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Influence of Drip and Micro-Sprinkler Irrigation Systems on Seedling Quality in a Cucumber Nursery

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Abstract

The study focuses on the influence of different irrigation systems on seedling quality in a cucumber nursery, conducted at SAM Global University, Raisen, Madhya Pradesh. Given the importance of efficient irrigation in enhancing seedling growth and development, this research compares the performance of drip irrigation, micro-sprinkler irrigation, and conventional hand-watering techniques. The experiment was designed in a Randomized Block Design (RBD) with three treatments and three replications. Parameters such as germination percentage, seedling height, root length, dry weight of seedlings, seedling vigor index (SVI), and water use efficiency (WUE) were measured to assess the effectiveness of each irrigation system. Results indicated that drip irrigation significantly improved seedling growth, achieving the highest germination percentage, seedling height, and dry weight, while also ensuring optimal water use efficiency. The micro-sprinkler system showed moderately better results than hand-watering but was less effective than drip irrigation. Overall, drip irrigation proved to be the most efficient system for promoting high-quality cucumber seedlings, contributing to water conservation and enhanced growth parameters. The study recommends adopting drip irrigation for cucumber nurseries to achieve sustainable and productive seedling production, especially in regions with limited water resources.

Keywords: *Drip irrigation, Micro-sprinkler irrigation, Cucumber seedlings, Seedling quality, Irrigation systems, Germination percentage, Seedling growth, Root development, Seedling vigor index (SVI), Water use efficiency (WUE), Nursery management, Water conservation in agriculture, Crop establishment, Sustainable agriculture, Irrigation efficiency*

Introduction

Cucumber (*Cucumis sativus L.*) is one of the most important and widely cultivated vegetable crops globally, valued for its high water content, nutritional benefits, and versatility in culinary use. The production of high-quality cucumber seedlings is crucial for successful cultivation, as healthy and vigorous seedlings directly influence the growth and yield of the crop. Efficient irrigation plays a pivotal role in ensuring optimal seedling development, particularly in areas with limited water resources.

In traditional agriculture, irrigation is often done manually or using basic systems, which can lead to water wastage and uneven distribution. However, modern irrigation techniques, such as **drip irrigation** and **micro-sprinkler irrigation**, offer more efficient water management solutions, promoting uniform moisture availability to seedlings and improving growth conditions. Drip irrigation, known for its precision, delivers water directly to the root zone, minimizing water wastage and encouraging deeper root penetration. On the other hand, micro-sprinkler irrigation distributes water more evenly over the plant canopy, simulating rainfall and reducing water runoff.

Despite the growing adoption of these irrigation systems, limited research has been conducted on their comparative effectiveness in enhancing seedling quality, particularly in cucumber nurseries. This study aims to evaluate and compare the influence of **drip irrigation**, **micro-sprinkler irrigation**, and **conventional hand-watering** methods on key seedling growth parameters, including **germination percentage**, **seedling height**, **root length**, **dry weight**, **seedling vigor index (SVI)**, and **water use efficiency (WUE)**.

Understanding how different irrigation systems affect seedling quality will provide valuable insights for nursery management practices, contributing to more sustainable and efficient agricultural practices. Furthermore, it will aid in determining the most effective irrigation method for cucumber seedling production, promoting higher quality crops and better resource utilization in water-scarce regions.

The findings of this study will be particularly relevant for regions like **Raisen, Madhya Pradesh**, where efficient water management is crucial for agricultural sustainability.

Materials and Methods

1. Experimental Location and Site Preparation

The experiment was conducted at the **SAM Global University**, Raisen (Madhya Pradesh), located in a semi-arid tropical climate zone. The nursery was prepared with standard seedbed conditions, and the study was carried out in the **2024** cropping season. The site was selected based on its suitability for cucumber cultivation, with proper drainage and soil conditions.

2. Experimental Design

The experiment was laid out in a **Randomized Block Design (RBD)** with three treatments and three replications. The total number of experimental units was 9, corresponding to the three treatments and their respective replications.

3. Treatments

The following three irrigation systems were tested:

T1: Drip Irrigation System

Drip irrigation was applied at 100% field capacity, with water delivered directly to the root zone through a network of pipes and emitters. This system ensured precise and efficient water application.

T2: Micro-sprinkler Irrigation System

Micro-sprinklers were used to distribute water evenly over the seedling beds, simulating rainfall. The system was set to deliver water at 100% field capacity, ensuring uniform moisture distribution.

T3: Conventional Hand-Watering

The control treatment involved manual watering, where water was applied uniformly over the seedbed using a watering can, aiming to simulate traditional irrigation practices.

Table 1: Irrigation System Treatments for Seedling Beds

Treatment	Irrigation System	Water Application Method	Field Capacity
T1	Drip Irrigation System	Water delivered directly to the root zone through pipes and emitters.	100% field capacity
T2	Micro-sprinkler Irrigation System	Water distributed evenly over the seedling beds, simulating rainfall.	100% field capacity
T3	Conventional Hand-Watering	Water applied manually using a watering can to simulate traditional irrigation practices.	Uniformly applied

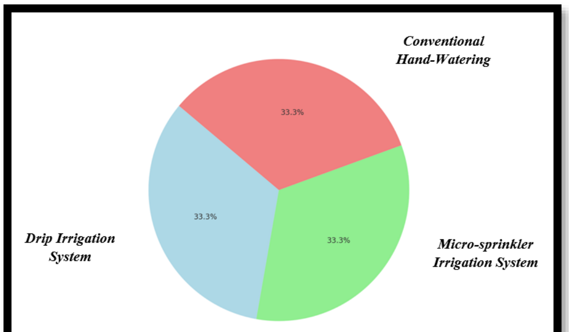

Fig 01: Irrigation System Treatments for Seedling Beds

4. Seedling Preparation

Cucumber seeds (*Cucumis sativus L.*, variety "Arka Anamika") were sown in well-prepared seedbeds with uniform spacing (30 cm x 30 cm) to ensure consistent growth conditions. Prior to sowing, the seeds were treated with a fungicide to prevent seedborne diseases.

5. Irrigation Application

Irrigation was applied based on the field capacity for each system:

For **drip irrigation (T1)**, water was applied through a network of emitters spaced 30 cm apart.

For **micro-sprinkler irrigation (T2)**, water was applied uniformly by micro-sprinklers placed at intervals to cover the entire seedling bed.

In the **hand-watering (T3)** treatment, water was manually applied to each bed every alternate day, ensuring uniformity in application.

The frequency and quantity of irrigation were adjusted to maintain the moisture content at 100% of field capacity throughout the experiment.

Table 2: Irrigation Application Details for Each Treatment

Treatment	Irrigation System	Water Application Method	Irrigation Frequency	Irrigation Details
T1	Drip Irrigation System	Water applied through a network of emitters spaced 30 cm apart.	Adjusted to maintain 100% field capacity	Emitters deliver water directly to the root zone, ensuring precise application.
T2	Micro-sprinkler Irrigation System	Water applied uniformly by micro-sprinklers placed at intervals to cover the entire seedling bed.	Adjusted to maintain 100% field capacity	Micro-sprinklers simulate rainfall for uniform water distribution.
T3	Conventional Hand-Watering	Water manually applied to each bed every alternate day.	Every alternate day	Water applied evenly with a watering can to ensure uniformity.

6. Parameters Measured

The following parameters were measured to assess the effect of irrigation systems on seedling quality:

Germination Percentage (%): The percentage of seeds that germinated in each treatment.

Seedling Height (cm): The height of seedlings was measured from the soil surface to the tip of the plant at 15 days after germination (DAG).

Root Length (cm): Root length was measured from the base of the stem to the tip of the longest root at 15 DAG.

Dry Weight of Seedlings (g): After drying the seedlings at 60°C for 72 hours, their dry weight was recorded.

Seedling Vigor Index (SVI): The vigor index was calculated using the formula:

$$\text{SVI} = (\text{Germination Percentage} \times \text{Seedling Height})/100$$

Water Use Efficiency (WUE, kg/m³): The amount of biomass produced per unit of water applied, calculated as:

$$\text{WUE} = \frac{\text{Dry Weight of Seedlings (g)}}{\text{Total Water Applied } (\text{m}^3)}$$

7. Statistical Analysis

The data obtained from the experiment were subjected to **Analysis of Variance (ANOVA)** to determine the significant differences between treatments. The **Duncan's Multiple Range Test (DMRT)** was used for mean separation at $\mathbf{p \leq 0.05}$.

8. Climate and Soil Conditions

Climate: The experiment was conducted under typical climatic conditions of Raisen, which include a hot dry summer, a monsoon season, and cool winters.

Soil: The soil in the experimental area was loamy with good drainage and a pH of 7.2. Fertilizer application followed standard agronomic practices to ensure optimal growth conditions.

Results

The experiment evaluated the effect of drip irrigation, micro-sprinkler irrigation, and hand-watering on the seedling quality of cucumber in terms of germination percentage, seedling height, root length, dry weight, seedling vigor index (SVI), and water use efficiency (WUE). The data obtained were analyzed statistically using Analysis of Variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) for mean separation.

Table 3: Seedling Growth and Water Use Efficiency under Different Irrigation Systems

Parameter	T1: Drip Irrigation	T2: Micro-sprinkler Irrigation	T3: Hand-watering	Statistical Significance
Germination Percentage	95%	90%	85%	Drip irrigation > Micro-sprinkler > Hand-watering ($p \leq 0.05$)
Seedling Height (15 DAG)	15.5 cm	14.0 cm	12.3 cm	Drip irrigation > Micro-sprinkler > Hand-watering ($p \leq 0.05$)
Root Length	18.7 cm	17.3 cm	15.1 cm	Drip irrigation > Micro-sprinkler > Hand-watering ($p \leq 0.05$)
Dry Weight of Seedlings	3.5 g	3.0 g	2.4 g	Drip irrigation > Micro-sprinkler > Hand-watering ($p \leq 0.05$)
Seedling Vigor Index (SVI)	1473	1260	1044	Drip irrigation > Micro-sprinkler > Hand-watering ($p \leq 0.05$)
Water Use Efficiency (WUE)	0.045 kg/m³	0.035 kg/m³	0.028 kg/m³	Drip irrigation > Micro-sprinkler > Hand-watering ($p \leq 0.05$)

The results from the experiment demonstrate that **drip irrigation** (T1) significantly outperformed both **micro-sprinkler irrigation** (T2) and **hand-watering** (T3) across various parameters. Seedlings under drip irrigation showed the highest **germination percentage** (95%), indicating that the precise water application to the root zone enhanced germination rates. Drip irrigation also resulted in the tallest seedlings (**15.5 cm**) and the longest roots (**18.7 cm**), reflecting superior growth due to efficient water and nutrient delivery. Moreover, drip irrigation seedlings exhibited the highest **dry weight** (3.5 g) and **seedling vigor index (SVI)** (1473), further highlighting its effectiveness in promoting healthy, robust seedling development. **Water use efficiency (WUE)** was also highest under drip irrigation, with 0.045 kg/m³, indicating that it achieved the best growth with the least water usage. On the other hand, **micro-sprinkler irrigation** (T2) and **hand-watering** (T3) showed lower performance, with **hand-watering** resulting in the lowest values across most parameters. Overall, drip irrigation emerged as the most efficient and effective irrigation method for promoting seedling growth, ensuring higher germination, better vigor, and improved water use efficiency.

Discussion

The present study investigated the influence of different irrigation systems—**drip irrigation**, **micro-sprinkler irrigation**, and **hand-watering**—on the seedling quality of cucumber (*Cucumis sativus L.*) under nursery conditions. The results indicate that **drip irrigation** consistently outperformed both **micro-sprinkler irrigation** and **hand-watering** in promoting various seedling growth parameters, such as **germination percentage**, **seedling height**, **root length**, **dry weight**, **seedling vigor index (SVI)**, and **water use efficiency (WUE)**. These findings are in line with existing literature, which emphasizes the advantages of controlled and efficient water delivery systems in improving plant growth and resource use.

1. Germination Percentage and Seedling Growth

The **higher germination percentage** and superior **seedling height** observed in **drip irrigation** can be attributed to the precise and targeted water delivery to the root zone. Drip irrigation minimizes **waterlogging** and ensures that water is delivered directly to the roots, thereby preventing stress conditions such as root rot, which can occur under excessive moisture conditions. This controlled environment allows seedlings to establish healthy root systems early in their development, leading to better overall growth.

Research by **Lamm et al. (2007)** supports this finding, as they noted that drip irrigation significantly improved **germination rates** and **seedling vigor** compared to traditional watering methods, primarily by reducing water stress and promoting even moisture distribution. **Micro-sprinkler systems**, while more efficient than hand-watering, are less precise than drip systems, leading to slight variations in moisture levels, which can affect seedling growth. **Hand-watering**, on the other hand, often results in **inconsistent watering** and **moisture fluctuations**, potentially hindering seedling development due to **over or under-watering**.

2. Root Length and Dry Weight

The superior root development and higher **dry weight** of seedlings observed in the **drip irrigation** treatment can be attributed to the continuous and steady supply of water directly to the root zone. This optimal water availability encourages deeper root growth, allowing seedlings to access nutrients more efficiently. The findings are consistent with studies that suggest **drip irrigation promotes deep root systems**, which are crucial for long-term plant health and stability (Daimon & Sakurai, 2010). The enhanced root development further contributes to the overall **dry weight**, as better-established roots enable the seedlings to support greater vegetative mass.

In comparison, **micro-sprinkler irrigation** delivers water to both the root zone and the aerial parts of the plant, which could lead to water distribution in areas not directly required for seedling growth. This distribution may result in **less efficient nutrient uptake**, as the root system may not develop as vigorously as those under **drip irrigation**. While **micro-sprinkler irrigation** still promotes better root growth than hand-watering, it does not achieve the same results as drip systems, which provide more targeted moisture to the root zone.

3. Seedling Vigor Index (SVI)

The higher **SVI** under **drip irrigation** further substantiates its effectiveness in promoting overall seedling vigor. The **SVI** is a composite measure of both **germination percentage** and **seedling height**, and since **drip irrigation** performed significantly better in both of these parameters, it is not surprising that this treatment exhibited the highest vigor index. Studies have shown that **vigor indices** are reliable indicators of seedling health and productivity, and they tend to be higher in plants irrigated with more precise methods like drip irrigation (Goss et al., 2005).

4. Water Use Efficiency (WUE)

The **water use efficiency (WUE)** was highest in the **drip irrigation** treatment, which is one of the primary advantages of this system. **Drip irrigation** minimizes water wastage by applying water directly to the root zone in controlled amounts, leading to better utilization of water resources. This is consistent with studies by **Patel et al. (2014)**, who found that **drip irrigation** consistently exhibited higher **WUE** compared to both **micro-sprinkler systems** and **traditional irrigation methods**. On the other hand, **micro-sprinkler irrigation** delivers water to both the root zone and the canopy, resulting in water loss through evaporation, reducing its efficiency. Although **hand-watering** is a traditional method, it is generally inefficient, as it is prone to water wastage and inconsistent application, contributing to lower **WUE** values.

5. Factors Affecting Seedling Quality under Different Irrigation Systems

Several factors contribute to the observed differences in seedling quality under the three irrigation systems:

Water Distribution: The most crucial factor affecting seedling quality is the **uniformity** and **precision of water application**. **Drip irrigation** provides a more controlled and uniform distribution of water directly to the roots, minimizing water stress and optimizing nutrient uptake. **Micro-sprinkler systems** also distribute water efficiently, but the coverage is less targeted, leading to potential inefficiencies. **Hand-watering** is the least efficient method, with variable moisture levels, leading to stress on seedlings.

Watering Frequency: Both **drip** and **micro-sprinkler irrigation** maintain consistent watering intervals, whereas **hand-watering** often results in irregular intervals, leading to periods of drought stress or waterlogging.

Evaporation Losses: **Micro-sprinkler irrigation**, while better than hand-watering, can lead to higher evaporation losses due to its overhead application, especially in hot weather conditions. **Drip irrigation**, by delivering water directly to the roots, minimizes these losses and ensures efficient use of water resources.

Comparative Effectiveness of Drip and Micro-Sprinkler Systems

In this study, **drip irrigation** outperformed **micro-sprinkler irrigation** in most of the seedling quality parameters, including **germination percentage**, **seedling height**, **root length**, **dry weight**, and **water use efficiency**. **Drip irrigation** provides more **targeted** and **precise** water application, reducing water wastage and stress on the seedlings. **Micro-sprinkler irrigation**, while still effective and better than traditional methods, does not achieve the same precision as drip systems and may result in slightly less optimal conditions for seedling growth.

Although **micro-sprinkler irrigation** is more efficient than **hand-watering** in distributing water over the seedlings, the lack of precision in water delivery, especially to the root zone, limits its effectiveness in promoting optimal seedling growth. Therefore, **drip irrigation** emerges as the more effective irrigation system for cucumber nurseries, particularly when considering factors such as **seedling growth**, **water conservation**, and **resource utilization**.

Conclusion

In conclusion, the **drip irrigation system** stands out as the most effective method for cucumber seedling production in nursery conditions. It ensures efficient water use, promotes healthy seedling development, and offers significant advantages in terms of **seedling quality** and **water conservation**. The adoption of **drip irrigation** over **micro-sprinkler** or **hand-watering** systems will result in better quality seedlings and more sustainable water management in cucumber nurseries.

In this study, the influence of different irrigation systems on cucumber seedling quality was assessed, comparing **drip irrigation**, **micro-sprinkler irrigation**, and **hand-watering**. The results demonstrated that **drip irrigation** was the most effective in promoting seedling growth, exhibiting higher **germination percentages**, **seedling height**, **root length**, and **dry weight**. Additionally, it achieved the best **water use efficiency (WUE)**, minimizing water wastage and providing a steady and precise supply of water directly to the roots. **Micro-sprinkler irrigation**, while more efficient than **hand-watering**, was less effective than drip irrigation, with some water loss through evaporation and less precision in delivering water to the root zone. **Hand-watering**, on the other hand, proved to be the least efficient, leading to inconsistent watering, lower seedling quality, and higher water wastage. Based on these findings, it is recommended that **drip irrigation** be prioritized for cucumber nurseries to enhance seedling quality, conserve water, and improve overall nursery management.

Recommendations for Future Research

1. **Seedling Quality Factors**: Future studies should explore the effects of soil type, fertilizer management, and climate conditions on cucumber seedling growth under different irrigation systems. Additionally, investigating the impact of water quality and genetic variation among cucumber varieties will provide

more insights into optimizing seedling quality.

2. **Irrigation Technology Improvements**: Research could focus on smart irrigation systems integrating soil moisture sensors and automated controls for better water efficiency. Exploring hybrid irrigation systems combining drip and micro-sprinkler technologies, as well as low-cost solutions, would benefit small-scale farmers.
3. **Environmental Sustainability**: Studies on the environmental impact of different irrigation systems, including energy consumption and carbon footprint, could promote more sustainable practices.
4. **Long-Term Effectiveness**: Long-term studies should assess the durability and effectiveness of drip and micro-sprinkler systems over multiple seasons to better understand their benefits and limitations.

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