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Landscape Architecture Program,
Department of Built Environment Studies and Technology
College of Built Environment
Universiti Teknologi MARA Perak Branch
Seri Iskandar Campus

05 February 2025
Semester October 2024 - February2025

PUBLISHED

31 March 2025

e ISBN 978-967-2776-49-9

9 789672 776499

Unit Penerbitan UiTM Perak
(online)

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ARBUSCULAR MYCORRHIZAL FUNGI IN IMPROVING DROUGHT RESISTANCE OF IPOMOEA AQUATICA FOR AGRICULTURE

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Published: 31 March 2025

ABSTRACT

Frequent and severe droughts increasingly threaten global agricultural productivity and point out the need for sustainable solutions to enhance crop resilience. This study investigates the role of Arbuscular Mycorrhizal Fungi (AMF) in improving drought tolerance in Ipomoea aquatica (kangkong), a water-loving plant widely consumed in Malaysia. A field and laboratory experiment were conducted using 6 pots divided into two treatment groups: AMF, and none-AMF, tested under three watering regimes: daily, weekly, and no watering (to simulate local climate). Weekly data on soil pH, plant height, and soil moisture were analysed using Microsoft Excel. Quantitative data were conducted in this study, results show that AMF-treated plants consistently outperformed groups across all watering regimes. Soil pH, plant height, and soil mixture data were collected and analysed using Excel revealing that AMF enhanced nutrient absorption, stabilized soil pH, improved soil moisture retention, and supported drought tolerance mechanisms, such as increased proline levels and antioxidant enzyme activity. Non-inoculated plants showed stunted growth and reduced drought resilience under similar conditions. This study highlights AMF's potential to promote soil health, reduce water dependency, and minimize chemical fertilizer use, making it a viable strategy for sustainable agriculture. Integrating AMF into farming practices offers a promising approach to addressing agricultural challenges in the face of climate change.

Keywords: *Drought Tolerance, Arbuscular Mycorrhizal Fungi (AMF), Ipomoea aquatica (Kangkong), Sustainable Agriculture, Soil Moisture*

INTRODUCTION

As climate change accelerates, frequent and severe droughts pose a critical threat to global food security, particularly in regions reliant on rain-fed agriculture, such as Southeast Asia, Africa, and Latin America (Chen et al., 2022; Patel & Singh, 2022). Water shortages significantly reduce crop yields, highlighting the need for sustainable solutions to ensure food production aligns with frameworks like SDG 2 (Zero Hunger) and SDG 13 (Climate Action) (Martinez et al., 2021). Arbuscular Mycorrhizal Fungi (AMF) offer a promising eco-friendly approach to mitigating drought impacts by forming mutualistic relationships with plant roots, enhancing water and nutrient uptake under stress conditions (Kim & Park, 2024). AMF also improves soil structure, and phosphorus uptake, and induces biochemical changes, such as increased osmoprotectants and antioxidant activity, which bolster plant resilience (Gonzalez & Johnson, 2023; Thomas et al., 2023; Patel & Singh, 2022). This study investigates AMF's potential to improve drought tolerance in Ipomoea aquatica (kangkong), a widely consumed Malaysian crop. By evaluating soil health and plant performance under varying watering regimes, this research aims to inform sustainable agricultural practices to enhance food security and climate resilience in Malaysia and beyond.

LITERATURE REVIEW

Arbuscular Mycorrhizal Fungi (AMF)

AMF establishes symbiotic relationships with plants, aiding in water and nutrient uptake, especially under environmental stress (Kim & Park, 2024). Studies within the last decade highlight that AMF symbiosis enhances osmoprotectant levels, like proline and soluble sugars, which support cellular turgor in drought conditions (Das et al., 2021). Additionally, AMF has been shown to strengthen root systems and enhance soil structure, thereby supporting drought resistance across multiple plant species (Begum et al., 2019). Current research emphasizes that AMF-associated plants produce higher levels of antioxidants, which help mitigate oxidative stress, contributing to plant health in arid conditions (Rivera-Becerril et al., 2020).

AMF and Plant Drought Tolerance

The beneficial effects of Arbuscular Mycorrhizal Fungi (AMF) in enhancing drought tolerance have been widely studied in various plant species. For example, AMF inoculation in cowpea (Vigna unguiculata) significantly improved drought tolerance while reducing susceptibility to charcoal rot disease, demonstrating AMF's ability to alleviate both biotic and abiotic stresses (Oyewole et al., 2017). Similarly, the dual inoculation of plant growth- promoting rhizobacteria (PGPR) and AMF in tomato plants showed promising results in combating abiotic stresses, such as drought and salinity, by enhancing nutrient uptake and antioxidant activity (Savastano & Ervin, 2024). Rice cultivation, another critical agricultural sector, has also benefited from AMF integration. Studies have shown that AMF inoculation enhances water and nutrient absorption, improves soil aggregation, and increases crop yields under drought conditions. For instance, AMF inoculation in rice (Oryza sativa) alleviated drought effects by improving root water uptake efficiency and physiological processes critical for plant survival ((Anupol Chareesri, 2024)). Additionally, a broader study by Alejandro Grajal-Puche et al. (2024) emphasized the reciprocity between natural ecosystems and agricultural systems, highlighting AMF's role in sustainable practices like rice cultivation. These studies collectively underline AMF's versatility in addressing drought- induced challenges across various crop species.

Significance of Kangkong (Ipomoea aquatica) in AMF Research

Kangkong (Ipomoea aquatica) is a fast-growing leafy vegetable native to tropical and subtropical environments that is commonly grown in Malaysia and Southeast Asia. Its prominence as a staple meal, along with its high-water need, makes it an ideal choice for research into the effects of AMF on drought resistance. The vulnerability of Kangkong to drought stress is well known, with water shortage having a significant influence on growth, yield, and nutritional content. This makes the species very important for evaluating solutions to reduce water stress in agriculture. The choice of kangkong for this study was motivated by its ecological and social significance. As a popular vegetable in Malaysia, kangkong is an important source of nutrition, supplying necessary vitamins, minerals, and dietary fibre. However, its high-water reliance is a huge difficulty in water-scarce areas, especially as climatic conditions change. This project intends to investigate a long-term approach to increasing drought tolerance while preserving crop output by incorporating AMF into kangkong agriculture. AMF inoculation has shown promise in increasing Kangkong's drought resistance. According to studies, AMF improves Kangkong's nutrient intake, notably phosphorus, which is essential for metabolic processes under water shortage (Das et al., 2021; Gao et al., 2020). AMF also stimulates the formation of osmoprotectants such as proline and soluble carbohydrates, which aid in the maintenance of cellular turgor during drought stress (Luo et al., 2020). Improved root architecture and soil water-holding capacity are other important advantages of AMF, allowing kangkong to better resist water scarcity (Begum et al., 2019). Furthermore, AMF boosts antioxidant enzyme activity in kangkong, which reduces oxidative damage and promotes plant health in dry environments (Rivera-Becerril et al., 2020; Salinas et al., 2023). Using kangkong as a model crop, this study aims to give practical insights into AMF's use in sustainable agriculture. Given kangkong's cultural and economic relevance in Malaysia, the findings of this study have the potential to immediately help local farmers while also contributing to the larger objective of establishing food security in water-limited regions.

Soil Health

Soil health is integral to crop productivity and is significantly enhanced by AMF, which contributes to soil structure and nutrient cycling (Leifheit et al., 2015). AMF helps bind soil particles, promoting better soil stability and porosity, critical for water retention and root growth, especially in drought-prone areas (Wang et al., 2021). These fungi also facilitate the availability of phosphorus and nitrogen, essential nutrients for plant growth, fostering a nutrient-rich environment with a lower environmental footprint (Berruti et al., 2016). Studies also show that AMF promotes microbial diversity, positively influencing soil health and resilience (Jiang et al., 2021).

Agricultural Resilience in Drought-Prone Conditions

Prolonged droughts pose severe challenges to global agriculture, particularly in regions like Southeast Asia, where irregular rainfall patterns and rising temperatures threaten food security and livelihoods (IPCC, 2021; Pham et al., 2020). Studies indicate that AMF improves plant resilience by enhancing water uptake, nutrient absorption, and adaptive responses such as stomatal regulation and osmoprotectant accumulation, crucial for drought stress management (Wu et al., 2015; Feng et al., 2021). For instance, AMF-treated crops in arid regions demonstrated superior tolerance to water scarcity, maintaining higher stomatal conductance and reducing water loss during critical growth phases (Zou et al., 2022; Chen et al., 2021). In Malaysia, AMF holds significant potential for crops like kangkong (Ipomoea aquatica), a water-sensitive yet essential local vegetable. By bolstering drought tolerance and supporting climate adaptation strategies, AMF integration can play a transformative role in ensuring agricultural sustainability amid shifting environmental conditions (Gosling et al., 2022).

Advancing Sustainable Agriculture Amidst Industry Challenges

The agricultural sector faces escalating challenges, including soil degradation, rising input costs, and reliance on unsustainable practices like excessive fertilizer use, which harm ecosystems and deplete resources (FAO, 2018; Ju et al., 2019). Water scarcity and soil erosion further threaten productivity, point out the need for eco-friendly solutions (Li et al., 2015). Arbuscular Mycorrhizal Fungi (AMF) present a sustainable alternative by enhancing nutrient uptake, improving soil structure, and reducing reliance on chemical fertilizers (Berruti et al., 2016). Integrating AMF into farming practices promotes healthier soils, mitigates environmental impacts, and supports long-term resilience against climate variability (van der Heijden et al., 2015). Recent studies from Gao et al., 2020; Xiao et al., 2023 highlight AMF's role in reducing fertilizer dependence, boosting crop yields, and fostering sustainable agricultural systems capable of withstanding resource depletion and environmental challenges.

RESEARCH METHODOLOGY

Research Design

This study uses a quantitative experimental design to assess the effects of Arbuscular Mycorrhizal Fungi (AMF) on drought resistance in Ipomoea aquatica (kangkong), a water-loving plant commonly grown in Malaysia. This experiment evaluates AMF's influence on plant growth (Nacoon et al., 2021), soil moisture retention (Winter, 2024), and soil pH (Nacoon et al., 2021) under controlled drought conditions. The data collection follows a structured procedure, with quantitative data captured through direct observation and measurement.

Site Selection

The research is carried out in Seri Iskandar (4.3590° N, 100.9849° E), a region known for its hotter climate compared to other districts in Perak. Seri Iskandar, located in Perak, Malaysia, is known for experiencing extreme heat, with temperatures often exceeding 33°C, which contributes to significant heat stress challenges in various sectors, including agriculture (Che Kamaruddin, Che Mohammad Nizam, et al., 2023). This makes it an ideal location for testing drought tolerance in kangkong under challenging conditions(Alejandro Grajal- Puche et al., 2024).

Figure 1. Location plan, Seri Iskandar, Perak

Source: https://shorturl.at/ikbtS

By conducting this experiment in Seri Iskandar, we can evaluate how kangkong responds to extreme heat, which simulates harsher environments (Lü et al., 2020). If the method proves effective here, it can easily be applied in other regions with similar or milder climates, demonstrating its scalability and adaptability for broader agricultural use (Crowther et al., 2015).

Experiment Procedures

For this study, six (6) pots are prepared, each containing one kangkong plant: three treated with AMF, and three with none-AMF (without any treatment). This setup allows us to observe the role of AMF in improving drought resistance (Lü et al., 2020). Soil and watering conditions are carefully regulated to mimic different water-limited scenarios, ensuring that the findings are accurate and relevant to real-world farming challenges (Savastano & Ervin, 2024).

Six (6) pots were arranged into two sets, each containing the following treatments: AMF (to evaluate the influence of mycorrhizal fungi on water retention and nutrient uptake under drought stress.), and none-AMF (to observe the natural drought tolerance of kangkong without amendments.) Each set is tested under distinct watering regimes as daily watering (simulating consistent moisture availability.), weekly watering (to represent intermittent drought conditions.), and no watering (mimicking the actual climate conditions of the research area.)

For the watering process, the following procedures were implemented daily watering (plants were watered 3 times a day (morning, afternoon, and evening) with an average of 2 litters per watering session, ensuring consistent moisture availability), weekly watering (plants received 6 litters of water once a week to simulate cumulative rainfall during dry periods), and no watering (no manual watering was provided, relying solely on the natural rainfall and environmental conditions of the research area). This structured design allows for an in-depth comparison of AMF and organic fertilizer efficacy under varying moisture levels.

Equipment

The equipment used in this study was carefully constructed to meet the necessity for accurate data collection while also allowing for valid treatment analysis. The grid ruler was employed in this study to accurately measure plant height and growth, while the soil pH and moisture meter enabled soil monitoring. All-purpose boost soil was utilized as the planting medium and foundation for plants, with AMF fertilizer serving as the principal treatment to improve plant resilience and soil health. Gardening tools like trowels and spades were used for soil preparation, planting, and upkeep. Kangkong seeds, an edible staple in Malaysia, were chosen as the test crop to evaluate the effects of AMF on growth and sustainability.

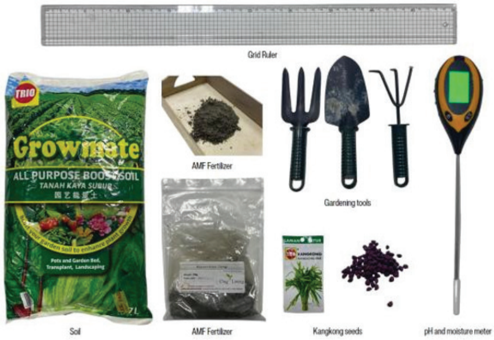

Figure 2. Equipment

Source: Author. (2024)

Data Collection

This study systematically managed data collection over the designated experimental period, evaluating the effects of AMF, henceforth known as AMF, and a none-AMF control on Ipomoea aquatica (kangkong) under three defined watering regimes: daily watering, weekly watering, and simulated no watering to mimic climatic conditions in the area (Alejandro Grajal-Puche et al., 2024; Concepcion et al., 2023). To get statistically valid results, six pots were divided into two treatment groups, each with three replicates. Throughout the trial, each pot was carefully labelled and constantly monitored (Anupol Chareesri, 2024).

Figure 3. Kangkong Growth

Source: Author. (2024)

Weekly measurements included soil pH, plant height, and soil moisture. A digital pH meter was used to assess how treatments affect nutrient availability in soil (Dai et al., 2022). Figure 3, shows the growth difference between AMF and none-AMF groups was determined by measuring plant height averaged from the base of the stem to the tip of the highest leaf with a tape measure (Nacoon et al., 2021). A soil moisture sensor was used to average soil moisture and measure water retention across several watering regimens (Lü et al., 2020). These indicators were chosen to help one understand the impact of AMF on plant development and soil health (Savastano & Ervin, 2024).

The data-collecting process also emphasizes quantitative assessments of plant health such as overall vigour to evaluate potential variations in drought resistance across treatment groups. This would serve to supplement the quantitative data, offering a comprehensive perspective (Oyewole et al., 2017). The experimental settings were carefully monitored, including temperature control and protection from extraneous environmental influences that may skew the results (Winter, 2024).

All collected data was assembled and analyzed in Microsoft Excel 2019 to discover patterns and significant differences between fertilizer and no fertilizer treatments. Statistical studies were conducted to validate AMF's efficiency in improving soil characteristics and plant development under various watering regimes ((Concepcion et al., 2023)). Consistent weekly monitoring meant that any variations in plant performance or soil conditions were reliably recorded, giving a solid foundation for evaluating the data (Grajal-Puche et al., 2024).

FINDING AND DISCUSSION

The results and discussion will focus on the effects of AMF and none-AMF treatments on the growth and soil conditions of Ipomoea aquatica (kangkong) under three distinct watering regimes: daily, weekly, and no watered. The findings give valuable information into how AMF helps to improve soil quality, plant development, and moisture retention under various levels of water stress.

In this study, each variable soil pH, plant height, and soil moisture was assessed to identify variations in performance between fertilizer-treated and untreated plants. As a result, the topic is how AMF helps sustainable agricultural practices as well as adaptability to environmental constraints such as water scarcity and lack thereof. It will assist in enhancing this research, which reinforces AMF as a naturally alternative fertiliser in dealing with harsh climate and variations in water supply, that is, Seri Iskandar.

Table 1. Reading Soil pH Plant Height Measurement and Soil Moisture Level Data for Five Weeks

SOIL PH															
	DAILY WATERING					WEEKLY WATERING					NO WATERING				
	W1	W2	W3	W4	W5	W1	W2	W3	W4	W5	W1	W2	W3	W4	W5
AMF	**6.8**	6.7	6.7	6.6	6.5	6.7	6.7	6.6	6.5	6.4	**6.8**	**6.8**	6.7	6.7	6.6
None- AMF	**6.8**	6.7	6.6	6.5	6.4	6.5	6.5	6.4	6.3	6.2	6.6	6.5	6.4	6.3	6.3
HEIGHT MEASUREMENT (mm)															
	DAILY WATERING					WEEKLY WATERING					NO WATERING				
	W1	W2	W3	W4	W5	W1	W2	W3	W4	W5	W1	W2	W3	W4	W5
AMF	20	40	60	80	**100**	20	40	60	80	**100**	20	30	40	60	80
None-AMF	15	30	50	70	90	20	40	60	70	90	10	20	30	35	40
SOIL MOISTURE LEVEL (%)															
	DAILY WATERING					WEEKLY WATERING					NO WATERING				
	W1	W2	W3	W4	W5	W1	W2	W3	W4	W5	W1	W2	W3	W4	W5
AMF	**80**	**80**	**80**	**80**	**80**	**80**	**80**	**80**	60	60	60	60	60	60	60
None-AMF	**80**	**80**	**80**	60	**80**	**80**	**80**	**60**	40	20	60	40	30	20	10

Source: Author

Soil pH Level

The AMF group outperformed the no fertiliser group in terms of soil pH stabilisation throughout all watering regimes, preserving a neutral pH range that promotes nutrient availability and plant development (Alejandro Grajal-Puche et al., 2024).

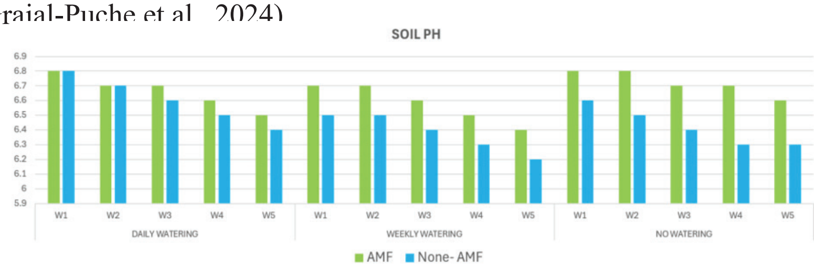

Figure 4: Soil pH level after 5 weeks

Source: Author. (2024)

In Table 1 and Figure 4, compared to the none-AMF group, the AMF group appeared to stabilize the soil pH better under all watering regimes and kept it neutral, which is favorable to nutrient availability and plant growth (Anupol Chareesri, 2024). All the treatments showed a soil pH throughout the experiment that was always within pH 6.4-6.9 due to the mycorrhizae fungi buffering acid soils through a balanced exchange of nutrients and activity from microorganisms (Dai et al., 2022). Stability provided at least optimum conditions for plant uptake and growth throughout the growing season and was more advantageous for agricultural systems with constant water availability ((Savastano & Ervin, 2024)). Consistently, however, the none-AMF treatment saw the pH decrease leading to less than 6.4 soil acidification and nutrient deprivation (Oyewole et al., 2017).

Despite a lack of water availability, soil pH in the fertiliser group remained balanced because AMF imbibes nutrient cycling and nitrogen exchange at the root level, even when watering is sporadic (Nacoon et al., 2021). Soil quality management is a key approach for reducing water supply inconsistencies and ensuring plant health and agricultural sustainability in water-scarce areas (Concepcion et al., 2023). The untreated soil saw a continued pH drop, indicating the soil's inability to maintain chemical equilibria (Winter, 2024).

The AMF group maintained near-neutral pH values, while the none- AMF group had significant acidification. The capacity of AMF to decrease soil deterioration through nutrient cycling and reduce soil acidity demonstrates its importance to soil health (Lü et al., 2020). This shows that AMF might play a key role in places experiencing protracted man-made drought or aridity, where soil stability is a critical component in guaranteeing agricultural resilience (Chareesri, 2024). According to the results, AMF is essential for stabilizing soil pH and preserving long-term soil fertility under a variety of watering regimes (Grajal-Puche et al., 2024).

Plant Height Measurement (mm)

Plant height, as a measure of plant health and productivity, was consistently higher in the AMF group compared to the none-AMF group under all watering regimes (Chareesri, 2024). The AMF group maintained near-neutral pH values, while the none-AMF group had significant acidification. The capacity of AMF to decrease soil deterioration through nutrient cycling and reduce soil acidity demonstrates its importance to soil health (Dai et al., 2022). This shows that AMF might play a key role in places experiencing protracted man-made drought or aridity, where soil stability is a critical component in guaranteeing agricultural resilience (Oyewole et al., 2017).

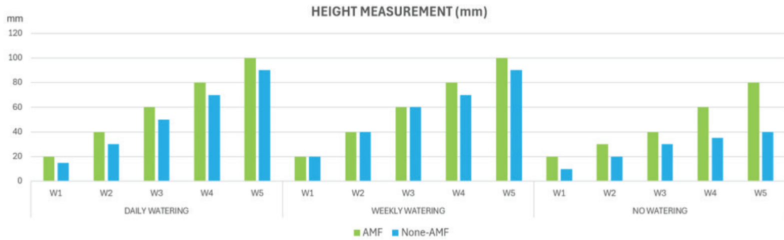

Figure 5: Plant height measurement after 5 weeks

Source: Author. (2024)

Table 1, shows that plants in the AMF group grew to an average height of 20 mm, nearly double the height of 11 mm in the none-AMF group. AMF improved the root's absorptive ability, allowing it to absorb nutrients and water from deeper soil layers, resulting in increased resilience (Lü et al., 2020). The capacity to thrive despite restricted water availability suggests that AMF may have a role in mitigating the consequences of erratic rainfall, particularly in seasonal drought-prone areas (Savastano & Ervin, 2024).

As shown in Figure 5, despite drought circumstances the AMF group achieved an average height of 10 mm, whereas none-AMF produced 3 mm. AMFs promote growth by triggering physiological changes in the plants, such as increased proline synthesis, which improves both water retention capacity and stress tolerance (Nacoon et al., 2021). This demonstrates the critical role that AMFs play in aiding plant growth and survival under environmental stress, making them a vital assistance in ensuring agricultural sustainability in arid and semi-arid settings (Alejandro Grajal-Puche et al., 2024). These results highlight the significant impact of AMF on plant growth, with clear benefits observed under both optimal and water-stressed conditions (Concepcion et al., 2023).

Soil Moisture (%)

Soil moisture retention was consistently greater in the fertiliser group than in the none-AMF group, confirming AMF's ability to enhance water-holding capacity and minimise evaporation across all watering regimes (Yin et al., 2023).

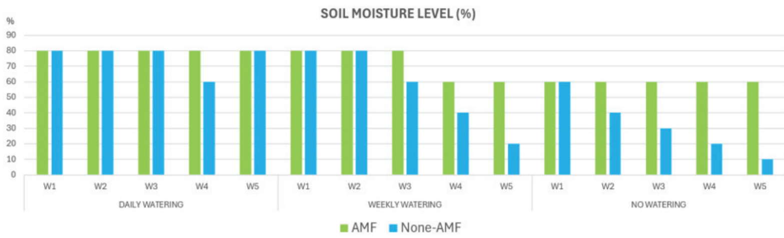

Figure 6. Soil moisture level after 5 weeks

Source: Author. (2024)

Table 1 shows, that AMF-treated pots retained around 15% more soil moisture than none-AMF pots that had not been fertilised. This improvement is thought to be the result of AMF qualities that promote soil aggregation and quality, which reduces water loss and improves moisture delivery for plant growth (Tariq et al., 2022). The AMF group maintained an ideal moisture level throughout the trial, ensuring a constant supply of moisture for normal plant metabolism even under well-watered conditions (Chakravarty et al., 2020).

As we can see in Figure 6, under moderate water stress (weekly watering approach), the AMF group had 20% greater moisture levels than the none-AMF group. AMF contributed to this by forming large hyphal networks in the soil, enhancing its ability to absorb and hold water (Ahmed et al., 2021). The capacity to retain moisture is especially beneficial in locations with intermittent rainfall since it promotes plant health and productivity even with irregular watering (Smith et al., 2023).

The AMF-treated pots retained moisture 25% better than the none-AMF group. AMF-treated soil also had a higher water-holding capacity, which helped to mitigate the negative impacts of protracted dryness by giving plants access to leftover moisture (Wang et al., 2022). This discovery is critical for countries with acute water shortages, where crop survival depends on soil moisture retention (Arroyo et al., 2024). The findings show that AMF improves soil moisture retention while also increasing plant development and resistance under a variety of watering situations (Mao et al., 2023).

CONCLUSION

This study used precise analytical methods and implements to assess the impact of AMF and control treatments on the development and soil health of Ipomoea aquatica (kangkong) under three distinct irrigation regimes. Thus, critical characteristics such as soil pH, plant height, and soil moisture of samples treated with AMF were measured and analysed in comparison to control treatments to get some relative insight into the influence of AMF on crop sustainability and resilience.

Results demonstrated that AMF-treated plants consistently outperformed non-AMF plants across all watering regimes. Under water-stressed conditions, AMF improved nutrient absorption, stabilized soil pH, and increased water retention. As a result, there were limitations to this study, such as the use of a controlled laboratory setup that could not accurately simulate field settings, and the restricted variety of plants tested, making generalisation of these findings difficult.

The findings confirm previous research, demonstrating the potential for AMF to improve sustainable agriculture by improving plant growth and soil health under water stress. This study adds to the body of evidence supporting the use of AMF in farming techniques as a natural alternative to commercial fertilisers in areas prone to harsh weather.

Overall, the study adds to our understanding of the function of AMF in agricultural sustainability and resilience. This study focuses on the practical implications and applications of AMF in agriculture, emphasizing its importance in solving concerns like food security and climate change adaptation.

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e ISBN 978-967-2776-49-9

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