Drip irrigation amount and plastic mulching affect soil hydrothermal properties, productivity, and water use efficiency of cucumber in two contrasting environments

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Abstract: Growing environment plays a major role in crop growth and performance, especially fruits and vegetables that are prone to hazardous environmental factors. Crops grown in open fields are subjected to unstable evaporative demand of the atmosphere and disease infestation due to excessive rainfall. In contrast, protected structures such as greenhouse, poly house, net house, among others, modify extreme climatic conditions and protect the crops. This study was conducted to compare soil hydrothermal properties, cucumber performance and water use efficiency under different drip irrigation regimes and plastic mulch under open-field and polyhouse conditions, in southwest Nigeria during the dry period of 2020/2021 growing season. Increasing drip irrigation water amount and plastic mulching significantly ($p < 0.05$) increased soil water content in both growing environments. The polyhouse maintained consistent soil water content within the crop root zone during the growing cycle, while water content varied in the open field. Plastic mulching increased soil temperature by 0.3°C to 1.0°C in both 0 - 10 and 10 - 20 cm soil depth only in the open field. Decreasing irrigation amount increased soil temperature in both soil depths and in both growing environments. Plastic mulching increased cucumber yield and water use efficiency, while irrigation four times a week gave the optimum cucumber yield. Fewer fruits and lower cucumber yield were obtained in the polyhouse compared with open field. Although the study underscores the importance of mulching in conserving irrigation water for plant uptake, under both polyhouse and open field, the polyhouse did not enhance the performance of this cucumber variety. Therefore, the combination of plastic mulching and irrigation amount four times a week under open-field conditions is recommended for the cultivation of the CU-999 cucumber variety in this region.

Keywords: growing environment, irrigation amount, plastic mulching, soil hydrothermal properties, crop performance

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1 Introduction

Cucumber (*Cucumis sativus* L.) is the most popular of the Cucurbitaceae family, and an important vegetable crop grown worldwide (Huh et al., 2008; Mathew, 2022). It is the fourth most cultivated

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vegetable in the world, and one of the best foods for the body's overall health (Natural News, 2016). In Africa, cucumber is not yet ranked, still considered a less important crop as a result of its limited use (Niyi et al., 2019).

Recently, the demand for cucumber in Nigeria has been increasing due to the continued awareness of its overwhelming health benefits, being a valuable source of conventional antioxidant nutrients including vitamin C, beta-carotene, and manganese, along with skincare among others (Umeh and Ojiako, 2018). Growing cucumber in the Nigerian southwest region and many other regions of the world relies more on rain-fed agriculture. Moreover, in the flood plains and valley bottoms, where farmers grow the crop during the dry season, the residual water in these ecosystems has not been able to meet the crop water requirement due to limited or no rains (Larson et al., 2003), mainly because cucumber is a heavy feeder of water especially during flowering and fruit development stage. To overcome this problem, irrigation has become the only solution.

Because of the several advantages over other irrigation methods, the drip irrigation method continues to be promoted because of water saving potentials, high water productivity, decreased nutrients leaching, and reduced pressure on limited water resources (Awe et al., 2016, 2017; Liang et al., 2019; Sezen et al., 2019; Liu et al., 2020). The availability of adequate moisture at critical stages of plant growth will not only optimize the metabolic process in plant cells but also increase the effectiveness of soil nutrients available to the crop. Consequently, water stress may produce harmful effects on the growth and yield of crops (Saif et al., 2003; Zain et al., 2014; Awe et al., 2020a; Zhao et al., 2020). Conversely, excess irrigation water could be detrimental to the plant by reducing aeration, causing an excessively damp climate within the root zone, and reducing crop yield (Irmak and Rathje, 2014). Therefore, scheduling water application is very critical to make efficient use of irrigation water.

Another soil management practice aimed at conserving soil water and reducing the need for frequent water application is mulching. The modification of the soil microclimate by mulching has been reported to favor seedling emergence, modify soil temperature, and suppress weed population (Dragumilo et al., 2025; Iqbal et al., 2020). Other positive effects of mulching include increased water use efficiency, reduction of evaporation loss from the soil surface, and addition of organic matter, thereby improving infiltration, increasing aggregation, and decreasing bulk density thereby increasing crop yield (Zhao et al., 2016; Wu et al., 2017; Fan et al., 2017; Amare and Desta, 2021; Kumar et al., 2024).

Combining mulching and drip irrigation could further improve crop water use efficiency, contribute to water-saving strategies, and improve crop productivity. In this context, several authors (Qin et al., 2016; Liu et al., 2017; Tian et al., 2017; Zhang et al., 2017; Rashid et al., 2019; Liao et al., 2021) have evaluated soil and crop responses to irrigation regimes and mulching, but results are not the same, majorly attributed to differences in climate, mulching material, soil type, crop characteristics, and cultural practices.

Crop growing environment plays a major role in determining the quality aspects of the fruits. Cucumbers grown in open fields are subject to strong sunlight, high temperatures, water stress, and wind, and these unfavorable conditions result in problems such as high water-demand during droughts, flower abortion, delayed fruit growth, and reduced yield and quality (Alsadon et al., 2016). In contrast, protected structures such as poly houses have been found to protect crops from unfavorable climatic conditions and abiotic and biotic stresses such as strong wind, heavy storms, excess solar radiation, and extreme temperature conditions, and create barriers to pests and diseases (Abhivyakti et al., 2016), providing microclimate that optimizes crop growth and development, productivity and quality on all year-round basis and even prolong the growing season (He and Qin, 2022; Ahmad et al., 2023, 2024). Different researchers have evaluated ambient conditions and cucumber performance under protective structures

(Alsadon et al., 2016; Goyal and Sharma, 2021; Kaur and Sharma, 2022). Alsadon et al. (2016) found that plastic-covered greenhouse modified the internal microclimate and improved the physiological processes and yield of cucumber.

The knowledge of physical properties is essential to manage soils to sustain soil functions for optimal crop productivity. Therefore, information on soil physical properties is necessary for proper irrigation system design and efficient water management. Despite the existence of information on changes in soil physical properties under drip irrigation regimes, mulching and their interaction elsewhere (Choudhary et al., 2012; Abd El-Wahed et al., 2017; Zong et al., 2023; Tan et al., 2024), the interaction effect of drip irrigation regime and mulching on soil physical properties and processes in cucumber culture under open-field and controlled environment in Ado Ekiti region, southwest Nigeria is poorly known. Therefore, the study aimed to evaluate if reduced drip irrigation amount and mulching provide proper soil hydrothermal conditions, increased cucumber yield and water use efficiency.

2 Materials and methods

2.1 Description of the study area

The research was carried out at the teaching and research farm, Ekiti State University, Ado-Ekiti, southwest Nigeria. The site is located on Longitude 4°45’ to 5°45’ E and Latitude 7°15’ to 8°5’ N at 434 m above sea mean level. The site is located in the humid tropical climate distinguished by dry and wet seasons, the total annual rainfall is about 1367.7 mm, while daily average temperature varies around 27°C. The major soil of the study area is Alfisol, classified as Typic Kandipludalf (Soil Survey Staff, 2014), with top sandy loam to subsoil clay texture (Fasina et al., 2005). Maize, watermelon, cucumber, and muskmelon were grown under open-field conditions and was left as fallow before the installation of the experiment, while the tomato was grown in polyhouse. The physical and chemical properties were determined for 0 - 30 cm soil depth for both fields and are presented in Tables 1 and 2.

2.2 Description of the polyhouse

The polyhouse, 8 m × 12 m in dimension, was installed with the top cover made of low-density, woven, laminated polyethylene UV sheet, while the four sides were covered with 8-mm mesh net. The steel structure (galvanized pipe) was sourced and fabricated locally, while the cover and side net were procured from Dizengoff West Africa (WA), Nigeria. The structure was oriented to allow adequate ventilation.

Table 1 Physical and chemical properties of soil in the open field condition.

Soil	pH_{H2O}	EC	OM	TN	Av. P	Ca	Mg	K	Na	Ex. Ac
layer, cm	1:2	dS m^{-1}	%	g kg^{-1}	mg kg^{-1}			$cmol_c$ kg^{-1}		
0-10	7.1	1.045	2.4	0.072	105.7	3.0	1.7	1.22	0.11	0.25
10-20	7.3	0.357	2.2	0.068	61.3	3.5	0.9	0.22	0.07	0.20

Soil	BD	Pd	Pt	Ksat	FC	PWP	Sand	Clay	Silt	Texture
0-10	1.46	2.85	0.4879	63.6	0.207	0.085	58.1	8.5	33.4	SL
10-20	1.64	2.48	0.3361	43.3	0.198	0.087	63.3	9.4	27.3	SL
20-30	1.50	2.62	0.4278	40.0	0.225	0.086	49.7	7.8	42.4	L

Note: EC: electrical conductivity; OM: organic matter; TN: total nitrogen; Av.P: available phosphorus; Ca: calcium; Mg: magnesium; K: potassium; Na: sodium; Ex. Ac: exchangeable acidity; BD: bulk density; Pd: particle density; Pt: total porosity; FC: field capacity; PWP: permanent wilting point; Ksat: saturated hydraulic conductivity.

SL: sandy loam; L: loam

Table 2 Physical and chemical properties of soil in the polyhouse condition

Soil layer, cm	pH_{H2O} 1:2	EC dS m^{-1}	OM %	TN g kg^{-1}	Av. P mg kg^{-1}	Ca	Mg	K	Na	Ex. Ac
						------------------------- $cmol_c$ kg^{-1} -------------------				
0-10	6.7	0.536	2.1	0.042	29.5	3.0	0.9	0.44	0.05	0.30
10-20	6.8	0.291	0.8	0.018	8.5	1.6	0.7	0.13	0.04	0.20

Soil layer, cm	BD	Pd	Pt	Ksat	FC	PWP	Sand	Clay	Silt	Texture
	------g cm^{-3}------		cm^3 cm^{-3}	cm h^{-1}	------cm^3 cm^{-3}-----		------------------%-----------------			
0-10	1.55	2.45	0.3673	174.6	0.206	0.084	58.0	8.1	34.0	SL
10-20	1.60	2.55	0.3742	65.7	0.206	0.084	58.3	8.1	33.6	SL
20-30	1.59	2.50	0.3658	45.4	0.213	0.092	56.3	10.3	33.5	SL

Note: EC: electrical conductivity; OM: organic matter; TN: total nitrogen; Av.P: available phosphorus; Ca: calcium; Mg: magnesium; K: potassium; Na: sodium; Ex. Ac: exchangeable acidity; BD: bulk density; Pd: particle density; Pt: total porosity; FC: field capacity; PWP: permanent wilting point; Ksat: saturated hydraulic conductivity.

SL: sandy loam

2.3 Experimental design and treatments

The experiment was a 2-factorial, laid out in complete randomized design in polyhouse and randomized complete block design in open-field in split plot arrangement and three replications. The main plot was irrigation amount comprising three irrigation regimes of equivalent depth at field capacity (D_{FC}), applied at different times in a week namely: $5D_{FC}$ - five irrigations per week, $4D_{FC}$ - four irrigations per week and $3D_{FC}$ - three irrigations per week, while the subplot consisted of mulching: No mulch (NM) and plastic mulch (M), giving six (6) treatment combinations namely $5D_{FC}$M, $5D_{FC}$NM, $4D_{FC}$M, $4D_{FC}$NM, $3D_{FC}$M, and $3D_{FC}$NM. Thus, there were a total of 18 experimental units that constituted the 3 x 2 factorial experiment and three (3) replications.

2.4 Land preparation, field layout, and installation of drip irrigation and plastic mulch

The site was cleared of existing vegetation and the packing of debris before marking out into plots. Tilling of soil and making of seedbeds were done with the use of hoes. Poultry manure (PM) at the rate of 20 ton PM ha^{-1} was spread evenly to the soil surface, mixed, and incorporated manually within the 10 cm soil depth (Enujeke, 2013). There were six (6) ridges in both growing environments, each ridge 11 m long and spaced 1 m apart. Each ridge was divided into three (3) experimental units, each experimental unit measuring 3 m × 1 m, and a space of 1 m between experimental units.

Non-perforated plastic mulch, cut to 3 m long and 1.5 m wide, was placed to cover the experimental units designated as mulched. The field layout showing the drip irrigation system and plastic mulch in both environments is shown in Figure 1.

The water delivery system consisted of a 3000 L tank that is connected and supplied water to the main line (1” PVC), then to the sub-mains (3/4” PVC), from the sub-mains to the drip lines and to the field via drip emitters (4 L h^{-1} discharge rate and 30-cm spacing).

2.5 Planting and field management

Before planting, the field was adequately irrigated for two days. Cucumber seed (Variety: African Giant, CU-999) was obtained from a government-accredited seed company. One seed of cucumber was planted at a spacing of 30 cm along each of the two drip lines, giving a plant population of about 33,333 plants per ha. Planting was done on 15th December 2020 in both growing environments, however, field attack by cattle caused replanting some plots in the open field on 30th December 2020. After planting, the field was irrigated uniformly for 10 days for crop establishment after which irrigation treatments were imposed. Weeding was done manually to remove weeds while other management practices of fertilization, crop protection, staking, and training for cucumber was strictly followed.

2.6 Irrigation water applied

Irrigation was scheduled by quantifying the time, in hours, to apply a given amount of water to the field using the equivalent depth at field capacity, the emitter flow rate, numbers of emitters, and area of the experimental unit. Thus, the time to irrigate was computed according to the equation (Awe et al., 2020a):

$$t(h) = \frac{D_{FC}\ x\ A}{d_e\ x\ n_e\ x\ I_E}$$

$$D_{FC} = \theta_{FC}\ x\ BD\ x\ d$$

Where,

t is the time to irrigate, h;

D_{FC} is equivalent depth at field capacity, m;

A is area of experimental unit, m^2;

d_e is emitter flow rate, m^3 hr^{-1};

n_e is number of emitters in an experimental unit;

I_E is irrigation efficiency, taken as 95% for the drip irrigation system;

θ_{FC} is soil water content at field capacity, g g^{-1};

BD is soil bulk density, g cm^{-3};

d is soil depth, m.

The total irrigation amount applied during the growing period was the sum of equivalent depth at field capacity.

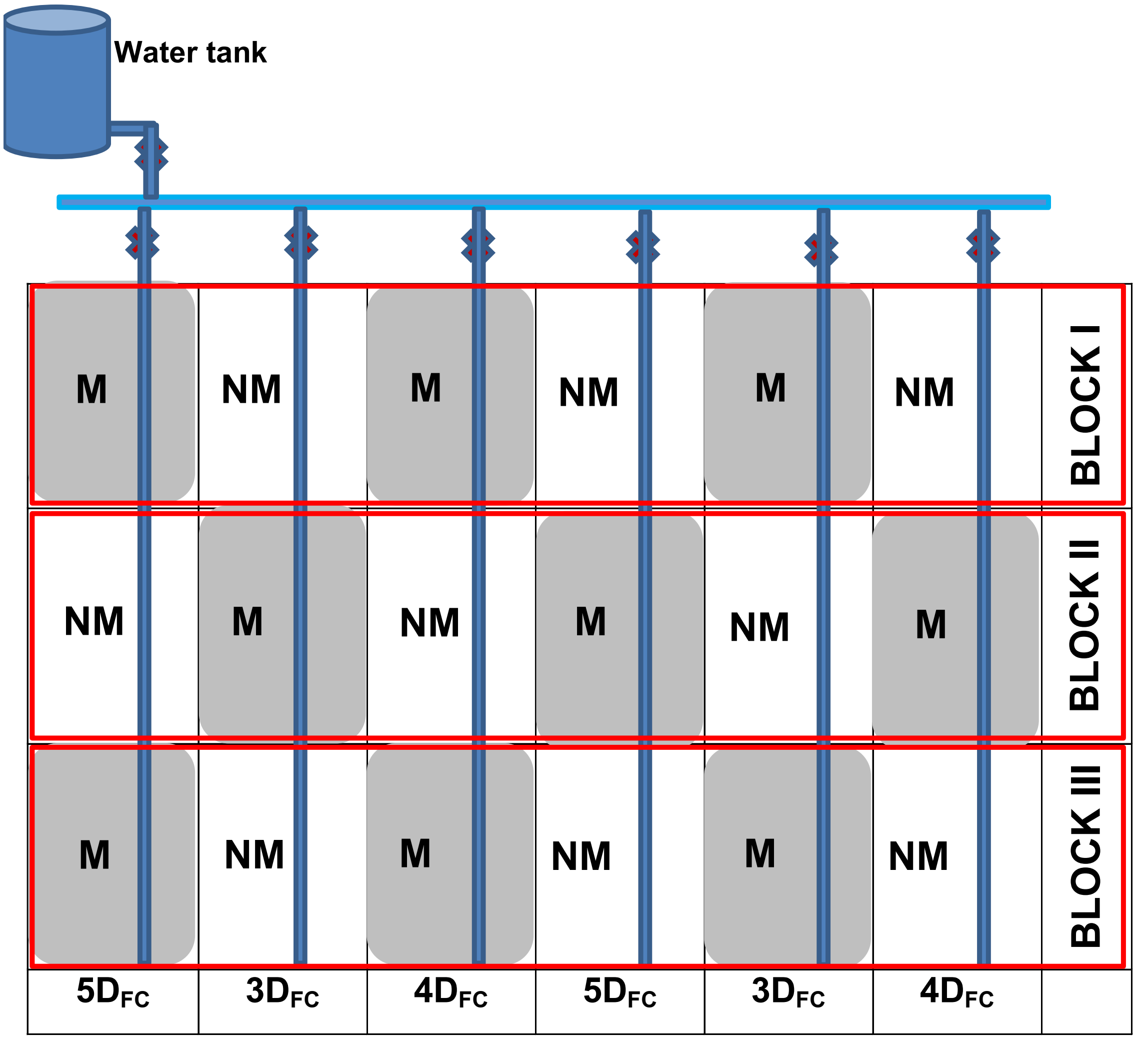
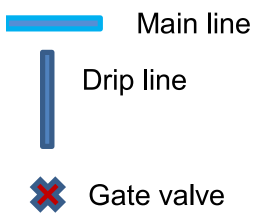


Figure 1 Field layout showing the different treatment combinations.

M: mulch; NM: no mulch; 5D$_{FC}$: five irrigations of equivalent depth at field capacity per week; 4D$_{FC}$: four irrigations of equivalent depth at field capacity per week; 3D$_{FC}$: thrice irrigations of equivalent depth at field capacity per week



2.7 Soil Sampling and laboratory analysis

Shortly after seedbed preparation, a mini profile, about 50 cm deep, was dug at the center of each field for soil sampling. Structured soil samples were collected from the center of soil layers 0 – 10 cm, 10 – 20 cm, and 20 – 30 cm using core samplers 57 mm diameter and 40 mm height. Disturbed soil samples were also collected from the same soil layers. The samples were transported to the laboratory, with the disturbed samples air-dried, and passed through 2-mm sieve for routine analysis of soil physical and chemical properties.

Soil bulk density was evaluated following the methodology described in Blake and Hartge (1986). Soil saturated hydraulic conductivity (Ksat) was determined using the constant-head permeameter following the methodology described in EMBRAPA (2011). Soil textural analysis was done using pipette method (Gee and Bauder, 1986; Suzuki et al., 2015). Soil particle density was determined using the volumetric flask method as described by Danielson and Sutherland (1986). Soil total porosity was obtained from the relation between soil bulk density and particle density (Danielson and Sutherland, 1986).

Soil pH was determined in a 1:2 soil water suspension using the digital electrode pH meter (Thomas, 1996). Organic matter was quantified using the wet oxidation method proposed by Walkley and Black (1934), while available phosphorus was determined by Bray and Kurtz (1945) method. Total nitrogen was obtained using the Kjeldahl digestion techniques (Bremner, 1960). Exchangeable bases (K, Ca, Mg, and Na) were extracted using ammonium acetate, and flame photometry (JENWAY PFP7 Flame Photometer) was used to read K and Na, while Ca and Mg were read using atomic absorption spectrophotometry (AAS, Perkins Elmer 2280 model). Cation exchange capacity (CEC) was obtained by the sum of the exchangeable bases K, Ca, Mg, and Na.

2.8 Data Collection

2.8.1 Leaf temperature

Leaf temperature was monitored in the morning (08:00) and afternoon (16:00) using an infrared thermometer. Air temperature was also measured during each measurement campaign. The diurnal change in leaf temperature was obtained as the difference between leaf temperature and air temperature.

2.8.2 Soil temperature

Soil temperature of the 0 - 10 and 10 - 20 cm layers was monitored in the morning (08:00) and afternoon (16:00) using a digital, 4-in-1 soil thermometer.

2.8.3 Soil water content

Soil water content of the 0 - 10, 10 - 20, and 20 - 30 cm layers was monitored using a digital soil moisture meter (SM: PY 1005).

2.8.4 Plant growth parameters

Vine length was measured using a flexible tape rule from the soil surface to the tip of the vine. Stem girth was determined using a digital-type vernier caliper, while the leaf area was obtained as 0.85 x leaf length x leaf breadth (Abegunrin et al., 2013).

2.8.5 Yield and yield components

All the cucumber plant stands in each experimental unit were used for the yield analysis. Cucumber harvesting started at about 40 days after planting, and this was done every 3-days intervals until about 60 days after planting. The number of fruits was the sum of fruits harvested during the harvest period. Fruit length and fruit diameter were obtained using flexible steel tape and vernier caliper, respectively. Fruit weight was obtained as the average weight of fruits from each plant using a sensitive, digital type weighing scale. Fruit yield was the sum of all fruits harvested in an experimental unit during the harvest period. The fruit yield was converted to ton per ha. Harvesting ended on 11th February 2021 in the polyhouse while it extended till 10 days after (21st February 2021) in the open field due to replanting.

2.8.6 Water use efficiency

Water use efficiency (WUE) was obtained as:

$$WUE\ (kgha^{-1}mm^{-1}) = \frac{Crop\ yield,\ \ kgha^{-1}}{Irrigation\ water\ applied,\ \ mm}$$

2.8.7 Weather data and evaporative demand of the atmosphere

Two mini-weather stations that record only minimum and maximum temperature and relative humidity were installed inside the polyhouse and within the open field. The evaporative demand of the atmosphere was measured in both sites, at 08:00 every day using a small pan evaporimeter (11 cm height and 24.5 cm diameter). The difference between two consecutive readings in 24 h, multiplied by the pan coefficient determined by Awe et al. (2020b) gives the evaporation.

2.9 Statistical analysis

Data was subjected to two-way analysis of variance (ANOVA) and where F-values were significant, means were separated using Duncan Multiple Range Test (DMRT) at 5% level of probability. The two growing environments, open-field versus polyhouse, were compared using t-test. All statistical analyses were done using SAS software (SAS version 8).

3 Results

3.1 Air temperature, relative humidity, evaporation, and irrigation water applied

The average daily minimum temperature ranged between 14.3°C and 21.7°C for open field and from 14.6°C to 18.6°C for polyhouse. The open field had daily maximum temperature ranging from 27.2°C to 42.1°C while the polyhouse had values between 44.6°C and 46.3°C. The relative humidity ranged from 76% to 94% for open field and between 89% and 95% for the polyhouse (Figure 2). The average daily minimum temperature was lower in the polyhouse by about 12% compared to open field. The average daily maximum temperature was higher in the polyhouse by about 22% compared to open-field while there was more water vapour in the atmosphere within the polyhouse by 5.6% compared to open field. The polyhouse had an average daily air temperature 3°C higher than that of open field.

Due to technical issues, evaporation monitoring started in the open field on 18th December 2020 while it commenced on 16th December 2020 in the polyhouse. During the comparable period, the average daily evaporative demand of the atmosphere, measured by the small pan evaporimeter (Ep), ranged between 3 and 9 mm day^{-1} for the open field and from 3 to 7 mm day^{-1} for the polyhouse. The cumulative evaporation was greater by about 13% in the open field than that of the polyhouse (Figure 3).

Figure 4 shows the time trend of the cumulative irrigation water applied during the growing cycle of cucumber for both open field and polyhouse conditions. There was a slight difference in the irrigation scheduling program. As a result of the replanting, irrigation scheduling was restarted on 13th January 2021 in the open field. However, the polyhouse received more irrigation water applications than the open field due to some rainfall (data not collected) received during the growing cycle in the latter. In the polyhouse, the total irrigation water applied was 1125.3, 918.8, and 712.3 mm for $5D_{FC}$, $4D_{FC}$, and $3D_{FC}$ treatments, respectively while in the open-field, the total irrigation water applied was 562.7, 449.3, and 336.0 mm for $5D_{FC}$, $4D_{FC}$, and $3D_{FC}$ treatments, respectively, resulting in water saving potential of about 20% and 40% in $4D_{FC}$ and $3D_{FC}$ treatments, respectively compared to $5D_{FC}$.

3.2 Soil water content

The spatio-temporal distribution of soil water content (SWC) of the cucumber field under drip irrigation depth and plastic mulch measured in the 0 - 30 cm soil depth in the two growing environments is shown in Figure 5. The results showed significant interaction ($P < 0.05$) between drip irrigation depth and plastic mulch on the average values of SWC in both growing environments. Over time, the effect of plastic mulching was obvious in both growing environments with mulched plots having higher SWC compared with unmulched plots (Figure 5A and 5B). On 28 DAP, the SWC was about 2%, 4% and 3% higher in mulched than unmulched plots in the 0 - 10, 10 - 20 and 20 - 30 cm soil layers, respectively for open field while mulched plots in the polyhouse had SWC about 12%, 9% and 5% greater than unmulched plots in same soil layers. In terms of irrigation depth, while treatment $4D_{FC}$ appeared having the highest SWC in the first two soil layers at 21 DAP, it was treatment $3D_{FC}$ that had the highest SWC in subsequent measurement campaigns but only in the surface layer in the open field. In the polyhouse, treatment $5D_{FC}$ had the highest SWC in the first two layers during both measurement campaigns. Comparing soil depths, no discernible trend in SWC was observed in the open field as the SWC was either higher or lower in the 0 - 10 cm surface layer than the subsurface layers, depending on whether measurement was made before (21 and 35 DAP) or after (28 DAP) irrigation, while in the polyhouse, the surface layer had the lowest SWC compared to subsurface layers and the trend was maintained during the measurement campaigns.

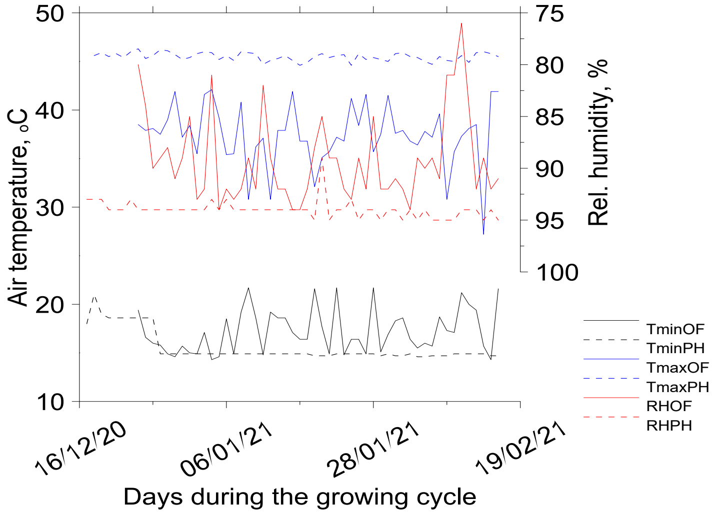


Figure 2 Temporal distribution of air temperature and relative humidity in the open field and polyhouse during the growing cycle of cucumber

TminOF: minimum air temperature in open field; TminPH: minimum air temperature in polyhouse; TmaxOF: maximum air temperature in open field; TmaxPH: maximum air temperature in polyhouse; RHOF: relative humidity in the open field; RHPH: relative humidity in the polyhouse

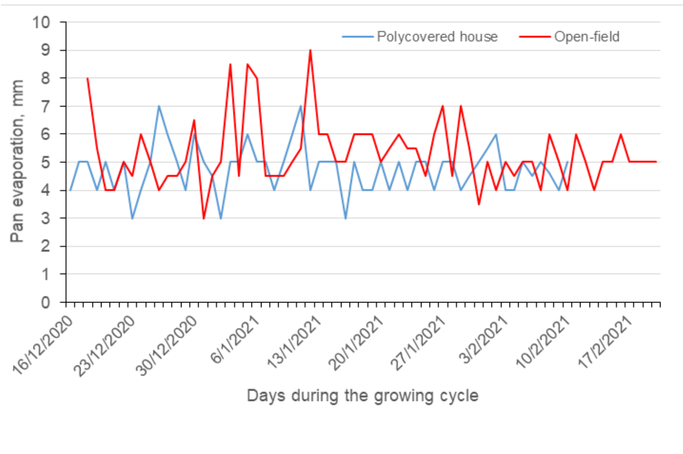
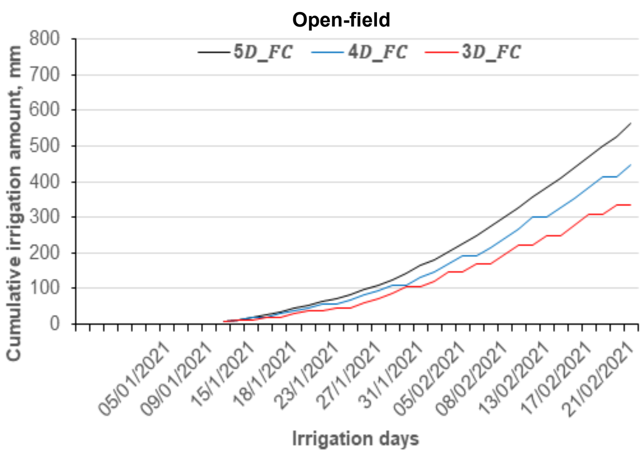


Figure 3 Temporal distribution of pan evaporation during the growing cycle of cucumber under open field and polyhouse conditions



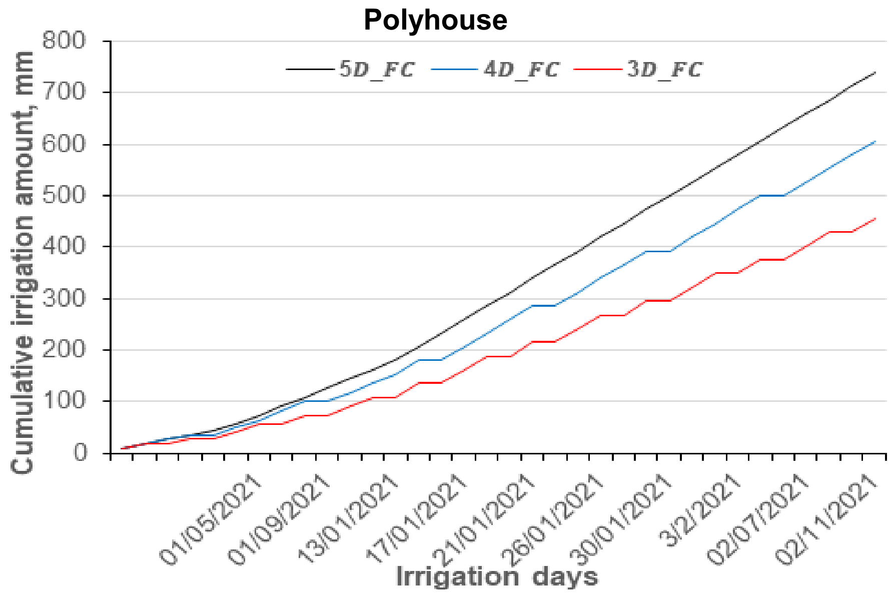


Figure 4 Cumulative irrigation water depth applied during the growing cycle of cucumber under open field and polyhouse conditions

5D_FC: Five irrigations per week; 4D_FC: four irrigations per week; 3D_FC: three irrigations per week

3.3 Soil temperature

Temporal distribution of soil temperature of the 0 cm - 10 cm and 10 cm - 20 cm soil layers of the drip irrigated cum plastic mulched cucumber in the two contrasting environments is presented in Figure 5.

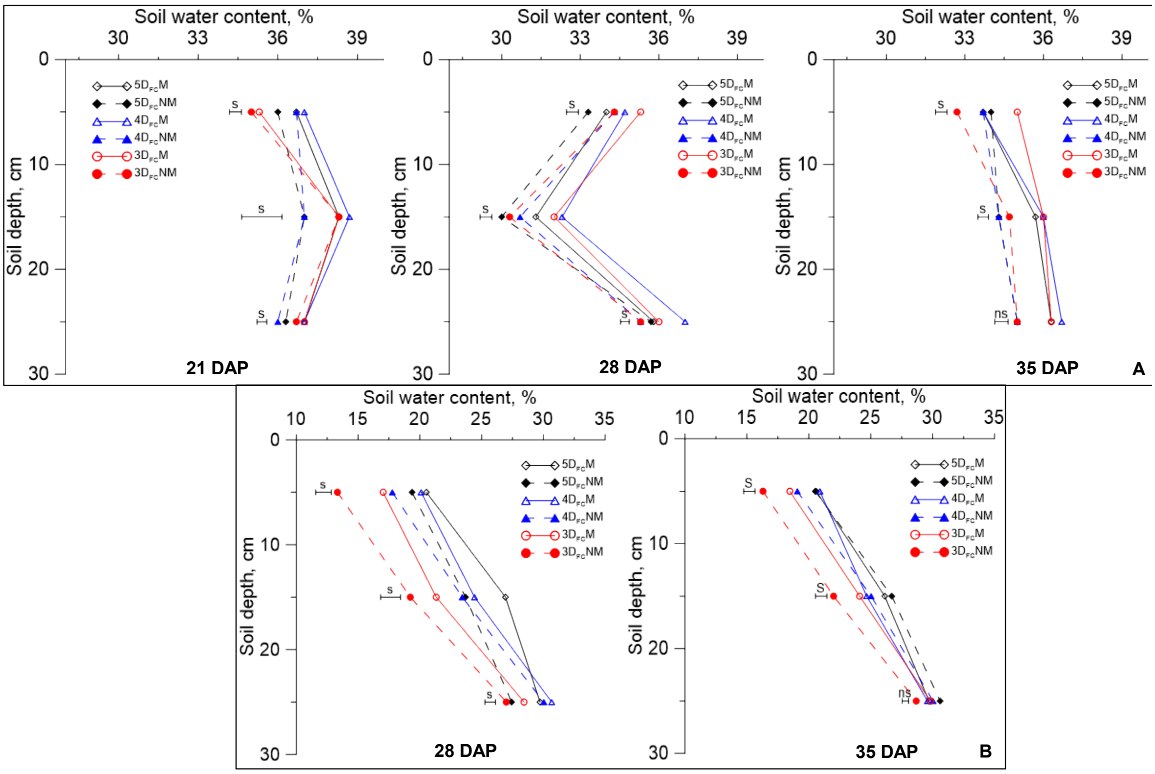


Figure 5 Spatio-temporal distribution of soil water content of the 0 - 30 cm soil depth of the cucumber field under drip irrigation depth and plastic mulching in A) open field and B) polyhouse

$5D_{FC}$: five irrigations of equivalent depth at soil field capacity per week; $4D_{FC}$: four irrigations of equivalent depth at soil field capacity per week; $3D_{FC}$: three irrigations of equivalent depth at soil field capacity per week;

M: plastic mulch; NM: no mulch; DAP: days after planting

s: significant; ns: not significant at 5% level of probability by Duncan Multiple Range Test

The capped horizontal bars are the standard error of the mean.

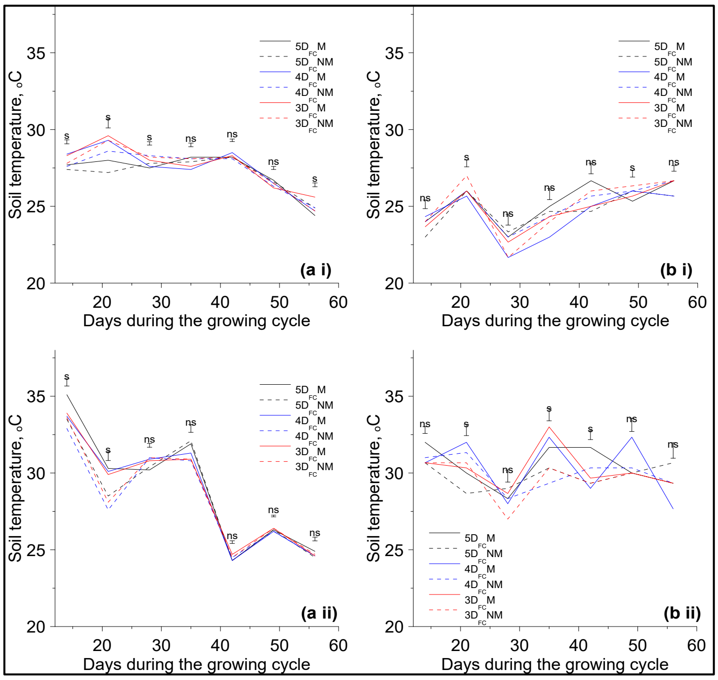


Figure 6 Temporal distribution of soil temperature of the 0 - 10 cm surface soil layer of the cucumber field under drip irrigation depth and plastic mulch measured at (i) 08:00 h and (ii) 16:00 h under (a) open field and (b) polyhouse conditions

$5D_{FC}$: five irrigations of equivalent depth at soil field capacity per week; $4D_{FC}$: four irrigations of equivalent depth at soil field capacity per week; $3D_{FC}$: three irrigations of equivalent depth at soil field capacity per week;

M: plastic mulch; NM: no mulch

s: significant; ns: not significant at 5% level of probability by Duncan Multiple Range Test

The vertical bars are the standard error of the mean.

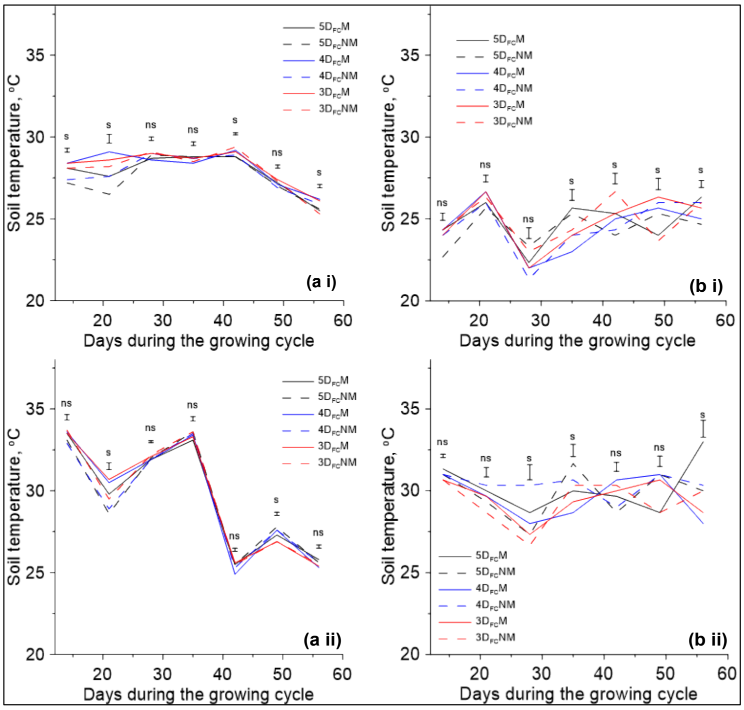


Figure 7 Temporal distribution of soil temperature of the 10 - 20 cm subsurface layer of the cucumber field under drip irrigation depth and plastic mulch measured at (i) 08:00 and (ii) 16:00 under (a) open field and (b) polyhouse conditions.

$5D_{FC}$: five irrigations of equivalent depth at soil field capacity per week; $4D_{FC}$: four irrigations of equivalent depth at soil field capacity per week; $3D_{FC}$: three irrigations of equivalent depth at soil field capacity per week;

M: plastic mulch; NM: no mulch

s: significant; ns: not significant at 5% level of probability by Duncan Multiple Range Test

The vertical bars are the standard error of the mean.

In Figures 6 and 7, there was a combined effect ($P < 0.05$) of drip irrigation depth and plastic mulching on soil temperature in both soil layers and growing environments, though not for all sampling campaigns. During the initial crop growth stage, morning and evening soil temperatures of both soil layers were greater (about 4°C) in the open field compared with the polyhouse, but over time soil temperature decreased in the open field (after 42 DAP in the morning and 35 DAP in the evening) while that of the polyhouse increased (after 26 DAP).

In the open field, mulched treatment had soil temperature about 0.3 °C and 0.5 °C greater than that of unmulched treatment in the 0 cm - 10 cm and 10 cm - 20 cm layers, respectively, in the morning, while during the evening period mulched treatment had soil temperature about 1.0°C and 0.5°C greater than unmulched treatment for the 0 - 10 and 10 - 20 cm soil layers, respectively; nevertheless, the difference was not beyond 25 DAP. Conversely, the effect of plastic film mulch was not clear in the polyhouse for the 0 cm - 10 cm surface layer in the morning throughout the cucumber growing cycle but mulched plot appeared having higher temperature in the mulched plot from 29 DAP. For the 10 - 20 cm soil layer, no clear trend was observed for the soil temperature.

Irrespective of mulching, decreasing irrigation water depth increased soil temperature in both soil layers during the growing cycle. Soil temperature measured in the morning was lower than that of the evening period although the difference canceled out from 40 DAP in the open field. Furthermore, the soil temperature was higher in both soil layers in the polyhouse compared with the open field from 25 DAP to harvest (Figures 6 and 7).

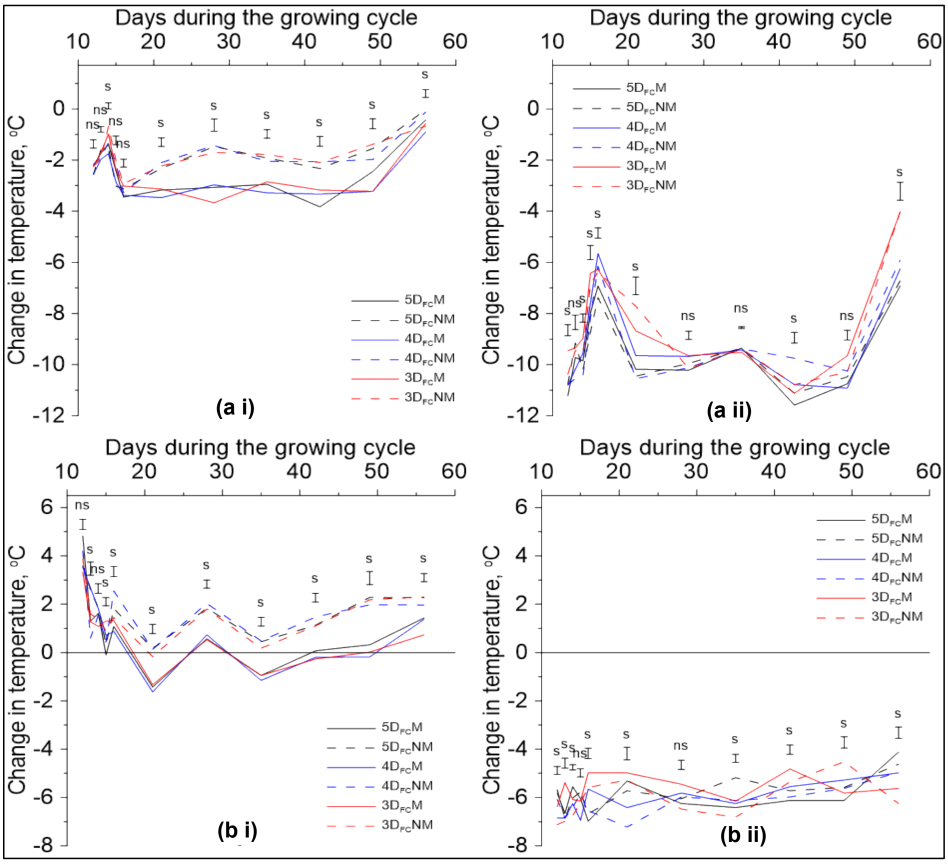


Figure 8 Diurnal changes in leaf temperature of the cucumber plant under drip irrigation depth and plastic mulch monitored at (a) 08:00 and (b) 16:00 in the (i) open field and (ii) polyhouse.

$5D_{FC}$: five irrigations of equivalent depth at soil field capacity per week; $4D_{FC}$: four irrigations of equivalent depth at soil field capacity per week; $3D_{FC}$: three irrigations of equivalent depth at soil field capacity per week;

M: plastic mulch; NM: no mulch

s: significant; ns: not significant at 5% level of probability by Duncan Multiple Range Test

The vertical bars are the standard error of the mean.

3.4 Diurnal changes in leaf temperature

Diurnal changes in leaf temperature of the polyhouse and open field condition measured at 08:00 and 16:00 are presented in Figure 8, with the combined effect of drip irrigation depth and plastic mulch significant ($P < 0.05$) on the diurnal changes in leaf temperature. The results showed that the diurnal changes in leaf temperature were more negative in the polyhouse than the open field during both measuring times. Furthermore, the effect of additional plastic film mulch was very distinct in the open field compared with the polyhouse (Figure 8 ai and bi) as mulched plots had more negative values of diurnal changes in leaf temperature compared with unmulched plots. It is interesting to note that none of the drip irrigation frequency or mulching was superior in terms of diurnal changes in leaf temperature in both growing environments.

3.5 Growth parameters

In the open field, cucumber vine length and stem girth differed significantly ($P < 0.05$) due to plastic mulching at 56 and 28 DAP, respectively, while irrigation effect was only significant on vine length at 28 DAP. In the polyhouse, plastic mulch effect was significant only on leaf area at 28 DAP, while irrigation effect was significant on vine length and leaf area at 56 DAP (data not shown). At 28 DAP, the combined effect of drip irrigation frequency and plastic mulching was significant ($P < 0.05$) on vine length and stem girth while the combined effect was not significant ($P > 0.05$) on any of the growth parameters in the polyhouse. At 56 DAP, the combined effect of drip irrigation depth and plastic mulch was significant ($P < 0.05$) only on vine length and leaf area in both growing environments (Table 3). Comparing the two growing environments, the growth parameters did not differ significantly ($P < 0.05$) except for vine length at 28 DAP. However, at 56 DAP, cucumber vine length and leaf area were significantly ($P < 0.05$) higher in the polyhouse, about 33% and 36%, respectively than that of the open field. Although the stem girth was higher in the polyhouse than the open field but the difference was not significant (Table 3).

Table 3 Comparison of cucumber plant growth parameters under open field and polyhouse conditions

		Vine length, cm			Stem girth, cm			Leaf area, cm^2		
		Open field	Polyhouse	MSD	Open field	Polyhouse	MSD	Open field	Polyhouse	MSD
Irrigation	Mulch	28 DAP								
$5D_{FC}$	M	84.6aA	80.7aA	10.3	8.4abA	10.0aA	3.0	123.8aA	198.0aA	128.7
	NM	81.1aA	120.8aA	42.6	7.9abA	9.8aA	2.6	155.8aA	174.3aA	170.1
$4D_{FC}$	M	79.4aA	126.8aA	63.6	9.0aA	8.8aA	2.3	145.0aA	197.2aA	128.2
	NM	48.8bA	106.9aA	65.9	6.5bA	9.9aA	5.0	134.1aA	151.0aA	40.9
$3D_{FC}$	M	80.5aB	123.8aA	25.6	8.2abA	8.8aA	2.4	144.7aA	240.8aA	126.7
	NM	58.6abA	96.8aA	42.1	6.5bA	8.3aA	2.4	122.9aA	103.6aA	75.4
		56 DAP								
$5D_{FC}$	M	123.7abB	186.9aA	23.8	9.4aA	11.9aA	4.0	224.8aB	309.8abA	51. 8
	NM	129.1aB	183.8aA	9.9	9.6aA	11.3aA	2.4	229.5aB	293.2aA	36. 8
$4D_{FC}$	M	128.4aB	174.0abA	32.8	11.4aA	11.7aA	3.6	207.7aB	445.7aA	54.3
	NM	94.0bB	180.3abA	45.4	8.4aA	11.3aA	4.7	217.5aB	373.1abA	91. 0
$3D_{FC}$	M	133.7aB	166.9bcA	22.6	11.2aA	10.6aA	3.8	215.9aB	309.8bcA	51.8
	NM	91.9bB	157.4cA	40. 1	9.0aA	10.3aA	2.2	207.0aB	293.2cA	36.8

$5D_{FC}$: five irrigations of equivalent depth at soil field capacity per week; $4D_{FC}$: four irrigations of equivalent depth at soil field capacity per week; $3D_{FC}$: three irrigations of equivalent depth at soil field capacity per week; M: plastic mulch; NM: no mulch

MSD: mean significant difference

Means in columns followed by different lowercase letters differed significantly among treatment combinations at 5% level of probability by Duncan multiple range test.

Means in rows followed by different uppercase letters differed significantly between open field and polyhouse at 5% level of probability by Tukey´s studentized test.

3.6 Yield components and water use efficiency

Yield components of cucumber grown under open field and polyhouse conditions are presented in Table 4. The main effect of irrigation depth was significant ($P < 0.05$) on the number of fruits, fruit length, and average fruit weight only in the polyhouse while the effect of plastic mulching was significant ($P < 0.05$) on all the measured yield components in both growing conditions. Number of fruits, average fruit weight, and fruit length (but not fruit diameter) differed significantly ($P < 0.05$) due to drip irrigation depth and plastic mulching in both growing environments, with the open field having higher number of fruits compared with polyhouse but bigger and longer fruits were obtained in the polyhouse. Furthermore, fruit diameter did not differ significantly ($P > 0.05$) among the treatment combinations in the open field, but the difference was significant ($P < 0.05$) inside the polyhouse (Table 4).

Table 4 Comparison of yield components of the cucumber grown under open field and polyhouse conditions

		No. of Fruits			Fruit Diameter, mm		
Irrigation	Mulch	Open field	Polyhouse	MSD	Open field	Polyhouse	MSD
$5D_{FC}$	M	22.0abA	12.7abB	8.1	48.6aA	49.4bA	3.5
	NM	16.7bA	8.7bcA	10.7	48.7aA	50.3abA	2.5
$4D_{FC}$	M	25.3aA	15.7aA	13.9	48.4aB	53.3aA	1.5
	NM	16.0bA	8.0bcA	8.2	48.5aA	52.0abA	6.1
$3D_{FC}$	M	24.0aA	9.7abcB	6.5	47.8aB	51.6abA	1.8
	NM	16.7abA	3.7cB	16	48.6aA	49.9abA	2.7
$Irrigation_{(p<0.05)}$		ns	s	-	ns	ns	-
$Mulch_{(P<0.05)}$		s	s	-	s	s	-
		Fruit Length, cm			Average Fruit weight, g		
$5D_{FC}$	M	24.5abA	24.8aA	2.1	302.8abB	398.0aA	57.7
	NM	24.4abA	21.1cB	1.7	291.2abA	306.1cA	39.6
$4D_{FC}$	M	24.9aA	23.5abB	0.5	316.0aB	403.7aA	42.4
	NM	25.5bA	21.4bcB	1.6	275.1bA	331.4abcA	75.9
$3D_{FC}$	M	24.8aA	21.7bcB	2	299.2abB	385.8abA	74.5
	NM	23.3bA	22.6abcA	3.8	280.6bA	319.9bcA	103.8
$Irrigation_{(P<0.05)}$		ns	s	-	ns	s	-
$Mulch_{(P<0.05)}$		s	s	-	s	s	-

5DFC: five irrigations of equivalent depth at soil field capacity per week; 4DFC: four irrigations of equivalent depth at soil field capacity per week; 3DFC: three irrigations of equivalent depth at soil field capacity per week

M: plastic mulch; NM: no mulch

MSD: mean significant difference

Means in columns followed by different lowercase letters differed significantly among treatment combinations at 5% level of probability by Duncan multiple range test

Means in rows followed by different uppercase letters differed significantly between open field and polyhouse at 5% level of probability by Tukey´s studentized test

ns: not significant; s: significant at 5% level of probability by Tukey´s studentized test

Drip irrigation depth significantly ($P < 0.05$) influenced cucumber yield only in the polyhouse; plastic mulching significantly ($P < 0.05$) affected cucumber yield while the interaction between the two factors was not significant ($P > 0.05$) on cucumber yield in both growing environments (Figure 9). Plastic mulch treatment had cucumber yield about 36% and 53% higher than unmulched treatment in the open field and polyhouse, respectively. In the open field conditions, $4D_{FC}$ had cucumber yield about 5% and 8% numerically higher than $3D_{FC}$ and $5D_{FC}$, respectively while in the polyhouse, $4D_{FC}$ treatment had significantly higher yield about 46% and 17% than $3D_{FC}$ and $5D_{FC}$, respectively. For the treatment combinations, cucumber yield was in the order $4D_{FC}M>3D_{FC}M>5D_{FC}M>5D_{FC}NM>3D_{FC}NM>4D_{FC}NM$ for open field and $4D_{FC}M>5D_{FC}M>3D_{FC}M>4D_{FC}NM>5D_{FC}NM>3D_{FC}NM$ for the polyhouse. Comparing the growing environments, open field had significantly higher ($P < 0.05$) cucumber yield than poly- covered house by 33% – 75% under the three drip irrigation regimes and mulching (Figure 9).

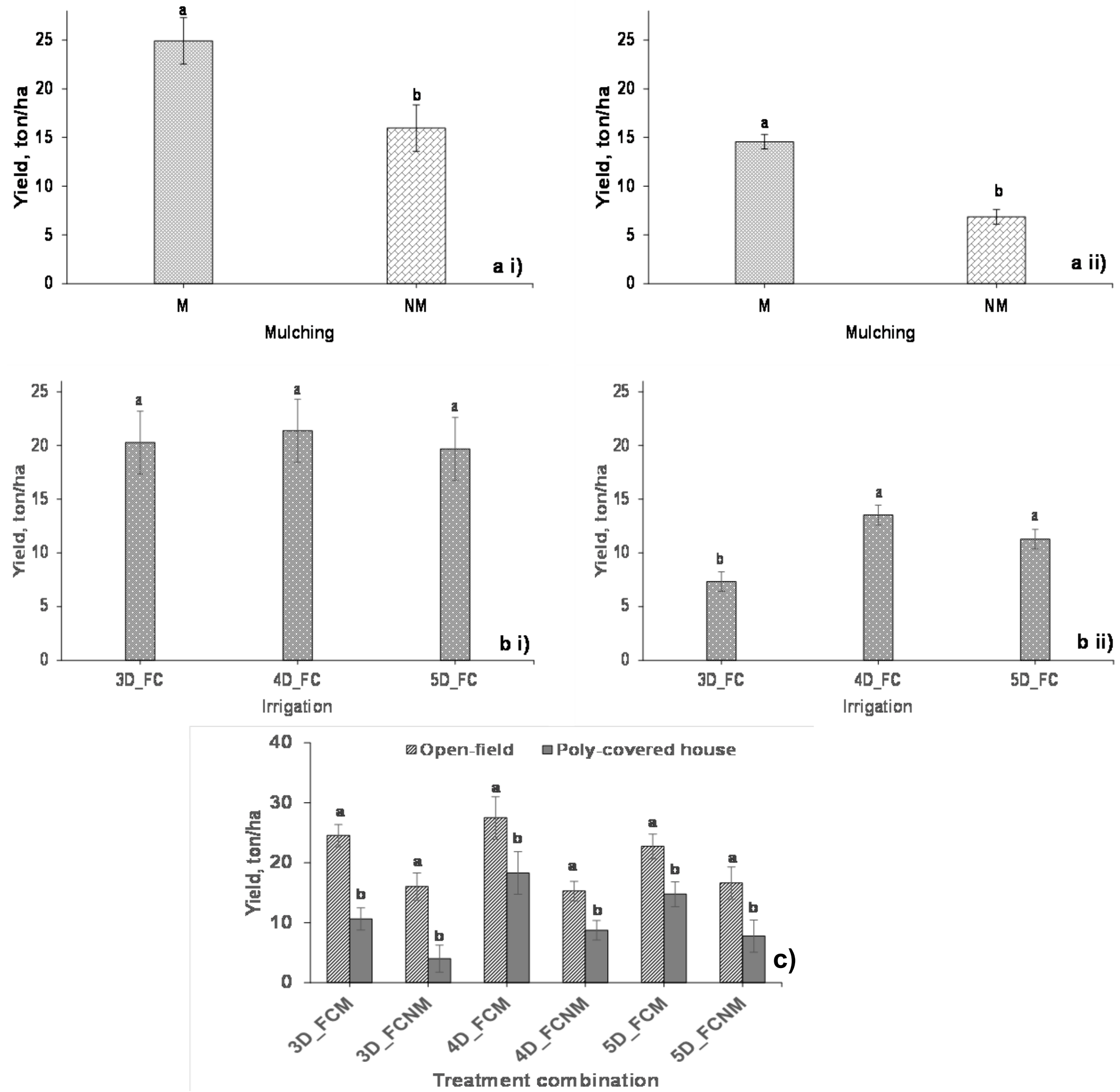


Figure 9 Effect of mulching in the open field (a i) versus polyhouse) (a ii); drip irrigation depth in the open field (b i) versus polyhouse (b ii); and their interaction (c) on cucumber yield

5D_FC: five irrigations of equivalent depth at soil field capacity per week; 4D_FC: four irrigations of equivalent depth at soil field capacity per week; 3D_FC: three irrigations of equivalent depth at soil field capacity per week;

M: plastic mulch; NM: no mulch

Bars with different letters differed significantly at 5% level of probability by Tukey´s studentized test

The capped vertical lines are the standard error of the mean.

The main effect of plastic mulching and drip irrigation amount was significant ($P < 0.05$) on water use efficiency (WUE) of cucumber, while the interaction effect of the two factors was not significant ($P > 0.05$) in both growing environments (Figure 10). As expected, mulched plots gave greater WUE compared with no mulch by 36% and 54% in the open field and polyhouse, respectively. WUE decreased with increasing irrigation amount in the open field (3DFC > 4DFC > 5DFC) while four times irrigations per week (4DFC) gave the highest WUE in the polyhouse. While treatment combination 3DFCM gave the numerically highest WUE in the open field, treatment 4DFCM gave the greatest WUE in the polyhouse, nevertheless, the open field cucumber had greater WUE compared with polyhouse cucumber (Figure 10).

Table 5 Pooled Pearson correlation between cucumber performance parameters, soil temperature and water content, and leaf temperature

	Yield	WUE	NOF	FrtLgth	FrtDia	FrtWt	PH	LA	SG	NOL	ST10M	ST20M	ST10E	ST20E	SWC10	SWC20	SWC30	LTM	LTE
Yield	1																		
WUE	.786**	1																	
NOF	.981**	.772**	1																
FrtLgth	.774**	.494*	.779**	1															
FrtDia	.193	.247	.105	.002	1														
FrtWt	.854**	.737**	.823**	.739**	.295	1													
PH	.468*	.471*	.505*	.317	-.270	.378	1												
LA	.532*	.497*	.527*	.424	.203	.253	.511*	1											
SG	.534*	.613**	.503*	.331	-.019	.345	.472*	.446	1										
NOL	.489*	.423	.539*	.406	.026	.319	.574*	.554*	.415	1									
ST10M	-.294	-.154	-.317	-.344	.013	-.068	-.149	-.668**	-.033	-.053	1								
ST20M	-.127	.142	-.219	-.253	.290	.170	-.274	-.435	-.124	-.107	.541*	1							
ST10E	-.456	-.340	-.463	-.228	.214	-.330	-.296	-.263	-.137	.048	.265	.209	1						
ST20E	-.367	-.256	-.365	.036	-.074	-.164	-.193	-.177	-.317	.123	.171	.432	.561*	1					
SWC10	.388	.460	.378	.166	.061	.349	.686**	.445	.586*	.741**	.108	.078	.115	-.011	1				
SWC20	.613**	.458	.609**	.536*	.150	.562*	.684**	.505*	.431	.557*	-.206	-.167	.070	.056	.688**	1			
SWC30	.640**	.558*	.675**	.351	.175	.607**	.538*	.241	.262	.509*	-.071	.022	-.116	-.143	.532*	.725**	1		
LTM	-.634**	-.424	-.670**	-.586*	-.158	-.532*	-.520*	-.771**	-.258	-.597**	.560*	.380	.320	.140	-.517*	-.650**	-.489*	1	
LTE	-.196	-.250	-.179	-.009	-.301	-.391	.281	.497*	-.118	.275	-.433	-.384	.092	.323	.234	.240	-.070	-.324	1

Note: WUE: water use efficiency; NOF: number of fruits; Frtlgth: fruit length; FrtDia: fruit diameter; FrtWt: fruit weight; PH: plant height; LA: leaf area; SG: stem girth; NOL: number of leaves; ST10M: morning soil temperature of the 10 cm depth; ST20M: morning soil temperature of the 20 cm depth; ST10E: evening soil temperature of the 10 cm depth; ST20E: evening soil temperature of the 20 cm depth; SWC10: soil water content of 0-10 cm layer; SWC20: soil water content of 10-20 cm layer; SWC30: soil water content of 20-30 cm layer; LTM: morning leaf temperature ; LTE: evening leaf temperature

** Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed).

3.7 Correlation between cucumber yield, water use efficiency, performance parameters, soil properties and leaf temperature

The correlation between cucumber yield components, water use efficiency, growth parameters, soil water content and temperature, and leaf temperature is presented in Table 5. As expected, cucumber yield had a positive, significant correlation with growth parameters ($P < 0.01$) and yield components ($P < 0.05$) except fruit diameter ($P > 0.05$). The correlation between cucumber yield and soil water content, except for the surface layer, was also positive and significant (P < 0.05). Cucumber yield showed no significant correlation with soil temperature. Leaf temperature monitored in the morning showed significant correlation (P < 0.05) with the measured variables except water use efficiency, fruit diameter, stem girth, and soil temperature, while leaf temperature monitored in the evening correlated significantly (P < 0.05) only with leaf area (Table 5).

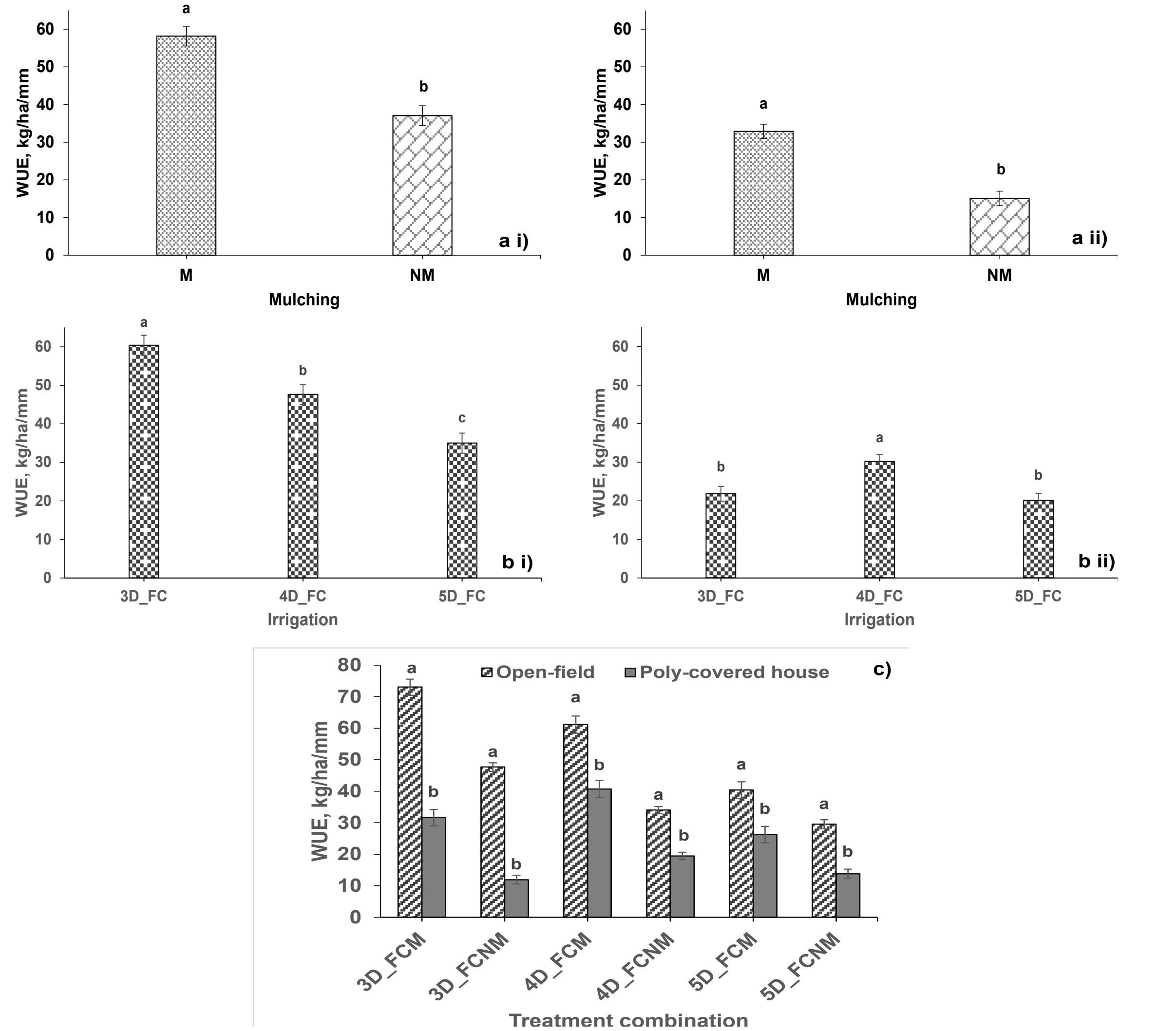


Figure 10 Effect of mulching in the open field (a i) versus polyhouse) (a ii); drip irrigation depth in the open field (b i) versus polyhouse (b ii); and their interaction (c) on water use efficiency (WUE) of cucumber.

5D_FC: five irrigations of equivalent depth at soil field capacity per week; 4D_FC: four irrigations of equivalent depth at soil field capacity per week; 3D_FC: three irrigations of equivalent depth at soil field capacity per week;

M: plastic mulch; NM: no mulch

Bars with different letters differed significantly at 5% level of probability by Tukey´s studentized test

The capped vertical lines are the standard error of the mean

4 Discussion

4.1 Weather conditions

The lower Epan in the polyhouse compared with open field agrees with results from previous studies (Farias et al., 1994; Yuan et al., 2001; Awe et al., 2020b; Sujitha et al., 2020). Rohith et al. (2024) using different water sources also reported high pan evaporation in the polyhouse compared to open field. According to Prados (1986) and Rosenberg et al. (1989), the reduced evaporation inside the polyhouse could be due principally to the partial opacity of the plastic film to radiation and limited wind speed, the principal factors controlling the evaporative demand of the atmosphere. Consistent with the findings of Rohith et al. (2024), the air temperature was higher in the polyhouse compared with the open field. Consequently, it is expected that with the elevated temperature, the rate of evaporation will increase, because at higher temperatures, water molecules move faster, possessing the needed kinetic energy to break away from liquid to become vapour. However, wind, an important parameter to move the water vapour away from the evaporating surface, is limited in the polyhouse compared with open field (Awe et al., 2020b). It should also be noted that the cucumber crop transpires at same time, emitting water vapour. Consequently, as the air within the polyhouse is filled with water vapour, there will be no adequate space to hold the excess water vapour, thereby slowing the evaporation rate.

4.2 Soil hydrothermal properties

As expected, the higher SWC from $4D_{FC}$ and $5D_{FC}$ and lower SWC from $3D_{FC}$ are attributed to high and low soil wetting from these treatments, respectively. This agrees with previous studies that reported higher SWC from more high-water applications (Awe et al., 2016, 2017; Mankotia and Sharma, 2020; Sahu et al., 2023; Zambrano et al., 2024). The higher soil water content measured under plastic mulch indicates the beneficial effect of mulching. According to Shaver et al. (2013), Khaskheli et al., 2022, and Zambrano et al. (2024), plastic mulch acts as a barrier against water vapor loss, preventing evaporation from the soil, and thus water becomes stabilized and stays longer in the soil profile, being readily available for crop growth. Furthermore, the soil water condition maintained in the soil layers under the polyhouse coupled with plastic mulch is attributed to the ability of the system of controlling the micro-climate created. Harinarayanan et al. (2022) also reported mulching maintained soil moisture under the polyhouse.

Soil temperature is an important factor influencing soil physical, chemical, and biological processes at various scales, as extreme soil temperatures could negatively impact water dynamics, decomposition and mineralization of organic matter, nutrient availability, seed germination and emergence, biological activities, root growth, and crop development (Silva et al., 2006; Veiga et al., 2010; Awe et al., 2015; Abhivyakti et al., 2016; Onwuka, 2018). Higher temperature in the two soil layers due to plastic mulch in the open field at the initial growth stage of the cucumber crop is attributed to the micro-climate created by mulch cover. Soil temperature under plastic mulch is a function of the thermal properties such as the reflectivity, absorptivity, and transmittivity of the mulch material with respect to the incoming solar radiation (Abhivyakti et al., 2016). The black plastic mulch has high shortwave absorbance, that is, the incoming shortwave radiation is first absorbed by the plastic mulch and transmitted to the soil by conduction (Laulina and Hasan, 2018). During the day, the air pocket within the micro-climate is heated up and the heat is transferred to the soil, a heat sink, hence the soil temperature increases due to plastic mulching. Warming effect of plastic mulching on the soil has also been reported (Ramakrishna et al., 2006; Abhivyakti et al., 2016; Laulina and Hasan, 2018; Gheshm and Brown, 2020; Zhao et al., 2023). From 25 DAP, increased crop canopy cover may be the reason for the lack of discernible trend in soil temperature among the treatment combinations. Jakhdhar (2010) also observed that increased soil temperature under black plastic mulch was limited to the early crop growing as a result of lesser canopy cover. Abhivyakti et al. (2016) did not find definite pattern in soil temperature due to mulching or no mulching under open field conditions.

In the polyhouse, the lack of discernible trend in soil temperature due to the treatment combinations throughout the cucumber growth period may be attributed to complex interactions among the soil, crop canopy, plastic film mulch, irrigation, and poly-cover. In this study, the higher soil temperature strictly followed the higher air temperature observed in the polyhouse compared with open field. Our results agree with the findings of Laulina and Hasan (2018) who found higher soil temperature in the greenhouse compared with open field. The double barrier created by plastic mulch and polythene covering may have prevented the escape of long wave solar radiation, resulting in more soil heat and hence higher soil temperature.

4.3 Diurnal changes in cucumber leaf temperature and performance

Diurnal changes in leaf temperature are the variations in leaf temperature that takes place during the day due to Earth's rotation, causing the surface temperature to fluctuate. The changes are occasioned by fluctuations in radiant energy absorbed by the leaves and the amount of heat energy transported away from the leaves (Jones and Rotenberg, 2001). The higher diurnal changes in leaf temperature in the open field result indicates cucumber is prone to water stress, while in the polyhouse, the crop showed less stress, which is attributed to the micro-climate in the polyhouse. These results agree with those observed by Alsadon et al. (2016) who indicated that the poly-covered covering material have significant influence on internal conditions, physiological processes, and productivity of cucumber plants.

Fewer fruits and lower yield observed in the polyhouse compared with the open field is attributed to limited pollination observed in the polyhouse, resulting from fewer pollinating insects accessing the polyhouse. Our results contradict those of Arunadevi et al. (2021) who found higher cucumber yield in the polyhouse compared with the open field. Another reason for the high yield in the open field could be full and direct exposure of the crop canopy to sunlight required for photosynthesis, which is limited in the polyhouse. In addition, there was no barrier to insect pollinators in the open field, ensuring adequate pollination, whereas in the polyhouse the entry of insect pollinators is restricted. Interestingly, the average fruit weight of cucumber was higher in the polyhouse than that in the open field, which could be attributed to limited competition for resource use (water, nutrients, and light) in the polyhouse.

Better cucumber performance observed under plastic mulching is attributed to the beneficial environmental conditions for optimum growth of the cucumber crop than the bare soil. These results are in agreement with those stated by Laulina and Hasan (2018), Abegunrin et al. (2020), and Priyadarsini et al. (2020). Mulching might have helped in attaining optimum growth by controlling of weeds, conserving soil moisture, maintaining optimum soil temperature, and curtailing certain pests and diseases. Enough soil moisture near root zone, and extended retention of moisture due to reduced evaporation could have led to a higher uptake of nutrients, resulting in proper growth and development of the plant (Demo and Asefa Bogale, 2024). Soil water content was positively correlated with cucumber yield. Cucumber is heavy feeder of water during the fruiting stage, therefore measures that conserve water, such as mulching, are required for optimum cucumber fruit set and development. High soil temperature due to mulching, especially during the early growth stage, could have provided a more suitable environment for plant growth and development, as cucumber is known to perform better under slightly elevated soil temperature (Haifa, 2014). Nevertheless, high air temperatures negatively affect cucumber during fruiting, resulting in curved, non-marketable fruits and high accumulation of cucurbitacin, an agent responsible for the bitterness in cucumber. The highest yield components observed from $4D_{FC}M$ in both growing environments agree with Sharma and Meshram (2015) who found that drip irrigation in combination with plastic mulch had higher crop yields under open field conditions. Santhosh et al. (2024) also recorded the highest cucumber yield under 100% irrigation water requirement and plastic mulch.

The high water use efficiency from $3D_{FC}$ in the open field agrees with other authors such as Çakir et al. (2017) and Zakka et al. (2020) who found highest WUE under the least irrigation amount. Fasina et al. (2021a, 2021b) found the highest WUE from four times irrigations per week in an open field environment. In the polyhouse, the lower water use efficiency obtained from $3D_{FC}$ compared to $4D_{FC}$ could be that decreasing irrigation frequency to three times a week ($3D_{FC}$) was not enough in meeting the water requirement of cucumber, resulting in yield reduction; hence, the low water use efficiency. The higher WUE from mulched plots in both growing environments is also attributed to the beneficial effects of mulching. Under unmulched condition, a considerable proportion of water that could have been available for plant uptake evaporates, resulting in less water for plant use. In the poly house, flower abortion due to limited pollination as already mentioned led to fewer fruits and low yield, hence lower WUE compared with open field.

5 Conclusions

We studied soil hydrothermal properties, productivity, and water use efficiency of cucumber under drip irrigation amount and plastic mulching in two growing environments. Atmospheric demand of the atmosphere was greater in the open field than in the polyhouse. Increasing drip irrigation water amount and plastic mulching increased soil water content in both growing environments. The polyhouse maintained consistent soil water content within the crop root zone during the growing cycle while the open field condition did not.

Plastic mulching increased soil temperature between 0.3°C and 1.0°C in the two soil layers only in the open field but no clear trend was observed due to mulching in the polyhouse. Decreasing irrigation water amount increased soil temperature in both soil layers in both growing environments. In general, the polyhouse increased soil temperature from vegetative growth stage to harvest.

Mulching minimized physiological stress as a result of negative diurnal changes in leaf temperature and the effect was more pronounced in the polyhouse. Polyhouse favored the growth of cucumber but limited pollination decreased the yield compared with open field. Nevertheless, plastic mulching increased cucumber yield traits and water use efficiency while irrigation amount four times a week gave the highest cucumber yield.

The combination of plastic mulching and irrigation amount four times a week and open field are recommended for the cultivation of this variety of cucumber in this region. Further studies are recommended for other varieties of cucumber such as self-pollinated type as well as evaluating artificial pollination options in the polyhouse.

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