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AI-driven intelligent irrigation management in eggplant

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Abstract
This article aims to evaluate the effectiveness of modern irrigation techniques and AI-driven management in eggplant cultivation. The study employs a review of previous research, including the FAO-56 method for calculating crop evapotranspiration and field experiments on water deficit and drip irrigation. Results indicate that while reducing irrigation can increase water productivity, it often leads to a decrease in total fruit yield, and the most water-efficient treatments are not always the most profitable. The authors conclude that while artificial intelligence offers new opportunities for automation, further field experiments are required to prove its effectiveness in maintaining yields and increasing profitability for farmers, particularly in the Indian context.

Keywords: *Solanum melongena* L., drip irrigation, water productivity, crop evapotranspiration, precision agriculture

Introduction

Eggplant (*Solanum melongena* L.) is an important vegetable crop. Watering plays a key role in the growth, flowering and fruiting of eggplant. However, increasing the volume of water will not always result in an increase in yield. Some treatments had increased water productivity with irrigation reduction however this caused a decrease in fruit yield (Karam *et al.*, 2011) [1]. With advancements in soil moisture sensors, weather monitoring and computer based predictions, there are many options available to farmers. However, the effectiveness of these irrigation systems need to be tested on eggplants. This article details information from previous studies, how modern irrigation techniques can be incorporated into eggplant farming and areas that require further research.

Why proper irrigation matters in eggplant cultivation?

Eggplant needs different amounts of water as it grows. Young plants need enough moisture for healthy root development, while older plants require more water as their leaves spread and they begin to flower and produce fruits. How quickly the soil dries out depends on the weather, rainfall and type of soil. This means that watering the plants at certain times may be effective at certain times but not others. Farmers must ensure the roots receive enough moisture, however, over watering can cause poor air circulation in the soil.
Using the FAO-56 method we can calculate how much water is used by crops via evapotranspiration using the formula:

$$ET_c = K_c \times ET_o$$

(Allen *et al.*, 1998) [2] Where ET_c stands for crop evapotranspiration, ET_o stands for reference evapotranspiration and K_c is the crop coefficient. The crop coefficient will vary depending on how far the plant has grown and the growing conditions. Therefore, the irrigation amounts and times should depend on the growth stage, soil type and local climate.

What field experiments reveal about eggplant irrigation?

Many studies have investigated how different irrigation methods impact the growth and yield of eggplants. Karam *et al.* (2011) [1] investigated the effects of full irrigation and different levels of water deficit on eggplants in Lebanon. It was found that reducing the amount of irrigation in the plants meant there was approximately 12%, 39% and 60% less fruit yield over one growing season. However, some of the treatments had increased water productivity, meaning more fruit was produced for each unit of water. This shows that reducing irrigation can increase water productivity however will decrease total yield.
Similar results were seen by Chartzoulakis *et al.* (1995) [3]. Under drip irrigation in greenhouses it was seen that reducing irrigation slightly would not have a significant impact on fruit yield. However, reducing the amount of water further resulted in decreased yield. This shows that eggplants can tolerate some reduction in irrigation however this will depend on the growing conditions.

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The growth stage of the crop will play an important role. Karam *et al.* (2011) [1] and Chartzoulakis *et al.* (1995) [3] looked into different levels of water deficit and irrigation respectively. The experiments were carried out under different conditions meaning we cannot recommend a specific amount of irrigation.

This shows that it is important to consider both the water usage and fruit yield when designing irrigation. Whilst less water may increase water productivity, it may not benefit the farmer if the amount of marketable fruit is affected. The irrigation should depend on the local conditions, crop requirements and expected profitability.

Drip irrigation and crop monitoring

Drip irrigation is commonly used in vegetable farming because it delivers water close to the plant roots. With drip irrigation, farmers can supply small amounts of water at regular intervals instead of watering the crop all at once. This helps maintain soil moisture, especially during important stages of plant growth. However, the system needs proper care. Water pressure should be maintained, water should reach the plants evenly, and irrigation should be carried out at suitable intervals. Regular maintenance is also necessary to keep the system working properly.

Çolak *et al.* (2018) studied how different drip irrigation methods affected the growth, yield and economic returns of eggplant. Different irrigation times and amounts were looked at using surface and subsurface irrigation. It was found that the crop yield would depend on the combination of irrigation techniques. Interestingly, treatments that had the most efficient water use weren't always the most profitable for the farmer. This is important as saving water will only be beneficial if the cost of irrigation and value of the crop is considered.

Knowing how the plant is doing can tell us a lot about the water requirements. When eggplants are experiencing water stress there may be changes in leaf temperatures and the amount of water held within the plant tissues. Çolak *et al.* (2015) looked into this by measuring the canopy temperature to determine water stress. Çolak *et al.* (2017) looked into leaf water potential to see how the plant responded to changes in available water.

Both measurements can help us identify water stress; however, they provide different information. Canopy temperature will depend on the weather conditions, sun and air temperature. Leaf water potential helps researchers determine how much water is available within the plant. When measured along with soil moisture, it provides a better understanding of how the crop responds to different irrigation practices.

This provides valuable information to improve irrigation. However, it doesn't show that fully automated irrigation systems will increase yield. Further field experiments are required to understand if using automated irrigation based on plant measurements will provide better results.

Evidence briefly

Published study	What it supports
Karam *et al.* (2011) [1]	Timing of Deficit, yield and water productivity
Chartzoulakis & Drosos (1995) [3]	Green house Drip-irrigation response
Çolak *et al.* (2015; 2017)	Canopy temperature and leaf water potential
Çolak *et al.* (2018)	Irrigation method, frequency and net returns

Role of AI in irrigation management

Artificial intelligence is becoming increasingly useful in farming, particularly for irrigation management. By monitoring soil moisture, weather conditions and previous watering schedules, farmers can make better decisions about when to irrigate and how much water their crops need. Some systems can fully automate the irrigation. This has been discussed by Saggi *et al.* (2022) [4], Del-Coco *et al.* (2024) [5] and Umutoni *et al.* (2024) [6].

However, they aren't well proven to be effective in eggplant farming. These technologies need to be compared with existing irrigation practices, such as watering based on soil moisture levels. What matters most is not just how well they estimate the crop's water needs, but whether they help maintain good yields, avoid wasting water and lower irrigation costs.

More field studies are needed to find out how useful these methods are under actual farming conditions.

Benefits, practical challenges and recommendations

Proper irrigation planning can help farmers use less water and save time spent checking their fields. However, high equipment costs, faulty sensors, poor internet connections and problems with irrigation valves can make these systems difficult to manage. Even a small mistake in estimating the crop's water needs can affect plant growth, especially when the plants are already under water stress. For farmers, it is important that these systems are simple to use, can be operated manually when needed and are easy to repair.

What is needed for a reliable field study?

In order to understand if modern irrigation methods are truly beneficial, they should be trialled under similar field conditions. The variety of crop, irrigation equipment and other farming practices should be kept the same. If comparing a new system with a poorly run traditional method it may give misleading results. It is important to record how irrigation decisions are made, the equipment used and when manual changes would need to be made.

When carrying out field studies other factors should be considered. Fruit yield, quality, water usage and costs should be considered. The cost of setting up and maintaining sensors, electricity and repairs should be considered, particularly for small farmers. Çolak *et al.* (2018) looked into crop performance and profitability under different drip irrigation practices. This shows that profitability is important. It is important to record any equipment failures, missing sensor data and discrepancies between planned and actual water. The most useful results will be those that show if the method will help the farmer produce good quality fruits, use water efficiently and increase profitability without increasing the costs of growing.

Water savings do not always mean higher profit

Reducing water may increase water productivity, however, it may not increase the farmer's profits. In some cases reducing irrigation can reduce the fruit yield. This may be acceptable in areas where water is scarce, but, may not be profitable for the farmer as they will have spent money on labour, preparing the land and harvesting. The irrigation should be analysed to see if it is helping reduce water costs, electricity costs and good quality fruit prices. Due to different soil types, crops and climates in different regions results shouldn't be directly applied.

Future research needs for Indian farmers

Further field studies are needed to understand how artificial intelligence can improve irrigation. The systems should be compared to traditional irrigation methods, soil moisture-based methods and crop water requirements. Trials should be carried out across different growing seasons, soil types and eggplant varieties. Other factors should be considered such as fruit yield, quality, electricity usage, repair costs and farmer profits.

For small and marginal farmers, cheaper irrigation systems that are easy to use and repair may be more beneficial. However, these methods should first be tested under field conditions to see how well they work.

Farmers can begin by using soil moisture sensors to decide when irrigation is needed. Once this method has been tested and shown to work reliably, automatic pumps and valves can be introduced. Regular maintenance, properly working sensors and a reliable water

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supply are also important for the system to work effectively. Future research should focus on equipment failures and challenges as this can directly impact crop growth.

Challenges and practical precautions

If the soil moisture sensors aren't correctly set up and calibrated they can give false readings. Systems that work well in one area may not work the same in another area due to different soil and climate conditions. It is important to have manual control over irrigation. Water flow should be checked and there should be a limit to how long the system runs for. Back-up should also be in place in case of power cuts or equipment failure.

The information given to farmers should be simple to understand. They shouldn't just know the soil is dry but how much water is needed and why irrigation is recommended. This has been discussed by Saggi *et al.* (2022) [4] and Umutoni *et al.* (2024) [6].

It is important to understand that not all water will be saved if less water is used in the field. Particularly if there is a collection of drain water. Water saving should be carefully measured. The benefits of a new irrigation method should be compared to a well-maintained system. Due to different growing conditions results shouldn't be assumed to be suitable for all farms.

Conclusion

Research has shown that correct irrigation plays an important role in the growth, fruit yield and water usage of eggplants. The amount of water, time and method can all impact crop production. Artificial intelligence provides new opportunities however the benefits need to be proven by field experiments.

More research is needed to find out whether these technologies can help farmers save water, maintain good fruit yields and earn better profits. For now, farmers can manage irrigation by considering the crop's growth stage, soil moisture and local weather conditions. Any irrigation method should be affordable and practical for farmers while helping them produce a good crop without unnecessary expenses.

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