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Research Paper

Evaluating the Impact of Drip Irrigation on Lettuce Yield in Polyhouse and Field Conditions

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ABSTRACT

A study was carried out to examine the influence of different irrigation levels utilizing a drip irrigation system on lettuce grown in polyhouse and open field conditions during the winter months of November to February for two consecutive years at the Experimental Farm of the Centre for Smart Agriculture, Centurion University of Technology and Management in Odisha, India. The FAO-56 Penman-Monteith method was used to calculate reference evapotranspiration. It was determined that lettuce required 219 mm and 339 mm of water for growth in polyhouse and open field conditions, respectively. There were five treatments: four irrigation levels (120%, 100%, 75%, and 50% of crop water requirements) using drip irrigation in polyhouse and one treatment of 100% crop water applied via drip in open field conditions. The effects of these treatments were evaluated in terms of biometric and crop yield results. The results of the experiment revealed that providing 100% of the water requirement through drip irrigation in a polyhouse (T_2) resulted in the greatest plant height, head diameter, number of leaves, fresh and dry weight of leaves, and crop yield. Cultivating lettuce in an open field had the lowest yield compared to all irrigation levels used in a polyhouse.

HIGHLIGHTS

- Estimation of lettuce water requirement under polyhouse and in open field condition
- Lettuce yield performance under different irrigation levels using drip

Keywords: Drip irrigation, Lettuce, Crop water requirement, Polyhouse

Polyhouses provide an ideal environment for crop cultivation that allows for high yield and superior quality. Due to their smaller land requirement, they increase land productivity and enable year-round crop production. The goal of utilizing poly houses for vegetable cultivation is to safeguard crops from biotic factors such as pests, diseases, and weeds and abiotic factors like temperature, humidity, and light and to produce high-quality vegetables all yearround, especially during the non-growing seasons. However, protected cultivation is a relatively new practice in India and is still in its infancy stage (Santosh and Maitra, 2022; Santosh and Maitra, 2021; Maitra *et al*. 2020 a, b).

Irrigation plays a vital role in determining the productivity and excellence of crops grown in greenhouses. Timing and quantity of water supply is critical for optimal growth (Santosh *et al*. 2021). With water conservation's increasing importance, innovative irrigation techniques like drip irrigation may be beneficial for reducing water consumption and enhancing irrigation proficiency (Zaman *et al*. 2017; Sucharita *et al*. 2021). Drip irrigation systems supply water and nutrients directly to the roots of the plants, leading to higher yield, conservation of

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water, and more effective irrigation (Nagaz *et al.* 2012).

Lettuce, a member of the Asteraceae family, is a commonly consumed vegetable, known for its high nutritional value (Stagnari *et al.* 2015). As a short-term and fast-growing crop, lettuce requires specific conditions to thrive, including a controlled climate, adequate water, and sufficient nutrients. One way to meet these requirements is through cultivation in protected environments such as greenhouses. These structures provide a more conducive climate for growth, protect plants from pests and diseases, shield them from weather variations, and lead to reduced costs of fertilization and leaching. Furthermore, yields tend to be higher and product quality improved when compared to open-field farming. That said, a proper irrigation system is essential to fully utilize the potential of greenhouse lettuce production.

The use of polyhouses in crop cultivation has grown in popularity in India, but there is a shortage of research on its adaptability to various climates, particularly when it comes to irrigation techniques. By conducting studies on this topic, it could lead to more efficient water usage, improvement in crop yields and quality, and be particularly beneficial for high-yield cultivars. This study aims to identify the ideal irrigation levels for lettuce grown in a polyhouse in a sub-humid region and establish the correlation between crop evapotranspiration within and outside of the polyhouse by utilizing meteorological data.

MATERIALS AND METHODS

An experimental field study was conducted over two consecutive winter seasons (2019-20 and 2021-21) at the Experimental Farm of the Centre for Smart Agriculture at Centurion University of Technology and Management in Odisha, India. The region has a sub-humid subtropical climate, with an average annual rainfall of 1390 mm, with about 80% occurring from June to October. The average monthly minimum temperature is 6°C in January, and the average monthly maximum temperature is 43.5°C in May. The average monthly relative humidity ranges from 35% in February to 96% during July and August. The soil at the experimental site is lateritic with a sandy loam texture.

Meteorological data, including daily maximum and minimum temperature, minimum and maximum relative humidity, actual sunshine hours, and daily wind speed, was collected daily during the crop growth period from the meteorological station at CUTM, Odisha. Daily reference evapotranspiration (ET_0) was estimated using the FAO Penman-Monteith method (Allen *et al.* 1998). The daily irrigation water requirement for lettuce crops was estimated using the following relationship.

$$WR = ET_0 \times Kc \times Wp \times A$$

Where,

WR = Crop water requirement (L d^{-1})

ET_0 = Reference evapotranspiration (mm d^{-1})

Kc = Crop coefficient

Wp = Wetting fraction (taken as 1 for close growing crops)

A = Plant area, m^2 (i.e. spacing between rows, *m* × spacing between plants, *m*)

The experiment was conducted in a walk-in tunnel greenhouse 4 m in length and 4 m in width, with heights at the center and sides of 3.0 and 2 m, respectively. The structure was made of arched galvanized pipes and covered with a 200-µm thick UV-stabilized polyethylene film. The polyhouse was positioned in a north-south direction, perpendicular to the sun's path. The experiment was arranged in a randomized block design (RBD) with five treatments and four replications.

The irrigation treatments were based on the calculated crop water requirement (CWR) for lettuce and were applied using drip irrigation. The treatments are as follows:

T_1: 120% of CWR inside polyhouse

T_2: 100% of CWR inside polyhouse

T_3: 80% of CWR inside polyhouse

T_4: 60% of CWR inside polyhouse

T_5: 100% of CWR outside polyhouse (open condition)

All treatments were randomly arranged in four replications (R_1, R_2, R_3, and R_4) as blocks for each treatment."

A drip irrigation system was installed on an area of 16 m^2 and consisted of a strainer filter, a 62 mm diameter main pipeline (5 m long Poly Vinyl

Chloride (PVC) buried at a depth of 0.5 m below ground level), a 16 mm LLDPE lateral line, and pressure compensating drippers with a 4 L/h discharge for every 4 plants. Lettuce was planted on raised beds, and standard horticultural management practices, such as weed control and pest protection, were carried out throughout the experiment.

Plant growth parameters, including seasonal increases in plant height, head diameter, the number of green leaves, leaves fresh weight, dry weight, and yield, were measured and recorded. Statistical analysis using SPSS software was performed to test the significance of the different treatments individually and in combination. An ANOVA was conducted using the method described by Gomez and Gomez (1984), and treatment means and variance were tested at a 5% significance level. The Duncan multiple range test was also conducted to determine the significance level between the treatments and groups of treatments.

RESULTS AND DISCUSSION

The Presence of a polyethylene cover in a polyhouse during the winter season alters the climate inside compared to the external environment. These alterations involve a decrease in radiation and wind speed and an uptick in temperature and humidity. These modifications can affect the development, yield, and quality of the lettuce grown inside the polyhouse.

Effect of poly film on climatic parameters

The regulation of growth in crops is heavily influenced by temperature. Each crop has a specific range of temperatures that it grows best in, referred to as the optimum temperature range. These requirements are typically based on the temperature at night. For example, lettuce thrives in a temperature range of 21-29°C during the day and 15-20°C at night, with the optimal temperature for color development being 21-24°C. Data collected over a two-year period from November to February revealed that the use of polyethylene in a polyhouse increases the temperature, with the maximum and minimum temperatures inside the structure being higher than those outside due to the interception of air within the structure.

The Fig. 1 illustrates the weekly average of daily maximum and minimum air temperatures during the winter months (November to February) in both polyhouse and open field conditions. As depicted in the Fig. 1, with the exception of the initial weeks, the polyhouse exhibited either equal or higher maximum and minimum air temperatures compared to the open field. The figure also reveals that the highest maximum temperature recorded during the winter season occurred in the polyhouse during the second week post-transplantation, reaching 42°C. Additionally, roughly eight weeks after transplantation in January, the polyhouse and open field recorded similar minimum and maximum temperatures. It is also worth noting that the average temperature in the polyhouse was 8% higher compared to the open field condition. This can be attributed to the poly film's ability to trap solar radiation and increase the temperature inside the structure.

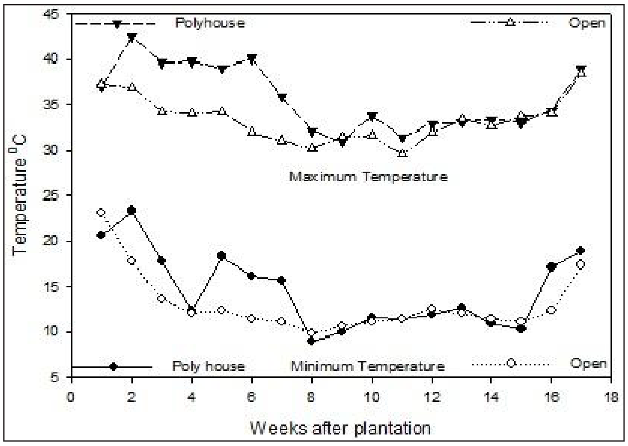

Fig. 1: The weekly average of daily maximum and minimum temperature in polyhouse and an open condition

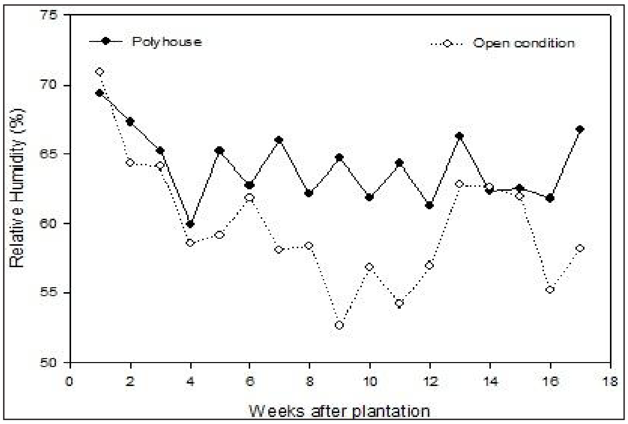

Fig. 2: The weekly average of daily mean relative humidity in polyhouse and an open condition

As depicted in Fig. 3, the amount of solar radiation transmitted through the poly film varies between 60-

80%, depending on the number of sunshine hours. During the extreme winter months of December and January (8-12 weeks after transplantation), there was a slight difference (20%) in the amount of net radiation received by plants in the polyhouse compared to those in open conditions. As the temperature increased during February (14-18 weeks after transplantation), this difference in solar radiation received also rose to 40%. The cladding materials used to cover the polyhouse significantly affect the radiation balance in comparison to the external environment due to their ability to attenuate (absorb and reflect) incident solar radiation, resulting in a decrease in the internal radiation balance and subsequently affecting evapotranspiration (Sentelhas, 2001).

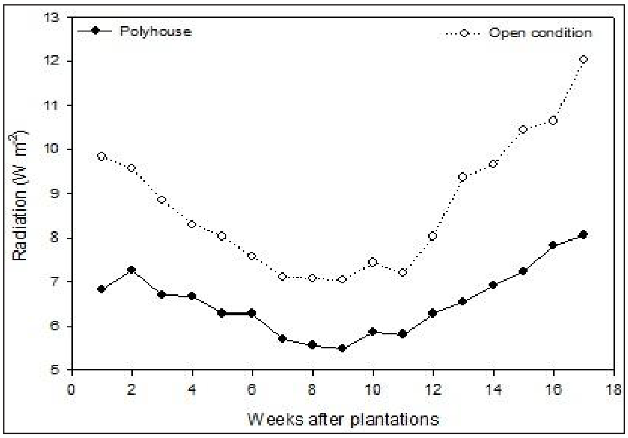

Fig. 3: The weekly average of daily Radiation (W m^{-2}) recorded in polyhouse and an open condition

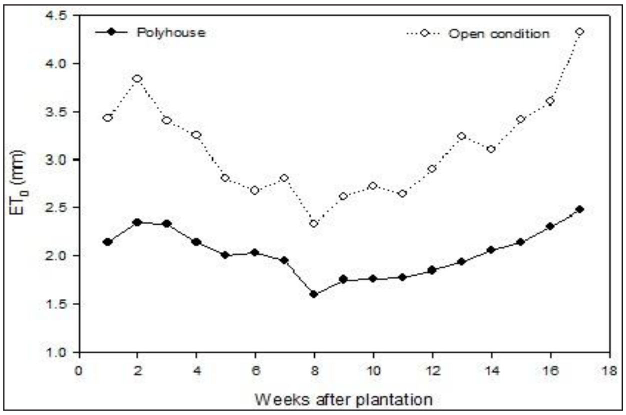

Fig. 4: The weekly average of daily reference evapotranspiration, ET_0 (mm) estimated for polyhouse and an open condition

Reference evapotranspiration (ET_0)

The FAO-56 Modified Penman-Monteith (PM) equation is commonly used to estimate the water requirements of lettuce crops and relies on microclimate data for irrigation planning. By measuring the relevant climatic data within the greenhouse, predictions about crop water requirements can be made using the evapotranspiration equation from the PM model. This method has also been implemented in greenhouses by other researchers, such as Chartzoulakis and Drosos (1997) and Baille (1994). Evapotranspiration in the polyhouse tends to be less than that of the open field due to the greenhouse effect and lower levels of radiation. Polyethylene sheet covers had the highest air temperatures, while the open field had the highest evapotranspiration throughout the season, in line with the findings of Abdrabbo (2001) and Salman *et al*. (1992). The difference in evapotranspiration between the inside and outside of the greenhouse varies depending on the meteorological conditions. The seasonal ET_0 in the polyhouse is lower than that of irrigated crops outside during the winter. The estimated ET_0 values, which range from 1.8 to 2.5 mm/day for 14 weeks, were lower in the polyhouse compared to the open condition. Many studies have also noted that evapotranspiration inside a greenhouse is around 60-80% of that observed outside (Rosenberg *et al*. 1989). Farias *et al*. (1994) observed that the reference evapotranspiration inside greenhouses was always lower, ranging from 45-77% of that observed outside. Braga & Klar (2000) observed that the values of reference evapotranspiration were 85% and 80% of the reference evapotranspiration observed outside for greenhouses oriented east/west and north/south, respectively. These results can be explained by the impact of the main factors of atmospheric evaporative demand, such as lower wind speeds, higher relative humidity, and lower levels of direct solar radiation inside greenhouses.

The relation between reference evapotranspiration (ET_0) inside and outside the Polyhouse

Fig. 5 shows the regression analysis of the daily reference evapotranspiration (ET_0) inside and outside the polyhouse during the experiment. The relationship between the reference evapotranspiration inside and outside the shade net house was found to be as follows:

$$ET_0 \text{ Open} = 1.9264\, ET_0 \text{ in} - 0.7592$$

where,

ET_0 Open = Reference evapotranspiration outside the polyhouse, mm

ET_0 in = Reference evapotranspiration inside the polyhouse, mm.

The results from the study revealed a strong correlation between crop evapotranspiration (ET_0) inside and outside the polyhouse, as indicated by a coefficient of determination (R^2) of 0.8415 during the growth period. The correlation between ET_0 inside and outside the polyhouse was found to be highly significant (r = 0.917). It was observed that the reference evapotranspiration inside the polyhouse (ET_0 in) was lower than the reference evapotranspiration outside the polyhouse (ET_0 open) during the growth period. In the early stages of the crop, ET_0 in was found to be greater than ET_0 open, however, as the crop progressed to the mid and late stages, ET_0 open gradually increased. On average, it was found that ET0 in was about 70% of ET_0 open. The data illustrates that the crop water requirement inside the polyhouse was less compared to the crop water requirement outside the polyhouse.

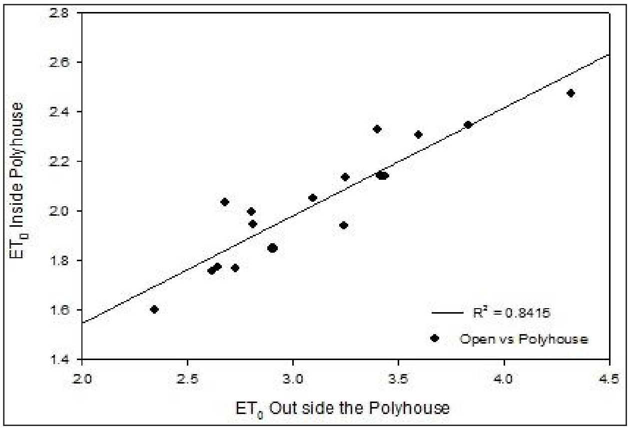

Fig. 5: Relation of daily reference evapotranspiration inside and outside the polyhouse

Irrigation water requirement of the Lettuce crop

The calculation of crop evapotranspiration involves multiplying reference evapotranspiration by the crop coefficient, which is dependent on the growth stage of the crop. For this study, the crop coefficient (Kc) value was obtained from FAO-50 (Allen *et al*. 1998). The irrigation water requirements for lettuce grown using drip irrigation were determined to be 0.25-0.33 l/plant/day for polyhouse cultivation and 0.66-0.89 l/plant/day for open field cultivation. The total seasonal water requirements for lettuce grown using drip irrigation in the polyhouse were estimated to be 219 mm, while the requirement for the open field was found to be 339 mm.

Growth and yield of lettuce

The data presented in Table 1 encompasses two years' worth of pooled information for various biometric parameters, including plant height, head diameter, number of leaves per plant, fresh weight of leaves, dry weight of leaves, and yield for lettuce crops. The results indicate that biometric parameters and yield are significantly higher for treatment T_2 (100% crop water requirement through drip irrigation in the polyhouse) compared to the other treatments inside the polyhouse and the open condition treatment. Specifically, the plant height under treatment T_2 (36.3 cm) was the highest among all treatments and was 39% taller than the plant height cultivated outside the polyhouse with drip irrigation (T_5). The head diameter for treatments T_1, T_2, T_3, T_4, and T_5 were recorded as 13.33, 13.49, 11.17, 10.36, and 9.77 cm, respectively. It was also observed that the head diameter of lettuce in the polyhouse was approximately 38% larger than that grown outside the polyhouse. The maximum number of leaves per plant was found in treatment T_2 (31.7), followed by treatment T_1 (30.7), with the lowest value recorded for treatment T_5 (20.45). The primary impact of reducing the irrigation level on lettuce growth was a reduction in leaf area as a result of a decrease in leaf number. Additionally, it was noted that an increase in the number of leaves under drip irrigation with optimal water application may have been attributed to better water utilization and an excellent soil-water-air relationship, along with a higher oxygen concentration in the root zone (Gornat *et al*. 1993). As the quantity of water supplied through drip irrigation was reduced, the number of lettuce leaves decreased significantly.

The lettuce plants that were irrigated with the entire requirement inside the polyhouse had higher fresh and dry weights for their leaves. The fresh and dry weights of well-irrigated plants (100% irrigation

Table 1. Effect of irrigation levels on biometric parameters and yield of Lettuce crop (pooled data of two seasons 2019-20 & 2020-21)

Treatment	Plant Height (cm)	Head Diameter (cm)	Leaves (No. plant^{-1})	Leaves Fresh Weight (g plant^{-1})	Leaves Dry weight (g plant^{-1})	Yield (t ha^{-1})
T_1 (120% WR + PH)	32.09 ab	13.22 a	30.84 a	399.76 a	35.22 a	31.65 ab
T_2 (100% WR+PH)	36.32 a	13.37 a	31.65 a	409.35 a	38.45 a	35.62 a
T_3 (75% WR+PH)	31.90 ab	11.26 ab	28.24 ab	357.44 b	28.54 b	29.42 ab
T_4 (50% WR+PH)	30.40 ab	10.36 b	25.63 ab	331.55 b	26.30 b	26.32 b
T_5 (100% Open)	26.20 b	9.66 b	22.34 b	291.32 c	23.62 b	18.04 c
CD (0.05)	7.6	2.4	6.2	29.9	6.01	7.4
CV (%)	14.9	12.6	13.1	5.9	12.1	17.5

WR = water requirement of crops; PH= polyhouse.

Note: *Differences among the means with the same letter are insignificant based on Duncan's test (p<0.05).*

water) inside the greenhouse were approximately 409 g and 38.3 g, whereas the treatments with 100% irrigation water requirement in the open condition (T_5) showed reductions of 40% and 60% in fresh and dry weight, respectively. Other studies, such as the one conducted by Karam *et al.* (2002), have reported that a decrease in irrigation water application significantly decreases the fresh weight of individual heads (P<0.05). The analysis of the observations showed that different levels of irrigation with drip irrigation had diverse effects on crop yield. The data indicate that irrigation treatment T_2 produced the highest yield of 35.73 t/ha. Similar findings have been reported by Jordan *et al.* (2003) and Bozkurt *et al.* (2009), who found that irrigation levels significantly influence lettuce crop yield and yield components. Similarly, the yield of lettuce (18.5 t/ha) was found to be the lowest for the treatment with 100% irrigation water application in the open condition (T_5). The increase in yield in the polyhouse can be attributed to the enhanced availability of water, humidity, and carbon dioxide, which increases leaf area and results in more photoassimilates, leading to increased dry matter accumulation and leaf expansion, resulting in increased interception of daily solar radiation by the canopy. Kirnak *et al.* (2016) also reported similar findings, indicating that the controlled environment has a significant influence on the growth and yield of lettuce.

CONCLUSION

This study aimed to examine the impact of various irrigation levels on the yield of lettuce grown under polyhouse and open field conditions during the winter season in Odisha, India. The total water requirement for lettuce was calculated to be 219 mm and 339 mm for polyhouse and open field conditions, respectively. The irrigation treatments were based on the calculated crop water requirement and applied using drip irrigation. The results showed that the highest plant height, head diameter, number of leaves, fresh and dry weight of leaves, and crop yield were attained when the plants were irrigated with the full water requirement in the polyhouse (T_2). The open field cultivation had the lowest yield compared to all irrigation-level treatments in the polyhouse. The analysis of the daily reference evapotranspiration inside and outside the polyhouse revealed a strong correlation between the two. The findings also indicated that different irrigation levels with drip irrigation had varying effects on crop yield, with irrigation treatment T_2 producing the highest yield. These results suggest that drip irrigation can be an efficient method for irrigating lettuce in polyhouse and open field conditions and that optimizing irrigation levels can improve crop yields.

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