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Impact of Different Irrigation and Fertigation Practices on the Growth and Productivity of Cucumber (*Cucumis sativus* L.) under Protected Environment

Bhawna Babal [a*], Sanjeev K. Sandal [a], Narender K. Sankhyan [a] and Prikxit [a]

[a] *Department of Soil Science, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, 176062, H.P., India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The study assessed the impact of various drip irrigation and fertigation strategies on cucumber growth under protected cultivation. Over two seasons, surface drip (I1) was compared with subsurface drip irrigation (I2) under five fertigation treatments (F1-F5). Results revealed that I2 significantly improved growth parameters and yield over I1, including 5.5% reduction in days to 50 per cent flowering and 4.3% decrease in days to first picking. Fruit count and plant height increased by 14.1% and 7.8%, respectively, with a 14.9% rise in yield. Among fertigation treatments, F3 (compost tea with 75% NPK) outperformed the recommended practice F5 (100% NPK), showing a

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*Corresponding author: E-mail: bhawnababal10@gmail.com;

7.8% faster approach to 50% flowering and reduced the number of days to first picking by 7.7%. F3 led to a 1.2% higher fruit count and a 6.2 and 14.7% increase in plant height and yield, respectively. The findings underscore the effectiveness of subsurface drip irrigation and integrated fertigation, particularly the F3, in enhancing cucumber production under protected conditions. The research highlights the potential of these practices in improving crop productivity and sustainability, especially in water-scarce areas.

Keywords: Cultivation; drip irrigation; fertigation; molybdenum.

1. INTRODUCTION

In India, the agricultural sector, a cornerstone of the economy, engages nearly half of the country's workforce. Historically, the focus of the initial Five-Year Plans was on achieving self-sufficiency in food grain production. However, over time, the role of horticulture has evolved remarkably, emerging as a vital segment within agriculture. It now offers extensive opportunities for crop diversification and contributes approximately 24.5% to the gross domestic product (GDP) from merely 8% of the total land area, highlighting its economic significance [1]. Within this horticultural spectrum, cucumber (*Cucumis sativus* L.) stands out as a globally cultivated crop, valued for its nutritional benefits and versatility in consumption, either raw or cooked. Notably, cucumber seeds are a source of oil beneficial for brain health, and the fruit, composed of about 96% water, is particularly favoured during the summer season for hydration. Cucumber is also recognized for its rich content in molybdenum, vitamins, and potassium, and has been traditionally used in remedying skin, kidney, and heart problems, acting as an effective alkalizer [2]. In India, cucumber occupies an area of 1.16 lakh hectares, yielding a production of 16.52 lakh metric tons (Anonymous, 2020-21). The shift towards protected cultivation, such as polyhouse farming, has been instrumental in enhancing both the productivity and quality of cucumber, surpassing those achieved through open-field cultivation.

Water and nutrient management are critical in optimizing plant growth, especially in controlled environments like polyhouses. Globally, water resources are increasingly scarce, compounded by competition from agricultural, industrial, and urban sectors. In response to these challenges, there is a growing emphasis on innovative irrigation techniques in the labour-intensive vegetable farming industry (Yadan et al., 2020). Drip irrigation has become a preferred choice in areas with limited water availability, primarily due to its precise control over water and fertilizer application. Fertigation, the process of delivering water-soluble fertilizers through drip irrigation systems, ensures consistent and regular nutrient supply to each plant. This method is recognized as the most effective way to maintain optimal fertility and water availability tailored to specific crop requirements [3]. Implementing drip fertigation can lead to significant savings in fertilizer use, ranging from 25-40% [4], and is known to enhance water use efficiency, thereby boosting crop yields and overall productivity [5].

Given these considerations, the prudent planning and deployment of available resources are imperative to enhance efficiencies and boost crop productivity through the adoption of optimal techniques. The primary objective of this study was to develop an effective fertilization schedule to maximize cucumber productivity using surface and subsurface drip irrigation systems under protected cultivation conditions.

2. MATERIALS AND METHODS

The experimental research farm was situated at 32º06'13'' N latitude and 76º33'09'' E longitude at an altitude of about 1323.05 m above mean sea level. The site lies in the Palam valley of Kangra district representing mid hills wet temperate conditions (Zone II) of Himachal Pradesh (Agarwal, 1978). Taxonomically, the soils of study area fall under order Alfisol and sub-group Typic Hapludalf. These soils have originated from rocks like slates, phyllites, quartzites, schists and gneisses, and are generally, acidic in reaction.

2.1 Experimental Details

The studies were carried out on cucumbers in 2021–2022 and 2022–2023 in a 105 m2 naturally ventilated polyhouse at Experimental Research Farm CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. The sets of treatments that were used in the experiments were as follows:

A. **Plot size:** 2m × 0.5 m
B. **Design:** Factorial completely randomized design (2 × 5)
C. **Replications:** 3
D. **Variety:** Him Palam Kheera 1
E. **Planting date:** 24th March, 2022 and 28th Feb, 2023
F. **Harvesting date:** 17th June, 2022 and 19th May, 2023

The inline drippers (30 cm apart) were used to administer the drip irrigation on daily basis. The inline drip system for sub-surface drip irrigation was buried at a depth of 7-8 cm, and FYM or vermicompost was used for subsurface layering, depending on the treatment. In a 15 x 7 m naturally ventilated polyhouse, a gravity fed drip irrigation system was installed. In all NPK treatments, 1/4 was used as the base and the remaining portion was fertigated. FYM/vermicompost was applied at the time of transplantation in all regimens, as suggested.

2.2 Statistical Analysis

The data generated from field and laboratory analysis were subjected to statistical analysis using the technique of analysis of variance for factorial completely randomized design for the interpretation of results as described by Gomez and Gomez [6]. The treatment differences were compared at 5 per cent level of significance (p=0.05).

3. RESULTS AND DISCUSSION

3.1 Days to 50% Flowering

During 2022, I_2 (subsurface drip irrigation) reached 50% flowering significantly earlier (19.82 days) compared to I_1 (surface drip irrigation) which took 21.01 days (Table 2). In 2023 also, I_2 took fewer days (23.56 days) to reach 50% flowering compared to I_1 (24.81 days), with a significant difference. Over the two years, I_1 showed a longer duration (22.91 days) to 50% flowering compared to I_2 (21.69 days), which was statistically significant. Among the fertigation treatments, during the first year, F_3 and F_4 reached 50% flowering significantly earlier (18.62 and 19.14 days, respectively) compared to F_1, F_2, and F_5. During the following year, F_2 showed the longest duration to 50% flowering (26.14 days), while F_3 was the earliest (22.61 days) which was statistically at par with F_4 (23.71) and F_5 (23.40). Over both years, F_3 consistently showed the earliest flowering (20.61 days), while F_2 took the longest (24.11 days). There were significant differences among the fertigation treatments, with F_3 and F_4 generally flowering earlier than F_1, F_2, and F_5.

Earlier flowering under subsurface drip (I_2) could be due to the more efficient water delivery and root zone moisture management of the subsurface system [7], which might positively influence the plant's developmental processes, including flowering. Among different fertigation schedules, F_3 and F_4, consistently showed the earliest flowering which might be due to the synergistic effects of inorganic and organic sources of nutrients over the sole inorganic [8].

3.2 Days to First Picking

Data presented in Table 2 showed that I_1 had a significantly longer period until the first picking, averaging 34.86 days, while I_2 facilitated an earlier picking at 33.27 days. This pattern persisted in 2023, with I_1 requiring 38.51 days to the first picking compared to I_2, which took 36.94 days. The pooled data from both years showed that I_1 had an average of 36.69 days to the first picking, while I_2 was quicker with an average of 35.11 days. Among various fertigation treatments, in the 2022 growing season, the shortest period to first picking was noted for F_3 at 31.09 days, significantly shorter than the other treatments but statistically similar to F_4 (32.14 days). In contrast, F_1 and F_2 reported longer durations of 35.45 and 36.71 days, respectively and were statistically at par with F_5 (34.94 days). In 2023, with F_3 (35.08 days), F_4 (36.49 days) and F_5 (36.75 days) took significantly fewer days for the first picking than F_1 (39.54 days), and F_2 (40.79 days). The pooled data reflected this trend, with F_3 and F_4 having the earliest average picking time at 33.08 and 34.31 days, respectively, significantly earlier than the other treatments.

These results demonstrate a consistent pattern over both years, with subsurface drip (I_2) leading to an earlier first picking compared to surface drip (I_1). This could be attributed to the more efficient water delivery and root zone moisture management of the subsurface system [9], potentially enhancing early plant development and accelerating fruit maturation. Furthermore, the type of fertigation significantly impacts the timing of the first harvest. F_3, associated with the earliest picking across both years, might have had a balanced nutrient profile involving both organic and inorganic fertilizers that favoured quicker transition from flowering to fruit set. In contrast, F_1 and F_2, associated with later pickings, may be attributed to the slow release of nutrients from the organic sources [10].

3.3 Total Number of Fruits Per Plant

In 2022, the subsurface drip irrigation (I_2) significantly outperformed the surface drip irrigation (I_1), yielding an average of 30.82 fruits per plant compared to I_1 26.21 fruits, respectively. This trend was consistent in 2023, with I_2 producing 31.14 fruits per plant, while I_1 had 28.10 fruits. The pooled data from both years further affirmed this pattern, showing a higher average of 30.98 fruits per plant for I_2, compared to 27.16 for I_1. Among different fertigation treatments, 2022 saw F_3, F_4, and F_5 leading with the highest numbers of fruits per plant, significantly more than F_1 and F_2. Specifically, F_3 produced 32.15 fruits, F_4 had 32.84, and F_5 yielded 32.32 fruits per plant, compared to the lower outputs of F_1 and F_2, which had 23.16 and 22.10 fruits, respectively. A similar pattern was evident in 2023, with F_3 (34.07), F_4 (33.90), and F_5 (33.13) again outperforming F_1 (23.73) and F_2 (23.28). The pooled analysis mirrored these findings, with F_3, F_4, and F_5 maintaining the highest fruit production, while F_1 and F_2 showed significantly lower numbers.

The consistent superiority of subsurface drip irrigation (I_2) in enhancing fruit production may be attributed to its efficiency in water and nutrient delivery (Elhindi et al., 2016). Fertigation treatments demonstrated that F_3 and F_4, likely providing a richer nutrient supply, resulted in a greater number of fruits per plant. This suggests that a higher or more targeted supply of nutrients, integrating organic and inorganic fertilizers, can have a significant impact on tomato yield [11].

3.4 Plant Height

Data presented in Table 2 showed a significant difference in plant height between surface drip irrigation (I_1) and subsurface drip irrigation (I_2). In 2022, I_1 recorded a lower plant height (304.40 cm) compared to I_2 (329.73 cm), and a similar trend was observed in 2023 with I_1 at 297.20 cm and I_2 at 318.81 cm. The pooled data also reflected this trend, with I_1 averaging 300.80 cm and I_2 averaging 324.27 cm. Among the fertigation treatments, during the first year of cultivation, F_3 recorded significantly higher plant height of 354.58 cm, followed by the F_4 and F_5 with the plant height of 327.20 and 333.13 cm, respectively while the lowest plant height was recorded under the F_2 treatment (280.18 cm) which was statistically at par with F_1 (290.23 cm). Similar to 2023, F_3 maintained the highest plant height (334.10 cm), with F_2 again showing the lowest (276.58 cm). The other treatments were intermediate. The pooled data from both years showed F_3 with the highest average plant height (344.34 cm) and F_2 with the lowest (278.38 cm), with F_1, F_4, and F_5 in the middle range.

Table 1. Treatment details

Treatments	Details
Irrigation	
I_1	Surface drip @ 60% of PE (pan evaporation) for first two months and 80% of PE, thereafter
I_2	Sub-surface drip @ 30 % of PE for first two months and 40 % of PE, thereafter
Fertigation	
F_1	Soil application of farm yard manure (FYM) @ 15 t ha^{-1} + compost tea fertigation @ 75 ml m^{-2} at 3 days intervals
F_2	Soil application of Vermicompost @ 7 t ha^{-1} + vermiwash through fertigation @ 75 ml m^{-2} at 3 days intervals
F_3	Soil application of FYM @ 10 t ha^{-1} + 75 % NPK ($\frac{1}{4}$ as basal + $\frac{3}{4}$ through fertigation) + compost tea fertigation @ 75 ml m^{-2} at 7 days intervals
F_4	Soil application of Vermicompost @ 5 t ha^{-1} + 75 % NPK ($\frac{1}{4}$ as basal + $\frac{3}{4}$ through fertigation) + vermiwash fertigation @ 75 ml m^{-2} at 7 days intervals
F_5	Soil application of FYM @ 10 t ha^{-1} + 100% NPK ($\frac{1}{4}$ basal + $\frac{3}{4}$ through fertigation) at 7 days intervals

Table 2. Effect of different irrigation and fertigation treatments on crop growth parameters and productivity of cucumber

Treatment /Year	**Days to 50% flowering**			**Days to first picking**			**Fruits per plant**			**Plant height (cm)**			**Yield (q ha^{-1})**		
	2022	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
Irrigation															
I_1	21.01^{b}	24.81^{a}	22.91^{b}	34.86^{b}	38.51^{a}	36.69^{b}	26.21^{b}	28.10^{b}	27.16^{b}	304.40^{b}	297.20^{b}	300.80^{b}	1851^{b}	2027^{b}	1939^{b}
I_2	19.82^{a}	23.56^{b}	21.69^{a}	33.27^{a}	36.94^{b}	35.11^{a}	30.82^{a}	31.14^{a}	30.98^{a}	329.73^{a}	318.81^{a}	324.27^{a}	2147^{a}	2330^{a}	2228^{a}
CD (p=0.05)	1.03	1.11	0.74	1.32	1.42	0.78	2.30	2.82	1.75	10.78	12.12	7.86	121	118	82
Fertigation															
F_1	20.95^{b}	25.09^{b}	23.02^{cd}	35.45^{b}	39.54^{b}	37.50^{c}	23.16^{b}	23.73^{b}	23.44^{b}	290.23^{c}	293.73^{c}	291.98^{c}	1814^{c}	1928^{c}	1871^{c}
F_2	22.07^{b}	26.14^{b}	24.11^{d}	36.71^{b}	40.79^{b}	38.75^{d}	22.10^{b}	23.28^{b}	22.69^{b}	280.18^{c}	276.58^{c}	278.38^{c}	1656^{c}	1785^{c}	1721^{d}
F_3	18.62^{a}	22.61^{a}	20.61^{a}	31.09^{a}	35.08^{a}	33.08^{a}	32.15^{a}	34.07^{a}	33.11^{a}	354.58^{a}	334.10^{a}	344.34^{a}	2316^{a}	2588^{a}	2427^{a}
F_4	19.14^{a}	23.71^{a}	21.42^{ab}	32.14^{a}	36.49^{a}	34.31^{a}	32.84^{a}	33.90^{a}	33.37^{a}	327.20^{b}	320.47^{ab}	323.83^{b}	2175^{b}	2392^{b}	2283^{b}
F_5	21.32^{b}	23.40^{a}	22.36^{bc}	34.94^{b}	36.75^{a}	35.85^{b}	32.32^{a}	33.13^{a}	32.73^{a}	333.13^{b}	315.18^{b}	324.15^{b}	2034^{b}	2199^{b}	2116^{b}
CD (p=0.05)	1.64	1.75	1.18	2.08	2.25	1.23	3.63	4.45	4.63	17.05	19.17	12.42	191	187	130

The significantly taller plant height observed under subsurface drip irrigation compared to surface drip, despite similar moisture levels, can be attributed to the direct water delivery to the root zone characteristic of subsurface irrigation. This method enhances root development and nutrient uptake efficiency [12], leading to more vigorous plant growth. The integration of NPK provides essential macro-nutrients in readily available forms, ensuring immediate nutrient uptake, while the addition of compost tea enhances soil health with organic matter and beneficial microorganisms. This holistic approach to fertigation, leveraging both the quick-release benefits of inorganic fertilizers and the long-term soil health benefits of organic amendments, creates an optimal growth environment, leading to the increased in plant height under F_3 treatment.

3.5 Yield

In 2022, the yield under subsurface drip irrigation (I_2) was significantly higher, averaging 2147 q ha^{-1}, compared to surface drip irrigation (I_1), which yielded an average of 1851 q ha^{-1}. This pattern was consistent in 2022, with I_2 producing a higher yield of 2330 q ha^{-1}, while I_1 yielded 2027 q ha^{-1}. When considering the pooled data from both years, I_2 showed a superior average yield of 2228 q ha^{-1}, compared to I_1's 1939 q ha^{-1}. The fertigation treatments also demonstrated distinct patterns in yield over both years. In 2022, the highest yield was observed in F_3 at 2316 q ha^{-1}, significantly surpassing the other treatments, followed by F_4 with 2175 q ha^{-1}and F_5 with 2034 q ha^{-1}. The treatments F_1 and F_2 reported lower yields at 1814 q ha^{-1}and 1656 q ha^{-1}, respectively. A similar trend was evident in 2023, with F_3 again leading at 2588 q ha^{-1}, followed by F_4 (2392 q ha^{-1}) and F_5 (2199 q ha^{-1}), while F_1 (1928 q ha^{-1}) and F_2 (1785 q ha^{-1}) produced lower yields. The pooled data reflected this trend, with F_3 achieving the highest average yield at 2427 q ha^{-1}, significantly higher than the rest of the treatments. F4 and F5 showed moderately high yields with averages of 2283 q ha^{-1}and 2116 q ha^{-1}, respectively. In contrast, F_1 and F_2 had the lowest average yields at 1871 q ha^{-1}and 1721 q ha^{-1}, respectively.

The consistently higher yields under subsurface drip irrigation (I_2) across both years suggest its efficiency in promoting plant growth and productivity, likely due to better water and nutrient delivery to the root zone minimizing water loss through evaporation and deep percolation [7]. Lower yields under the sole organic treatments may be attributed to the slow release of nutrients from the organic sources Hartz et al, [10] which may not have matched with the periods of peak requirement of the crop [14,15].

4. CONCLUSION

This study conclusively demonstrated that in cucumber cultivation under protected conditions in Himachal Pradesh, India, the use of subsurface drip irrigation (I_2) and integrated fertigation strategies significantly enhanced growth parameters and yield. Subsurface irrigation outperformed surface drip in terms of early flowering, first picking, fruit count, plant height, and yield, underscoring its efficacy in optimal water and nutrient delivery to the root zone. Particularly, fertigation treatments combining organic and inorganic nutrients, notably F_3, were superior in promoting earlier flowering and higher fruit productivity. These findings highlighted the importance of adopting efficient irrigation systems and balanced nutrient management approaches in horticulture, especially in regions facing water scarcity. The research underscored the potential of these practices in not only improving cucumber yield but also in contributing to the sustainability and resource efficiency of protected cultivation systems.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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