting global warming to 1.5 °C above pre-industrial levels. Thus, developing a strong basis to support nature-based carbon sequestration is a matter of urgency.

The goal of the pilot project was to find the optimal solution for the use of land improvement and irrigation systems in cost-effective forest growth and carbon sequestration. The pilot is also a step towards creating a validated and approved tool for mitigating climate change through carbon sinks created through afforestation in arid areas, or in other words, planting trees where none have grown in recent times.

To achieve the objectives of the pilot, the main experiment set out to test different plant substrate-water interactions. In addition, companion experiments and studies were carried out to explore possibilities for agroforestry and to understand some tree and shrub species' specific physiological behaviours.



Biodiversity in agroforestry systems

Agroforestry systems often successfully integrate food production with biodiversity conservation. Numerous studies have shown positive impacts of both arable and pasture system agroforestry on floral, faunal, and soil microbial diversity.

Agroforestry areas can enhance biodiversity in several ways, including providing habitats, creating ecological corridors between habitats, and offering an alternative to traditional soil degrading agricultural systems. Overall, high plant diversity is beneficial to biodiversity.

Value for local communities is an important success factor

Well-implemented carbon sequestration projects seek to deliver value for a broad range of stakeholders. In the history of afforestation, the concepts that have proven the most successful are those where the growing biomass offers financial returns for the local communities.

While carbon sequestration is one valuable ecosystem service, the project would ideally also offer other benefits, such as the following:

- food production
- erosion protection
- biodiversity conservation

This pilot project addresses the multi-faceted needs listed above by creating forests in dry areas and providing new ecosystem services. By integrating afforestation and sustainable irrigation practices, land value and productivity can be enhanced for future generations of farmers.

Irrigation-based afforestation in dry areas is not in conflict with food production, as it can complement and enhance existing agricultural practices. Agroforestry is an alternative agricultural land-use system that can improve the income of local farmers and ensure enough fodder for livestock in a changing climate. As a case in point, agroforestry systems were cited among the main recommendations of the initiative for the Adaptation of African Agriculture to climate change at the 22nd UN Climate Conference (COP22) .

This afforestation pilot project encompasses three different yet complementary environmental and societal aspects:
1. CO_2 sequestration
2. marginal land reclamation
3. improving farmers' revenues locally

The project's initial phase involved extensive research in identifying suitable tree species, irrigation methods, and soil improvements that would be most effective for the specific environment. Additionally, the project team collected carbon accumulation data using destructive methods to assess the potential impact of the proposed afforestation efforts accurately.

Additionality

Additionality is a defining characteristic of efforts such as carbon sequestration projects. It refers to the extent to which a project results in carbon sequestration or emission reductions that would not have occurred in the absence of the project.

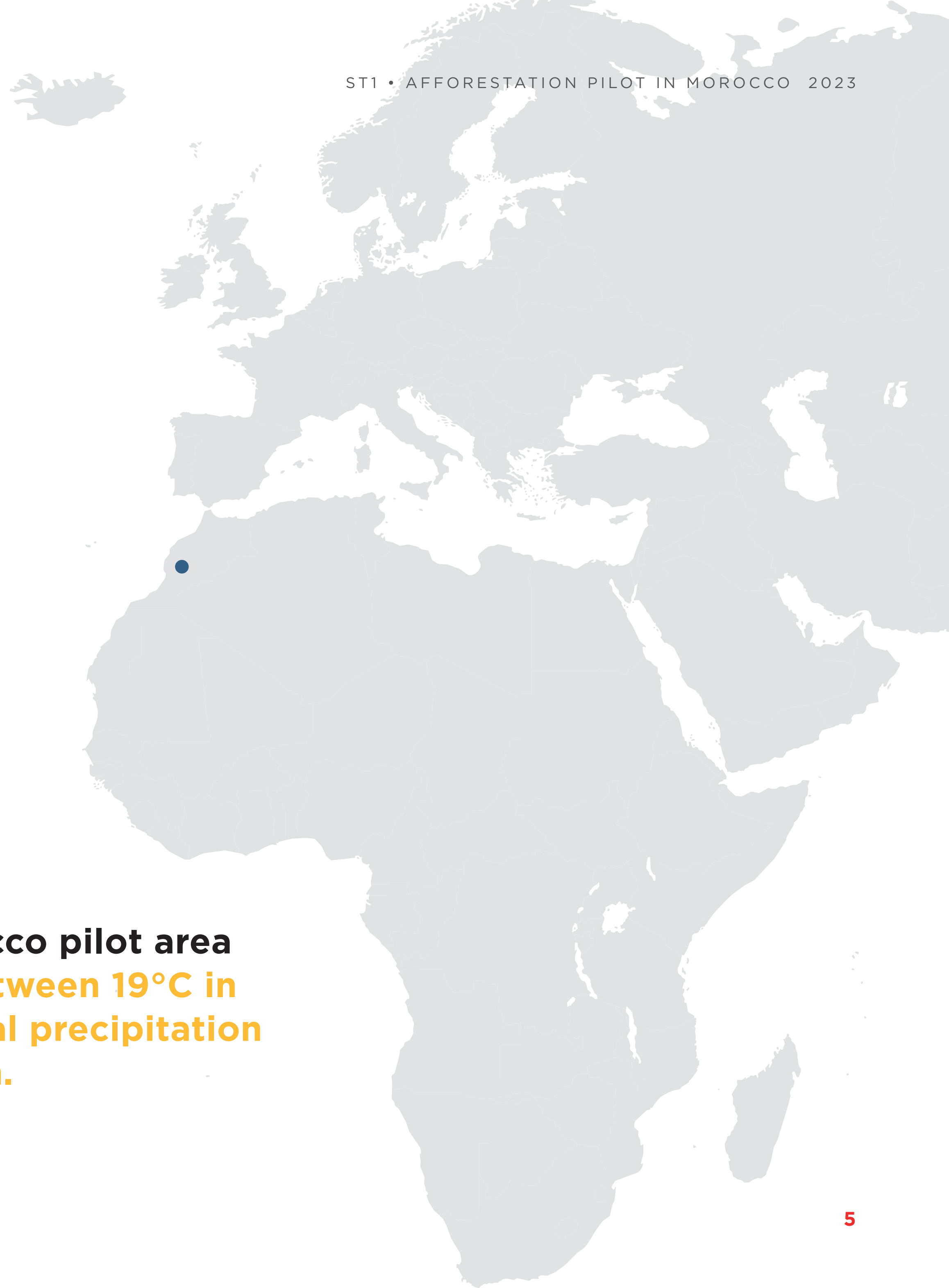
From a voluntary carbon market perspective, the type of irrigation-based afforestation initiated by the pilot project does not leave any questions regarding additionality. Forests would not grow in such an environment without human intervention and the actions taken by the project.

Pilot location and climate

The pilot project took place in Benguerir, Morocco, covering 2 hectares on an experimental farm owned by Mohammed VI Polytechnic University and 1.7 hectares on an experimental mine owned by OCP.

The area where the two sites are located has a predominantly hot, semi-arid climate characterized by drought and extreme temperatures. In addition to dryness and heat, the occasional strong and hot winds are typical challenges. The surroundings are fairly representative of North Africa's semi-arid areas which can be taken into biomass production through a modest irrigation regime.

The project was conducted in a region where alternative income opportunities and new ways of adding value to agriculture are highly sought after due to the effects of low precipitation on production. Farmers in the area are typically sheep farmers who also grow selected plants.



Climate conditions in the Benguerir, Morocco pilot area

Average maximum temperature ranges between 19°C in winter and 37°C in summer. Average annual precipitation during the 2010–2020 period was 250 mm.

Tree species selection and irrigation methods

Tree species were selected based on these qualities:
- Ability to grow quickly
- Adaptability to the region's climate
- High diversity in terms of water needs, drought avoidance strategies, and usefulness

The irrigation treatments were defined on the basis of recommendations from the Regional Center for Forestry Research of Marrakesh. In Morocco, reforestation programs in hot, arid areas typically use tank irrigation, providing 30 litres of water per tree eight to ten times a year for the first two years to improve survival. Therefore, in this pilot project, a starting volume of 30 litres of water per tree was administered monthly to adhere closely to this practice. This volume was augmented slightly later.

The origin of the water used for the experiment was groundwater. However, desalinated seawater would be the most sustainable option for a larger-scale project.

Irrigation methods, soil amendments, and tree species

Tree species:
- Moringa
- Eucalyptus
- Acacia
- Carob
- Pine
- Paulownia
- Pistacia

Irrigation methods:
- Sub-surface drip irrigation
- Tank irrigation
- No irrigation (rainfed)

Soil amendments:
- Biochar
- Peat moss

Crop species:
- Wheat
- Quinoa
- Green pea
- Fava bean

Design of the experiment

The main experimental area on both sites is divided into two smaller experiments. The first sub-experiment consists of three replicates or repeated tests.

In each replicate, three different irrigation treatments were tested:
- Rainfed, with no irrigation
- Tank irrigation
- Drip irrigation

In addition, three different soil amendment treatments were set up on each irrigation level. Finally, in each combination of irrigation and soil amendment, seven different tree species were planted with eight repetitions, of which four seedlings were sampled for destructive biomass measurements in the two years subsequent to planting.

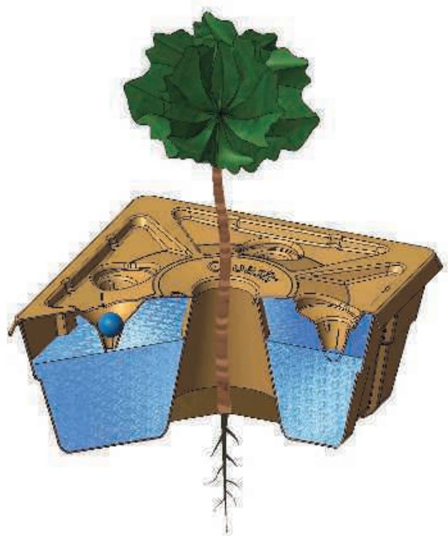
The second sub-experiment was conducted to complement the first. It was set up in the fourth block to study peat and biochar mixtures and the effectiveness of the Growboxx.

Given the importance of the water component in the project, Growboxx, a so-called plant cocoon designed to conserve water around seedlings' rhizosphere to assist their survival and growth, was evaluated in tank irrigation and rainfed treatments.

Limited use of irrigation water

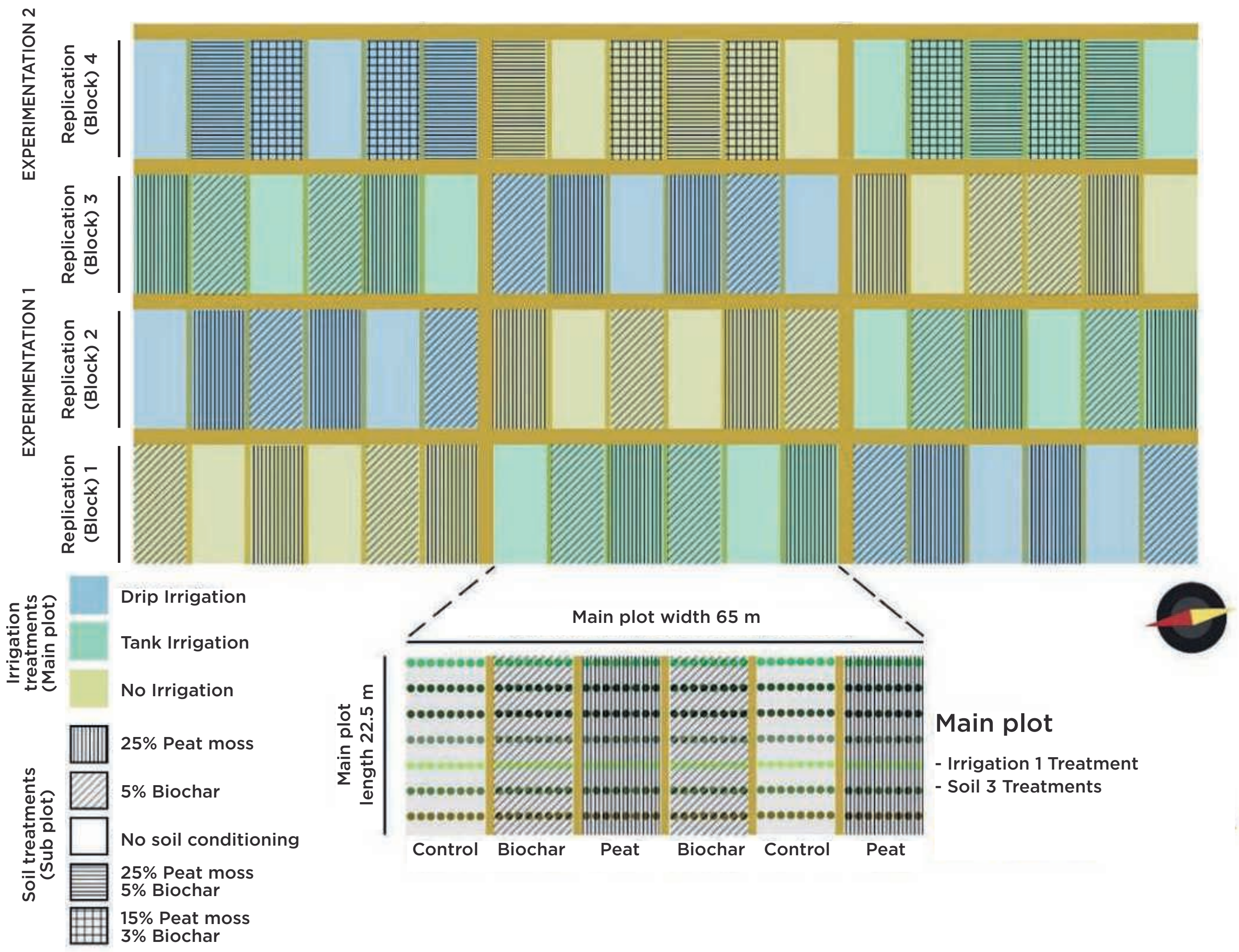
Irrigation water is used in limited volumes, in amounts that would be insufficient for agricultural production. The amount used is three to five times lower than what is required for tree species commonly grown in the area, such as olive or citrus trees.

The findings indicate that a carbon sequestration project utilizing the experimental amount of water employed in this pilot would not compete with agricultural production for land and resources. Rather, it could serve as a means of valorizing marginal land that has limited access to water.



The design of the Growboxx plant cocoon.

Set-up in the experimental farm



A total of 5,376 tree seedlings were planted for the farm experiment, with most of the planting taking place in spring 2019. Fortunately, that year, the area experienced abundant rainfall in spring, just after planting. This greatly aided the establishment and growth of seedlings.

In contrast, 2021 was a very dry year in Morocco, with scarce rain in the spring. If seedlings were planted during that period without irrigation, their survival could have been at risk. This comparison highlights the significant impact weather conditions have on land use and management in dry regions.

Collected data

Field measurements involved gauging parameters directly in the field. The measurements included tree height, the diameter of the tree when surpassing 5 cm and 130 cm, crown diameters at the largest axis, and the perpendicular diameter.

Destructive measurement methods were used to estimate the dry biomass and the relative carbon stocks above and belowground.

Main findings

Species showed high survival rates with limited irrigation

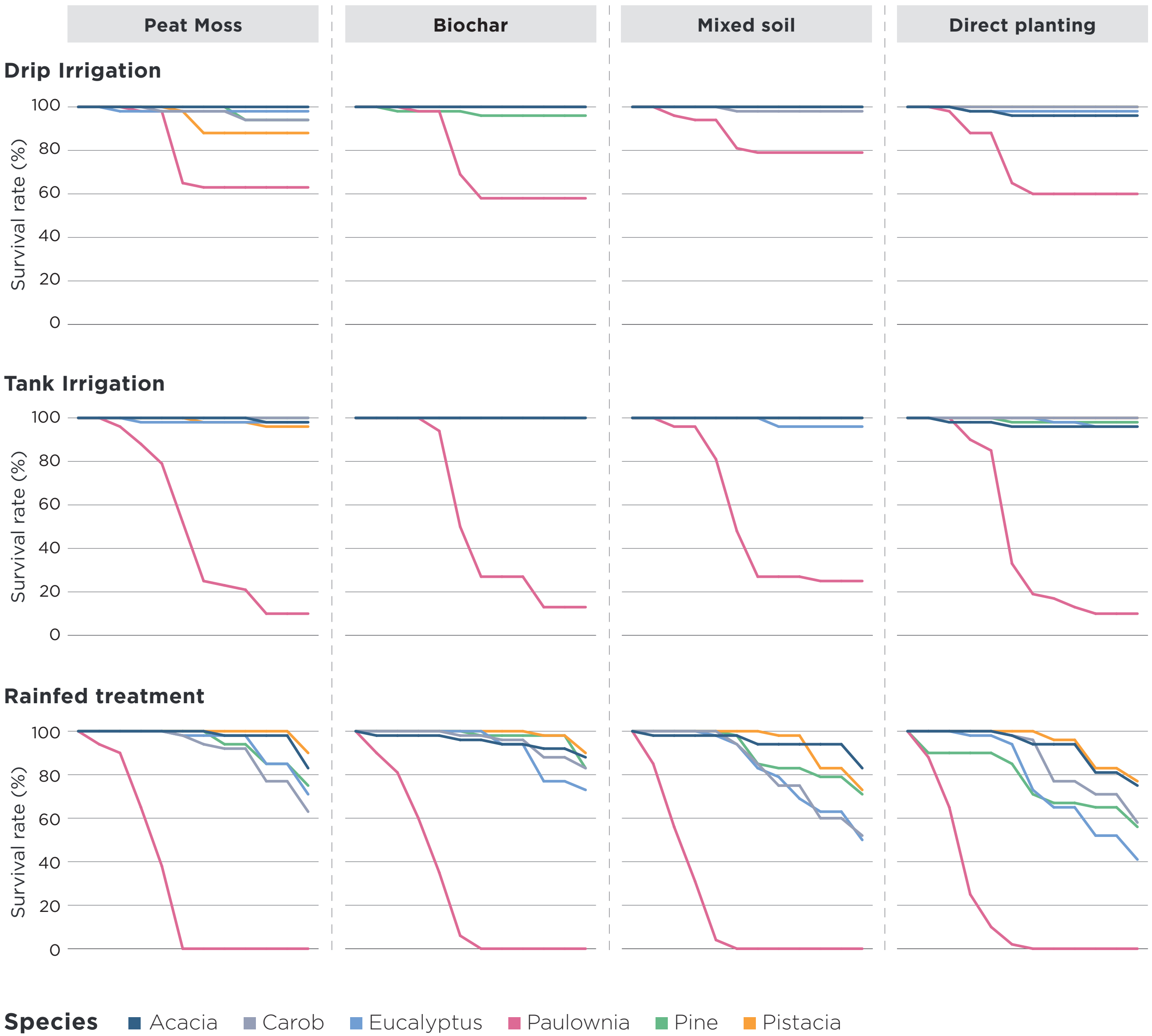
For the most part, the studied species adapted well to the region's harsh conditions and the low amount of irrigation provided. The only exception was paulownia, which showed a very high mortality rate even in the best of the experimented water and soil conditions.

Both drip-irrigated and tank-irrigated treatments showed high survival rates compared to relying solely on rainfall. These irrigation methods kept the survival rate over 90%.

Soil amendments did not play a significant role in seedling survival when irrigation was used but proved beneficial in non-irrigated conditions. Forestry services in arid and semi-arid zones could therefore use these findings to increase the success of afforestation and reforestation efforts where irrigation is infrequent. However, a cost-benefit study is needed to assess the expense of the organic amendments.

Another important parameter to monitor was the development of the soil organic matter over the three years of the study. We found that the added peat moss did not stabilize and degraded over time, particularly in drip irrigation, where the soil consistently stayed humid. In contrast, biochar demonstrated its stability as a form of carbon and could constitute a long-lasting carbon sink in irrigated forestry projects in arid areas.

Planted species survival rate over 28 months in treatment



Biomass carbon sequestration

As for the carbon sequestration potential of the various studied combinations, across all irrigation and soil amendment combinations, eucalyptus and moringa showed the highest sequestration levels two years after planting.

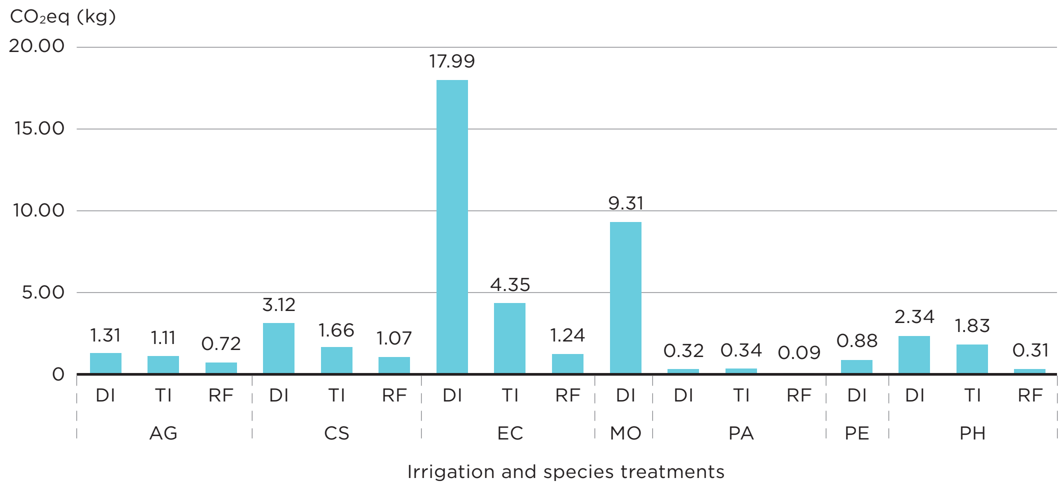
While carob and pine trees had lower sequestration values, they showed potential to sequester more carbon in the future using the same water levels. This is due to the fact that, gauging from their height and diameter development, they were still in the fast-growing phase.

The unit of measure tn CO_2eq/ha refers to the amount of carbon dioxide equivalent (CO_2eq) that is sequestered or stored in a given area of land, typically measured in metric tons (tn) per hectare (ha).

When the sequestration level per area is extrapolated using a stand density of 750 to 1,250 plants per hectare, in the first two years, sequestration levels could reach 13.5 to 22.5 tn CO_2eq/ha for eucalyptus, 7 to 11.6 tn CO_2eq/ha for moringa, or 2.3 to 3.9 tn CO_2eq/ha for carob trees.

These results show that forests or agroforests in dry areas could constitute a significant carbon pool over time.

Carbon sequestred in the biomass per tree – 2021

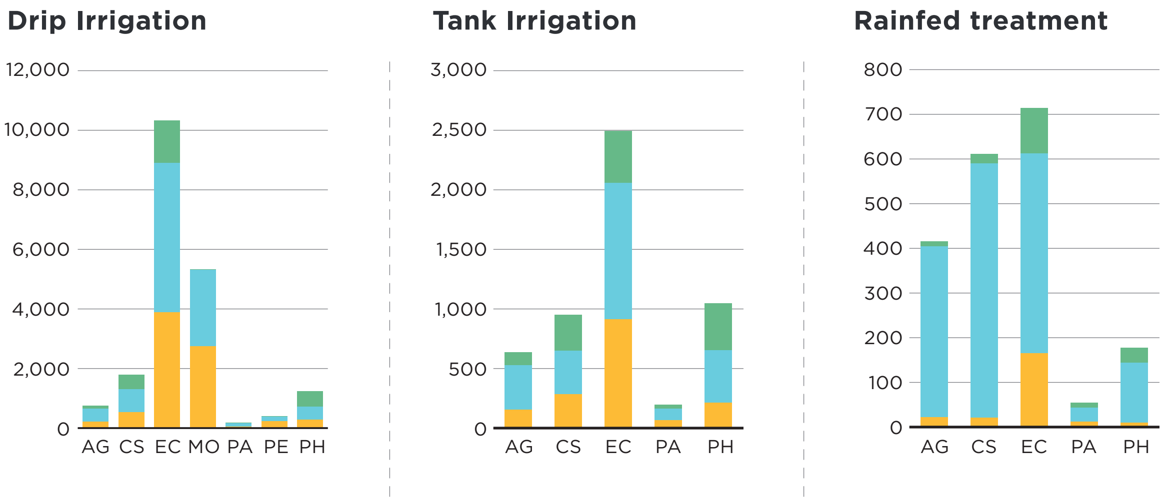


Carbon sequestered from April 2019 to mid-2021
DI: drip irrigation, TI: tank irrigation, RF: rainfed, no irrigation
AG: Acacia, CS: Carob, EC: Eucalyptus, MO: Moringa, PA: Pistacia, PE: Paulownia, PH: Pine

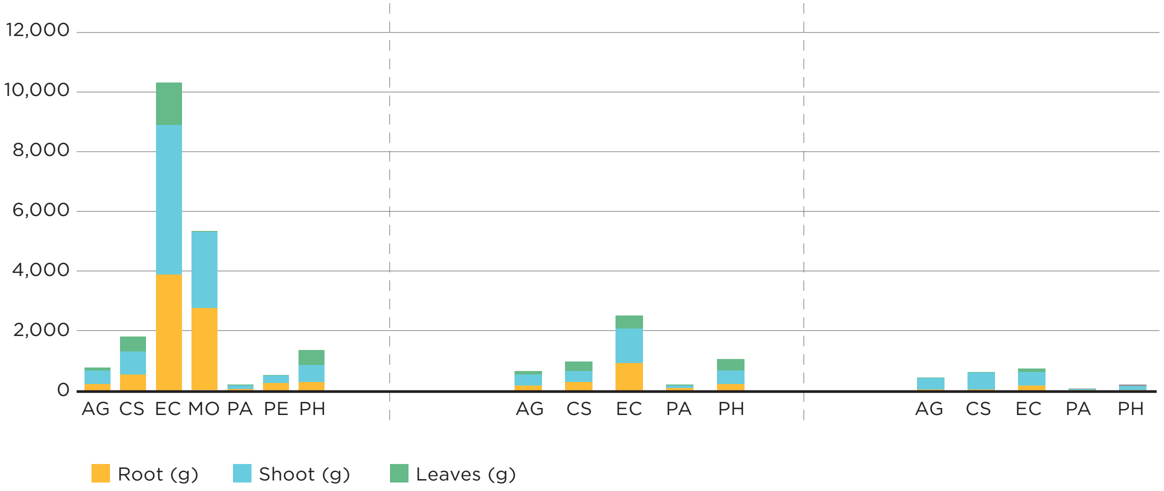
Sequestration level per area in the first two years.

Stand density	750 trees/ha	1,250 trees/ha
Eucalyptus	13.5 tCO_2/ha	22.5 tCO_2/ha
Moringa	7.0 tCO_2/ha	11.6 tCO_2/ha
Carob	2.3 tCO_2/ha	3.9 tCO_2/ha

Biomass dry weight developed in the first two years after planting



Diagrams above are the same as below, but they are presented on the same Y-axis scale.



Biomass dry weight developed the first two years after planting per tree organ, species, and treatment.
AG: Acacia, CS: Carob, EC: Eucalyptus, MO: Moringa, PA: Pistacia, PE: Paulownia, PH: Pine

Regarding carbon distribution among the tree organs, most of the carbon is sequestered in the stems or in the root system, although the roots may have higher levels than reported due to fine roots lost during sampling.

Water use efficiency for carbon sequestration

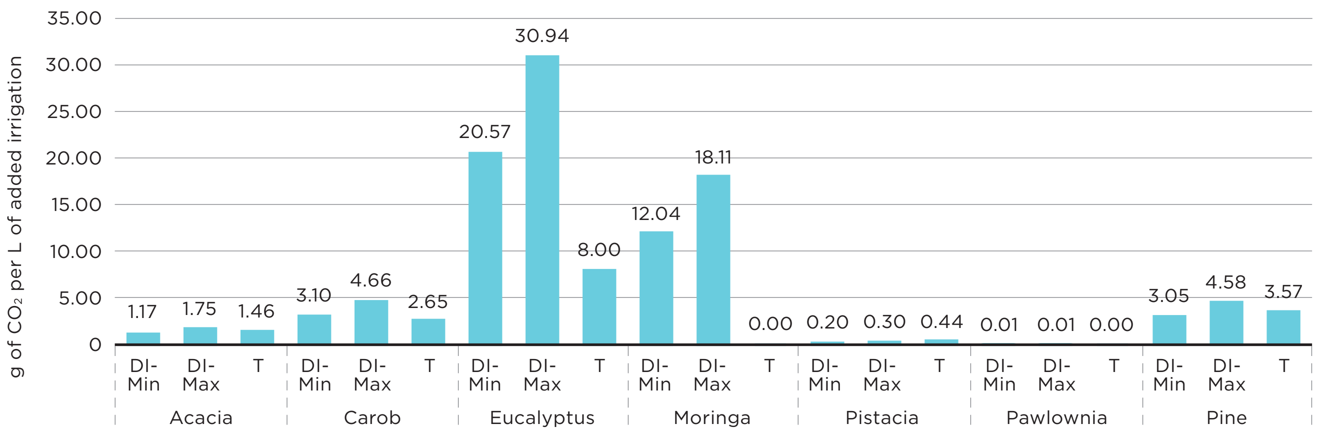
The study also examined water use efficiency for carbon sequestration, which refers to the amount of carbon that can be captured and stored for a given amount of water used. Factors affecting this efficiency include plant species and growing conditions.

As for sequestered carbon, eucalyptus trees were the most efficient, followed by moringa trees, while pistacia had the lowest water use efficiency due to its slow growth.

Regarding irrigation methods, sub-surface drip irrigation was mainly the most efficient. In a scenario where water is traded for carbon, this would translate to various costs to sequester 1 ton of CO_2 depending on the plant species and type of desalinated water used. However, with current numbers, the water cost to sequester 1 ton of CO_2 in the best combination, in other words, eucalyptus in drip irrigation, could vary from 9.7 to 19.4 € and from 16.7 to 33.3 € for the second-best option, moringa.

To explore more possibilities to conserve water even further, the Growboxx was tested on four species, and the results showed significant advantages over the other treatments regarding water-use efficiency when irrigated. However, the solution provided no advantage when relying on rainfall alone. In the tank irrigated treatment, the seedlings' height from the Growboxx treatment was generally on the same level or slightly lower than the other soil treatments despite receiving only 34% of the water volume, showing the high water use efficiency that can be achieved through these boxes.

Water use efficiency per species and irrigation treatment during 2020-21



Different tree types, starting from the left: eucalyptus, pine, acacia, and moringa. The crop type in the front is common wheat.

Small scale agroforestry trials

Finally, an agroforestry trial was conducted in drip-irrigated plots to assess how trees affect the yields of four crops: quinoa, fava bean, peas, and common wheat. Results showed that the soil type and the distance between the crops and trees significantly impacted the yields.

The two promising crops, quinoa and fava bean, showed higher yields around pistacia and pine, while the lowest yields were observed around *Eucalyptus camaldulensis*, which was a general trend.

Based on these findings, the study therefore recommends that to support afforestation efforts with crops in a dry environment, it is best to plant quinoa or fava beans around pine, moringa, or pistacia trees while avoiding planting near eucalyptus trees.

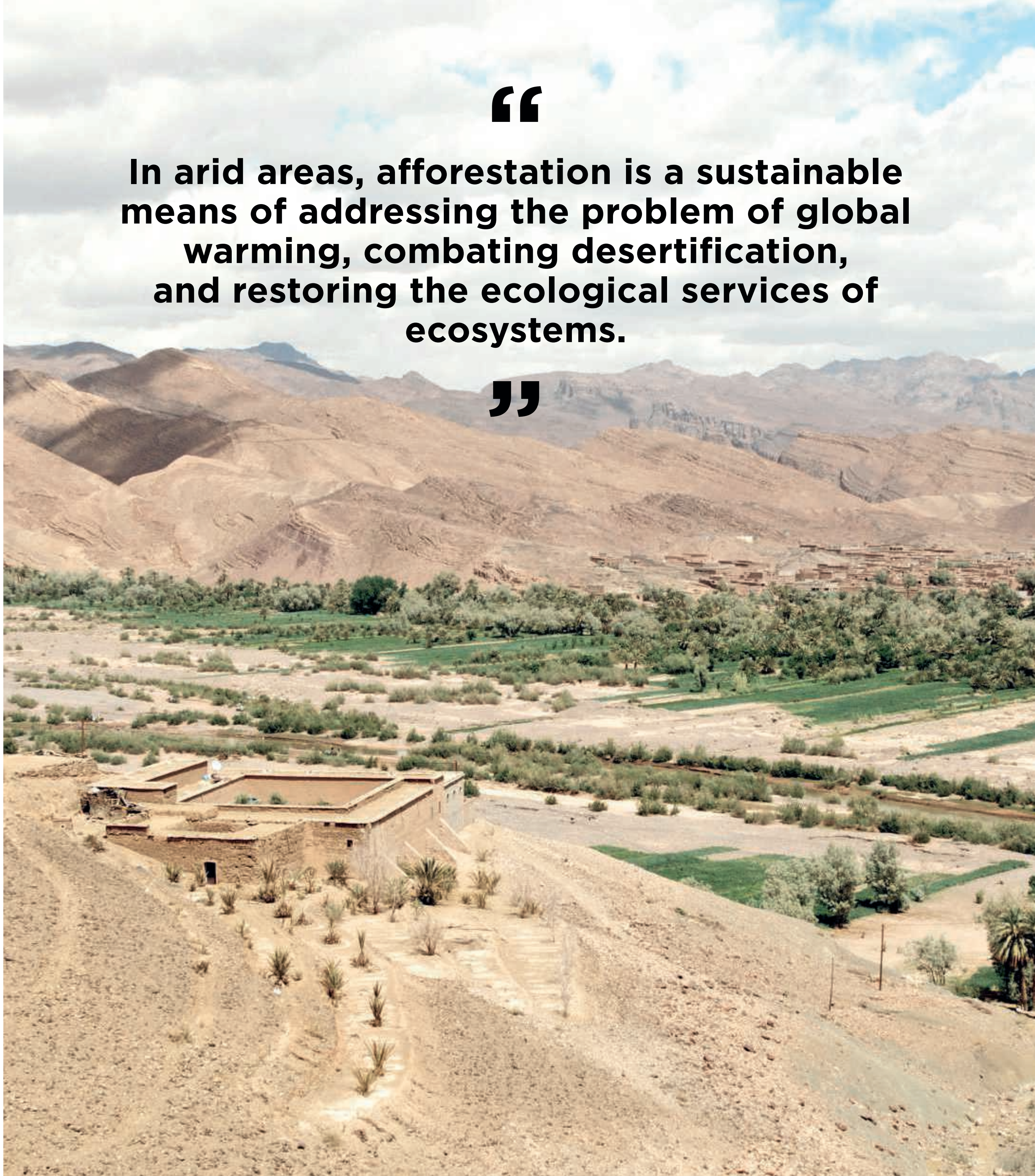
Carbon sequestration with multi-faceted agricultural value

The results of the pilot showed that a carbon farming project through afforestation in arid areas is a viable solution for carbon sequestration.

While eucalyptus emerged as the top choice for carbon sequestration in irrigated dry ecosystems, it is highly water-competitive and can limit plant bio-diversity and crop growth in agroforestry systems.

Because the aim of a carbon farming project would be to deliver benefits beyond carbon sequestration, multi-species systems that provide agricultural value locally are recommended. Species like moringa and carob, which showed a lower carbon sequestration potential, provide other products. For example, moringa is cultivated for its young seed pods and leaves, which serve as vegetables. Carob yields locust bean gum, which is used as a thickening agent in food technology. Moreover, these species appeared less water competitive and better adapted for agroforestry, increasing the provided ecosystem services.

To maximize carbon sequestration and production, mixed systems with moringa and carob as the main tree coupled with shrubs, other perennial crops, or quinoa and fava beans in alleys could be considered. Eucalyptus trees could be used as windbreakers.



Next steps: optimizing growth and water use

Additional studies are needed to optimize the tree species' growth and improve the water-use efficiency of the system. In fact, a more thorough experiment primarily focusing on irrigation levels, frequency, and distribution is needed.

In addition, the use of the studied soil amendments in sandier soil should be explored, since there is an increased need for soil water-holding capacity improvement in such soils. Additional confirmation studies are needed to verify the results found in the agroforestry experiment. Also, more crops need to be tested to widen both our understanding of the crop and tree interaction and provide farmers with more options between trees.

Global value and local profitability

In arid areas, afforestation is a sustainable means of addressing the problem of global warming, combating desertification, and restoring the ecological services of ecosystems. Therefore, trees need to be integrated within the framework of restoration and desertification control programs in areas with low production potential, making these fragile environments profitable through different pathways, including the carbon market. Moreover, woody plantations can contribute to food security and supply various products and services.

A solid starting point for future carbon sequestration projects in arid areas

The collaboration between St1, Mohammed VI Polytechnic University, the Natural Resource Institute of Finland, and OCP Group has been a success, and we can all agree that we have completed a meaningful project. While each of the project partners brought valuable expertise, the learning curve was steep for all parties involved. We – quite literally – dug deep to create a solid starting point for future carbon sequestration projects in arid areas.

We believe it is crucial to take steps and cooperate internationally with different actors to find solutions to climate change and other environmental and humanitarian crises we are facing. We would especially like to show our gratitude to Mohammed VI Polytechnic University for all the hard work and effort their organization has invested into the project.

The keen interest in our endeavour has only grown in the years that the project has operated. We are pleased to have been able to share our discoveries earlier in the project and to do so as well now, with our final results.

Furthermore, we are delighted to report that the results reported here are not the end of this research. Mohammed VI Polytechnic University will continue to take measurements in the project area, and we will gather more information in the coming years.

We are grateful for the funding for this project provided by the Business with Impact (BEAM) program of Business Finland. We also warmly thank all our stakeholders, business partners, and other parties who have contributed to this worthy endeavour and shown interest in this crucial topic.

We look forward to a promising future for forestation efforts in arid areas.

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