sustainability

Article

An Affordable System Solution for Enhancing Tree Survival in Dry Environments

Hakan Gürsu

Industrial Design Department, Faculty of Architecture, Middle East Technical University, 06800 Ankara, Turkey; info@hakangursu.com

Abstract: Water scarcity inhibits plant growth, especially in arid regions. Traditional irrigation methods often lack efficiency and sustainability. This study investigates AquaTrap, a biomimetic design, as a potential solution. The study highlights AquaTrap's advantages by analyzing its design and previous research on bioinspired water harvesting. It highlights its ability to increase water efficiency and support sustainable plant growth in dry areas. Biomimicry inspires AquaTrap's design, which mimics natural systems to capture and deliver water to plant roots. To collect condensation while repelling water, the stack uses superhydrophobic materials. Plant roots then receive this accumulated water for growth. Compared to traditional methods, AquaTrap offers many advantages. Its stand-alone design eliminates complex infrastructure and minimizes evaporation. Additionally, delivering water directly to the roots reduces waste and increases water efficiency. This technology holds promise for introducing new vegetation, restoring plant life, and promoting sustainable agriculture in arid regions. Further research is needed to explore the potential of AquaTrap in a variety of field conditions, optimize it for different plants and environments, and evaluate its economic feasibility for widespread use. AquaTrap also has significant potential for sustainable forestry, as it can significantly increase the survival and growth of trees in water-scarce environments. System solution opportunities and modular structure provide crucial support during the most critical adaptation period of afforestation. By reducing water consumption and increasing efficiency, it supports the establishment and maintenance of healthy forests, which are vital for ecosystem resilience and biodiversity.

Keywords: biomimetic eco-solution; water harvesting; arid areas; water conservation; drip irrigation

Citation: Gürsu, H. An Affordable System Solution for Enhancing Tree Survival in Dry Environments. *Sustainability* **2024**, *16*, 5994. https://doi.org/10.3390/su16145994

Academic Editors: Marc A. Rosen and Ali Ayoub

Received: 27 May 2024
Revised: 8 July 2024
Accepted: 10 July 2024
Published: 13 July 2024

Copyright: © 2024 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Water scarcity is a pressing global crisis that is silently intensifying. It is defined as the inability of freshwater resources to meet the needs of both humans and the environment [1]. Factors such as population growth, climate change, and inadequate water management exacerbate this crisis, directly impacting over 40% of the global population [2]. Water scarcity can be classified into two primary categories: physical scarcity, which refers to the insufficient availability of freshwater, and economic scarcity, which pertains to limited access to clean water or the inability to afford it [3]. Implementing rational strategies, such as afforestation, sustainable water management, efficient resource use, and appropriate treatment methods, can effectively alleviate the negative impacts of global climate change [4]. People widely acknowledge these measures as some of the most effective options for addressing this problem [2,5].

The repercussions of water scarcity are profound. This issue causes land degradation and compels people to migrate from drought-prone regions to metropolitan areas. In underdeveloped regions, the lack of reliable irrigation water poses significant challenges, resulting in crop spoilage, contributing to food insecurity, and compromising agricultural production quality [6]. Competition for limited water resources can exacerbate pre-existing social and political tensions, leading to social unrest [1].

Tackling water scarcity necessitates a comprehensive and diverse strategy. An essential aspect is adopting integrated water management, acknowledging the interconnectedness of all water sources, including surface water, groundwater, and wastewater [2]. This method integrates various strategies to guarantee water security for both human populations and the natural environment. Although constructing sustainable water infrastructures, such as dams and canals, is crucial, high investment costs and limited accessibility present challenges for long-term macro-solutions [7]. At both regional and global levels, ensuring the preservation of water resources through wastewater treatment and the regulation of water-consuming industries is paramount. Furthermore, the use of water-efficient equipment and sustainable micro-farming practices is progressively gaining strategic importance [5]. Nature also contains hidden sources of potential water. This article explores the feasibility of using young trees as a form of early-stage life support, focusing on employing natural techniques, particularly biomimetic systems, to utilize the often-overlooked natural water source arising from the constant exchange of water vapor between soil and air, a consequence of the greenhouse effect.

1.1. Problem

The first few years after transplanting freshly planted trees, especially within the first one to two years, are crucial for their survival and establishment. During this period, the availability of a sufficient water supply is vital [2]. This stage is critical for trees planted using the "tube stock" approach, which involves transferring plants originally cultivated in containers into the soil [2,3,5]. Moving young trees from tube stock to the ground exposes them to significant "water stress" until their roots reach an adequate depth. Supplemental watering is necessary for the survival of these trees until their root systems develop sufficiently to independently extend and capture water [1]. Newly planted trees undergo a critical period in the early years after transplantation, as their root systems have not fully developed to effectively absorb water and nutrients from the soil. The vulnerability of these young plants to water scarcity underscores the importance of adhering to regular watering routines to ensure their survival and optimal growth [4]. Insufficient water availability during this crucial phase can result in stunted growth, compromised well-being, and elevated mortality rates [7,8]. Research conducted by Harris, Clark, and Matheny in the field of arboriculture emphasizes the necessity of providing freshly planted trees with adequate water throughout the establishment phase. According to their studies, the initial phase, known as the establishment period, is crucial for the growth of a robust root system that can support the tree throughout its lifespan [2,4]. The previous study of Kozlowski, Kramer, and Pallardy showed that the root system extends beyond the initial root ball into the surrounding soil, a process highly dependent on the presence of water [3]. Developing an effective irrigation plan for recently planted trees, particularly those planted from tube stocks, is critical for mitigating the negative effects of transplant shock and facilitating healthy establishment [5]. Experts recommend deep, infrequent watering to promote the formation of deeper roots and enhance long-term drought resistance. Additionally, the use of mulch can help preserve soil moisture [6].

This manuscript aims to provide a comprehensive overview of the challenges associated with water scarcity, particularly in the context of newly planted trees, and to propose effective strategies for ensuring their successful establishment and growth [8,9]. This study examines the AquaTrap proposal as a solution to various problems in arid environments. This innovative support system caters to the specific water needs of newly planted seedlings [2,10]. It is adaptable to different tree species and environmental conditions, providing multiple uses and long-term services for sustainable afforestation [8]. The cost-effective structure includes a customized biomimetic membrane system and strong carrier frames. In dry areas, young trees utilize this equipment to support their growth. The self-powered system efficiently collects excess moisture from the soil and directs it toward the roots. This study evaluates the infrastructure, suitability, efficiency, and effectiveness of the AquaTrap proposal.

1.2. Can Increasing Afforestation Be a Potential Solution to Global Water Scarcity?

Better Yield Technology (IYT) boosts afforestation, which sustains habitats. Habitat enhancement can alleviate water shortages. Trees improve water retention, avoid erosion, provide microclimate control, biodiversity, and carbon storage [4].

1. Trees improve water retention by acting as natural reservoirs, minimizing water scarcity. Trees absorb rain through transpiration and interception, slowing surface runoff and evaporation. Researchers found plants absorb 70–80% of precipitation [5]. Trees store and slowly release groundwater and streamflow into the soil. This process helps conserve water and ensures a steady supply, especially during droughts.
2. Erosion Control: Tree roots anchor soil, reducing erosion and landslides. This function preserves rich soil and controls water [11,12]. Tree roots stabilize the topsoil and prevent wind- and water-induced land degradation. Water retention and plant growth require topsoil protection.
3. Microclimate Effect: Trees preserve water by shading and releasing water vapor. This microclimate modulation cools and humidifies, reducing temperature extremes and soil water evaporation. Nearby areas have reduced water stress, enhanced vegetation, and reduced drought risk [12].
4. Biodiversity: Afforestation fosters ecological balance by creating diverse habitats for various plant and animal species. Biodiversity improves water security by regulating water quality, providing flood and drought buffers, and promoting soil health [13,14].
5. Carbon Sequestration: Trees mitigate climate change by absorbing carbon dioxide and reducing greenhouse gas emissions. Afforestation enhances ecosystems and water availability. Despite its benefits, afforestation has drawbacks. High evapotranspiration from fast-growing, non-native trees may restrict water availability.

This is concerning due to arid and semi-arid water limitations [15]. To protect local biodiversity and ecosystems, afforestation must be planned and maintained. Remember that afforestation cannot address water problems. A multifaceted approach is necessary for the protection and sustainability of water resources [1,16]. Tree species should be determined by water scarcity and planting location. Afforestation projects require careful planning, sustainable management, and community participation [17,18]. Reducing emissions and minimizing the negative effects of climate change on water supplies are crucial aspects of these projects [19] (Table 1).

Table 1. Impact of water scarcity of different sectors in 2020–2040 * [2,3,12–14,20].

Sector	Impact of Water Scarcity	Estimated % of Global Water Use (2020)	Forecasted % of Global Water Use (2030)	Forecasted % of Global Water Use (2040)
Agriculture	Reduced crop yields, food insecurity	70	71	72
Industry	Production disruptions, economic losses	20	19	18
Domestic	Limited access to clean water, sanitation challenges	10	10	10

* The estimated and forecasted percentages are based on various sources and may vary depending on specific data sets and methodologies. The impact of water scarcity on sectors can also vary significantly depending on various factors, including geographical location, climate change, and economic development.

1.3. Global Water Scarcity Problem

Economic progress, life, and sustainability require clean water. Unfortunately, overestimating water's resource value can mask its ecological and socio-economic benefits. Undervaluation generates global shortages and pollution [12]. Because the biosphere needs water, water issues can improve public health, poverty, employment, food security, climate change mitigation and adaptation, biodiversity protection, and ecosystem preservation. Climate adaptation requires water-related choices because most natural disasters are water-related (Table 1) [21,22]. Since 1970, stopping the rapid loss and degradation of healthy rivers have been critical, since freshwater ecosystems hold 10% of Earth's species! Water-related potential is vital to a net-zero carbon economy because the water industry emits 10% of global carbon [23–25]. Plastic enters rivers and seas at a rate of 8 million tons per year, threatening marine life and ecosystems [26]. Tripled ocean nitrogen concentrations since pre-industrial times have caused plants and algae to flourish and destroy marine biodiversity [27]. Treatment of wastewater cleans water. In addition to environmental concerns, insurance, fashion, and food and beverage companies require water. Water efficiency improves community water security and lowers business risks [28]. Hospitality requires 380 to 1500 L per room per day, which may aggravate water scarcity in water-scarce areas and jeopardize adjacent communities [18]. Fashion absorbs 4% of global freshwater, second only to agriculture, requiring appropriate water management [22]. In water-rich areas, many people overlook its value. Given climate change's impact on precipitation patterns, assessing the value of accessible drinking water necessitates an understanding of all industries' water footprints. To promote climate-friendly supply chain transformations, corporate strategy must consider water [26,28].

- Climate Change (20–30%): Warmer temperatures increase evaporation, exacerbating water scarcity and droughts. Changes in precipitation can produce floods and severe droughts. Melting glaciers and snowfall affect water supplies [2,29].
- Global population growth (30–40%) raises household, agricultural, and industrial water consumption. Cities' dense populations and substantial infrastructure make this difficult. Water disparity causes shortages in areas with limited access [3,30].
- Water Pollution (10–20%): Industrial waste, agricultural runoff, and inadequate sanitation pollute waterways. Pollution reduces resources by making water unsafe for drinking, agriculture, and other uses [29,31].
- The distribution of water is unequal, with some areas having enough and others lacking. Inefficient water management exacerbates this imbalance, generating scarcity in water-rich areas [30,32].

This generic summary of estimated percentages from many sources may vary by technique. Each factor's importance depends on geography and water issues. Water scarcity requires the mitigation of climate change, sustainable water management, reduction in pollution, and equitable allocation of resources.

1.3.1. Water Stress

Water, essential to life, cycles naturally to maintain availability and movement. Our planet's ecosystems depend on this ongoing cycle of resource redistribution and replenishment throughout the atmosphere, land, and oceans. This method is essential to understanding Earth's complicated biosphere. Water molecules evaporate into water vapor using solar energy [29]. Many variables affect the evaporation from seas, lakes, rivers, and soil. High humidity saturates the air with water vapor, reducing evaporation, while high temperatures enhance molecular energy. Fast winds transfer water vapor from aquatic bodies, promoting evaporation [12,19,32]. In the natural water cycle, solar radiation encourages water evapotranspiration from oceans, lakes, rivers, and moist soil. Clouds form when vapor condenses on small particles and moves to cooler, higher air. Through infiltration and percolation, precipitation fills surface and groundwater reservoirs after saturation. Unabsorbed precipitation runs off land surfaces to streams, rivers, and the ocean, Earth's principal water source [9]. This cycle maintains the planet's balance and supports life by providing water to plants and animals. The water cycle, as it regulates heat transmission and weather patterns, determines regional climates. To protect water supplies and vulnerable ecosystems, we must understand and appreciate this complicated process [2].

1. Evaporation: Process: Solar radiation overcomes intermolecular interactions and turns water into gas. The "Clausius–Clapeyron equation" [33] links temperature and vapor pressure. At the liquid–air barrier, evaporation occurs. Seas, lakes, rivers, damp soil,

and plant transpiration all contribute to evaporation. Timing: Temperature, humidity, wind speed, and water body surface area affect evaporation [34,35].
2. Condensation: After releasing thermal energy, water vapor condenses around condensation nuclei in a cooler, higher atmosphere. Water vapor molecules create droplets or ice crystals on dust, salt, or air pollutants [36]. Higher tropospheric temperatures are lower than surface temperatures; hence, condensation occurs. Air pressure and temperature affect height. Condensation time varies depending on temperature, relative humidity, and condensation nuclei [37,38].
3. Precipitation: Water vapor condenses into heavy droplets or ice crystals, preventing their persistence in the atmosphere. They then become rain, snow, sleet, or hail. Different air temperatures and pressures cause different precipitations. Regional climate patterns and wind directions affect rainfall distribution and intensity [37,39].
4. Interception: Leaves and branches intercept rainwater, causing evaporation or drips. This process is common in forest and grassland areas with abundant flora [40].
5. Infiltration: Water seeps through soil and rock. This replenishes groundwater and reservoirs, hydrating plants. Infiltration occurs whenever precipitation meets the ground, but soil type, vegetation cover, and slope affect the rate [41,42].
6. Percolation: Water can reach groundwater aquifers by infiltration. Aquifers are freshwater-rich rock or soil strata [3,41]. Porous soils and rocks allow water to percolate. According to geology and local factors [43], fast and slow percolation may differ.
7. Runoff: Procedure surface or subsurface runoff occurs when saturation, impermeable surfaces, or steep slopes prevent precipitation from penetrating. Rivers, streams, and the ocean receive surface runoff. Landscape features locate runoff. Impervious surfaces, such as steep slopes or cities, generate the most surface runoff. Subsurface runoff can be experienced by anyone with permeable soils and unsaturated subsurface layers [44,45].
8. Storage: Reservoirs store water at various stages of the water cycle. The most water is in oceans, followed by lakes, glaciers, snowfields, and aquifers. Water in reservoirs can last for days in plants or centuries in oceans [43]. Storage reservoirs are separated by geography. The NOAA reported in 2023 that 71% of Earth is ocean [46].

1.3.2. Water Scarcity and Access

Limited natural water resources: low precipitation in arid regions limits surface and groundwater supplies. Climate change increases evaporation and erratic weather, worsening water scarcity [47]. Competition over water demand, population growth, urbanization, and industrial development strain finite water supplies for agricultural irrigation [48].

1.3.3. Inefficient Irrigation

Water use efficiency (WUE) is low in conventional irrigation technologies, such as flood irrigation, due to significant water losses from evaporation, deep drainage, and runoff [49]. Excessive irrigation can cause soil degradation and salt accumulation, reducing soil fertility by draining important nutrients. This decreases crop yield and agricultural land suitability [50]. Conventional irrigation pumping methods can increase energy consumption, leading to higher greenhouse gas emissions and operational expenses for farmers [48].

1.3.4. Moving Forward

Mitigating challenges implementing water-efficient irrigation technology, such as drip irrigation and precision agriculture, can greatly increase WUE and reduce water losses. Investing in sustainable water management measures, such as rainwater gathering, infrastructural improvements, and community water conservation, is recommended. Researching drought-resistant crops can improve food security and minimize dependence on water-intensive agriculture practices [2,46].

1.3.5. Effects

Inefficient irrigation and water scarcity can reduce agricultural productivity, resulting in food poverty and social unrest in susceptible locations [51]. Environmental degradation: Water scarcity, salinization, and soil degradation can harm the environment, causing desertification, biodiversity loss, and ecosystem disruption [52]. The impact of water shortages on agricultural productivity might worsen poverty, hamper economic growth, and cause rural-to-urban migration for alternative livelihoods [53].

1.3.6. Consequences

a. Reduced Food Production: Water scarcity and inefficient irrigation practices significantly impact agricultural productivity, leading to food insecurity and potential social unrest in vulnerable regions [51].
b. Environmental Degradation: Water scarcity, salinization, and soil degradation can have detrimental effects on the environment, leading to desertification, biodiversity loss, and disruption of natural ecosystems [52].
c. Socio-economic Challenges: Water scarcity and its associated limitations on agricultural production can exacerbate poverty, hinder economic development, and lead to migration from rural areas to urban centers in search of alternative livelihoods [54].

Water scarcity and inefficient irrigation practices remain significant challenges in arid environments, threatening food security, environmental sustainability, and socio-economic well-being. Implementing innovative solutions, promoting sustainable water management practices, and fostering international cooperation are crucial for addressing these challenges and ensuring a secure water future for arid regions (Table 2).

Table 2. Challenges and impacts of arid environments [48,49,52].

Challenge	Impact	Mitigation Strategies
Water scarcity	Reduced food production, environmental degradation, socio-economic hardships	Rainwater harvesting, improved water infrastructure, water conservation practices
Inefficient irrigation practices	Low water use efficiency, salinization, soil degradation, high energy consumption	Implementing water-efficient technologies (drip irrigation and precision agriculture), improved water management practices
Climate change	Increased water scarcity, unpredictable weather patterns	Investing in renewable energy sources for irrigation, adopting climate-smart agricultural practices

Can nature provide alternative, creative, and innovative solutions to water scarcity and stress problems, just like many others? Examining the solutions developed by plant species to meet nature's water needs can be a beneficial starting point for the AquaTrap solution.

2. Biomimetic Systems

Biomimetics, stemming from Otto Schmitt's groundbreaking research in the 1950s, represents a multidisciplinary approach that derives inspiration from biological systems to innovate technological solutions [54]. This field endeavors to replicate biological structures, processes, and functions to tackle engineering hurdles and optimize the performance of human-made systems. Encompassing diverse applications such as materials science, robotics, architecture, and medicine, biomimetics aims to foster the development of more efficient, sustainable, and adaptable technologies [55]. It is imperative to impart biomimetics education to the next generation of designers to effectively address contemporary challenges and develop innovative solutions. Biomimetics, described as the "interdisciplinary collaboration of biology, technology, and other fields of innovation", seeks to pragmatically resolve real-world issues [56] by leveraging our understanding of biological systems. Smart materials, alternatively termed responsive materials, or stimuli-responsive materials, exhibit dynamic responses to external stimuli, enabling them to adapt their properties or behavior in real time [54]. These materials can undergo reversible changes in their physical, chemical, or mechanical properties in response to various stimuli, such as temperature, pH, light, or electric fields. Smart materials hold immense promise for diverse applications, including actuators, sensors, drug delivery systems, and self-healing materials, due to their ability to perform specific functions autonomously or in response to specific environmental cues [57,58]. The adaptation of organisms to their environments through surface modification has long been a subject of fascination and study in biology and materials science [59]. Biological surfaces have a wide range of useful qualities, such as not letting water stick to them, cleaning themselves, not turning foul, and stopping adhesion. These qualities have led to the creation of biomimetic surfaces with specific qualities and uses [59]. Researchers want to make synthetic surfaces that can perform and function at the same level across a wide range of applications, from anti-icing coatings to biomedical implants [60,61]. They plan to achieve this by copying the micro- and nanostructures found in nature. In summary, biomimetics and smart materials represent two cutting-edge fields at the intersection of biology, materials science, and engineering, with the potential to revolutionize technology and address pressing societal challenges. By harnessing nature's design principles and leveraging the adaptive capabilities of living organisms, researchers are paving the way for the development of next-generation materials and devices with unprecedented functionality and performance [53,54,59].

2.1. Biomimetics and Water (Hydrophobicity)

One of the interesting solutions of utilizing surfaces that do not retain water and efficiently absorb it, mimicking natural examples such as the skin of sharks, frogs, or the surfaces of leaves, holds significant promise as a biomimetic solution for collecting and transferring water. The hydrophobicity (water-repelling and reducing water adhesion) and micro/nanostructures found in these natural surfaces can contribute to their ability to repel water and facilitate efficient water transfer systems. By drawing inspiration from these biological systems, engineers and researchers can develop innovative materials and designs for various applications, including water collection, transportation, and management. Research by Bhushan and Jung has highlighted the potential of biomimetic surfaces inspired by lotus leaves, butterfly wings, and other natural structures in water-repellent and self-cleaning applications [61]. Natural and biomimetic artificial surfaces are used for super hydrophobicity, self-cleaning, low adhesion, and drag reduction. Moreover, studies have demonstrated the development of bioinspired surfaces with tailored microstructures for enhanced water collection and transport capabilities [62]. The hydrodynamics of water strider locomotion. Incorporating these biomimetic solutions into practical systems could lead to more efficient and sustainable water management technologies, benefiting various sectors, such as agriculture, industry, and water supply infrastructure [63].

2.2. Biomimetic Water Collection: "Lotus Effect" (Lotus Leaf/Nelumbo Nucifera)

The lotus effect is a self-cleaning phenomenon exhibited by the leaves of lotus plants. The surface of the lotus leaf is covered in microscopic waxy bumps and hairs, which create a rough texture. This roughness prevents water droplets from adhering to the surface and instead causes them to bead up and roll off, taking dirt and debris with them. Inspired by the lotus effect, researchers have developed biomimetic materials and coatings with similar properties for various applications, including self-cleaning surfaces, anti-fouling coatings, and water-resistant textiles. By understanding and replicating the hierarchical surface structures and low-surface-energy characteristic of lotus leaves, biomimetic materials aim to achieve enhanced water repellency and self-cleaning behavior in artificial systems [53]. This interdisciplinary approach, drawing from principles of biology, materials science, and surface chemistry, holds promise for the development of advanced materials with practical applications in diverse fields (Table 3).

Table 3. A comprehensive overview of the four key principles of the lotus effect, each with a brief description of its significance in creating water-repellent surfaces [59].

Design Principle	Description
Microscale and Nanoscale Hierarchical Structures	Lotus leaves possess a hierarchical structure consisting of microscale bumps covered with nanoscale wax crystals. This structure creates a rough and textured surface that minimizes the contact area between water droplets and the leaf surface.
Low Surface Energy	The wax coating on lotus leaves provides them with a low surface energy, making them highly hydrophobic. This low surface energy causes water droplets to minimize contact with the surface, forming nearly spherical droplets with high contact angles.
Self-Cleaning Mechanism	As water droplets roll off the surface, they pick up particles and debris, effectively cleaning the surface in the process. This self-cleaning mechanism is facilitated by the combination of the hierarchical surface structure and low surface energy, promoting the easy removal of water droplets and any adhered contaminants [61].
Enhanced Water Repellency	The combination of hierarchical surface structures and low surface energy results in exceptional water repellency, preventing water from wetting the surface and promoting self-cleaning behavior. The spherical shape of water droplets and their easy removal from the surface contribute to the maintenance of cleanliness and the preservation of hydrophobic properties over time.

Hydrophobic compounds integrated into biomimetic materials prevent water adhesion, allowing water droplets to roll off the surface. As water droplets roll off the biomimetic surface, they also carry away dust, dirt, and debris, ensuring water collection efficiency over time (Figures 1 and 2).

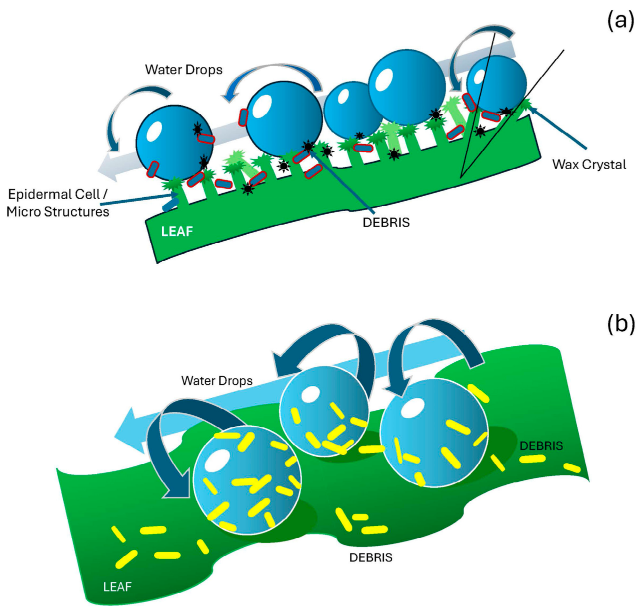

Figure 1. Lotus effect (**a**,**b**). In the mechanisms of biomimetic water collection systems, water droplets encounter the hierarchical surface structures of biomimetic materials, like a lotus leaf, which minimizes the contact area and "promotes water repellency" [64].

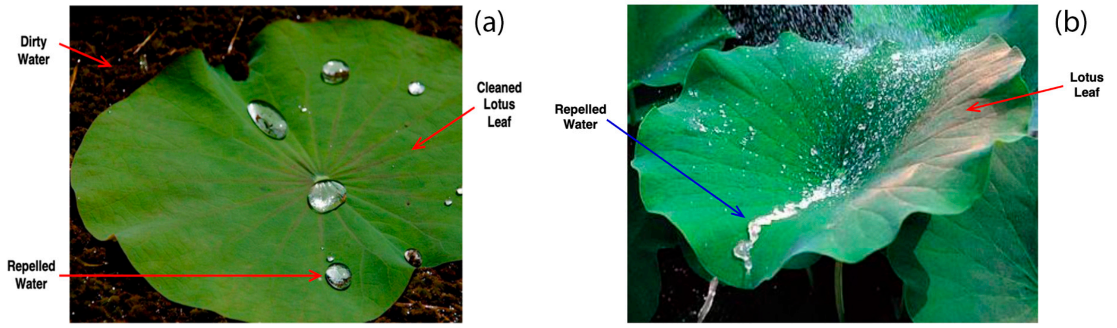

Figure 2. "Lotus Effect" (**a**). Cleaned lotus leaf in dirty water/(**b**). Natural cleansing of lotus leaf (adapted from Rame-Hart (2015)) [65].

2.3. Biomimetic Water Collection: The Inspiration of "Banana Leaves" (Musa acuminata)

Biomimetic water collection, inspired by the efficient water-repellent properties of banana leaves, holds promise for addressing water scarcity and sustainability challenges. The investigation of the biomimetic principles derived from banana leaves and their application in designing innovative water collection systems has great potential for future sustainable solutions (Table 4), [66]. Biomimetic principles inspired by banana leaves:

a. Hierarchical Surface Structures: Banana leaves exhibit micro- and nanoscale hierarchical structures, including ridges, grooves, and wax crystals. These structures minimize the contact area between water droplets and the leaf surface, promoting water repellency and easy shedding.
b. Hydrophobicity: The presence of hydrophobic compounds, such as waxes and oils, on the surface of banana leaves enhances their water-repellent properties. This hydrophobicity prevents water adhesion and facilitates the runoff of water droplets.

Table 4. Outline of the design principles and mechanisms utilized in biomimetic water collection systems inspired by banana leaves [66–68].

Design Principle	Description
Micro- and Nanostructured Surfaces	Banana leaves possess hierarchical surface structures at the micro- and nanoscales, comprising ridges, grooves, and wax crystals. These structures minimize the contact area between water droplets and the leaf surface, promoting water repellency and easy shedding (Figure 3).
Hydrophobicity	The surface of banana leaves is coated with hydrophobic compounds, such as waxes and oils, enhancing their water-repellent properties. This hydrophobicity prevents water from adhering to the leaf surface, facilitating the collection and runoff of water droplets (Figure 3) [69].
Self-Cleaning Mechanism	When water droplets roll off the surface of banana leaves, they carry away dust, dirt, and debris, effectively cleaning the leaf surface. This self-cleaning mechanism ensures the maintenance of water collection efficiency over time.

Biomimetic solutions offer myriad advantages across diverse problem domains. Biomimetic water collection systems, in particular, present sustainable alternatives by harnessing natural processes and mitigating environmental impacts. Inspired by the efficiency of natural systems, biomimetic designs optimize water collection and utilization, thereby fostering greater efficiency and resource conservation. Moreover, biomimetic methodologies afford the development of adaptable water collection systems capable of accommodating diverse environmental conditions and applications. This study and proposal, titled "AquaTrap", provide a comprehensive examination of biomimetic water collection mechanisms inspired by banana leaves (Figure 3). It underscores their potential to address pressing water challenges and promote sustainable development amidst water scarcity [64].

The biomimetic potential of banana leaves represents a promising frontier for the development of innovative technologies aimed at addressing contemporary challenges in the areas of water scarcity, sustainable agriculture, and environmental engineering (Figure 4). This discussion explores the future potential and possible applications of banana leaf biomimetics, supported by academic references.

a. Sustainable Water Harvesting: Banana leaf-inspired surfaces, with their hierarchical micro- and nanostructures coupled with hydrophobic properties, offer significant potential for enhancing water harvesting technologies. These biomimetic designs can improve the efficiency of rainwater capture and fog harvesting systems, especially in arid and semi-arid regions where water scarcity is a prevalent issue. The self-cleaning properties inherent in banana leaf structures also ensure long-term operational efficiency by preventing the accumulation of dust and debris [68].

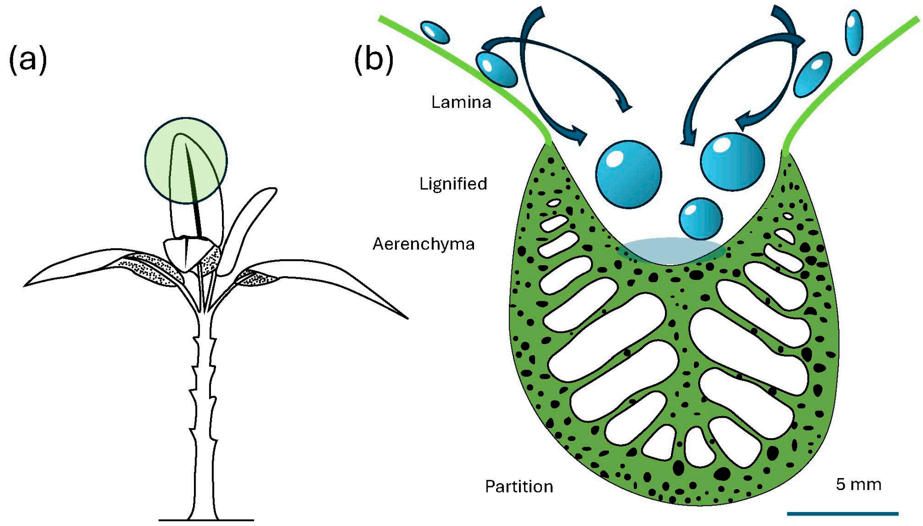

Figure 3. (**a**) Banana leaf and (**b**) section of leaf body [69].

Figure 4. Banana leaf photos (free stock photo).

b. Agricultural Applications: In agriculture, the application of banana leaf biomimetics can revolutionize irrigation methods by developing materials that deliver water directly to plant roots with minimal evaporation losses. This approach could significantly reduce water usage in irrigation, addressing the critical need for water conservation in agricultural practices [70]. Furthermore, the self-cleaning feature of biomimetic materials can reduce the maintenance requirements of agricultural equipment and structures.

c. Environmental Engineering and Green Architecture: Biomimetic designs inspired by banana leaves are poised to make substantial contributions to green architecture and environmental engineering. For example, building surfaces mimicking the water-repellent and self-cleaning characteristics of banana leaves can lead to the development of structures that require less maintenance and are more resistant to weathering. Additionally, such surfaces can enhance rainwater harvesting systems integrated into building designs, contributing to sustainable water management practices [66].

d. Advanced Coatings and Materials Science: The exploration of banana leaf biomimetics extends into the development of advanced coatings and materials science. By replicating the micro- and nanostructures found on banana leaves, scientists can create surfaces with unique properties, such as extreme water repellency, self-cleaning capabilities, and enhanced light reflection or absorption. These materials have broad applications, ranging from waterproof clothing and anti-fouling surfaces to solar panels with increased efficiency [67].

The biomimetic potential of banana leaves is vast, with applications spanning from sustainable water harvesting and agriculture to green architecture and advanced materials science. As the research in this field progresses, the integration of these biomimetic solutions into practical applications promises to contribute significantly to sustainable development and environmental conservation efforts. The ongoing exploration of and innovations in banana leaf biomimetics underscore the importance of interdisciplinary collaboration in harnessing nature-inspired solutions to meet the challenges of the future.

2.4. Biomimetic Solutions for Future Possibilities

The remarkable water-repellent properties of certain plant surfaces, such as the lotus leaf (*Nelumbo nucifera*) and banana leaf (*Musa acuminata*), offer valuable models for biomimetic solutions in water management and self-cleaning technologies. The lotus leaf exhibits the "lotus effect", where water droplets bead up and readily roll off, taking dirt and contaminants with them [69]. This is due to a hierarchical surface structure of waxy micropumps and nanoscale hairs, creating a superhydrophobic surface that minimizes water contact [62,71]. Similarly, banana leaves also possess a waxy cuticle layer and intricate micro-vein networks that promote water runoff [72]. These natural water repellency mechanisms have inspired the development of various biomimetic products. The lotus effect inspires superhydrophobic coatings that can enhance water resistance, stain resistance, and self-cleaning abilities in textiles, building materials, and solar panels [71]. Banana leaf-inspired designs could lead to improved water drainage systems, packaging materials that maintain freshness, and microfluidic devices for precise fluid control [72,73]. The potential for even more innovative applications is vast. Researchers envision self-cleaning smart windows, anti-icing surfaces for aircraft and wind turbines, and water-repellent surfaces for efficient condensation and water collection systems [74]. These enhanced surface properties could find applications in fields ranging from sustainable architecture to advanced biomedical devices. Drawing inspiration from the water-repellent wonders of nature, the AquaTrap project seeks to develop cutting-edge biomimetic solutions for water harvesting and management in arid environments. By studying and mimicking the intricate surface structures and processes found in plants like the lotus and banana leaf, AquaTrap aims to create materials and structures that can not only repel water, but strategically collect, store, and utilize it for maximum efficiency.

3. Materials and Methods

3.1. Target of this Study

Inspired by the natural properties of banana leaves and the lotus effect, the AquaTrap system is a biomimetic design solution that specifically supports newly planted trees during their crucial root development phases, particularly in arid environments. This innovative system helps trees adapt to their new surroundings without disrupting the ecological balance, thereby promoting habitat growth with minimal interference. By effectively capturing water vapor typically lost to the greenhouse effect and directing it to the root zones of plants, AquaTrap maximizes the efficiency of water collection and distribution. This approach, inspired by the water-repellent properties of banana leaves and the self-cleaning lotus effect, addresses the increasing demand for economically, ecologically, and practically feasible solutions in the face of climate change, particularly in agriculture and water management. The system's adaptable physical membrane dimensions are tailored to the specific data of its implementation area, ensuring optimal performance in diverse conditions. AquaTrap not only provides immediate support through rainfall capture, but also ensures long-term maintenance for robust root growth. This result of improved water management efficiency and offers a more sustainable approach to irrigation, making AquaTrap a versatile and effective alternative for promoting sustainable forestry in arid climates.

3.2. Methodology

This study aims to monitor the AquaTrap system's daily water collection levels using real-time data and evaluate its performance. A common way to figure out evapotranspiration (ET) is to use the Penman–Monteith equation, which is used for both predictive calculations and real-time measurements. ET is the process of water evaporating from the soil surface and transpiration from plants. This research focuses on two primary data sets.

- Theoretical Calculations Based on Design Parameters (Data Sheet 1/Table 5): Using theoretical information from global data systems, this research method entails calculating the soil's ET_o value using target field data and the Penman–Monteith equation. The objective is to establish a fundamental understanding of the system's expected performance and identify potential areas for optimization during the project's development phase, focusing particularly on Data Sheet 1. The goal is to assess the level and sustainability of water loss in the target soil area to ensure efficient operation of the AquaTrap system. Based on these data, this study aims to develop a method for calculating the minimum membrane area required to support each young sapling's survival.

Table 5. (Data Sheet 1). Descriptive ET_o values in Antalya, Akseki, Turkey: ET_o Value adjustments based on the "Penman–Monteith Equation" for 3. Different relative humidity levels (start: May 2022; end: 30 April 2023).

Month	RH = 40%	RH = 50%	RH = 60%	ET_o (mm/day for m^2)	Deviation
January	0.33	0.24	0.21	0.26	−0.03
February	0.34	0.25	0.22	0.27	−0.02
March	0.34	0.25	0.22	0.27	−0.02
April	0.34	0.25	0.22	0.27	−0.02
May	0.338	0.247	0.221	0.269	+0.00
June	0.54	0.36	0.31	0.40	+0.131
July	0.55	0.34	0.29	0.38	+0.111
August	0.51	0.33	0.28	0.37	+0.101
September	0.50	0.32	0.27	0.36	+0.091
October	0.51	0.33	0.28	0.37	+0.101
November	0.52	0.34	0.29	0.38	+0.111
December	0.54	0.36	0.31	0.40	+0.131

- Real-Time Calculations Based on Real Raw Data (Data Sheet 2/Table 6): In this stage, actual field measurements are collected to make more realistic evaluations. These calculations provide a more accurate assessment of the system's performance by considering the influence of real operating conditions and environmental factors. This phase will validate the global system data in the field and determine whether sufficient water is available throughout the year.

Table 6. (Data Sheet 2). Real-time measurements of AquaTrap system: ET_o Data table (study in Antalya, Akseki, Turkey). Example (cover area (m^2) day) (2022–2023) (RH changes, between 40–60%; the yearly average was 48–51%).

Month	RH = 40% (m^2)	RH = 50% (m^2)	RH = 60% (m^2)	ET_o (mm/day for m^2)
January	0.14	0.14	0.14	0.26
February	0.17	0.14	0.12	0.27
March	0.20	0.18	0.17	0.27
April	0.20	0.16	0.15	0.27
May	0.30	0.26	0.20	0.269
June	0.42	0.37	0.31	0.40
July	0.43	0.36	0.28	0.38
August	0.43	0.33	0.34	0.37
September	0.39	0.32	0.32	0.36
October	0.37	0.31	0.30	0.31
November	0.35	0.30	0.24	0.27
December	0.30	0.24	0.19	0.26

- By determining water loss values, this study examines the accurate calculation of the tension membrane area required to collect sufficient water for the survival of plant species in the target region. This study also delves into the fundamental framework of a support system that aims to gather the desired daily net water volume of 1.5 L [2,3,6].

All available data were analyzed to evaluate the system's effectiveness and identify areas for improvement. The detailed description of each stage is as follows:

1. Data Collection: Relevant system design parameters and specifications were collected from engineering drawings, technical documents, and expert opinions.
2. Theoretical Modeling: Established theoretical models and equations were used to perform calculations based on the collected design parameters. These models consider the physical principles and operating characteristics of the system.
3. Performance Estimation: To further develop the product, we used the results of theoretical calculations to estimate the system's expected performance metrics, such as efficiency, output, and resource consumption.

This study employs a dual approach to compare the predicted performance measurements based on theoretical calculations with those obtained from field data. This includes examining the AquaTrap system's efficiency, water output, and the method for calculating the water-trapping membrane area in dry environments. These performance predictions are crucial for identifying potential design improvements and optimizing the system's effectiveness before proceeding to empirical testing in later stages [7,8].

4. AquaTrap

4.1. A Biomimetic Solution for the Efficient Irrigation of Newly Planted Trees

AquaTrap represents a groundbreaking innovation in irrigation technology, leveraging biomimicry to address the critical challenge of establishing newly planted trees. This system addresses the problem of water loss from evapotranspiration, a natural process that the greenhouse effect intensifies. AquaTrap, inspired by nature's ingenuity, captures water vapor that is often lost from the soil and redirects it directly to the root zone of target plants. This not only ensures the vital moisture needed for seedling survival and healthy root development, but also fosters a sustainable approach to water management in agriculture. It embodies biomimicry's power by mimicking the inherent capabilities of specific plants and biological systems. Like how certain organisms condense and direct moisture efficiently, AquaTrap (awarded a the Green Dot Design Award) addresses the crucial need for consistent water supply during the vulnerable early stages of tree growth. This period is paramount for establishing a robust root system, the foundation for a tree's long-term health. Drawing inspiration from the remarkable water-harvesting abilities of banana leaves and the lotus effect's exceptional droplet repellency, AquaTrap seamlessly integrates these natural phenomena to enhance water collection, retention, and delivery.

A meticulously designed biomimetic membrane is at the heart of AquaTrap. Replicating banana leaves' intricate venation patterns, ridges, and grooves effectively capture and channel rainwater, ensuring every precious drop reaches the tree's roots. The membrane's surface, inspired by the lotus effect, features microscopic bumps and a hydrophobic coating. This design minimizes evaporation by encouraging droplet coalescence and keeping water in. Complementing this biomimetic membrane is a sophisticated drip irrigation system that precisely delivers the collected water directly to the root zone. This targeted delivery maximizes water utilization by minimizing waste and promoting optimal plant growth and health.

The AquaTrap system's biomimetic foundation offers a multitude of benefits to newly planted trees:

- Enhanced Water Collection: AquaTrap's banana leaf-inspired membrane effectively captures and channels rainwater, maximizing water harvesting even during minimal rainfall events.
- Reduced Evaporation: The membrane's lotus-effect surface minimizes evaporation, ensuring that collected water remains available for plant use.
- Efficient Drip Irrigation: The integrated drip irrigation system delivers water directly to the root zone, preventing waste and optimizing water utilization.
- Promotes Tree Adaptation: By providing a consistent and readily available water source, AquaTrap facilitates rapid tree adaptation and establishment, reducing stress and mortality rates.
- AquaTrap's biomimetic design promotes sustainable water management practices, conserving precious water resources and minimizing environmental impact.
- AquaTrap stands as a testament to the power of biomimicry in addressing real-world challenges. By harnessing nature's ingenious designs, AquaTrap revolutionizes irrigation practices, ensuring efficient water use, promoting tree health, and contributing to a more sustainable future for agriculture.

4.2. Concept

The critical initial years following the transplantation of newly planted trees, particularly those within the first 1–2 years, represent a significant period during which the survival and establishment of them are highly dependent on adequate water supply (Figure 5). This phase is crucial for trees planted with a method known as "tube stock", where plants initially grown in containers are transplanted into the ground. In other words, young trees transferred from tube stock to the ground are under the threat of serious "water stress" problem until their roots reach a sufficient level. Until the root system of these trees develops sufficiently to spread out and capture water independently, supplemental watering is essential for their survival. The early years of post-transplantation are a vulnerable time for newly planted trees, as their root systems are not yet fully established to efficiently absorb water and nutrients from the surrounding soil [74]. This highlight the susceptibility of these young trees to water stress, emphasizing the importance of regular watering schedules to ensure their survival and healthy development [75,76]. Water stress during this critical period can lead to reduced growth, diminished health, and increased mortality rates. The research on arboriculture integrates the concept of providing newly planted trees with sufficient water to support the establishment phase [2,3,77].

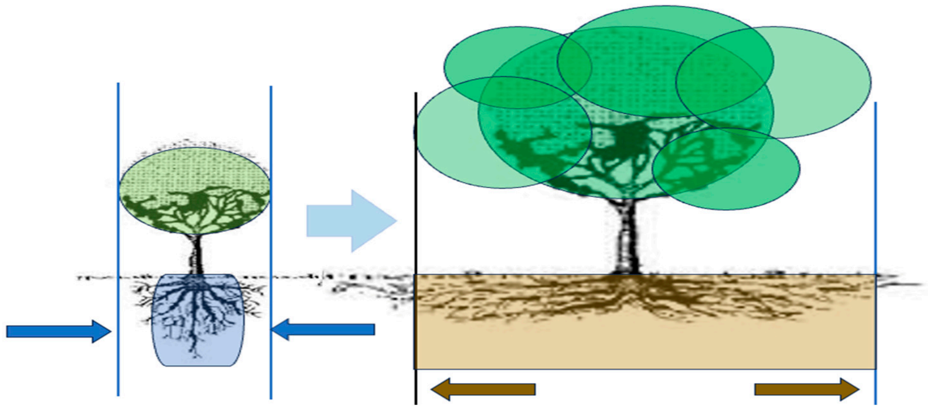

Figure 5. The problem: "Tube stock to Self-Standing Transition in Soil" for root development.

The establishment period, which can last from one to three years, is pivotal for the development of a robust root system capable of sustaining the tree throughout its life [76]. During this phase, the root system expands beyond the original root ball into the surrounding soil, a process that is heavily reliant on the availability of water. Implementing an effective watering strategy for newly planted trees, especially those planted from tube stocks, is essential for mitigating transplant shock and promoting successful establishment. Deep, infrequent watering practices are recommended to encourage deeper root growth and improve drought resilience over time [77]. Additionally, the use of mulches can help retain soil moisture, reduce temperature extremes, and minimize competition from grass and weeds, further supporting the tree's establishment [77,78]. The provision of adequate water to newly planted trees, particularly in their first 1–2 years post-transplantation period, is critical for their survival, growth, and establishment. Academic literature underscores the significance of this period and the need for appropriate water management practices to support the development of a healthy and extensive root system. Addressing the water needs of these young trees is a fundamental aspect of urban forestry and landscape management, ensuring the long-term success and sustainability of tree planting initiatives.

4.3. The Idea/System Proposal

"AquaTrap" embodies an innovative support system meticulously tailored to cater to the precise water requirements of newly planted saplings thriving in arid environments, with adaptability contingent upon the specific needs of diverse species and environmental conditions. It constitutes a cost-effective solution, comprising a bespoke biomimetic membrane system and robust bearing frames, strategically deployed as life-sustaining apparatus for nascent trees in arid regions. Functioning as a self-contained unit, it adeptly captures and channels surplus moisture from the soil, as well as precipitation and artificial irrigation, such as sprinkler systems, toward the root zone. Central to its operation is the utilization of a UV-protected film, engineered by biomimetic principles, which serves as the conduit for directing water-repellent water to designated channels and subsequently to the roots of the trees. This sophisticated mechanism optimizes the utilization of available water resources, mitigating the detrimental effects of water scarcity prevalent in arid environments. The system further accentuates its versatility through the incorporation of low-cost special PVC profiles, meticulously crafted to frame and tension the membrane materials, thereby ensuring structural integrity and longevity. Moreover, the adaptability of AquaTrap is underscored by its customizable attributes, allowing for the adjustment of the film's coloration to align with specific environmental requirements. This holistic approach not only enhances the efficacy of water distribution, but also underscores a commitment to sustainability by minimizing resource wastage and optimizing water conservation efforts. In support of its efficacy, scholarly research underscores the critical role of tailored water management solutions in bolstering the resilience of tree saplings in arid climates [79]. Furthermore, the integration of biomimetic principles into product design is heralded as a promising approach to addressing environmental challenges and fostering sustainable development [70]. By harnessing insights from academic literature and leveraging advanced engineering principles, AquaTrap emerges as a pioneering solution poised to significantly enhance the survivability and vitality of young trees in arid ecosystems (Figure 6).

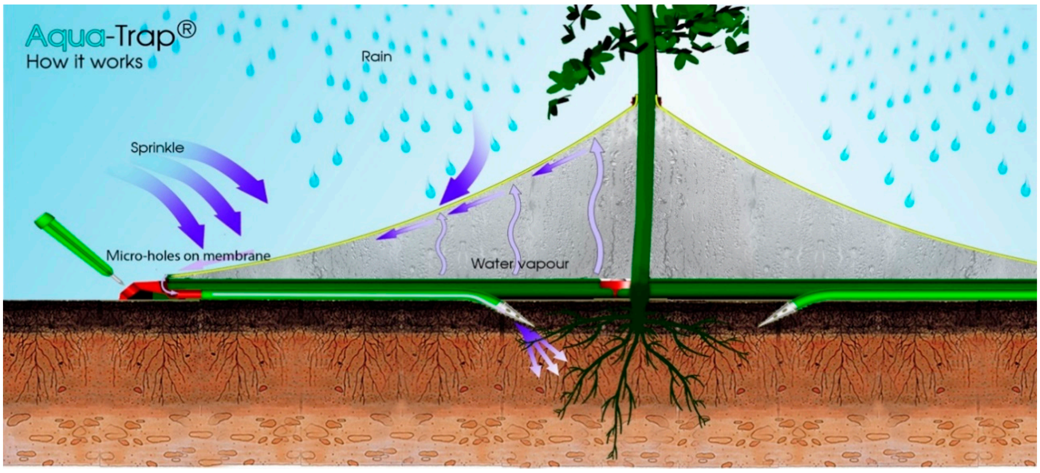

Figure 6. AquaTrap.

4.4. System Parts/Assembly

The accurate assessment of the daily depletion of soil moisture in the target area during its driest and hottest periods is crucial for the optimal operation and effectiveness of the AquaTrap system. Ref. [80] argues that newly planted saplings must meet their physiological needs through efficient water allocation strategies, stressing the significance of specialized water management systems in improving seedling survival in arid conditions. Additionally, ref. [81] showcase the vital importance of proper water management techniques in enhancing the resilience of young trees during critical growth phases, highlighting the necessity for effective water distribution mechanisms. These scientific studies reveal that, regardless of the species, a newly planted sapling requires an average of 25 L of water to reach its roots over a span of 30 days. The AquaTrap system is designed to account for potential losses and leaks, providing a continuous supply of 1 L of water daily to each sapling, totaling 30 L per tree per month. Based on this empirical evidence and the developed scientific framework, the AquaTrap solution is created as a flexible system that can be customized to ensure the survival of newly planted seedlings. For instance, if a new tree sapling is planted in an area losing 100 mL of water per m^2 per day, the aim is to collect 1 L of water daily with a 10 m^2 membrane system. To optimize the system's performance in the target area, it is recommended to install 3.3 m $\times$ 2 m square modules per tree and direct the water toward the roots (Figure 7). The carrier profiles of the system are primarily constructed from specially designed extruded PVC material measuring 6 m in length. The team adopted a sustainable approach by using recycled plastic materials for intermediate and corner connections, while polypropylene (PP) materials are utilized for the pipes responsible for water distribution to the roots. The membrane material, made of nylon and coated for enhanced functionality, is tinted as needed. This material combination not only offers an economical option, but also improves product durability and sustainability, aligning with environmental conservation objectives (Figure 8).

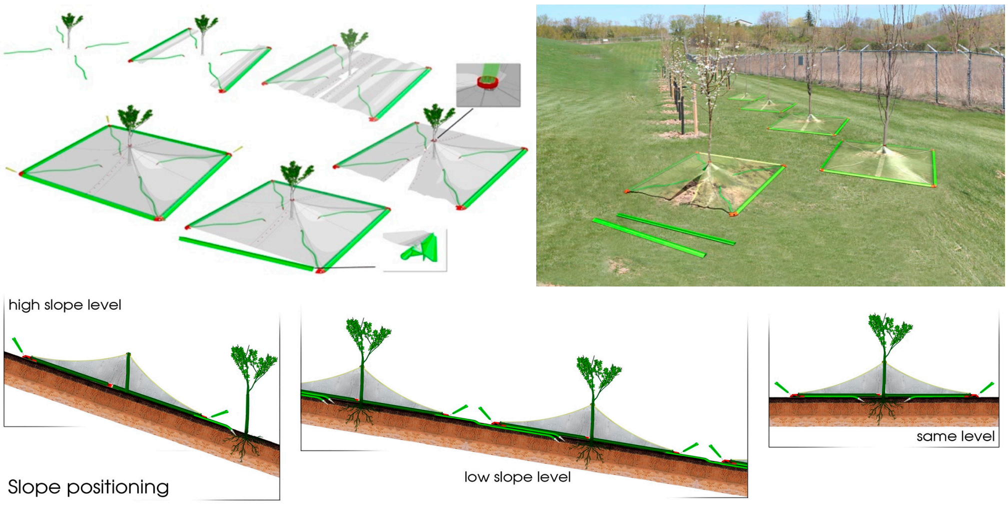

Figure 7. Assembly of the AquaTrap unit.

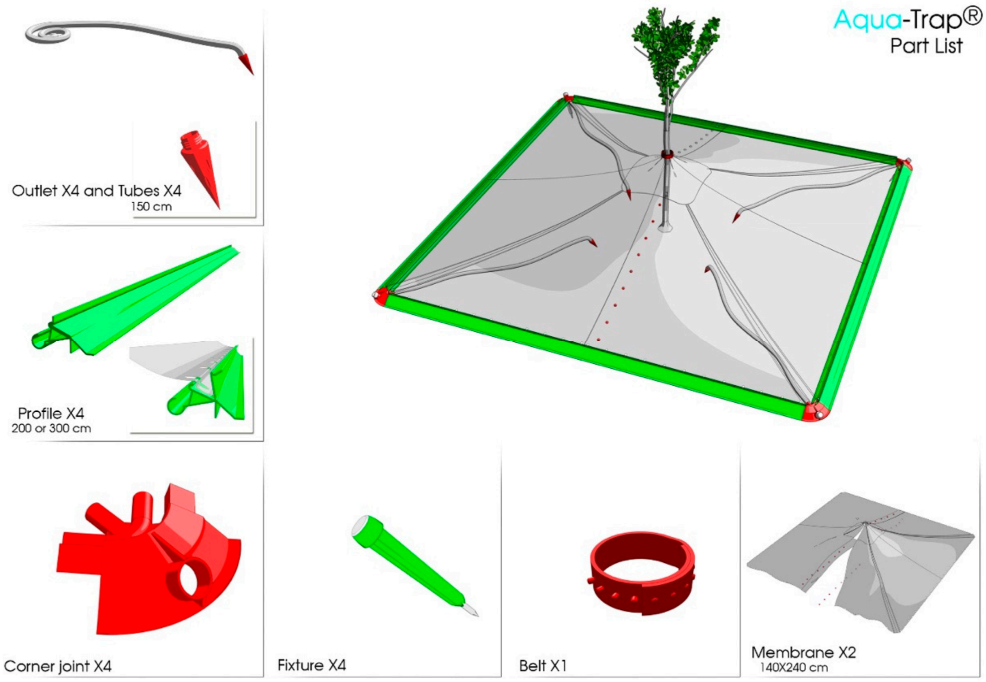

Figure 8. Part list of the AquaTrap unit.

4.5. Potential Advantages of the AquaTrap System

The AquaTrap system embodies a multifaceted approach to sustainable agriculture, specifically addressing the challenges associated with water scarcity and the efficient establishment of young trees. By integrating the insights from both provided lists, a comprehensive overview of its benefits, articulated through an academic lens, emerges as follows:

1. Water Usage Efficiency: The AquaTrap system revolutionizes traditional irrigation practices by reducing water requirements by approximately one-sixth, a feature especially critical in arid regions where water resources are precious and scarce.
2. Evaporation Capture and Redirection: It ingeniously captures water that would otherwise evaporate and redirects it toward the root zones of plants, maintaining optimal moisture levels. During peak hot seasons, the system can collect and redistribute water in the range of 200–450 cc/m^2 daily, thus ensuring efficient water use.

3. Design Simplicity and Reusability: Characterized by its simple assembly and disassembly, the AquaTrap system offers cost-effectiveness and suitability for repeated use across diverse planting sites. This design simplicity underlines the system's adaptability and ease of handling, promoting its application in various agricultural contexts.
4. Root Zone Moisture Enhancement: By significantly improving moisture levels within the root zone, the system facilitates enhanced root development and plant growth, crucial for the successful establishment of saplings.
5. Organizational Efficiency: The grid system inherent in the AquaTrap design aids in the systematic planting of trees, ensuring effective spacing and promoting uniform growth among young trees.
6. Cost-Effectiveness and Storage: The affordability and compact nature of the system enhance its storability and accessibility, making it an ideal choice for both small-scale gardeners and large-scale agricultural operations.
7. Integration with Sprinkler Systems and Rainwater Collection: AquaTrap's compatibility with existing surface sprinkler systems, coupled with its efficiency in maximizing rainwater collection, exemplifies its versatility and commitment to maximizing water usage efficiency.
8. Drought Resilience: In areas experiencing limited rainfall, the system proves its worth by collecting sufficient water to sustain young trees, highlighting its adaptability to varying climatic conditions and its role in mitigating drought impact.
9. Minimized Water Loss: The membrane structure central to the AquaTrap's design effectively minimizes water loss through evaporation, ensuring a continuous supply of water directly to the roots where it is most needed, thereby enhancing plant resilience.
10. Versatile Installation: Offering flexible installation options across different surfaces, the system caters to a wide array of flat and angular terrains and planting environments, underscoring its broad applicability.
11. Sustainable Water Management: The AquaTrap system adopts an eco-conscious approach by efficiently reclaiming lost moisture, contributing significantly to sustainable water management practices and environmental stewardship.
12. Environmental Preservation: Through the utilization of recycled plastics in its construction, the system not only supports environmental preservation efforts, but also contributes to waste reduction, aligning with global sustainability goals.
13. Wide Accessibility: The availability of the AquaTrap system in retail outlets, including supermarkets, at an affordable cost, ensures its accessibility to a broad spectrum of users, from individual gardeners to large-scale agricultural producers, encouraging its widespread adoption and use.
14. Weed Suppression: The use of colored nylon not only aids in moisture retention, but also inhibits the growth of unwanted weeds under the canopy of trees. This dual function enhances the system's efficiency by conserving water and reducing the labor and resources needed for weed control.
15. Modular Composition: The AquaTrap system is comprised of easily interchangeable parts, facilitating quick assembly, disassembly, and modifications as needed. This modularity ensures that the system can be tailored to specific requirements, enhancing its utility across various settings.
16. Scalability: Its design permits scaling from as small as 1 m^2 (1×1 m) to as large as 64 m^2 (8×8 m), offering unparalleled flexibility to accommodate different land sizes and water needs. This scalability makes the AquaTrap suitable for a wide range of applications, from small garden plots to larger agricultural fields.
17. Reusability: The AquaTrap's components are designed for repeated use, significantly reducing the need for continuous investment in new irrigation infrastructure. This reusability not only lowers costs, but also decreases environmental waste, aligning with sustainable agriculture practices.
18. Sustainability: Utilizing recycled plastics in the construction of AquaTrap components underscores the system's commitment to environmental preservation. By repurposing

waste materials, AquaTrap contributes to the circular economy and minimizes its ecological footprint.

19. Ease of Packaging, Storage, and Transport: The compact and lightweight design of the AquaTrap system ensures ease of packaging, storage, and transportation, addressing logistical challenges and reducing carbon emissions associated with shipping.

This synthesized list encapsulates the AquaTrap system's comprehensive advantages, illustrating its significant potential to transform irrigation practices, enhance plant growth, and contribute to sustainable environmental management.

5. Results and Discussions

5.1. Real-Time AquaTrap Application: "Evapotranspiration Monitoring for Pomegranate Tree Irrigation" in Akseki, Antalya

This field study investigates the application of real-time evapotranspiration (ET_o) monitoring to optimize irrigation management in a young pomegranate orchard (3–5-year-old trees) located in Akseki, Antalya, Turkey. The primary goal is to determine annual water loss rates and establish an efficient irrigation strategy based on real-time ET data.

The field study employs a two-phase approach. The first phase involves the continuous monitoring of meteorological data (radiation, temperature, humidity, and wind speed) and their conversion into real-time ET_o values. Although direct measurements of specific geographic conditions were not feasible, we made estimations using data from local government and FAO/Crop Water resources. This phase aims to establish a baseline for accurate ET_o calculations. The second phase focuses on irrigation optimization. By combining real-time ET data and estimated parameters, this study calculates the appropriate membrane size needed to collect 1–1.5 L of water per square meter per day for each tree. This data-driven approach aims to improve water use efficiency and ensure adequate water availability for optimal pomegranate growth and yield. The field study demonstrates the potential of real-time ET monitoring to optimize irrigation in pomegranate orchards (Pomegranate seedlings thrive on soil that is both moist and cool, even in hot and dry weather. They thrive in areas with elevations as high as 1350 m. Hence, it is necessary to carry out irrigation during seasons of inadequate rainfall. Consistent irrigation is crucial for achieving high-quality and plentiful crops, as well as preventing fruit skin cracking and fruit breaking). Even with estimations for certain parameters, this approach proves effective in calculating ET and determining optimal membrane size. This translates to significant water savings compared to traditional irrigation methods, highlighting the potential for enhanced sustainability in water use and environmental impact (Figure 9).

Figure 9. Pomegranate tree application area in Akseki, Antalya Turkey.

5.1.1. Evapotranspiration Monitoring

The meteorological data for Akseki GPS Akseki (a district in the Antalya Province in the Mediterranean region of Turkey): altitude 1050 mt, latitude: 37°03′4.20″ N, and Longitude: 31°47′1.79″ E in May 2023.

a. Net radiation (Rn):

- Average daily solar radiation (Rs): For May in Akseki, Antalya, we estimated an average daily solar radiation (Rs) value of around 5.5 kWh/m^2 day. This can be based on the historical solar radiation data for the region or by using solar radiation estimation tools.
- Net radiation (Rn): Assuming a typical albedo (reflectivity) of 0.2 for vegetation, which also estimate the net radiation (Rn) using the following formula:

$$Rn = (1 - albedo) * Rs$$

$$Rn = (1 - 0.2) * 5.5\ kWh/m^2\ day$$

$$Rn = 4.4\ kWh/m^2\ day$$

b. Soil heat flux (G): For daily time scales, soil heat flux (G) is typically negligible compared to net radiation (Rn). Therefore, it can assume:

$$G = 0\ MJ/m^2\ day$$

c. Atmospheric pressure (P): The average atmospheric pressure at sea level is around 1013 hPa. For Akseki, Antalya, which is located at an altitude of approximately 1000–1050 m above sea level, you can estimate an average atmospheric pressure (P) of around 870 hPa.

d. Mean air temperature (T): May is typically a warm month in Akseki, Antalya, with average mean air temperatures (T) ranging from 15 °C to 20 °C. The average temperature is 17.5 °C (24 h temperature average).

e. Average relative fumidity (RH): Relative humidity (RH) can vary depending on the specific location and time of day. For Akseki, Antalya, in May, you can estimate an average RH of around 60% (RH also changes in the range of 35–75% in May).

Using the Estimated Calculation of the Data in the Penman–Monteith Equation. The Penman–Monteith equation is a widely used method for estimating evapotranspiration (ET), which is the combined process of water evaporation from the soil surface and transpiration from plants. It considers various factors that influence ET, including the estimated values for Rn, P, T, and RH. You can plug them into the Penman–Monteith equation to calculate the estimated ET value:

$$\lambda E = (Rn - G) + s\ (e - e_s)/(1 + s/\gamma).$$

λE: Latent heat flux (rate of evapotranspiration);
Rn: Net radiation (incoming solar radiation − outgoing terrestrial radiation) = 4.4 kWh/m^2 day;
G: Soil heat flux = 0 MJ/m^2 day;
s: Slope of the saturation–vapor pressure curve;
e: Actual vapor pressure;
e_s: Saturation vapor pressure;
γ: Psychrometric constant.

f. Important Considerations:

1. These are just average values, and the actual meteorological data and ET values may vary depending on the specific conditions in Akseki, Antalya, in May (May is the highest evaporation period of the year in Antalya).
2. The Penman–Monteith equation is a complex and data-intensive method. For more accurate ET_o estimations, each application would need to have access to real-time meteorological data from a local weather station or use a specialized ET_o estimation model in the target region.
3. Pre-cooked ET_o values are always estimated, but actual ET_o may vary due to several factors like soil type, plant cover, and management practices.

4. Continuous monitoring of soil moisture and adjustments to irrigation schedules are crucial for efficient water management systems like AquaTrap. The actual meteorological conditions and ET_o values may differ from these estimates. For more precise information, we need to rely on real-time weather data and specialized ET estimation tools.

5.1.2. Calculations

Measure data and the calculation process to (potentially) determined an ET_o value for checking the target value (1–1.5 mm/m^2 day) for Akseki, Antalya, in May with the Penman–Monteith Equation (Table 5) as follows:

a. Data:
Net radiation (Rn): 4.4 kWh/m^2 day (converted from estimated daily solar radiation).
Soil heat flux (G): 0 MJ/m^2 day (negligible for daily time scales).
Atmospheric pressure (P): 870 hPa (adjusted for Akseki's altitude).
Mean air temperature (T): 17.5 °C (average for May).
Relative humidity (RH): 60% (average for May).

b. Calculation Steps:

1. Slope of saturation–vapor pressure curve (s):

$$s = 6.65 * 10^{-5} * P * T/(1000 + T)$$
$$s = 6.65 * 10^{-5} * 870 \text{ hPa} * 17.5\ °\text{C}/(1000 + 17.5\ °\text{C})$$
$$s = 0.0023 \text{ kPa m}^{-1}\ °\text{C}^{-1} \text{ (approximately)}$$

2. Actual vapor pressure (e):

$$e = (RH/100) * e_s$$

(a) Saturation vapor pressure (e_s):

$$e_s = 0.6108 * \exp(17.23 * T/(237.3 + T))$$
$$e_s = 0.6108 * \exp(17.23 * 17.5\ °\text{C}/(237.3 + 17.5\ °\text{C}))$$
$$e_s = 2.06 \text{ kPa (approximately)}$$

(b) Actual vapor pressure (e):

$$e = (60/100) * 2.06 \text{ kPa}$$
$$e = 1.24 \text{ kPa (approximately)}$$

3. Psychrometric constant (γ):

$$\gamma = (0.622 * P)/(P - e_s)$$
$$\gamma = (0.622 * 870 \text{ hPa})/(870 \text{ hPa} - 1.24 \text{ kPa}) \quad (1)$$
$$\gamma = 0.65 \text{ kPa}\ °\text{C}^{-1} \text{ (approximately)}$$

4. Latent heat flux (λE):
Here is where the iterative process might be needed: We are aiming for an ET_o value (λE) close to 144 mm/day. Using the estimated values above, we can calculate an initial λE:

$$\lambda E = (Rn - G) + s\,(e - e_s)/(1 + s/\gamma)$$
$$\lambda E = (4.4 \text{ kWh/m}^2 \text{ day} * (2.778 \text{ MJ/kWh}) * (10^6 \text{ J/MJ})) +$$
$$(0.0023 \text{ kPa m}^{-1}\ °\text{C}^{-1} * (1.24 \text{ kPa} - 2.06 \text{ kPa}))/$$
$$(1 + 0.0023 \text{ kPa m}^{-1}\ °\text{C}^{-1}/0.65 \text{ kPa}\ °\text{C}^{-1})$$
$$\lambda E \approx 9.2 \text{ MJ/m}^2 \text{ day (approximately)}$$

5. Converting MJ/m^2 day to mm/day:

$$ET\ (mm/day) = \lambda E * (24\ h/day) * (10^3\ J/MJ) * (1\ m^2/10^6\ mm^2)$$
$$ET\ (mm/day) \approx 9.2\ MJ/m^2\ day * 24\ h/day * 10^3\ J/MJ * 1\ m^2/10^6\ mm^2$$
$$ET\ (mm/day) \approx 221\ mm/day\ (approximately)$$

This initial theoretical calculation resulted in an ET value (221 mm/day/m^2) much higher than the target ET_o of 150 mm/day m^2.
Since the calculated ET is higher than the target ET_o, let us try lowering the estimated relative humidity (RH) slightly, as lower humidity typically leads to a higher ET (RH in the range of 40–60% in May).

6. Recalculations with a low RH: The recalculation with an adjusted relative humidity (RH) of 55% is presented below:
   (a) Actual vapor pressure (e):

$$e = (RH/100) * e_s\ \text{(We already have } e_s \text{ from previous calculation: 2.06 kPa)}$$
$$e = (55/100) * 2.06\ kPa$$
$$e = 1.13\ kPa\ (approximately)$$

   (b) Psychrometric constant (γ):

$$\gamma = (0.622 * P)/(P - e_s)$$
$$\gamma = (0.622 * 870\ hPa)/(870\ hPa - 1.13\ kPa)$$
$$\gamma = 0.65\ kPa\ ^\circ C^{-1}\ \text{(Remains the same as previous calculation)}$$

   (c) Latent heat flux (λE):

$$\lambda E = (Rn - G) + s\,(e - e_s)/(1 + s/\gamma)$$
$$\lambda E = (4.4\ kWh/m^2\ day * (2.778\ MJ/kWh) * (10^6\ J/MJ)) + (0.0023\ kPa\ m^{-1}\ ^\circ C^{-1} * (1.13\ kPa - 2.06\ kPa))/(1 + 0.0023\ kPa\ m^{-1}\ ^\circ C^{-1}/0.65\ kPa\ ^\circ C^{-1})$$
$$\lambda E \approx 10.3\ MJ/m^2\ day\ (approximately)$$

   (d) Converting MJ/m^2 day to mm/day:

$$ET\ (mm/day) = \lambda E * (24\ h/day) * (10^3\ J/MJ) * (1\ m^2/10^6\ mm^2)$$
$$ET\ (mm/day) \approx 10.3\ MJ/m^2\ day * 24\ h/day * 10^3\ J/MJ * 1\ m^2/10^6\ mm^2$$
$$ET\ (mm/day) \approx 247\ mm/day\ (approximately)$$

7. Iteration result:
When the measured relative humidity decreased from 60% to 55%, the calculated ET_o value increased from 221 mm/day to 247 mm/day. But, it is still higher than the target ET_o of 150 mm/day (AquaTrap target value).
8. Important considerations:
   (a) This is still an iterative process, and the optimal measurements will also depend on the specific conditions.
   (b) The estimated data points may not reflect the actual conditions perfectly (three sensors are not enough).
   (c) ET_o values are ($\pm$ 15%) and the actual ET may vary due to factors like soil type, plant cover, and management practices.

5.1.3. Minimum Membrane Cover Area Calculation

Minimum membrane area (m^2) = 1.5 L/ET_o value [1.5 L is the daily target amount).

Cover area (m^2) = Water need (liters/day)/(ET_o (mm/day) * 1000 * (1 − Error rate)) = 1.5/(0.38 * 1000 * (1 − 0.15))

1. Total water needed: We need to consider both the daily water needs of the tree (1.5 L) and the 15% error rate for potential water loss.

- Total Water Needed = Daily Water Need (1.5 L) * (1 + Error Rate).
- Total Water Needed = 1.5 L * (1 + 0.15).
- Total Water Needed = 1.725 L (rounded to two decimal places).
- Cover Area Calculation: Now, we can use the ET_o value, and the total water needed to calculate the required cover area (Table 6).
- Cover Area (m^2) = Total Water Needed (liters/day)/(ET_o (mm/day) * 1000 * (1 − Error Rate)).
- Calculated ET_o for May (according to RH = 40%):
- ET_o value (from previous table) = 0.38 mm/day.
- Total Water Needed (calculated above) = 1.725 L/day.
- Error Rate = 0.15.
- Cover Area (m^2) = 1.725/(0.38 * 1000 * (1 − 0.15)).
- Cover Area (m^2) ≈ 4.97 (rounded to two decimal places). Average 5 m^2 membrane is enough to collect 1.5 L of water for each tree.

5.2. Results of the AquaTrap Prototype Test in Akseki/Antalya

a. Effects on ET rates: Measurements conducted in May (a period characterized by heavy rainfall and high humidity) revealed that the observed ET_o values were higher than those previously estimated by FAO/Crop Water (by 30–55%). This suggests that the region may face a higher demand for water than previously anticipated.
b. The field experiment with AquaTrap conducted in Akseki, Antalya, Turkey, demonstrates promising results, emphasizing the potential of this biomimetic irrigation system to improve water management practices in arid regions. The results are evaluated in two stages: the verification of ET_o values (the verification stage of the water source and the transportation of this water to the roots) and the comparison of these results with theoretical expectations.
c. According to theoretical calculations conducted before the field study, it was found that the required membrane surface area under the tree canopy could be reduced by 35% in this field study. However, the high ET_o rates have altered these results.
d. The findings of the study indicate that AquaTrap effectively captures and delivers water to newly planted pomegranate trees, significantly supporting their growth and survival in a water-limited environment. An experiment providing around 1 L of water per day to pomegranate seedlings for 30 days suggests the potential for sustaining growth despite theoretical losses (observed at 15% in membranes and 5–8% in water transfer pipes). This indicates that the daily target of 1.5 L can be exceeded.
e. When calculating the membrane area for different regions and species, it is considered that the calculation system can be adapted to include a standard deviation value to preserve the target water quantity based on the margin of error. It has been observed that increasing membrane quality (the lotus effect) can enhance efficiency and reduce losses in field applications.
f. Following the field tests and calculations, it was determined that a 2.5 × 2.5 m^2 membrane cover for pomegranate trees in the Akseki, Antalya region is adequate for reaching the daily 1.5 L target. Despite using a 3 × 3 m^2 cover in the practical application, it was found that 1.7–1.8 L of water could be harvested daily with an ET_o value of 0.20 in the soil during spring months, such as May, when evaporation is most

pronounced. Consequently, the AquaTrap system in the Antalya/Akseki, Turkey application shows promise for future efficiency, as suggested by the achieved results.

In addition to the field tests, the AquaTrap initiative has made substantial contributions to afforestation and life support during the plant's critical adaptation process. During the one-year field tests, we conducted field observations and small spot studies, although further verification of these effects through additional testing remains necessary. These may provide insights for future research. We hypothesize that the capacity to accumulate, direct, and transfer to the roots depends on the potential of the applied membrane area. The sprinkler, which operates on the same principles, is extraordinary for its ability to conserve water and reduce the duration of irrigation. The sprinkler's rapid transfer of drops falling on the membrane cover (lotus effect) to the roots in the AquaTrap system during the unit time of irrigation demonstrates its potential to meet the targeted 1.5 L/day water requirement in a brief time. Similarly, even in the absence of sufficient soil moisture, the target tree's roots receive an adequate amount of water within minutes.

Recommendations for Future Research

a. Long-Term Impact Assessment: Long-term studies evaluating the sustainable effectiveness of AquaTrap on tree growth, yield, and water use efficiency are predicted to be beneficial for the product's development and results.
b. Effect of External Precipitation: Although the product's capacity to collect water during external precipitation events (such as rain or hail) has been observed, this input has not been measured. It is necessary to measure this feature at a different study level, as it may yield higher results than theoretical studies. Storing collected water within the system, depending on its density, could lead to much more effective results.
c. Comparative Analysis: Comparing the performance of AquaTrap with other irrigation systems under changing environmental conditions and water availability scenarios is expected to demonstrate the solution's effectiveness more intensively.
d. Economic Feasibility Assessment: Demonstrating the economic feasibility of the AquaTrap application, including initial investment costs, maintenance requirements, potential savings in water usage, and labor, is crucial for its widespread adoption.

5.3. Potential Effects of RH, Soil Moisture, and AquaTrap-like Systems for Sustainable Forestry

Agriculture, which constitutes 72% of global freshwater consumption according to the FAO, is particularly vulnerable to ecological degradation, climate change, and water scarcity [79]. Increasing water shortage and contamination underscore the need for sustainable water management practices in agriculture. Addressing these challenges requires a comprehensive approach to water resource management in both agricultural and forestry practices. Efficient water utilization in agriculture necessitates the implementation of intelligent strategies, advanced technologies, and collaborative efforts involving policymakers and stakeholders across various sectors. Soil moisture is an important factor in forest health [80]. Research into the benefits of innovative technologies, such as AquaTrap, and other soil moisture conservation systems for sustainable forestry practices has yielded promising results. These technologies can significantly enhance the survival and growth of trees, particularly in arid regions, by reducing water requirements through efficient water retention and targeted distribution to the root zones. A two-way evaluation of AquaTrap, including both theoretical analysis and prototype testing, demonstrated that the system effectively met its objectives. Field observations indicated that an AquaTrap system with a 6 m^2 membrane application could provide over 1.5 L of water per day year-round to pomegranate trees in the Antalya/Akseki region, even under the driest conditions (average yearly moisture content: 45–48%), regardless of the existing soil moisture content. It is anticipated that systems like AquaTrap, with flexible dimensional values (up to a maximum of 64 m^2 with a minimum 0.0236 ET_o value), can produce efficient results, even under extreme conditions. Their ability to adjust dimensions in accordance with the water requirements dictated by the target soil, climate, and plant species accounts for this. The literature suggests that increasing soil moisture can lead to various indirect benefits [79–82]. Beyond mitigating soil erosion and forest fire risks, it is essential to assess the effectiveness of systems like AquaTrap in reducing reliance on chemical pesticides. Numerous studies affirm the importance of soil moisture restoration systems in enhancing ecosystem resilience [83,84]. The viability of newly planted trees largely depends on soil moisture levels and the acclimation period. Many studies emphasize the significant impact of soil moisture on the successful growth of seedlings during droughts.

Relative humidity (RH) has a significant impact on the environment and the resources required for organisms to survive and adapt. As relative humidity decreases, water loss accelerates. In dry conditions, low relative humidity and minimal water vapor in the air create an imbalance in vapor pressure between a newly planted tree's leaves and the surrounding air. This leads to increased water vapor emission from the leaves through transpiration, exceeding the air volume and causing water stress.

AquaTrap is an eco-friendly and effective solution for newly planted plants facing water deficits due to unfavorable low relative humidity conditions. The primary goal is to collect evaporated water and channel external water sources (such as rainfall and irrigation) into the root zone. Utilizing a physical barrier, AquaTrap surrounds the plant and soil interface, ensuring a consistent water supply, even during sporadic rainfall or irrigation. Especially in arid environments, inadequate humidity can be detrimental, causing dehydration stress in plants due to excessive water loss. Dehydration leads to leaf desiccation, slowing growth, reducing root formation, and increasing vulnerability to pests and diseases. Water stress also hinders efficient photosynthesis due to decreased humidity, which has a significant impact on plant growth and development. AquaTrap addresses these challenges by improving growth, increasing resilience to dehydration stress, and promoting water absorption from roots, all of which reduce risks. Additionally, it supports efficient techniques, like proper irrigation and mulching, to counteract the negative effects of low relative humidity on newly planted trees. By regulating soil moisture, decreasing transpiration, and meeting plants' water needs, AquaTrap effectively manages water in arid conditions, optimizing plant growth and health.

"Soil moisture is a critical parameter for sustainable agriculture and forestry as it directly reflects the proportion of water retained in the uppermost soil layer" [83]. This variable is vital for numerous processes and applications, including numerical weather forecasting, flood forecasting, and agricultural drought assessment. Soil moisture variability is also crucial for water resource management, assessing greenhouse gas emissions, civil protection, and the epidemiological modeling of waterborne diseases. While soil moisture is essential in agriculture, optimizing water content and water consumption is also vital in forestry. Effective water management is the primary factor determining trees' life and growth. In dry climates, devices such as AquaTrap efficiently collect and channel water to the root zones, aiming to reduce water consumption through precise irrigation methods. These concepts align with the increasing demand for water conservation techniques in sustainable forestry and promise to address future challenges.

1. Fighting Moisture Stress: By reducing moisture stress, encouraging root development, and reducing transpiration, systems like AquaTrap significantly increase the survival rates of newly planted trees, especially in harsh environments. This is especially important for reforestation projects and drought-prone areas. Traditional irrigation methods can be inefficient and inadequate, and as the humidity of the environment decreases, it can become increasingly difficult for newly planted trees to survive due to increased evaporation [83]. Systems like AquaTrap have been developed to overcome this difficulty by collecting the condensation losses caused by this evaporation and directing it to the root area of the sapling. Soil moisture conservation significantly improves the survival and growth rates of newly planted tree seedlings. Adequate soil moisture promotes root development and nutrient uptake, increasing their chances of survival and growth [79,82]. This targeted water distribution ensures that the

most important part of the young tree receives the moisture it needs for survival and initial growth.

2. Reducing Water Consumption: Traditional irrigation methods often lead to water loss and wastage. Directing water directly to the root zone and conserving soil moisture can significantly improve water use efficiency. The lotus-effect method directs the water droplets falling on the external surface of the tension membrane during short-term external rainfall movements first to the system's collection channels and then to the tree's roots, thereby increasing the moisture in the root area and enhancing plant development [80,84].
3. Root Development and Nutrient Uptake: Adequate soil moisture in the root zone is important for healthy root development. Roots play a vital role in absorbing water and nutrients from the soil that are necessary for trees to grow. AquaTrap systems support optimal root development by maintaining consistent moisture levels around the roots. This allows the tree to access more water and nutrients from the surrounding soil, leading to faster and healthier growth [83,85].
4. Reduced Sweating: In hot, dry conditions, trees lose water through transpiration, a natural process in which they release water vapor from their leaves. Excessive transpiration can stress the tree and stunt its growth. AquaTrap systems help reduce transpiration rates in young trees by preserving soil moisture. This preserves water within the plant and allows it to focus its energy on growth and development [81].
5. Controlling Erosion: The term "slope erosion" describes the process by which water and wind wear away the top layer of soil along a hillside. Blown or washed topsoil can accumulate at the hill's base or pollute surrounding bodies of water as sediments. Erosion on the slope reduces soil fertility, which, without control measures, eventually renders the land wholly unfit for plant growth. Soil moisture conservation aids in erosion control by stabilizing the soil and regulating water flow. This is particularly important on sloping terrains or areas prone to heavy precipitation [83,84].
6. Mitigating Forest Fire Risk: High soil moisture and dense understory vegetation can significantly reduce forest fire risk [85]. By promoting these conditions, AquaTrap can help mitigate this threat.
7. Reducing Chemical Pesticide Use: Healthy trees tend to be more resistant to pest infestations and similar systems, by ensuring tree survival and growth, can potentially reduce our reliance on chemical pesticides [86].
8. Enhancing Biomass Production: Healthy trees that grow faster and produce more wood can significantly increase biomass production. AquaTrap, by promoting the growth of such trees, can encourage biomass production [87].
9. Boosting Carbon Sequestration: Adequate soil moisture helps trees absorb more carbon dioxide and store it in their biomass. This implies that AquaTrap and similar systems can play a crucial role in mitigating greenhouse gas emissions and combating climate change [88].
10. Supporting Biodiversity: High soil moisture creates a favorable environment for the development of diverse plant and animal species, enhancing biodiversity. AquaTrap and similar systems, by providing these conditions, can aid in habitat protection and species diversity conservation [89,90].
11. Improving Soil Health: Adequate soil moisture enhances soil health by promoting soil microbial activity and nutrient cycling. AquaTrap and similar systems, by facilitating these processes, can contribute to establishing healthy and productive forest ecosystems [90–92].

By effectively managing soil moisture, AquaTrap-like systems offer a promising approach to sustainable forestry in a world facing water scarcity challenges. Further research can explore the long-term effects of these systems on different tree species and soil types for even more comprehensive understanding.

However, it is important to remember that AquaTrap is one tool within a broader approach to sustainable forestry. Combining these systems with other practices, like mulching and proper planting techniques, can further enhance the benefits for tree health and ecosystem resilience.

5.4. The Future of AquaTrap Systems and Potential Challenges

Reflecting on the thorough discussions surrounding the AquaTrap system, this innovative solution has great potential in addressing the important challenges of water conservation and sustainable agriculture. The system's design, which focuses on efficiency, reusability, and environmental sustainability, highlights its usefulness in dry and water-scarce regions, offering a promising way to improve young tree survival rates and encourage healthier plant growth through optimized water management (Figure 9). However, for the AquaTrap system to reach its full potential and gain widespread adoption, several areas for development and improvement have been identified. These considerations are vital for enhancing the product's effectiveness and broadening its applicability across various agricultural contexts [90–92]. Possible areas for development:

1. Scalability: While the system has shown effectiveness on a small scale, its ability to be scaled up to larger agricultural operations is a key area to explore. Adapting the system for use in extensive farming landscapes could increase its impact, addressing water scarcity on a wider scale.
2. Material Innovation: Further research into the materials used for the AquaTrap system could improve its durability, cost-effectiveness, and environmental impact. Exploring biodegradable or more sustainable materials may enhance its eco-friendliness and appeal to a broader audience.
3. Technological Integration: Incorporating smart technology, such as sensors for moisture levels and automated water release mechanisms, could boost the system's efficiency and user-friendliness. This integration solution would allow for more precise water management possibilities and can easily tailored to the specific needs of each plant or tree.
4. Market Penetration Strategies: To expand the AquaTrap system's market reach, innovative marketing and distribution strategies are crucial. Collaborations with agricultural organizations, endorsements from sustainability advocates, and using social media for awareness campaigns could increase visibility and adoption rates.
5. Customization and Flexibility: Improving the system's ability to adapt to different trees, soil types, and climatic conditions would make it a more versatile solution for global agricultural challenges. AquaTrap offers customizable options for various agricultural needs, and it can also enhance its usefulness and appeal to a wider range of users.
6. Educational Initiatives: Developing educational programs and materials to educate farmers, gardeners, and agricultural stakeholders about the benefits and operation of the AquaTrap system can facilitate its acceptance and use. Training sessions, workshops, and demonstration projects could be effective tools for engagement and knowledge sharing.

6. Conclusions

Considering the comprehensive analysis, discussions, and first field study results, the AquaTrap system emerges as a pivotal innovation in the realm of agricultural water management, particularly in the context of enhancing the survival and growth of young trees in arid and semi-arid regions. This novel system, characterized by its low-cost, high-efficiency water conservation strategy, represents a significant leap forward in addressing the urgent need for sustainable agricultural practices in the face of global water scarcity challenges. AquaTrap's design philosophy—centered on the capture and redirection of evaporating water back to the plant's root zone—demonstrates a profound understanding of the critical balance required to maintain soil moisture levels, thereby ensuring plant health and growth. This mechanism not only reduces the demand for traditional irrigation methods, but also optimizes water usage by leveraging natural processes and resources, such as rainwater and condensation. The AquaTrap system's efficacy in reducing water usage compared to conventional irrigation practices underscores its potential to significantly mitigate water waste in agriculture, a sector notorious for its high water consumption.

Furthermore, the AquaTrap system's adaptability to various environmental conditions and compatibility with different plant species highlight its versatility and potential for widespread application. The system's design, which facilitates easy assembly and disassembly, offers a practical and user-friendly solution for farmers and gardeners, further enhancing its appeal and potential for widespread adoption. The strategic use of recycled plastics in the construction of the AquaTrap system not only enhances its sustainability credentials, but also aligns with the growing global imperative for environmentally responsible manufacturing practices. This approach not only contributes to the reduction in plastic waste, but also promotes a circular economy model within the agricultural sector. However, for the AquaTrap system to fully realize its potential and achieve widespread adoption, it is imperative to address several key areas for development. These include scalability for large-scale agricultural operations, material innovations for enhanced durability and sustainability, integration of smart technologies for precision water management, and comprehensive market penetration strategies to facilitate access and affordability for all farmers. The future of the AquaTrap system lies in its ability to evolve in response to these challenges through continuous research and development, strategic partnerships, and robust community engagement initiatives. By doing so, AquaTrap can significantly contribute to global efforts toward sustainable agriculture, enhancing food security, and promoting environmental stewardship.

In conclusion, the AquaTrap system represents a transformative potential solution in the landscape of water management technologies for agriculture. Its innovative approach to capturing and utilizing evaporative water loss offers a sustainable, efficient, and cost-effective method for supporting plant growth in water-scarce environments. As the world grapples with the dual challenges of water scarcity and the need for sustainable agricultural practices, the AquaTrap system stands out as a beacon of hope and innovation. With targeted improvements and strategic dissemination, it has the potential to become an integral component of global agricultural systems, paving the way for a more sustainable and water-efficient future. Furthermore, the AquaTrap project supports sustainable forestry by improving soil moisture levels, which is critical for tree survival and growth, particularly in water-scarce regions. This technology helps establish and maintain healthy forests, which are essential for ecosystem resilience and biodiversity. Integrating such water-efficient systems can significantly improve sustainable forestry practices, thereby contributing to the overall health and sustainability of forest ecosystems. These projects offer promising avenues for further academic research and practical applications, emphasizing the critical role of innovative water management solutions in promoting environmental sustainability.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data related to this article are available in this manuscript.

Conflicts of Interest: The author declares no conflict of interest.

References

1. United Nations Sustainable Development Goals. Clean Water and Sanitation. Available online: https://unstats.un.org/sdgs/report/2022/The-Sustainable-Development-Goals-Report-2022.pdf/ (accessed on 26 May 2024).
2. Harris, R.W.; Clark, J.R.; Matheny, N.P. *Arboriculture: Integrated Management of Landscape Trees, Shrubs, and Vines*, 4th ed.; Prentice Hall: Upper Saddle River, NJ, USA, 2004.
3. Gilman, E.F. *An Illustrated Guide to Pruning*, 3rd ed.; Cengage Learning: Boston, MA, USA, 2011.
4. Shigo, A.L. *Modern Arboriculture: A Systems Approach to the Care of Trees and Their Associates*; Shigo and Trees, Associates: Snohomish, WA, USA, 1991.

5. Kozlowski, T.T.; Kramer, P.J.; Pallardy, S.G. *The Physiological Ecology of Woody Plants*; Academic Press: Cambridge, MA, USA, 1991.
6. Leakey, R.R.B. *Living with the Trees of Life: Towards the Transformation of Tropical Agriculture*; CABI: Wallingford, UK, 2012.
7. Perry, T.O. Tree Roots: Facts and Fallacies. *Arnoldia* **1982**, *42*, 21–27. [CrossRef]
8. Fisher, J.B. Tropical Tree Roots. In *Tropical Trees as Living Systems*; Fisher, J.B., Ed.; Cambridge University Press: Cambridge, UK, 1987; pp. 401–441.
9. FAO (Food and Agriculture Organization of the United Nations). *Coping with Water Scarcity: An Action Framework for Agriculture and Food Security*; FAO Water Reports No. 38; FAO: Rome, Italy, 2013.
10. Available online: https://water.unl.edu/landscapewater/tree-watering (accessed on 13 December 2023).
11. Mancosu, N.; Snyder, R.L.; Kyriakakis, G.; Spano, D. Water Scarcity and Future Challenges for Food Production. *Water* **2015**, *7*, 975–992. [CrossRef]
12. 1749-1756.UNIDO. Water and Industry: A Shared Responsibility. 2019. Available online: https://www.unido.org/ (accessed on 26 May 2024).
13. WWAP. The United Nations World Water Development Report 2023: Water Security for the Planet. UNESCO. 2023. Available online: https://www.unesco.org/en/wwap/wwdr (accessed on 26 May 2024).
14. World Wildlife Fund. *Trees and Water: A Vital Connection*; World Wildlife Fund: Gland, Switzerland, 2019.
15. FAO. *The Role of Trees in Soil and Water Conservation*; Food and Agriculture Organization of the United Nations (FAO): Rome, Italy, 2017; Available online: https://www.fao.org/3/i0410e/i0410e.pdf (accessed on 16 November 2023).
16. IUFRO. *The Impact of Trees on Microclimate and Water Resources*; International Union of Forest Research Organizations (IUFRO): Vienna, Austria, 2018; Available online: https://www.iufro.org/science/task-forces/forests-water-interaction-changing-environment/ (accessed on 26 May 2024).
17. Report of the Open-Ended Working Group on the Post-2020 Global Biodiversity Framework on Its Fourth Meeting by Convention on Biological Diversity (CBD) (2020). Available online: https://www.cbd.int/doc/c/3303/d892/4fd11c27963bd3f826a961e1/wg2020-04-04-en.pdf (accessed on 26 May 2024).
18. Climate Change 2021 The Physical Science Basis the Role of Forests in Climate Change Mitigation by Intergovernmental Panel on Climate Change (IPCC). 2021. Available online: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf (accessed on 26 May 2024).
19. FAO. *The Global Forest Resources Assessment 2020*; Food and Agriculture Organization of the United Nations (FAO): Rome, Italy, 2020; Available online: https://reliefweb.int/report/world/global-forest-resources-assessment-2020-key-findings?gad_source=1 (accessed on 26 May 2024).
20. WWAP. *The World Water Development Report 2022*; United Nations World Water Assessment Programme (WWAP): Perugia, Italy, 2022; Available online: https://reliefweb.int/report/world/united-nations-world-water-development-report-2022-groundwater-making-invisible-visible?gad_source=1 (accessed on 26 May 2024).
21. Available online: https://www.weforum.org/agenda/2023/01/water-climate-adaptation-mitigation-davos2023/ (accessed on 26 May 2024).
22. Available online: https://wwf.panda.org/discover/our_focus/freshwater_practice/freshwater_biodiversity_222/16 (accessed on 26 May 2024).
23. Available online: https://theriverstrust.org/key-issues/fisheries-wildlife (accessed on 26 May 2024).
24. Available online: https://www.water.org.uk/news-item/global-water-industry-net-zero-commitments-top72-million-people-served/ (accessed on 12 October 2023).
25. UNESCO World Water Assessment Programme [573], UNESCO. Director-General, 2009–2017 (Bokova, I.G.) ISBN: 978-92-3-100146-8, 978-92-3-100155-0 (ePub). Available online: https://unesdoc.unesco.org/search/N-EXPLORE-d7f14ee1-de95-4259-ba38-99b9133b89b5 (accessed on 26 May 2024).
26. Available online: https://www.nationalgeographic.com/environment/article/plastic-pollution (accessed on 26 May 2024).
27. Available online: https://iksadyayinevi.com/wp-content/uploads/2023/10/advancements-in-aquaculture-sustainable-practices-innovations-and-applications.pdf (accessed on 5 December 2023).
28. International Water Management Institute (IWMI). *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*; Earthscan: London, UK, 2007.
29. Vörösmarty, C.J.; Green, P.J.; Salisbury, J.; Lammers, R.B. Global water resources: Vulnerability from climate change and population growth. *Science* **2000**, *289*, 284–288. [CrossRef] [PubMed]
30. Chimonides, S.J. Irrigation management under water shortage conditions. In *Water Resources Management under Drought or Water Shortage Conditions*; Tsiourtis, N.X., Ed.; Balkema: Rotterdam, The Netherlands, 1995; pp. 73–78.
31. Water Scarcity by World Wildlife Fund. Available online: https://www.wwf.eu/?11685466/New-report-Europes-water-scarcity-challenge (accessed on 26 May 2024).
32. Hoekstra, A.Y.; Mekonnen, M.M. The water footprint of humanity. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 3232–3237. [CrossRef] [PubMed]
33. Du, M.; Zhang, J.; Wang, Y.; Liu, H.; Wang, Z.; Liu, C.; Yang, Q.; Hu, Y.; Bao, Z.; Liu, Y.; et al. Evaluating the contribution of different environmental drivers to changes in evapotranspiration and soil moisture, a case study of the Wudaogou Experimental Station. *J. Contam. Hydrol.* **2021**, *243*, 103912. [CrossRef]

34. Linsley, R.K.; Kohler, M.A.; Paulhus JL, H. *Hydrology for Engineers*, 3rd ed.; McGraw-Hill: New York, NY, USA, 1982.
35. Available online: https://www.iwmi.cgiar.org/assessment/files_new/synthesis/Summary_SynthesisBook.pdf (accessed on 15 November 2023).
36. Wallace, J.M.; Hobbs, P.V. *Atmospheric Science: An Introductory Survey (Vol. 92)*; Academic Press: Cambridge, UK, 2006.
37. Rockström, J.; Steffen, W.; Noone, K.; Persson, Å.; Chapin, F.S., III; Lambin, E.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J.; et al. Planetary boundaries: Exploring the safe operating space for humanity. *Ecol. Soc.* **2009**, *14*, 32. Available online: https://www.stockholmresilience.org/download/18.8615c78125078c8d3380002197/ES-2009-3180.pdf (accessed on 26 May 2024). [CrossRef]
38. Trenberth, K.E.; Jones, P.D. *Observations: Surface and Atmospheric Climate Change Climate Change 2007—The Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the IPCC.*; Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M.C., Averyt, K.B., Tignor, M., Miller, H.L., Eds.; Cambridge University Press: Cambridge, UK, 2007.
39. Beguería, S.; Vicente-Serrano, S.M.; Reig, F.; Latorre, B. Standardized precipitation evapotranspiration index (SPEI) revisited: Parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. *Int. J. Climatol.* **2014**, *34*, 3001–3023. [CrossRef]
40. Freeze, R.A.; Cherry, J.A. *Groundwater*; Prentice-Hall: Hoboken, NJ, USA, 1979.
41. Beven, K.; Germann, P. Macropores and water flow in soils. *Water Resour. Res.* **1982**, *18*, 1311–1325. [CrossRef]
42. Dingman, S.L. *Physical Hydrology*, 2nd ed.; Prentice Hall: Upper Saddle River, NJ, USA, 2002.
43. Domenico, P.A.; Schwartz, F.W. *Physical and Chemical Hydrogeology*, 2nd ed.; John Wiley & Sons Inc.: New York, NY, USA, 1998.
44. Heath, R.C. Basic Ground-Water Hydrology. US Geological Survey. 1983. Available online: https://www.usgs.gov/publications/basic-ground-water-hydrology (accessed on 26 May 2024).
45. Ibrahim, B.; Mensah, H. Linking Environmental Water Scarcity and Options for Adaptation in the MENA Region. *J. Water Resour. Prot.* **2017**, *9*, 378–392. [CrossRef]
46. Doorenbos, J.; Kassam, A.H. *FAO Irrigation and Drainage Paper No. 33: Yield Response to Water*; Food and Agriculture Organization of the United Nations: Rome, Italic, 1979; 193p, Available online: https://www.scirp.org/reference/ReferencesPapers?ReferenceID=552874 (accessed on 26 May 2024).
47. Millennium Ecosystem Assessment (MEA). *Ecosystems and Human Well-Being: Synthesis*; Island Press: Washington, DC, USA, 2005; Available online: https://www.millenniumassessment.org/documents/document.356.aspx.pdf (accessed on 7 December 2023).
48. Available online: https://www.fao.org/global-soil-partnership/resources/highlights/detail/en/c/1412475/ (accessed on 14 December 2023).
49. Rosegrant, M.W.; Cline, S.A. Global food security: Challenges and policies. *Science* **2003**, *302*, 1917–1919. [CrossRef] [PubMed]
50. Barker, R.; van Koppen, B.; Shah, T. *A Global Perspective on Water Scarcity and Poverty: Achievements and Challenges for Water Resources Management*; International Water Management Institute (IWMI): Colombo, Sri Lanka, 2000; Available online: https://publications.iwmi.org/pdf/H026191.pdf (accessed on 7 October 2023).
51. World Bank Group. *High and Dry: Climate Change, Water, and the Economy*; World Bank: Washington, DC, USA, 2016; Available online: http://hdl.handle.net/10986/23665 (accessed on 26 May 2024).
52. Vincent, J.F.V.; Eva, O.A.B.; Bogatyrev, N.R.; Bowyer, A.; Pahl, A.-K. Biomimetics: Its practice and theory. *J. R. Soc. Interface* **2006**, *3*, 471–482. [CrossRef] [PubMed]
53. Yildirim, M.; Candan, Z. Smart materials: The next generation in science and engineering. *Mater. Today Proc.* 2023; *in press*. [CrossRef]
54. Hwang, J.; Jeong, Y.; Park, J.M.; Lee, K.H.; Hong, J.W.; Choi, J. Biomimetics: Forecasting the future of science, engineering, and medicine. *Int. J. Nanomed.* **2015**, *10*, 5701–5713. [CrossRef]
55. International Standardization Organization: Biomimetics—Terminology, Concepts and Methodology (18458). 2015. Available online: https://www.sis.se/api/document/preview/918837/ (accessed on 14 May 2023).
56. Available online: https://youmatter.world/en/definitions/definitions-what-is-biomimicry-definition-examples/ (accessed on 19 October 2023).
57. Wang, X.; Liang, Y.; Pu, Z.; He, J.; Yang, S. Transforming waste to treasure: Superhydrophobic coatings from recycled polypropylene for high-value application. *Prog. Org. Coat.* **2024**, *188*, 108248. [CrossRef]
58. Zheng, L.; Wu, X.; Lou, Z.; Wu, D. Superhydrophobicity from microstructured surface. *Chin. Sci. Bull.* **2004**, *49*, 1779–1787. [CrossRef]
59. Yu, C.; Sasic, S.; Liu, K.; Salameh, S.; Ras, R.H.; Van Ommen, J.R. Nature–Inspired self–cleaning surfaces: Mechanisms, modelling, and manufacturing. *Chem. Eng. Res. Des.* **2020**, *155*, 48–65. [CrossRef]
60. Wang, D.; Sun, Q.; Hokkanen, M.J.; Zhang, C.; Lin, F.-Y.; Liu, Q.; Zhu, S.-P.; Zhou, T.; Chang, Q.; He, B.; et al. Design of robust superhydrophobic surfaces. *Nature* **2020**, *582*, 55–59. [CrossRef] [PubMed]
61. Hu, D.L.; Chan, B.; Bush, J.W.M. The Hydrodynamics of Water Strider Locomotion. *Nature* **2003**, *424*, 663–666. [CrossRef] [PubMed]
62. Sun, T.; Feng, L.; Gao, X.; Jiang, L. Bioinspired surfaces with special wettability. *Acc. Chem. Res.* **2005**, *38*, 644–652. [CrossRef]
63. Parvate, S.; Dixit, P.; Chattopadhyay, S. Superhydrophobic Surfaces: Insights from Theory and Experiment. *J. Phys. Chem. B 2020 124*, 1323–1360. [CrossRef]

64. Safiuddin, M.; Hossain, K.; Collins, C.M. June 7th International Materials Specialty Conference Potential Applications of Self-Cleansing Nano Lotus Leaf Biomimicked Coating in Different Construction Sectors 15, 2018 Fredericton, New Brunswic Potential Applications of Self-Cleansing Nano Lotus Leaf Biomimicked Coating in Different Construction Sectors. 2018. Available online: https://www.researchgate.net/publication/326493399_Potential_Applications_of_Self-Cleansing_Nano_Lotus_Leaf_Biomimicked_Coating_in_Different_Construction_Sectors (accessed on 26 May 2024).
65. Barthlott, W.; Neinhuis, C. Purity of the sacred lotus or escape from contamination in biological surfaces. *Planta* **1997**, *202*, 1–8. [CrossRef]
66. Latthe, S.S.; Terashima, C.; Nakata, K.; Fujishima, A. Superhydrophobic surfaces developed by mimicking hierarchical surface morphology of lotus leaf. *Molecules* **2014**, *19*, 4256–4283. [CrossRef] [PubMed] [PubMed Central]
67. Bhushan, B.; Jung, Y.C. Natural and biomimetic artificial surfaces for superhydrophobicity, self-cleaning, low adhesion, and drag reduction. *Prog. Mater. Sci.* **2011**, *56*, 1–108. [CrossRef]
68. Ennos, A.R.; Spatz, H.-C.; Speck, T. The functional morphology of the petioles of the banana, Musa textilis. *J. Exp. Bot.* **2000**, *51*, 2085–2093. [CrossRef] [PubMed]
69. Callies, M.; Quéré, D. On water repellency. *Soft Matter* **2005**, *1*, 55–61. [CrossRef]
70. Barthlott, W.; Mail, M.; Bhushan, B.; Koch, K. Plant Surfaces: Structures and Functions for Biomimetic Innovations. *Nano-Micro Lett.* **2017**, *9*, 23. [CrossRef] [PubMed]
71. Quéré, D.; Reyssat, M. Non-adhesive lotus and other hydrophobic materials. *Phil. Trans. R. Soc. A* **2008**, *366*, 1539–1556. [CrossRef] [PubMed]
72. Extrand, C.W.; Moon, S.I. Repellency of the Lotus Leaf: Contact Angles, Drop Retention, and Sliding Angles. *Langmuir* **2014**, *30*, 8791–8797. [CrossRef] [PubMed]
73. Guo, Z.; Liu, W.; Su, B. Superhydrophobic surfaces: From natural to biomimetic to functional. *J. Colloid Interface Sci.* **2011**, *353*, 335–355. [CrossRef]
74. Available online: https://www.miamidade.gov/parks/library/guide_tree_book.pdf (accessed on 22 September 2023).
75. Del Campo, A.D.; Segura-Orenga, G.; Ceacero, C.J.; González-Sanchis, M.; Molina, A.J.; Reyna, S.; Hermoso, J. Reforesting drylands under novel climates with extreme drought filters: The importance of trait-based species selection. *For. Ecol. Manag.* **2020**, *467*, 118156. [CrossRef]
76. Zhang, S.; Fang, G.; Zhang, D.; Ju, M.; Zhong, H. Water resources optimal allocation model for coordinating regional multi-level water resources managers' interests. *Front. Environ. Sci.* **2023**, *11*, 1152296. [CrossRef]
77. Malagnoux, M.; Sène, E.H.; Atzmon, N. Forests, Trees and water in arid Lands: A Delicate Balance. *Unasylva* **2007**, *58*, 24–29. Available online: https://www.fao.org/3/a1598e/a1598e06.htm (accessed on 30 November 2022).
78. Available online: https://www.fao.org/one-health/areas-of-work/water/en (accessed on 21 July 2023).
79. Ma, Y.; Van Dam, R.L.; Jayawickreme, D.H. Soil moisture variability in a temperate deciduous forest: Insights from electrical resistivity and throughfall data. *Environ. Earth Sci.* **2014**, *72*, 1367–1381. [CrossRef]
80. Manoli, G.; Bonetti, S.; Domec, J.; Putti, M.; Katul, G.; Marani, M. Tree root systems competing for soil moisture in a 3D soil–plant model. *Adv. Water Resour.* **2014**, *66*, 32–42. [CrossRef]
81. Araki, R.; Mu, Y.; McMillan, H. Evaluation of GLDAS soil moisture seasonality in arid climates. *Hydrol. Sci. J.* **2023**, *68*, 1109–1126. [CrossRef]
82. Silva, T.P.; Bressiani, D.; Ebling, É.D.; Reichert, J.M. Best management practices to reduce soil erosion and change water balance components in watersheds under grain and dairy production. *Int. Soil Water Conserv. Res.* **2024**, *12*, 121–136. [CrossRef]
83. Available online: https://eos.com/blog/slope-erosion/ (accessed on 26 May 2024).
84. Nabeshima, E.; Kubo, T.; Hiura, T. Variation in tree diameter growth in response to the weather conditions and tree size in deciduous broad-leaved trees. *For. Ecol. Manag.* **2010**, *259*, 1055–1066. [CrossRef]
85. Fuller, L.; Quine, C.P. Resilience and tree health: A basis for implementation in sustainable forest management. *For. Int. J. For. Res.* **2015**, *89*, 7–19. [CrossRef]
86. Lozano-Parra, J.; Schnabel, S.; Pulido, M.; Gómez-Gutiérrez, Á.; Lavado-Contador, F. Effects of soil moisture and vegetation cover on biomass growth in water-limited environments. *Land Degrad. Dev.* **2018**, *29*, 4405–4414. [CrossRef]
87. Fang, X.; Zhu, Y.; Liu, J.; Lin, X.; Sun, H.; Tang, X.; Hu, Y.; Huang, Y.; Yi, Z. Effects of Moisture and Temperature on Soil Organic Carbon Decomposition along a Vegetation Restoration Gradient of Subtropical China. *Forests* **2022**, *13*, 578. [CrossRef]
88. Wang, L.; Wang, X.; Chen, L.; Song, N.; Yang, X. Trade-off between soil moisture and species diversity in semi-arid steppes in the Loess Plateau of China. *Sci. Total Environ.* **2020**, *750*, 141646. [CrossRef]
89. Heikinheimo, M.; Venäläinen, A.; Tourula, T. A soil moisture index for the assessment of forest fire risk in the boreal zone. In Proceedings of the International Symposium on Applied Agrometeorology and Agroclimatology, Volos, Greece, 24–26 April 1996; pp. 549–556.
90. Traore, K.; Birhanu, B. Soil Erosion Control and Moisture Conservation Using Contour Ridge Tillage in Bougouni and Koutiala, Southern Mali. *J. Environ. Prot.* **2019**, *10*, 1333–1360. [CrossRef]

91. Sadanandan Nambiar, E. Interplay between nutrients, water, root growth and productivity in young plantations. *For. Ecol. Manag.* **1990**, *30*, 213–232. [CrossRef]
92. Ravi, C.; Akhilesh, R. Effect of Soil Moisture on Composition and Diversity of Trees in Tropical dry Forest. *MOJ Ecol. Environ. Sci.* **2018**, *3*, 1–3. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.