A REVIEW OF STUDIES ON IRRIGATION AND SOIL MANAGEMENT PRACTICES OF GREENHOUSE EGGPLANT FARMING

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ABSTRACT

Greenhouse farming offers a controlled environment that can significantly enhance crop yield and quality, but it also present unique challenges related to water usage and soil health. The focus of this review paper, through an empirical analysis of existing literature was to address these four areas; irrigation water use efficiency, soil managements, nutrient uptake, and crop performance of eggplant production in greenhouse

Keywords: Greenhouse; irrigation; soil management; water use efficiency

1. INTRODUCTION

Greenhouse farming is gaining more popularity globally, especially in developing world like Nigeria, driven by the need for more controlled environments to increase agricultural productivity and meet the growing demand for high-quality crops. One notable example of this trend is the investment in large-scale greenhouse farms in Taraba State, Nigeria, which aims to employ over 300 youths (Agricdemy, 2024). This project highlights the potential of greenhouse farming to create jobs, increase food production, and improve the quality of crops in the country.

Private and public organizations, such as the National Centre for Agricultural Mechanization (NCAM), Ilorin, Nigeria are also embracing greenhouse farming. NCAM recently acquired seven sets of 8 x 24 meter quonset greenhouses as part of its efforts to promote modern agricultural practices across the country. These greenhouses are part of Nigeria's broader push to improve food security, reduce dependency on imports, and boost the agricultural sector by providing optimal growing conditions for various crops.

As the adoption of greenhouse farming continues to rise, the practice is expected to play a significant role in enhancing the global agricultural output. By providing a controlled environment, greenhouses help mitigate the challenges posed by erratic weather conditions, pests, and diseases, ensuring that crops can thrive throughout the year.

1.1 Objective

The objective of this study was to identify best practices and gap in current research, and provide actionable insight for enhancing sustainable greenhouse eggplant cultivation.

2. GREENHOUSE CONSTRUCTION AND FARMING

The construction of greenhouses is based on three critical considerations: ventilation, light transmission, and heat retention (Agricdemy, 2024). These factors directly impact the effectiveness of the greenhouse in providing the optimal growing environment for plants. Two primary materials are used for greenhouse construction: glass and plastics (mouldable polymers).

Common fruits and vegetables grown in greenhouses include tomatoes, sweet peppers, hot peppers, cucumbers, lettuce, sweet melons, and eggplants, with tomatoes being one of the most popular crops. These crops are typically grown from hybrid seeds that are designed for self-pollination and disease resistance, further enhancing their suitability for greenhouse environments. The use of greenhouses for these crops has significantly improved yield consistency and quality, while also extending the growing season and reducing the risk of crop failure due to adverse weather conditions (Omobowale, 2020; Aboaba *et al.*, 2022).

The growing adoption of greenhouse technology in developing nation like Nigeria offers significant potential for the future of agriculture globally, contributing to sustainable farming practices, job creation, and increased food production. As greenhouse agriculture continuous to gain importance in controlled environment farming, understanding the interaction between water, especially deficit irrigation and soil management practices (though less explored), could further improve water use efficiency and soil management practices in greenhouse crop production

3. METHODOLOGY

This study adopts a systemic empirical review approach to analyze past research on irrigation and soil management practices in greenhouse eggplant production. A comprehensive search was conducted using electronic databases such as Scopus, Science Direct, and goggle scholar. The keyword used included; greenhouse eggplant irrigation; soil management in eggplant production; drip irrigation and eggplant yield; and organic amendments of greenhouse eggplant.

Peer-reviewed journal articles, conference papers, and theses that focused on greenhouse-based eggplant (solarium melongera) production with empirical data on irrigation system or soil management were selected for review while studies not specific to greenhouse conditions, or purely theoretical papers without empirical results were excluded. Searches were limited to studies published between 2010 and 2024 to ensure recent and relevant data. The extracted data which included irrigation system used, soil management practices, key findings regarding eggplant (growth, yield and soil health), geographical location and environmental conditions, were analyzed to identify trends, gaps, and best practices.

The quality and reliability of each study were assessed using a modified version of the critical appraisal skill programme (CASP) checklist, focusing on clarity of objectives, methodology rigor, and replicability of findings.

3.1 Irrigation, Water Use Sufficiency, and Crop Yield in Greenhouse

In a comprehensive study by Li *et al.* (2022), the authors investigated the estimation of evapotranspiration for greenhouse-grown eggplant using a refined crop coefficient model. Their research emphasized the critical role of accurately determining crop water requirements to enhance irrigation strategies and optimize yield outcomes. Over a three-year experimental period, they measured the crop coefficient (Kc) at various growth stages, revealing a significant variation in Kc values: 0.23 during the initial stage, peaking at 1.05 during mid-season, and declining to 0.87 by the end of the season. Notably, the study found a strong linear correlation (R^2 = 0.873–0.901) between the adjusted local Kc and the measured Kc values across years, highlighting the model's reliability. Furthermore, the average adjusted Kc and local Kc were found to be 66.3% and 61.8% lower than the FAO-56 recommended values, validating higher water use of efficiency of drip irrigation over traditional irrigation method. This research not only validated the crop coefficient method as an effective tool for estimating daily evapotranspiration but also provided actionable insights for optimizing irrigation practices, thus promoting sustainable water use in greenhouse environments. These findings are particularly relevant for improving the economic viability and resource efficiency of greenhouse-cultivated eggplant, aligning with broader agricultural sustainability goals.

In the study conducted by Salim and Alalwany (2021), the water requirements of the eggplant crop (*Solanum melongena*) were rigorously examined using localized drip irrigation techniques, with a comparative analysis against traditional surface irrigation methods. The research revealed that the total water consumptive use for the drip irrigation system was markedly lower at 5,967 m^3/ha, resulting in an impressive water use efficiency of 20.3 kg/m^3. In contrast, traditional irrigation consumed 10,965 m^3/ha, yielding only 9.2 kg/m^3 efficiency. This study demonstrated that drip irrigation not only reduced water usage by approximately 54.68%, but increased yield by 20% (from 100.88 tons/ha to 121.06 tons/ha) in comparison with the conventional method. These findings underscore the vital importance of adopting efficient irrigation practices, particularly in water-scarce regions, and highlight the potential for modern irrigation technologies to enhance agricultural productivity and sustainability in crop production. The implications of this research advocate for a paradigm shift in irrigation management to optimize both water resources and crop yields effectively.

Ouma *et al.* (2024) conducted a comprehensive study assessing the impact of deficit drip irrigation regimes on the performance of eggplants, which is crucial in the context of climate change and water scarcity. The research utilized a randomized complete block design (RCBD) over two growing seasons on sandy clay loam soil, testing various irrigation levels based on field capacity: 25%, 50%, 75%, and 100%, alongside a control with no irrigation. The study emphasized the importance of optimizing irrigation water use efficiency (IWUE), with results indicating significant differences in plant growth, yield, and fruit quality across treatment levels ($p < 0.05$). Notably, the highest yield of 39.1 tons/ha and an IWUE of 18.1 kg/m3 were achieved at the 75% field capacity treatment (T3), whereas the control (zero irrigation) exhibited the lowest yield of 13.5 tons/ha. These findings suggest that irrigating eggplants at 75% field capacity not only maximizes yield but also enhances water conservation, highlighting the potential for effective irrigation strategies in sustainable eggplant cultivation. This study aligns with the objectives of the current research, which aims to explore how different irrigation regimes influence eggplant yield under varying soil management practices.

Karam *et al.* (2011) conducted field experiments to investigate the effects of deficit irrigation on the yield and water use of eggplants (*Solanum melongena L.*) over two growing seasons (2008 and 2009). The study evaluated eight irrigation treatments, including both full and varying deficit irrigation levels, with a focus on different growth stages—vegetative growth, flowering stage, fruiting stage and fruit ripening. Results indicated that in 2008, deficit irrigation significantly reduced fruit yield by 35%, 25%, and 33% during the respective growth stages compared to a well-irrigated control yielding 33.0 t ha^{-1}. However, this yield reduction was somewhat offset by an increase in average fruit weight. In 2009, the control (full irrigation) yielded 33.7 t ha^{-1}, with reductions of 12%, 39%, and 60% for the 80%, 60%, and 40% deficit treatments, respectively. Notably, the study found that applying deficit irrigation just before flowering not only conserved water but also led to minimal yield loss, presenting an optimal strategy for enhancing water productivity in semi-arid regions. This research supports the idea that strategic water management can effectively balance yield and resource conservation in greenhouse eggplant cultivation, aligning with the objectives of the current study on deficit irrigation and soil management practices.

In a study conducted by Darko *et al.* (2019), the impact of deficit irrigation on eggplant yield and quality was examined under varying irrigation treatments. The researchers implemented four irrigation regimes: full irrigation (100% ETc), and three deficit levels (90%, 80%, and 70% ETc) on eggplant crops. Darkoet al. (2019) reported that irrigation at 90% ETc increased the protein content from 1.4% to 1.6%, carbohydrate from 8.0g to 8.5g per 100g of fruit. This research underscores the potential of deficit irrigation strategies in improving water use efficiency while maintaining eggplant production quality in water-scarce environments.

Wakchaure *et al.* (2020) investigated the effects of plant growth regulators (PGRs) and deficit irrigation (DI) on canopy traits, yield, water productivity, and fruit quality of eggplant (*Solanum melongena* L.) in the water-scarce Deccan Plateau of India. Their study, conducted over two growing seasons (2016–17 and 2017–18), revealed that applying PGRs at concentrations of 1.38 mg L^{-1} significantly improved canopy volume by 25% compared to untreated controls. Additionally, the use of DI at 60% of crop evapotranspiration led to a 15% increase in fruit yield, achieving an average yield of 18.4 tons/ha, compared to 16.0 tons/ha under full irrigation. The findings highlighted that the combination of PGRs and DI not only enhanced water productivity but also improved fruit quality, as demonstrated by 12% increase in the fruit total soluble.

3.2 Irrigation Regimes and Fertilization in Greenhouse

Ali *et al.* (2021a) conducted a comprehensive study on the effects of various irrigation regimes and fertilization strategies on the growth of eggplants (Solanum melongena L.) in a field setting. Their research evaluated four irrigation levels (100%, 80%, 60%, and 40%) in combination with three types of fertilizers: chemical, organic, and developed organic fertilizers. The results indicated that higher irrigation at 100% water requirement enhanced growth rate with height of 89.8cm, average of 7 branches and 198.22g while irrigation at 40% water requirement had 67.3cm height, 5 branches and fruit weight of 198.22g. This study underscores the importance of optimal irrigation and fertilization practices in maximizing eggplant production, particularly in regions facing water scarcity. The findings are particularly relevant for developing efficient irrigation strategies that not only increase yields but also promote sustainable agricultural practices in eggplant cultivation.

In recent research, Ali *et al.* (2021b) investigated the impact of different irrigation regimes and fertilizer applications on the yield and water use efficiency of eggplants (*Solanum melongena* L.) in field conditions. Conducted over two growing seasons, the study implemented four distinct irrigation levels (100%, 80%, 60%, and 40%) alongside three types of fertilizers: a chemical fertilizer, an organic fertilizer, and a developed organic fertilizer. The findings revealed that higher irrigation levels significantly increased fruit yield, with the highest yield recorded at 45,150 kg/ha for the 100% irrigation treatment, while the lowest yield of 27,920 kg/ha was observed at the 40% irrigation level. Additionally, the developed organic fertilizer produced yields of 38,780 kg/ha, compared to 36,290 kg/ha from the organic fertilizer. The study also highlighted that water use efficiency (WUE) ranged from 8.26 to 12.54 kg/mm, indicating a strong correlation between irrigation levels and productivity. This research underscores the importance of optimizing irrigation strategies to enhance both yield and water use efficiency in eggplant cultivation, particularly in water-scarce regions.

In the context of water management in greenhouse eggplant cultivation, Bader *et al.* (2020) examined the effects of water deficit and foliar application of amino acids on growth and yield under two different drip irrigation systems. Their study highlighted that the Grand flow regulators (GR) irrigation system significantly outperformed the T-Tape system in terms of relative water content (74.71%), total yield (5.97 tons/ha), and field water use efficiency (2.11 kg/m3). They found that irrigation levels also played a crucial role; specifically, the 100% irrigation level yielded the highest relative water content (79.32%) and total yield 6.93 tons/ha while the lowest water uptake capacity was observed at the T-Tape system under varying irrigation levels. Notably, the application of 200 mg/L amino acids resulted in optimal growth parameters, showcasing the importance of integrating nutrient management with efficient irrigation practices to enhance productivity in water-scarce conditions. This research underscores the potential benefits of tailored irrigation strategies and nutrient applications in maximizing the yield of eggplant in arid environments.

In their study, Al-Hadidi and Sweity (2022) investigated the impact of deficit irrigation (DI) employing treated wastewater (TWW) on the productivity and quality of greenhouse-grown eggplant (Lalli). The research utilized a plot-based experimental design where TWW was applied under four DI scenarios targeting different soil moisture contents—60%, 80%, 100%, and 120% of the crop evapotranspiration rate (ETc). The findings revealed significant variations in both the physico-chemical properties of the soil and crop yields, with eggplant yields recorded at 20.8, 22.1, 28.1, and 23.25 tons/ha for the respective treatment scenarios. Irrigation at 60% had the highest WUE compared to 100, 80 and 40% irrigation water regimes but irrigating at 100% produced the highest yield. Although microbial contamination was noted under TWW irrigation, with fecal coliform detected, no E. coli or Salmonella were found. This study underscores the efficacy of combining DI with TWW to optimize both yield and quality of eggplants, highlighting the potential for sustainable irrigation practices in greenhouse cultivation.

In a recent study by Ji *et al.* (2022), the effects of irrigation amount on eggplant cultivation within a solar greenhouse were investigated, highlighting the critical role of water management in optimizing plant growth and yield. The researchers implemented a deficit irrigation strategy, reducing water supply by 10%, 20%, and 30% from the maximum theoretical demand. Their findings revealed that the 10% reduction treatment (T1) significantly enhanced soil nutrient levels, with soil catalase, urease, and alkaline phosphatase activities increasing by approximately 25%, 30%, and 20%, respectively. This led to improved plant growth metrics, including an increase in plant height by 15%, root vigour by 18%, and fruit quality, with soluble sugar, soluble protein, and free amino acid contents in the fruit rising by 10.8%, 12.3%, and 6.7%, respectively. Notably, this research underscores the potential of tailored irrigation practices to enhance eggplant production while contributing to sustainable water resource management in greenhouse settings.

3.3 Soil Management Practices and Shading in Greenhouse

In a study conducted by Kutaiba *et al.* (2017), the growth response of eggplant (*Solanum melongena* L.) to various shading treatments within a greenhouse setting in a tropical region was thoroughly examined. The research revealed significant enhancements in plant growth parameters as a result of shading. For instance, plants subjected to shading throughout their growth reached an average height of 156.2 cm, compared to only 123.2 cm for those in unshaded conditions. Additionally, the total leaf area for shaded plants was recorded at 13,199.3 cm², markedly higher than the 8,435.5 cm² observed in the control group. The study also found a positive correlation between shading and chlorophyll content, with values reaching up to 24.2 mg/g in shaded plants. Utilizing a factorial experimental design, the findings highlighted how shading effectively modifies the greenhouse microclimate, leading to improved growth conditions. These results emphasize the importance of optimizing environmental factors, such as light intensity, to enhance the productivity of eggplant and potentially other crops in similar climatic conditions.

4. RESEARCH GAP

Despite extensive research on eggplant cultivation, several critical knowledge gaps persist in understanding the combined effects of deficit irrigation and soil management practices in greenhouse settings (Table 1). While previous studies have examined irrigation regimes or soil management practices individually, limited research has investigated their interactive effects on eggplant production, particularly in controlled environments. Most existing studies on deficit irrigation in eggplant focus on open-field cultivation, with insufficient data on its application in greenhouse systems where environmental conditions differ significantly. The physiological responses of greenhouse-grown eggplants to various combinations of deficit irrigation and soil management practices remain poorly understood, especially in tropical and subtropical climates.

Furthermore, there is limited research on the temporal dynamics of soil physicochemical properties under different irrigation-soil management combinations in greenhouse settings. Current literature lacks comprehensive data on how various soil management practices influence water use efficiency under deficit irrigation conditions.

Table 1. Empirical Review of Past Studies on Irrigation and Soil Management Practices for Greenhouse Eggplant Cultivation

Author(s)	Methodology	Results	Knowledge Gap
Karam *et al.* (2011)	Field experiment with deficit irrigation levels on eggplant yield and water use across different growth stages.	Deficit irrigation before flowering conserved water with minimal yield loss, optimizing water productivity in semi-arid regions.	Need for strategies that balance water conservation and yield maximization, especially for greenhouse conditions in water-scarce environments.
Kutaiba *et al.* (2017)	Greenhouse study on the effect of shading treatments on eggplant growth in a tropical region.	Shading improved plant growth, with taller plants and increased leaf area in shaded conditions.	Lack of understanding on optimizing greenhouse environmental conditions in conjunction with irrigation levels for eggplant yield.

Author(s)	Methodology	Results	Knowledge Gap
Darko *et al*. (2019)	Four irrigation regimes (100%, 90%, 80%, and 70% ETc) applied to eggplants to assess yield and quality under deficit conditions.	A 10% reduction in irrigation increased protein and carbohydrate content while improving fruit quality.	Limited information on how deficit irrigation affects soil and plant health over time, especially when combined with various soil management techniques.
Bader *et al*. (2020)	Examined water deficit and amino acid foliar application under two drip irrigation systems for eggplant.	Grand flow regulators improved yield, water use efficiency, and relative water content. Foliar application of amino acids enhanced growth under water stress.	Lack of research on combining soil management strategies and nutrient applications with optimized irrigation to support water-limited greenhouse environments.
Wakchaure *et al*. (2020)	Combination of plant growth regulators (PGRs) and deficit irrigation on yield, water productivity, and fruit quality of eggplant.	Applying PGRs increased yield by 15%, while DI at 60% ETc enhanced water productivity by 12%.	Insufficient research on integrating plant growth regulators with soil management and deficit irrigation to enhance productivity under water constraints.
Ali *et al*. (2021a)	Evaluated four irrigation levels and three types of fertilizers to understand their effects on eggplant growth and yield.	Higher irrigation levels significantly boosted plant growth and yield, with best performance seen at 100% ETc.	Lack of investigation into the combined effects of different irrigation regimes and soil management on greenhouse crop yield and quality.
Salim and Alalwany (2021)	Comparative analysis of drip and traditional surface irrigation for eggplant water requirements.	Drip irrigation reduced water usage by 54.68% and increased yield by 20% over traditional irrigation	Insufficient data on combining efficient irrigation methods with different soil management practices to enhance yield and resource use.

Author(s)	Methodology	Results	Knowledge Gap
Li *et al*. (2022)	Empirical study using a refined crop coefficient model to estimate evapotranspiration for greenhouse-grown eggplant over three years.	Found significant variation in crop coefficient values at different growth stages and demonstrated that traditional irrigation schedules could lead to water overuse.	Lack of adaptation of irrigation schedules and crop coefficient models specifically for greenhouse-grown eggplant in water-scarce regions.
Ouma *et al*. (2024)	Field study evaluating different deficit irrigation regimes (25%, 50%, 75%, and 100% of field capacity) for eggplant.	Best yield and irrigation water use efficiency were achieved at 75% field capacity.	Limited exploration of the effects of different deficit irrigation levels combined with diverse soil management practices in greenhouse settings

5. CONCLUSION AND RECOMMENDATION

The interaction between irrigation regimes and soil management practices in protected eggplant cultivation remains poorly understood, particularly in the context of water-scarce environments. Furthermore, the economic implications of various combinations of irrigation and soil management strategies have not been adequately evaluated, making it difficult for farmers to make informed decisions about adopting water-efficient technologies. There is also limited information on the physiological responses of eggplant to different water-soil management combinations under protected cultivation, hindering the development of optimal production procedures.

Also, while several studies have examined traditional soil management practices, research on innovative approaches such as containerized growing systems and their interaction with deficit irrigation regimes is limited. The effects of these combinations on soil health, nutrient cycling, and sustainable greenhouse production require further investigation.

Research is also needed to develop region-specific recommendations for optimal combinations of irrigation regimes and soil management practices, particularly for the southern Guinea savannah agro-ecological zone of Nigeria. This knowledge gap hampers the development of effective guidelines for greenhouse eggplant producers in similar agro-ecological zones.

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