Himachal Journal of Agricultural Research 51(1): 111-118 (2025)

Effect of drip irrigation and INM-based fertigation on productivity of cucumber intercropped with lettuce under protected conditions

Saurabh Thakur[1*], Sanjeev K Sandal[1], NK Sankhyan[1], Anil Kumar[2], Parveen Sharma[3] and Aanchal[1]
Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur-176062, Himachal Pradesh, India

Manuscript received: 26.04.2025; Accepted: 26.05.2025

Abstract

An experiment was conducted in a naturally ventilated polyhouse to study the effect of drip irrigation and integrated nutrient management-based fertigation on productivity of cucumber intercropped with lettuce. The results showed that sub-surface drip irrigation recorded significantly better crop growth and productivity as well as water use efficiency compared to the surface drip irrigation treatments. Whereas, among the fertigation treatments, application of 150% NPK + 2.5 t ha^{-1} vermicompost + foliar application of vermiwash showed better results as compared to the other fertigation treatments during the study. The interaction effect was also found significant and the combination of sub surface drip irrigation and application of 150% NPK + 2.5 t ha^{-1} vermicompost + foliar application of vermiwash exhibited superior results. The results also depicted that on comparing control with other treatments, other treatments registered statistically better crop growth and productivity of cucumber and lettuce than control.

Keywords: Protected cultivation, drip fertigation, cucumber, lettuce

The rapidly increasing population and rising water demand from multiple industries are placing a great deal of strain on the supply of water. With only 2.4% of land and 4% of water resources, India, which has 17% of the world's population, must also make efficient use of its water resources (Dhawan 2017). Approximately 83% of water is used for irrigation in agriculture, making it the greatest user of water. Conventional irrigation technologies waste between 50 and 70% of water due to evaporation, field application and distribution losses. Furthermore, traditional irrigation techniques also contribute to the increasing the risk of groundwater contamination from the chemicals and nutrients that leak from the crop's root zone (Mohammadi *et al*. 2019). Nowadays, it is essential to implement cutting-edge agricultural technologies and management strategies to boost productivity per unit area in order to meet food demand and reduce resource consumption. In these ways, a drip irrigation system can increase water use efficiency and lower the overall amount of irrigation water needed. The effective and gradual localized administration of water drop by drop to a point or grid of points on or just below the soil surface close to the plant's root zone is known as drip irrigation. Micro-irrigation also offers an added advantage in undulating topography with poor soil water retention and transmission characteristics (Saroch *et al*. 2015). As it enables effective water management, this approach is popular and compared to conventional irrigation, it can cut water use by 50–80% and when used properly, optimal irrigation levels can boost economic returns by increasing water use efficiency (Kadasiddappa and Rao 2018).

After water, fertilizer is one of the most important agricultural inputs. It is well recognized that, in addition to the financial aspect, the negative environmental effects of careless fertilizer and water use can have far-reaching consequences. In addition to preserving the appropriate concentration and distribution of nutrients and water in the soil, the simultaneous use of micro irrigation and fertilizer application (fertigation) creates new opportunities for managing the water and nutrient supply to crops. Improved fertilizer control and more effective nutrient distribution are made possible by it, which leads to less plant stress, earlier harvests, higher yield uniformity and improved crop quality (Gebremeskel *et al*. 2018; Zakhem *et al*. 2019). Fertigation has the potential to

[1]Department of Soil Science; [2]Department of Agronomy; [3]Department of Vegetable Science,
*Corresponding author email thakursaurabh413@gmail.com

increase output by around 40% while saving 30% on fertilizer (Sivanappan and Ranghaswami 2005). Moreover, the right combination of water and nutrients is a prerequisite for obtaining higher yields and better quality (Sandal and Kapoor 2015). Even though India has a wide variety of agroclimatic conditions, vegetable-growing methods have mostly been restricted to local and seasonal needs. The protected production of vegetable crops is the best way to make better use of land and other resources in the current circumstances of dramatically shrinking land holding and steady demand for vegetables. Additionally, because of the weather's unpredictability, crops grown in open fields are regularly exposed to temperature variations, humidity variations, wind direction changes and other factors that have a detrimental effect on crop productivity. Polyhouse-protected crops are sheltered from bad weather, pests, diseases and too much sunlight. Additionally, it improves the quality and output of produce due to better management and an increase in photosynthetic rate. The polyhouse's increased warmth speeds up germination, which leads to an early bonus price from the market due to the early harvest. Therefore, by growing crops in polyhouse farmers may increase their revenue, market competitiveness and economic resilience. A common member of the Cucurbitaceae family, the cucumber (*Cucumis sativus* L.) produces cucumiform fruits that are eaten as vegetables. Cucumbers are low in calories, fat, salt and cholesterol and high in nutrients like calcium, potassium, magnesium and folate. Lettuce (*Lactuca sativa* L.) belongs to the family Asteraceae and is one of the most significant crops within the category of leafy vegetables. Lettuce's great nutritional value and potential medical benefits have led to a massive global increase in its consumption. It is a cool-season crop that thrives in temperatures between 12ºC and 20ºC. Keeping in view the above aspects, the present study entitled "Effect of drip irrigation and INM-based fertigation on productivity of cucumber intercropped with lettuce under protected conditions" was carried out.

Materials and Methods

The present investigation was carried out in 2022-23 at the experimental farm of CSK HPKV, Palampur in a naturally ventilated polyhouse. The experimental site is located within the Kangra district of Himachal Pradesh at the Palam valley which is present at 1290 metre altitude, 32°06' N latitude and 76°03' E longitude. The location lies in the mid hill sub humid agroclimatic zone of Himachal Pradesh in the North Western Himalayas receiving average annual rainfall of about 2500 mm. As per the Thornthwaite's classification, the research farm is located in the Wet Temperate Zone (Aggarwal *et al.* 1978). The mean weekly weather data during the crop growth is presented in figure 1. An automated drip irrigation system was installed within the polyhouse and control

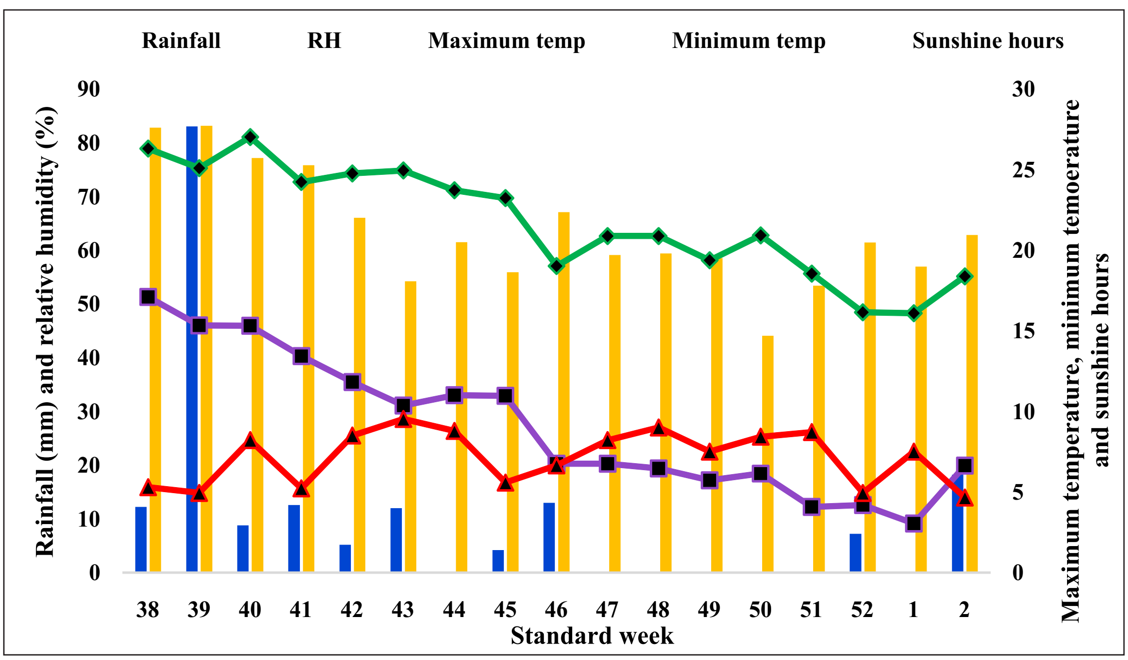

Figure 1: Mean weekly weather data during crop growth period in 2022-23

valve was installed on each lateral line placed 30 cm from each other to control the water flow. For subsurface drip irrigation treatments, the drip lines were buried 8 to 10 cm below the soil surface, ensuring effective water delivery directly to the root zone and minimizing evaporation. For the NPK fertigation treatments, a 500-liter fertigation tank was connected to the main irrigation line and fertigation was administered with each irrigation starting from third week after transplanting. Vermicompost was incorporated into the soil before transplanting and in the conventional basal application method, half of the nitrogen dose, along with the full doses of phosphorus and potassium were applied at the time of transplanting, with the remaining nitrogen applied one month after transplanting. Weekly foliar applications of vermiwash were also given to the crops. The study consisted of three different drip irrigation schedules, three INM (Integrated Nutrient Management) based drip fertigation schedules, and a control treatment where lettuce was excluded and only cucumber was cultivated. So, the experiment consisted of a total of ten treatments each replicated thrice within a factorial randomized block design. The recommended dose of fertilizer used for the crop was 200, 315 and 100 kg ha^{-1} of urea, single super phosphate and muriate of potash, respectively. The cucumber crop was transplanted in September 2022 while the lettuce crop was transplanted as an intercrop in October 2022. The variety used for cucumber and lettuce was him palam kheera and green wave, respectively. The treatment details are presented in table 1.

Results and Discussions

Days to first harvest

The data on the effect of drip irrigation and INM fertigation on number of days to the first harvest is presented in table 2. The results revealed that treatment

Table 1: Detailed description of treatments

Treatment	Drip placement	Drip irrigation rate (litre/sqm/day)				
		Sep	Oct	Nov	Dec	Jan
A) Drip irrigation schedule						
D1	**Surface**	2.0	2.0	2.5	2.0	1.5
D2	**Sub surface**	2.0	2.0	2.5	2.0	1.5
D3	**Surface**	2.5	2.5	3.0	2.5	2.0
B) INM based fertigation schedule						
F1	Vermicompost @ 2.5 t ha^{-1} + 75 per cent NPK (basal) + 75 per cent NPK fertigation + foliar application @ 7.5 ml/sqm at weekly intervals					
F2	Vermicompost @ 5 t ha^{-1} + 50 per cent NPK (basal) + 75 per cent NPK fertigation + foliar application @ 7.5 ml/sqm at weekly intervals					
F3	Vermicompost @ 7.5 t ha^{-1} + 25 per cent NPK (basal) + 75 per cent NPK fertigation + foliar application @ 7.5 ml/sqm at weekly intervals					
C) Control						
C	**Surface irrigation (D3)** Vermicompost @ 2.5 t ha^{-1} + 25 per cent NPK (basal) + 75 per cent NPK fertigation + foliar application @ 7.5 ml/sqm at weekly intervals					

Table 2: Effects of drip irrigation and INM based fertigation on days to first harvest of cucumber and lettuce

Treatment/Year		Days to first harvest	
		Cucumber	Lettuce
Drip irrigation			
	D1	37.11	35.11
	D2	32.89	31.78
	D3	35.00	32.67
	CD (5%)	1.75	1.27
INM fertigation			
	F1	33.89	32.11
	F2	34.89	33.33
	F3	36.22	34.11
	CD (5%)	1.75	1.27
Control Vs others			
	Control	37.67	0.00
	Others	35.00	33.19
	CD (5%)	2.26	1.65

D1 took higher days to first harvest in cucumber and lettuce i.e. 37.11 and 35.11 days, respectively over other drip irrigation treatments, whereas the least days to first harvest were observed under treatment D2 for cucumber and lettuce (32.89 and 31.78 days, respectively). However, in cucumber crop D2 was significantly better than D1 and D3 but for the lettuce crop D2 was significantly superior than D1 but D3 was found to be at par with D2. Between the surface drip irrigation systems, D3 showed early harvest in comparison to D1 in cucumber and lettuce. Among the integrated nutrient management based fertigation schedules, treatment F3 registered higher days to first harvest for cucumber and lettuce (36.22 and 34.11, respectively) which was significantly higher than treatment F1 (33.89 and 32.11, respectively) but was statistically at par with F2 in both crops (34.89 and 33.33 days, respectively). The days taken to first harvest under control vs others was found to be significantly higher under control for cucumber (37.67 days) as compared to the other treatments (35.00 days). In case of lettuce the other treatments took 33.19 days to first harvest, whereas lettuce was not grown in the control treatment. Sub surface drip irrigation (D2) significantly reduced the number of days required to achieve the first harvest compared to surface drip irrigation treatments (D1 and D3). Subsurface drip irrigation delivers water directly to the root zone, sharply reducing evaporation and maintaining steady moisture levels that keep nutrients readily available for plant uptake. In INM treatments, the F1 using soluble NPK provided plants with a continuous, easily absorbed nutrient supply, which spurred vigorous vegetative development and hastened the onset of flowering and fruit set. In contrast, higher vermicompost applications (5 and 7.5 t ha^{-1}) depend on soil microbes to break down organic matter, resulting in slower nutrient release and consequently delayed harvests. Although the control plots received ample water, their lack of supplemental fertilization led to limited nutrient availability, limiting growth and extending the time to first harvest. Moreover, subsurface placement of water and nutrients encourages roots to proliferate in zones where resources are most concentrated, further boosting early yield components. These findings underscore the importance of pairing precise fertigation schedules with the right balance of organic amendments to align nutrient release with crop demand and maximize both growth and timeliness of harvest. The results are in line with Pawar *et al*. (2018) and Shukla *et al*. (2020).

Number of fruits per plant

A scrutiny of data presented in table 3 on the effect of drip irrigation and integrated nutrient management-based fertigation on number of fruits per plant of cucumber depicted that sub-surface drip irrigation treatment i.e. D2 (25.16) showed significantly higher total number of fruits per plant than the surface drip irrigation treatments i.e. D1 and D3 (22.56 and 24.33, respectively). Between the surface drip irrigation treatments, D3 in which more water was applied showed statistically better results than D1 in which less water was applied. Among the integrated nutrient management-based fertigation treatments, treatment F1 registered the maximum number of fruits per plant (25.07) and was significantly superior than F2 (24.21) and F3 (22.77). Moreover, treatment F2 showed

Table 3: Effects of drip irrigation and INM based fertigation on number of fruits per plant of cucumber

Treatments	Number of fruits per plant			
	D1	**D2**	**D3**	**Mean**
F1	23.23	26.33	25.64	25.07
F2	22.94	25.03	24.65	24.21
F3	21.51	24.11	22.70	22.77
Mean	22.56	25.16	24.33	
CD (5%)	**D**	**F**	**D x F**	
	0.37	0.37	0.64	
Control	21.92			
Others	23.98			
CD (5%)	0.48			

significantly higher number of fruits per plants than treatment F3. When compared with control, other treatments recorded significantly better results over control (23.98 and 21.92, respectively). The interaction between drip irrigation and fertigation treatments was significant and the highest number of fruits per plant were obtained from D2F1 (26.33) followed by D3F1 (25.64) and the lowest was recorded under D1F3 (21.51). Subsurface drip irrigation significantly outperformed surface drip in cucumber fruit number by delivering water evenly and directly to the root zone, which maintained optimal moisture levels and minimized surface evaporation. This consistent hydration promoted lush vegetative growth, boosting the plant's photosynthetic capacity and ensuring a steady supply of carbohydrates for fruit formation. Within fertigation treatments, the F1 treatment, characterized by balanced, soluble nutrients, further amplified these benefits by matching nutrient release to the plant's peak growth stages, driving efficient translocation of sugars and minerals into developing fruits. In contrast, surface drip systems encourage more weed growth at the soil surface, limiting nutrient uptake and diverting resources away from the crop. These factors combined to reduce fruit set under surface irrigation. Overall, pairing subsurface drip irrigation with a precisely timed, soluble fertilizer delivers uniform moisture and nutrient availability, optimally supporting both vegetative vigor and high fruit counts. The results are in conformity with Padmaja *et al*. (2021) and Rathod and Shaikh (2023).

Marketable yield

The perusal of data on the effect of drip irrigation and integrated nutrient management based fertigation on the marketable yield of cucumber and lettuce has been presented in table 4. Under the drip irrigation treatments, D2 registered significantly higher fruit yield for cucumber and lettuce (19.10 and 1.61 kg m^{-2}) compared to other treatments, followed by D3 (17.41 kg m^{-2} and 1.57 kg m^{-2}, respectively), whereas the lowest marketable yield was obtained from treatment D1 (16.32 and 1.51 kg m^{-2}, respectively). While comparing the integrated nutrient management based fertigation schedules, it was observed that the maximum marketable yield of cucumber and lettuce was recorded in treatment F1 (18.39 and 1.61 kg m^{-2}, respectively) and was found to be significantly superior to other treatments, whereas the lowest marketable yield was observed in treatment F3 (16.79

Table 4: Effects of drip irrigation and INM based fertigation on marketable yield (kg m^{-2}) of cucumber and lettuce

Treatments	Cucumber			
	D1	D2	D3	Mean
F1	16.73	19.90	18.53	18.39
F2	16.51	19.00	17.45	17.65
F3	15.73	18.41	16.24	16.79
Mean	16.32	19.10	17.41	
CD (5%)	**D**	**F**	**D x F**	
	0.26	0.26	0.45	
Control	14.08			
Others	17.61			
CD (5%)	0.34			
Treatments	**Lettuce**			
	D1	**D2**	**D3**	**Mean**
F1	1.57	1.65	1.61	1.61
F2	1.52	1.61	1.56	1.57
F3	1.45	1.58	1.54	1.52
Mean	1.51	1.61	1.57	
CD (5%)	**D**	**F**	**D x F**	
	0.02	0.02	0.03	
Control	0.00			
Others	1.57			
CD (5%)	0.02			

and 1.52 kg m^{-2}, respectively). While comparing the control and other treatments, it was found that control showed significantly lower marketable yield of cucumber (14.08 kg m^{-2}) compared to the other treatments (17.61 kg m^{-2}). For the lettuce crop, the other treatments showed higher marketable yield (1.57 kg m^{-2}), while in control lettuce was not transplanted. The interaction between drip irrigation and integrated nutrient management-based fertigation was found to be significant and significantly highest marketable yield of cucumber (19.90 kg m^{-2}) and lettuce (1.65 kg m^{-2}, respectively) was observed in D2F1 and the lowest in D1F3 (15.73 and 1.45 kg m^{-2}, respectively). Subsurface drip irrigation consistently outperformed surface systems by delivering water directly into the root zone, maintaining uniform moisture that minimizes evaporation and preserves soil nutrients in solution for immediate plant uptake. By reducing evaporation losses, sub surface drip irrigation ensured that essential nutrients remain dissolved in the soil solution, making them readily available for plant uptake. Moreover, the direct water application encouraged the development of a deeper and more extensive root system, further enhancing the plant's capacity to absorb water and nutrients (Yang *et al*. 2023), thereby resulting in higher marketable yield. In treatment F1, the yield was significantly higher than in other treatments. The abundant and consistent supply of readily available nutrients in F1 contributed to improved metabolic processes and vegetative growth within the plants. These processes include the synthesis of photosynthates and their subsequent translocation from the source (leaves) to the sink (fruits), leading to earlier fruit set and higher overall marketable yield. The control treatment, while receiving sufficient water, lacked the additional nutrient inputs provided by the integrated nutrient management-based fertigation treatments. This nutrient deficit resulted in reduced vegetative growth, a lower number of fruits per plant and ultimately a lower marketable yield. Similar results were reported by Shukla *et al.* (2020) and Padmaja *et al*. (2021).

Stover yield

The table 5 presents the data regarding the effect of drip irrigation and integrated nutrient management based fertigation on stover yield of cucumber. Among the drip irrigation treatments, treatment D2 showed maximum stover yield of 1.60 kg m^{-2} which was significantly higher than D1 and D3 having 1.44 and 1.50 kg m^{-2} stover yield, respectively. Under the different fertigation schedules, treatment F1 recorded highest yield i.e. 1.55 kg m^{-2} followed by treatment F2 (1.51 kg m^{-2}), while the lowest stover yield was observed in F3 (1.47 kg m^{-2}). Treatment F1 was significantly better than treatment F2 and F3, while treatment F2 was significantly better than treatment F3. Stover yield in control vs others was found to be significantly higher in other treatments compared to control (1.51 and 1.37 kg m^{-2}, respectively). Furthermore, the interaction effect between the drip irrigation and integrated nutrient management based fertigation was significant and treatment D2F1 recorded maximum stover yield (1.66 kg m^{-2}) and was significantly better than other treatments followed by D2F2 (1.60 kg m^{-2}), while the least value was observed in D1F3 (1.41 kg m^{-2}). Subsurface drip irrigation creates a consistently moist root environment that encourages roots to spread deeper and explore a larger soil volume, resulting in stronger vegetative growth and stover yield. In the F1 treatment, plants received a

Table 5: Effects of drip irrigation and INM based fertigation on stover yield (kg m^{-2}) of cucumber

Treatments	Stover yield			
	D1	D2	D3	Mean
F1	1.46	1.66	1.55	1.55
F2	1.44	1.60	1.49	1.51
F3	1.41	1.55	1.46	1.47
Mean	1.44	1.60	1.50	
CD (5%)	D	F	D x F	
	0.02	0.02	0.03	
Control	1.37			
Others	1.51			
CD (5%)	0.02			

steady supply of readily available nutrients, which improved metabolic activity and directed more carbohydrates toward stem development. Additionally, integrating inorganic fertilizers with vermicompost helped establish a balanced pool of immediate and slow-release nutrients, sustaining microbial soil health and promoting continuous nutrient availability. This synergy between water placement and nutrient management not only maximized uptake but also minimized nutrient losses through leaching or surface evaporation. By contrast, the control plots relying solely on lower rates of traditional fertilizers experienced limited root proliferation and nutrient access, leading to markedly reduced biomass. The results align with those by Arshad *et al*. (2014) and Sahu *et al*. (2023).

Water use efficiency

The data presented in table 6 revealed that, across the different drip irrigation schedules, significantly higher water use efficiency of cucumber and lettuce was observed in sub surface drip irrigation system i.e. D2 (209 and 16.90 g m^{-2} mm^{-1}, respectively), while the lowest was observed in surface irrigation system in which more water was applied i.e. treatment D3 (153 and 13.34 g m^{-2} mm^{-1}, respectively). Between the surface drip irrigation treatments, less application of water (D1) resulted in higher water use efficiency in cucumber and lettuce compared to treatment D3 in which more water was applied. Under the integrated nutrient management based fertigation treatments, F1 registered significantly superior water use efficiency for cucumber and lettuce (188 and 15.77 g m^{-2} mm^{-1}, respectively), followed by F2 (180 and 15.38 g m^{-2} mm^{-1}, respectively) and the lowest water use efficiency in the fertigation treatments was recorded in F3 (172 and 15.03 g m^{-2} mm^{-1}, respectively). While comparing the control with other treatments, it was found that control showed significantly lower water use efficiency in cucumber and lettuce (125 and 0 g m^{-2} mm^{-1}, respectively) than the other treatments (180 and 15.40 g m^{-2} mm^{-1}, respectively). Subsurface drip irrigation (D2) achieved the highest water-use efficiency by delivering water directly to the root zone, which minimized evaporation, maintained consistent soil moisture, and enhanced nutrient uptake resulting in more yield per unit of water applied. Among the fertigation regimes, F1 stood out because of its ample, soluble nutrient supply synchronized perfectly with irrigation events, boosting plant growth and maximizing yield relative to water use. The constant availability of NPK in F1 ensured that crops never experienced nutrient stress, allowing every drop of water to support productive biomass formation. In contrast, the control plots though heavily irrigated lacked sufficient fertilizer, leading to nutrient limitations that suppressed plant growth and reduced water use efficiency. Overall, combining subsurface drip systems with a precisely timed, nutrient-rich fertigation schedule optimizes both water and nutrient utilization, delivering superior crop performance and

Table 6: Effects of drip irrigation and INM based fertigation on water use efficiency (g m^{-2} mm^{-1}) of cucumber and lettuce

	Treatment/Year	Water use efficiency	
		Cucumber	Lettuce
Drip irrigation			
	D1	178	15.94
	D2	209	16.90
	D3	153	13.34
	CD (5%)	5	0.18
INM fertigation			
	F1	188	15.77
	F2	180	15.38
	F3	172	15.03
	CD (5%)	5	0.18
Control Vs others			
	Control	125	0.00
	Others	180	15.40
	CD (5%)	6	0.23

sustainable resource management. The results are in line with the findings of Sahu *et al*. (2023) and Mattar *et al*. (2021).

Conclusions

The study demonstrates that integrating subsurface drip irrigation with enhanced fertigation levels, supplemented by vermicompost and vermiwash, significantly improves cucumber and lettuce's growth, yield and water use efficiency under naturally ventilated polyhouse conditions. Subsurface drip irrigation not only expedited the time to first harvest but also increased the number of fruits per plant, marketable yield, stover yield and water use efficiency compared to surface drip irrigation. Notably, the fertigation schedule comprising 150% NPK combined with 2.5 t ha^{-1} vermicompost and foliar application of vermiwash yielded superior crop performance compared to other treatments. These findings underscore the efficacy of combining advanced irrigation techniques with integrated nutrient management based fertigation, offering a sustainable approach to optimize resource utilization and maximize cucumber and lettuce productivity under protected conditions.

Conflict of interest: The authors declare that there is no conflict of interest among the authors in this research paper.

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