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Transforming High Altitude Barren Lands into Climate Resilient Assets

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ABSTRACT

The rapid growth of the global population, the progressive depletion of water resources, and the loss of arable land pose critical risks to food security, necessitating the creation of new production areas and efficient resource management. Mountainous terrain at altitudes of 1750-2000 meters, traditionally classified as unsuitable for agriculture due to rocky soil, high lime content, and harsh climate conditions, offers a strategic advantage; the long winter delays vegetation development, thereby mitigating the risk of spring frost, a phenomenon increasingly observed in low plains, while perfectly meeting the specific chilling requirements of the Malatya apricot. The soil was improved through the addition of sulfur and leonardite; in the absence of natural water sources, the orchard survived without external irrigation, relying on rainfall and passive atmospheric moisture, avoiding the need to pump 35 million liters of water seasonally. The methods achieved a 95% sapling survival rate. The project's success was validated by the first symbolic harvest in 2024; more importantly, following the 2023 earthquake, this micro scale trial expanded to a 10,000 tree projected biological carbon uptake of approximately 226 tons of CO_2 annually at full maturity. The results show that previously idle land can become a productive agricultural asset under these conditions.

INTRODUCTION

Following the 2023 earthquakes, Kahramanmaraş, Malatya, and certain other cities in the Southeastern Anatolia region faced critical socioeconomic challenges. Traditional lowland agriculture is becoming increasingly unsustainable due to climate change and high water demand, estimated at approximately 1000 mm annually.[1] Until now, apricot cultivation has been concentrated at altitudes below 1500 meters.[2] Above this threshold, TARSIM conducted trials in the 1500–1750 meter zone, indicating that this belt could serve as an alternative regarding frost risk.[3] However, current studies and field data continue to focus on elevations below 1750 meters.

Our project and research activities are situated beyond these established limits, specifically within the 1750–2000 meter range.

The difference between the 1750 mt and 2000 mt elevations represents not merely a topographical distinction but also a strategic advantage. The bioclimatological principle known as Hopkins' Bioclimatic Law states that every 100 meter increase in altitude delays vegetation development by approximately four days.[4] Every 1°C drop in temperature results in a shift of roughly one week in the phenological calendar.[4] As the project site is located approximately 150 meters above the 1750 meter threshold emphasized in existing literature, the estimated flowering period shifts by 10–12 days, thereby placing the phenological cycle outside the critical window for April frosts. In summary, the 1750–2000 meter belt serves as a strategic buffer zone against climate related thermal fluctuations for apricot cultivation in Malatya.

The Malatya apricot, belonging to the Prunus genus within the Rosaceae family was registered with an EU Geographical Indication in 2017 [5]; the key to its yield stability lies in its requirement for a chilling period of up to 1,000 hours at temperatures below 7.2°C during winter. This prolonged chilling requirement is a biological evolutionary mechanism essential for breaking endodormancy, regulating the synthesis of growth inhibitors such as abscisic acid, and activating gibberellins to ensure proper bud development. As a result of climate change, low plains increasingly fail to meet these thresholds, whereas the study area naturally guarantees these critical thermal hours. Beyond apricots, this model holds potential for scaling to other high value "*Prunus*" species; for instance, small scale trials indicate that almond trees, which share similar ecophysiological resilience profiles but require fewer chilling hours (up to 600), can be cultivated using passive water harvesting and leonardite sulfur soil amendment methods.
Rising global temperatures and declining precipitation are leading to the increasing over irrigation of plains used for traditional agriculture. Recent analyses show that the increasing use of artesian irrigation disrupts soil mineral balance and causes anoxia in the root zone, thereby inhibiting sapling development and driving salinity levels up by as much as 100%. In recent decades, dramatic drops in groundwater levels have necessitated deeper drilling operations.[11] When high mineral and salt concentrations in irrigation water combine with excessive irrigation and high evaporation rates, these salts accumulate on the surface, poisoning the topsoil and triggering irreversible chemical degradation.[12]

To break this destructive irrigation cycle and eliminate reliance on groundwater, this study employs a Passive Atmospheric Water Harvesting model. By capturing ambient moisture generated by diurnal temperature fluctuations, it operates within a zero irrigation framework.[14,20] This approach isolates root systems from salinization related with artesian water irrigation.[12] Another constraint involves issues related to sulfur application in highly calcareous and alkaline soils (pH > 8.0). These conditions hinder plant growth by severely limiting the bioavailability of essential micronutrients such as iron, zinc, and manganese.[10] The microbial oxidation process requires the activation of powdered sulfur [15], a step that can be optimized through the water retention capacity provided by humic acids, which also enhance the soil's moisture retention.[16] A comparative study evaluating soil amendments demonstrated that leonardite performed more consistently and effectively than alternatives like biochar and vermicompost in lowering pH and increasing soil moisture retention.[17] Data regarding the performance of all these regulators under extreme conditions such as dryland farming at altitudes reaching 2,000 meters are not available in the existing literature.

One of the biggest advantages of the project site is its proximity to the Afşin Elbistan lignite deposits, allowing locally available raw leonardite to be used as a low cost soil amendment. The leonardite mineral occurs as an overburden layer atop lignite seams. Classified as industrial waste that reduces coal combustion efficiency and thus requires removal, it is also one of the most significant natural reservoirs of humic and fulvic acids for agricultural use. Strategically converting these abundant mineral deposits into low cost agricultural inputs stabilizes nutrient uptake in high lime environments, enhances carbon sequestration, and overcomes key financial barriers highlighted by Engin and Cöcen[18]. This approach addresses the reclamation of unproductive lands by transforming mining waste into valuable soil amendments. While existing literature extensively covers lowland apricot phenology and standard soil amendment methods, there remains a critical gap regarding agricultural models that integrate zero irrigation practices with industrial waste recycling.

Consequently, this study fills this gap by evaluating the feasibility of reclaiming marginalized high altitude areas through dryland farming as a strategic model for regional agricultural revitalization.

GOAL OF THE PROJECT

The main objective of this project is to transform unproductive, mountainous terrain, currently classified as marginal highland, placed at an altitude of approximately 2,000 meters, into a productive dry farming orchard. By implementing integrated rehabilitation strategies, the project seeks to establish a climate resilient ecosystem capable of supporting high value crops. Beyond ecological innovation, the initiative aims to turn rocky terrain into a living oasis and restore land productivity, and carries a socio economic motivation driven by regional recovery responsibility after a disaster. The project site consists of fragmented land featuring soil pockets nestled between rocky outcrops, accumulations of soil formed over centuries of erosion. Traditional agriculture, practiced in this region for generations, had previously been abandoned due to harsh climatic conditions and high soil alkalinity.

To validate this model, the study seeks to answer the following fundamental questions:

1. How can the combined application of elemental sulfur and the humic and Fulvic acids in leonardite improve the pH balance and nutrient availability of soil with extremely high lime content? [17]
2. At high altitude, apricot trees bloom later. How can this “late blooming” characteristic be used as a strategic advantage to bypass the increasing frequency of spring frosts caused by climate change?[6]
3. Apricot trees normally need about 1,200 mm of water annually. How can they survive on only 450–500 mm of natural rainfall, without external irrigation? [1]

Figure1: Transformation of steep, rocky and previously uncultivated high altitude land into an apricot orchard

METHODOLOGY

This project started with a research phase initiated before the 2023 earthquake disaster. Initial feasibility analyses were conducted in 2021 to map the nutrient profile and alkalinity of the marginal land. These initial analyses indicated high pH and high calcium carbonate levels, prompting the development of a soil amendment strategy centered on leonardite and sulfur. The project progressed to the conceptual testing phase in 2022; the 2023 earthquakes drove the project to expand the scope to include a socio economic rehabilitation phase.

Site Selection, Land Reclamation, and Soil Analysis

The study area was selected on a steep, fragmented hillside ranging from 1750 to 2000 meters in elevation; rather than a uniform plain, it was a mosaic of rocky outcrops interspersed with scattered pockets of soil formed by centuries of erosion. Historically, these micro zones had been suitable for agriculture, though they were later deemed unsuitable due to high lime content and rocky terrain. Thousands of tons of stone were removed during land preparation. Instead of being discarded, these stones were repurposed for traditional stone house construction and terracing.

Soil samples collected from various points across the site were analyzed; the results confirmed a high pH value of approximately 8 and a lime content of around 20%, alongside insufficient organic matter. To overcome these soil limitations, a two stage reclamation strategy was implemented:

1. Elemental Sulfur: Added directly to the soil matrix to lower alkalinity and enhance nutrient uptake.
2. Leonardite: Added into each planting hole to balance soil chemistry and increase water retention capacity.

Infrastructure and Energy Solutions

Energy: Off grid solar power system supported all essential facility operations by meeting daily residential needs, powering water purification, and handling the charging cycles for battery charged agricultural equipment.

Water and Resource Management: Local water sources are extremely scarce. The capacity of the historic Roman or Byzantine cistern located in the center of the plateau is strictly limited to 3 tons. Water purified through reverse osmosis and carbon filtration systems is used exclusively for hygiene and drinking purposes.

Sapling Selection and Risk Management

Sourcing traditional commercial saplings was deemed unsuitable due to adaptation issues and high costs. Following the failure of the initial trials due to cold shock, the preference was for smaller, 1 to 2 year old saplings sourced from local vendors, as they possess superior adaptability. A trenching method was employed to ensure survival under harsh conditions; the saplings were kept underground during winter prior to permanent planting to facilitate gradual acclimatization. This approach offered a 70% cost advantage compared to large commercial saplings and promoted faster root development despite limited water resources. The selected varieties, Hacıhaliloğlu and Kabaaşı, are known for their cold resistance, high yields and high dry matter content, making them ideal for drying.

Project Timeline and Phased Implementation

The project's implementation phase spanned three years. It began in 2021 as a school based initiative involving 500 saplings and associated analysis. Following the earthquake disaster in 2023, the project expanded to include four local families who owned land, enabling them to establish their own production areas. The total number of trees and the cultivated area reached 10,000 trees. The primary objective is to transform the model from a private orchard into a regional employment program by hiring local seasonal workers.

Year	Phase	Key Development
2021–2022	Research & Pilot	Soil analysis and initial trial planting
2023	Expansion	Infrastructure development and planting of 1,000 saplings
2024	Social Scaling	Expansion to four local families and approximately 10,000 trees
2026	First Commercial Harvest	Approximately 2 tons of fresh apricots harvested

Table 1: Project Timeline

A catastrophic frost event in 2025 affected commercial apricot production across Türkiye. As of August 2026, the first commercial harvest was completed, producing approximately 2 tons of fresh apricots. Older trees reached fruit bearing age, with individual yields generally ranging between 1 and 5 kg. The younger trees, currently 1–2 years old, have not yet entered the fruit bearing stage.

Planting and Zero Irrigation Strategy

Phenology and Climate Modeling: Regional meteorological data were used to analyze frost risk and temperature fluctuations. Due to the absence of an active meteorological station directly on the project site, data from the nearest official station were integrated into the climate model by applying the environmental adiabatic lapse rate. A 10m x 10m planting grid was implemented across the orchard to maximize sunlight exposure and ensure adequate air circulation.

Passive Water Harvesting and Moisture Retention: This project establishes a strict "Zero Irrigation" model that eliminates reliance on pumped groundwater or external water infrastructure. In this model, external irrigation has been replaced by passive water harvesting and soil cultivation, performed both mechanically and manually. At an altitude of approximately 2,000 meters, rapid atmospheric cooling causes ambient moisture to condense; the leonardite amended soil captures this moisture, creating a localized micro irrigation cycle directly within the root zone. Without the high moisture retention capacity of this leonardite mixture, the captured morning dew would rapidly evaporate under the sun's rays. To further preserve this moisture, the soil is cultivated twice a year to disrupt capillary channels and prevent the evaporation of subsoil moisture. [10] This structural moisture stress forces root systems to penetrate deeper into the substrate, establishing a robust root architecture.[11] Within this zero irrigation framework, energy consumption for water supply is limited to the preparation of pest control. As no irrigation is applied, the trees survive entirely on 450–500 mm of annual rainfall and natural dew formation. To verify local microclimate conditions, data loggers were installed at various points across the site, enabling comparative analyses to develop a precise, site specific climate model. Figure 3 shows the marked diurnal temperature variation at the project site compared with the Elbistan plains. Figure 4 provides direct temperature and relative humidity measurements indicating nighttime conditions favorable for dew formation.

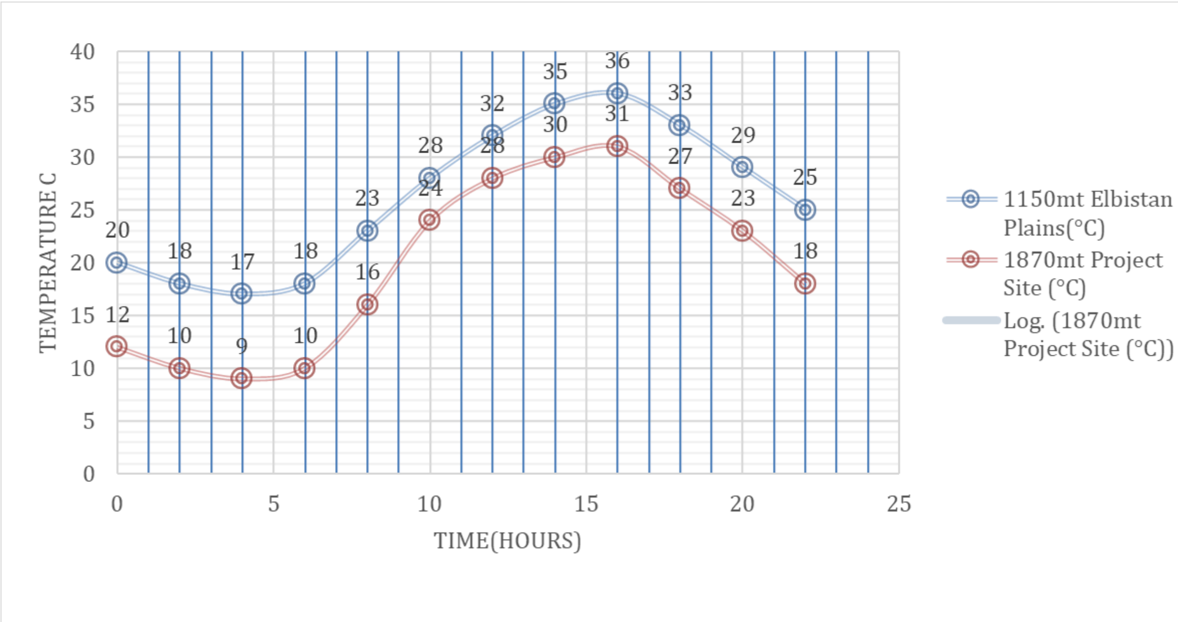

Figure 2. Microclimatic diurnal temperature fluctuations (6:00 AM–10:00 AM) monitored via on-site data loggers across the 1750–2000 m belt, demonstrating the rapid thermal transition that drives intensive dew formation

Another moisture harvesting method observed empirically involved the stones found on the site; this process relied on the shading effect and the fact that the stones did not synchronize with the soil regarding temperature fluctuations, thereby facilitating condensation.

June 2026 measurements recorded with an Elitech temperature and humidity logger showed increasing relative humidity and decreasing temperature during nighttime. The data indicate high potential for dew formation between approximately 21:00 and 05:00, when temperature approached the dew point and relative humidity reached its highest levels.

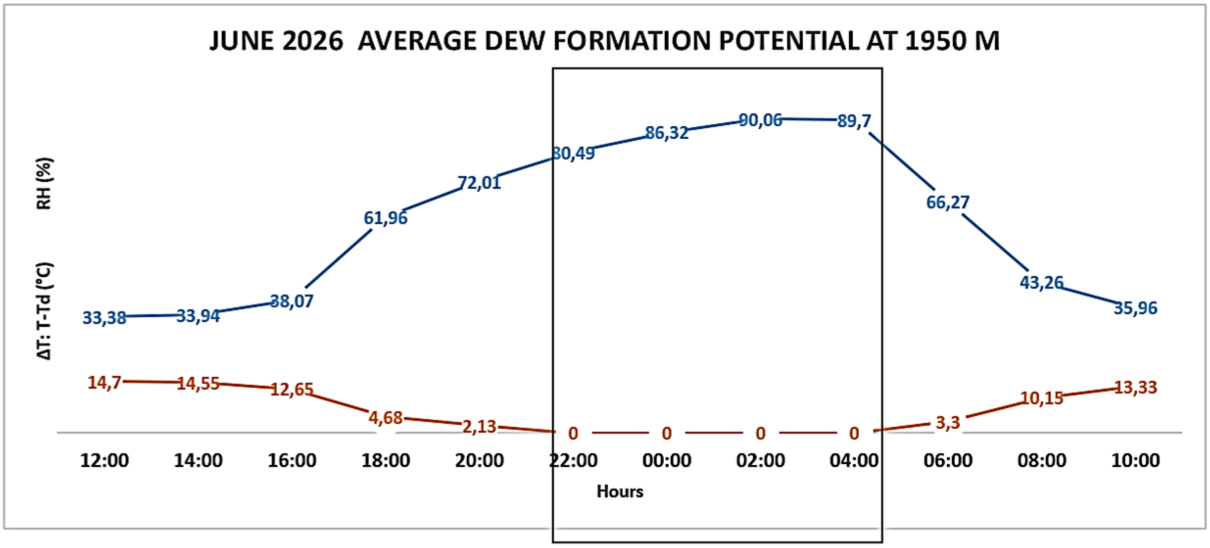

Figure 3: Average dew formation potential at 1,950 m in June 2026, based on Elitech temperature and relative humidity measurements.

Ecosystem Engineering and Social Innovation

The high altitude of the project site and the sparse surrounding natural forest and vegetation limit the number of natural pollinators. Although apricot trees are self pollinating, research confirms that honeybees significantly enhance fruit set and quality through cross pollination. To address this ecological constraint, a beekeeping operation was initiated with a single hive and expanded through natural swarming. By the third year, the operation had grown to eight hives, yielding 200 kg of honey.

Figure 2. Off.grid infrastructure: The high thermal mass stone house constructed from cleared site rocks, equipped with a rooftop photovoltaic solar power system.

Soil Improvement Strategy

The soil improvement strategy was formulated based on comprehensive laboratory soil analysis reports. These reports identified critical deficiencies in organic matter and high alkalinity as the primary factors hindering cultivation. In line with expert recommendations, leonardite was incorporated into the remediation process. According to the soil analysis reports, the application of leonardite in conjunction with elemental sulfur served three critical functions

1. Humic acids act as natural chelating agents, ensuring the bioavailability of nutrients despite high lime content.
2. They improve the soil's water holding capacity; this forms the technological backbone of our dry farming model.
3. It initiates long term ecological recovery by stimulating microbial activity.

The functional mechanism of the leonardite mixture is illustrated in Figure 4. Under highly alkaline conditions, carboxylic and phenolic groups derived from humic and fulvic acids form negatively charged reactive sites. This ionization triggers a robust Cation Exchange Capacity mechanism; the high density of negative charges sequesters excess calcium (Ca) and magnesium (Mg) ions, thereby preventing the formation of insoluble carbonate precipitates that would otherwise bind the soil. (Figure 4)

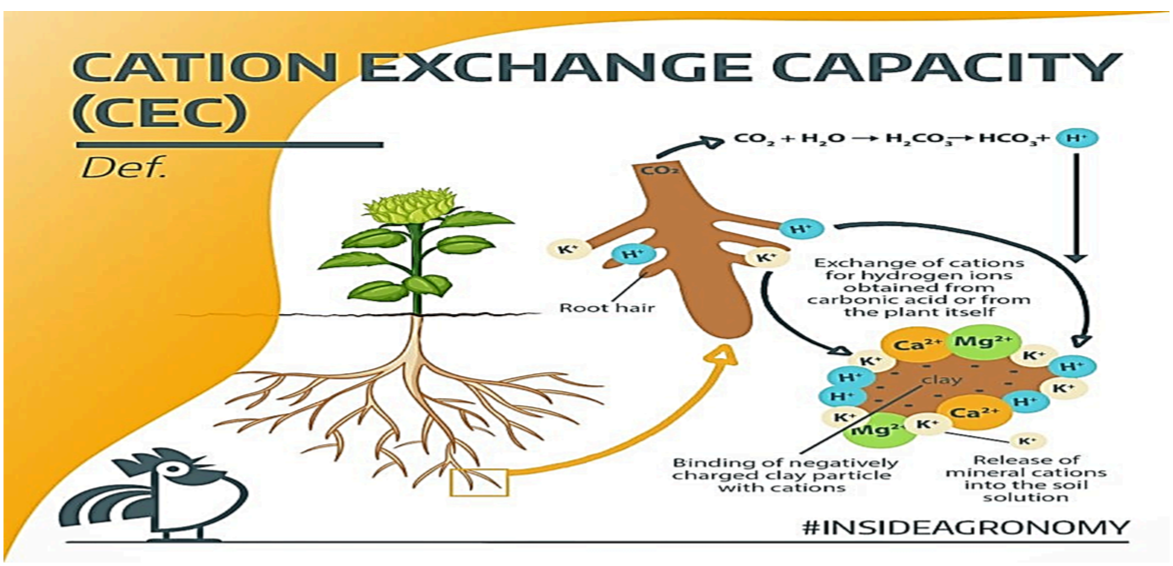

Figure 4. Operational chemical mechanism of the leonardite

As shown in the chemical equations in Figure 4, the interaction between dissolved carbon dioxide and water generates carbonic acid and free hydrogen (H) ions. The release of these hydrogen ions provides a localized pH buffering capacity directly within the rhizosphere. By binding dominant cations and lowering the pH, this mechanism unlocks vital nutrients, accelerating the bioavailability and root uptake of essential potassium (K) ions, while maintaining significant water holding capacity in the root zone.

Leonardite is a mineral extremely rich in organic matter, formed through the oxidation, under pressure of plant and animal remains that did not fully carbonize during the millions of years long process of lignite coalification. The combined application of sulfur and leonardite balanced excessively high lime content and alkalinity, facilitating nutrient absorption and enhancing water holding capacity.

	Leonardite		Plain Soil	
DAY	CT	DR	CT	DR
6th day	6,67	6,1	7,18	4,53
9th day	7,58	6,82	6,22	5,8
12th day	7,88	6,78	6,32	6,28

Table 2: Leonardite and Plain Soil Moisture Measurements

CT = Control Treatment   DR = Drought/Water Restriction

The water retention role of leonardite is supported by time dependent soil moisture measurements using a HOBO H21-002 Micro Station data logger equipped with a 10HS soil moisture sensor. In this experiment, soil moisture in the upper 5 cm was measured 6, 9, and 12 days after the beginning of water restriction. Leonardite added soil maintained higher moisture levels than plain soil. These results provide experimental support for the use of leonardite to improve the retention of limited water inputs under dry conditions.

Economic Framework

The project's economic foundation rests on resource efficiency and strategic asset management. Through the reclamation of marginal upland areas, ecologically challenging terrain is transformed into productive agricultural assets. A key driver of financial sustainability is the zero irrigation policy, which eliminates the need for costly water infrastructure and pumping, thereby reducing annual operating expenses by approximately 70% compared to traditional orchards. In summary, the direct capital expenditure amounts to 106,700 USD, a remarkably low figure for establishing this ecosystem.

RESULTS

1. Soil Stabilization and Tree Survival: The initial 500 test saplings planted in 2022 were the learning period and 220 sapling deaths are excluded from the final data calculations. While the project volume expanded to approximately 10,000 trees with the participation of extended family

members, the survival analysis was conducted with our monitored group, which reached 3,000 trees by 2025. Challenges such as cold shock and salinity associated with artesian irrigation led to adaptive methods including zero irrigation practices, mechanical netting to protect against rabbit damage, and trench burial to facilitate cold adaptation. Annual survival records for this group between 2023 and 2025 showed an overall survival rate of approximately 94.6%. The 90 trees lost in a 2024 forest fire were separately recorded as catastrophic external losses. No control group receiving no intervention was established; consequently, these survival results reflect the performance of the integrated management system rather than the isolated effects of leonardite or sulfur.

2. Comparative Analysis of the Land Reclamation Strategy: Each year, soil samples were collected from multiple points across the area and mixed to represent the overall soil conditions; the samples taken from 30-40 cm depth were tested by accredited laboratories. Soil pH, salinity, lime content, and organic matter were analyzed using standardized laboratory methods TS 8334:1990, TS EN ISO 10693:2014, and TS 8336:1990. Three representative soil analysis reports from 2021, 2022, and 2026 were selected for comparison. This comparative approach (Figure 5) allows us to move beyond static data and best reflects the soil's response to the interventions.

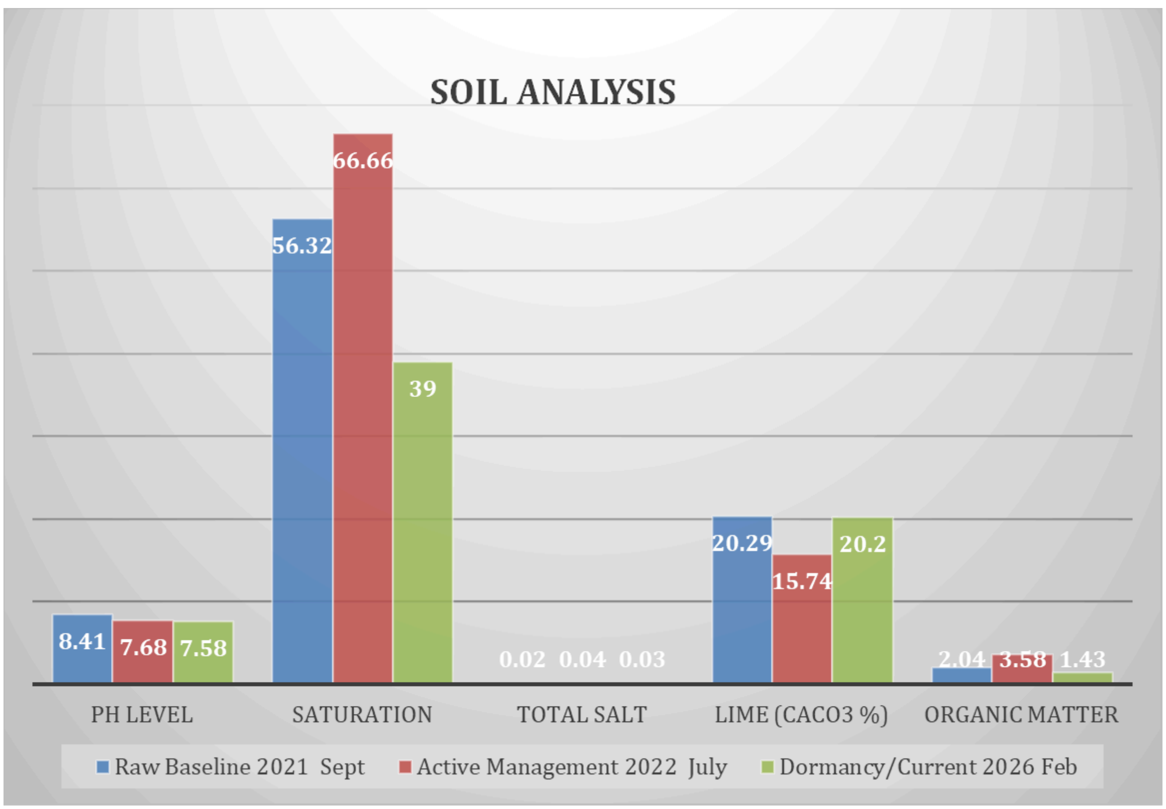

Figure 5. Soil Reclamation Analysis tracking pH, saturation, active lime, and organic matter across three distinct orchard lifecycle phases from 2021 to 2026

• pH Level Analysis: The reduction from a highly alkaline 8.41 to a near neutral 7.58 represents a major success of the project. The 2026 data indicate that the application of sulfur has created a lasting buffering effect.

To illustrate the full chemical magnitude of this pH reduction, the logarithmic variation in hydrogen ion concentration [H+] is quantified using the fundamental soil chemistry equation

$$\mathrm{pH} = -\log_{10}\left[\mathrm{H}^{+}\right]$$

Baseline Concentration (2021): $\left[\mathrm{H}^{+}\right]_{2021} = 10^{-8.41}\ \mathrm{mol/L}$

Final Concentration (2026): $\left[\mathrm{H}^{+}\right]_{2026} = 10^{-7.58}\ \mathrm{mol/L}$

Logarithmic Shift Factor: $\frac{\left[\mathrm{H}^{+}\right]_{2026}}{\left[\mathrm{H}^{+}\right]_{2021}} = \frac{10^{-7.58}}{10^{-8.41}} = 10^{0.83} \approx 6.76$ Times Fold

• Active Lime (CaCO3) Analysis: As expected, the lime content remained relatively stable over the study period, reflecting the structure of the region. The soil management strategy was not intended to reduce the total lime content, but rather to mitigate its adverse effects on nutrient availability .A notable point here is that, despite the high lime content, no typical lime induced chlorosis was observed.[10]

• Organic Matter Analysis: The rise to 3.58% in 2022 demonstrates the effectiveness of leonardite and organic fertilization, while the drop to 1.43% in February 2026 represents the organic fuel consumed by the saplings during the growing season, an expected biological outcome.

• Saturation Analysis: The decrease to 39.00% indicates a shift toward sandy loam soil characteristics during dry/cold months. This is ideal for our dry farming model; it prevents waterlogging during winter snowmelt, while the moisture retention properties of leonardite may contribute to maintaining moisture around the root zone.[10,17]

•Total Salt Analysis: Results were recorded at 0.02% and 0.04%; the soil is classified as non-saline. Soil salinity initially increased from 0.02% to 0.04% during the period of artesian irrigation, later decreased with the zero irrigation strategy, and remained within the non-saline range during the monitoring period.

3) Frost Risk: The high altitude climate delayed the trees' flowering period by approximately 3–4 weeks compared to the Malatya plains. This phenological shift confirms the hypothesis following the

catastrophic frost event of April 2025. While apricot orchards at lower altitudes suffered massive blossom loss and subsequent crop failure due to early season frost, flowering in the project area began in late April, falling outside the frost window.[13]
In 2024, the initial test area yielded a symbolic total of 150 kg of produce across the orchard. In 2025, pollination failed to occur due to extreme cold, resulting in no fruit production; however, not a single tree died from the frost. On the contrary, growth and shoot development were observed in the trees as spring arrived.

4)Comparison of Mechanical Tillage and Irrigation: By implementing a zero irrigation policy and preserving existing soil moisture through mechanical tillage, significant energy and cost savings were achieved by avoiding the pumping of approximately 35 million liters of water per season. This figure is based on a conservative agricultural benchmark of 3.5 m^3 of annual water requirement per tree for 10,000 apricot saplings.

5)Carbon Sequestration and Water Conservation: The planting of approximately 10,000 apricot trees has created significant carbon sequestration potential. According to published studies on the subject, the annual carbon sequestration of a mature apricot tree is 22.6 kg of CO_2. Consequently, once this ecosystem reaches full maturity, it will have the potential to sequester approximately 226 tonnes of CO_2.[20] As emissions were not quantitatively calculated due to a wide range of variables such as tractor fuel, soil tillage, sapling production, transportation, fertilizer inputs, construction activities, the shorter growing season at this altitude, and the potential contribution of soil incorporated leonardite to soil carbon storage, this figure represents potential biological carbon uptake rather than a precise net carbon balance.

6)Employment: The active participation of dozens of relatives of earthquake survivors in this process reduced costs and motivated local residents to become productive on their own land again. Active employment opportunities were provided to the relatives of those directly affected by the earthquake during tasks such as planting saplings, clearing stones from the land, and infrastructure development. This process represents not merely physical labor, but also a project of collective rehabilitation and re-establishing roots in ancestral lands.

While this initial effort provides immediate relief to the community, upcoming harvest seasons will create a lasting source of income for the region. Malatya possesses a deeply rooted cultural framework for seasonal agricultural labor. Since the harvest period will be delayed by at least two weeks, operations will commence only after regional orchards at lower altitudes have fully concluded their activities. This deliberate timing creates a vital economic impact: instead of facing immediate seasonal unemployment, the local pool of migrant laborers can transition directly to the project site, thereby earning additional income for several weeks.

7)Financial Overview and Social Impact: The project required a total capital expenditure of $106,700 for basic infrastructure and sapling planting. To convert this volume into premium dried apricots, the next strategic phase of our roadmap involves integrating an on site, solar powered drying facility. Based on expected yields, dried fruit conversion rates, and current market assumptions, annual gross revenue is estimated to range between 2.2 million and 3 million USD, subject to variation due to factors such as climate related yield fluctuations, inflation, the seasonal nature of the labor force, export opportunities, and certification requirements. Table 3 provides an overview of revenue modelling.

The project's greatest achievement is transforming a piece of unproductive land, previously viewed as a "dead investment" following the earthquake, into a community asset. Fieldwork validated the feasibility of apricot cultivation under a zero irrigation regime, while small scale trials also indicated potential for almonds.

Production regions, spanning from the Mediterranean basin to California's Central Valley, which supplies a significant share of the world's almonds, are increasingly threatened by rising winter temperatures and severe groundwater depletion. Relocating to marginal mountainous areas at elevations of up to 2,000 meters offers the potential to mitigate these challenges by leveraging prolonged chilling periods and delaying phenological flowering to avoid late spring frosts.

Stage	***Yield per Tree***	***Total Yield (Fresh)***	***Total Yield (Dried)***	***Price Range (USD/kg)***	***Projected Revenue (USD)***
Initial Yield (Year 3)	–	150 kg total	negligible	–	–
Early Maturity (Years 6–7)	40–50 kg	~400–500 tons	~100 tons	$6–8	~$0.6M–$0.8M
Full Maturity (Years 10–12)	~150 kg	~1,500 tons	~375 tons	$6–8	~$2.2M–$3M

Table 3: Multi stage yield projections for total 10.000 tree, drying conversion rates, and revenue modeling from initial planting to full maturity

DISCUSSION

The results of this study show that marginal mountainous regions can be high value agricultural assets and efficient carbon sinks without the depletion of traditional resources. A 95% seedling survival rate supports the performance of the management system under a zero irrigation framework. A 3-4 week phenological delay provides the bioclimatic buffering capacity of the ecosystem[4]. While lowlands experience severe crop loss due to unpredictable early season frosts, delayed budding allowed the trees to survive the critical frost window. This resilience was experimentally observed in a severe frost event on April 11-14, 2026; official agricultural assessments and regional damage reports from the Malatya Governorate and the Turkish State Meteorological Service confirmed widespread crop damage due to frost in low lying regional plains[26], while no frost related damage was recorded in the project area.

The role of beekeeping similarly extends beyond pollination efficiency. By filling the ecological gap left by limited natural pollinators, it has supported stable fruit set and improved fruit quality. [7,8]

FUTURE WORKS

The project's long term vision aims to bridge the gap between production facilities and international export standards. A significant bottleneck in the traditional apricot industry is the reliance on open air tent based sulfur fumigation, a process that often leads to chemical residues and dust contamination, rendering the product unsuitable for high end global markets. To address this, the next phase of the project focuses on adopting advanced solar drying cabinets, similar to the energy efficient models developed by Inonu University.

These cabinets offer a superior alternative to traditional methods by providing a controlled, dust free environment where fruit can be dried to precise moisture levels using only solar energy. This technology preserves the apricots' natural color and high Brix nutritional profile without the need for excessive sulfur treatment or washing. By integrating these solar powered cabinets, the project aims to improve product quality and support future food safety and certification requirements.

LIMITATIONS

As this study was conducted under real-world field conditions rather than under controlled experimental settings, it is not possible to isolate the individual effects of each intervention. Long term yield data remain limited, and certain future yield, economic, and carbon values are based on projections. Furthermore, the study represents a single area characterized by its unique climate, geology, local apricot varieties, and access to family labor. Consequently, additional field tests under varying conditions are required to establish the model's broader applicability.

CONCLUSIONS

This study confirms the feasibility of reclaiming marginal, high altitude lands through integrated ecological and economic strategies. By combining soil amendment using leonardite and elemental sulfur with phenological adaptation and a zero irrigation dry farming model, the project achieved an exceptional sapling survival rate of 95%. Strategically avoiding irrigation infrastructure and substituting expensive synthetic inputs with local industrial by products enabled an investment of 106,700 USD for a 1,000 decare area, while saving 35 million liters of water annually.

Social dimensions are equally significant; the reliance on collective family labor and the preservation of local traditions stand out in this regard. Ultimately, by establishing a scalable model for climate resilient agriculture, this project demonstrates that even environments facing the most challenging conditions can be transformed into productive and socially empowering ecosystems.

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