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EFFECT OF DRIP IRRIGATION FREQUENCY, N-FERTILIZATION, AND MULCHING ON YIELD, NITROGEN, AND WATER USE EFFICIENCIES OF CUCUMBER (*Cucumis sativus* L.) IN IKOLE-EKITI, NIGERIA

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ABSTRACT

Soil moisture conservation, proper irrigation scheduling and nutrient management are crucial for sustainable cucumber production. A field experiment was set up over two years (2018 and 2019) to investigate the effects of irrigation frequency, black polyethylene mulching, and nitrogen fertilization on cucumber yield, water use efficiency (WUE) and nutrient use efficiency (NUE) at Ikole-Ekiti, Nigeria. The experiment was a 3 x 2 x 2 factorial in a randomized complete block design (RCBD) with a split-plot arrangement and the main plot as drip irrigation frequency: twice per week (I_4), three times per week (I_5), and four times per week (I_6), while the sub-plots were nitrogen fertilization; (no fertilizer, N_0 and 180 kg/ha urea, N_{180}) and mulching (no mulch, NM and mulch, M). The highest yield (8.39 and 8.51 t/ha) with the best WUE was obtained from treatment I_4MF (F, fertilization), while the lowest (5.81 and 5.79 t/ha) was obtained from I_6MF for the respective years. The combination of variables significantly (P<0.05) influenced cucumber yield, WUE, and NUE, and significant correlations were obtained (r=0.87** and 0.85**) between WUE and fruit yield for the study years. The treatment I_4MF therefore, could successfully be adopted to reduce water and fertilizer application for improved cucumber yield in the field.

Contribution/Originality: This study is one of very few studies to have investigated irrigation water use efficiency of cucumber, particularly in Ikole-Ekiti, and its N-fertilizer use efficiency by employing the ^{15}N isotopic technology of the International Atomic Energy Agency (IAEA) in Nigeria at large.

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1. INTRODUCTION

The best quality cucumber production depends on adequate moisture and soil nutrients as cucumber has a shallow, sparse root system (Randall & Locascio, 1988). It is suggested that reduced water application and proper fertilizer input with careful management for obtaining increased marketable cucumber yield can greatly contribute to water saving. There is also a need to preserve moisture in cucumber production fields in order to enhance water and nutrient utilization. There is also a need to formulate a irrigation scheduling that balances water and nutrient saving and yield improvement. Drip irrigation technology has been advocated to ensure the optimal use of water and nutrients for agriculture and improving irrigation efficiency (Awe, Fasina, Shittu, Jejelowo, & Oparemi, 2016).

There is a requirement for proper soil moisture conservation in cucumber fields to avoid moisture stress during the intense dry season when evapotranspiration is high. This is necessary as irrigation water scheduling is crucial to making the most efficient use of drip irrigation systems, because excessive irrigation decreases yield while insufficient irrigation causes water stress and reduces production (Awe et al., 2016). Tan, Fulton, and Nuttall (1983) reported that irrigation significantly increased cucumber yield compared to non-irrigation. Likewise, decrease in the irrigation rate below 100% pan evaporation also reduced the marketable yield of cucumber (Simşek, Tonkaz, Kaçıra, Çömlekçioğlu, & Doğan, 2005). It has been reported that cucumber has a high water consumption rate and that fruit yields were highest when adequate water was applied with increasing amounts of N fertilization.

One of the best ways in water management practice to increase water use efficiency (WUE) is mulching. Mulch is any protective material spread on the surface of soil to prevent and/or reduce solar radiation effects and evaporation. Mulch, when used in the field, moderates soil temperature and increases water infiltration during intense rain and conserves soil moisture (Khurshid, Iqbal, Arif, & Nawaz, 2006). Some studies have been conducted to study the effect of drip irrigation and mulch on yield improvement of many crops in different agro-ecological regions and under various soil conditions (Tomasz, Frąszczak, Kałużewicz, Krzesiński, & Lisiecka, 2010; Yaghi, Arslana, & Naoum, 2013). Higher yields were obtained with drip irrigation in some studies (Sivanappan, Rajagopal, & Paliniswami, 1974) and plant growth following mulching is often at least twice that on bare soil (Tomasz et al., 2010). Polyethylene mulching, in combination with drip irrigation and frequent injection of nutrients, can be used in irrigation systems (fertilization) to enhance water and nutrient use efficiency (Bowen & Frey, 2002). The beneficial influence of drip irrigation and fertilizer application on yield and water efficiency of cucumber cultivated in the field was reported by Awe et al. (2016).

Little or no work has been done in Nigeria on the combined effect of drip irrigation frequency, N fertilization, and mulching on the yield and growth of cucumber. The present investigation was conceived to determine the effects of drip irrigation frequency, N-fertilization, and polyethylene mulch on marketable fruit yield, nutrient use efficiency (NUE), and WUE of cucumber.

2. MATERIALS AND METHODS

2.1. Experimental Site

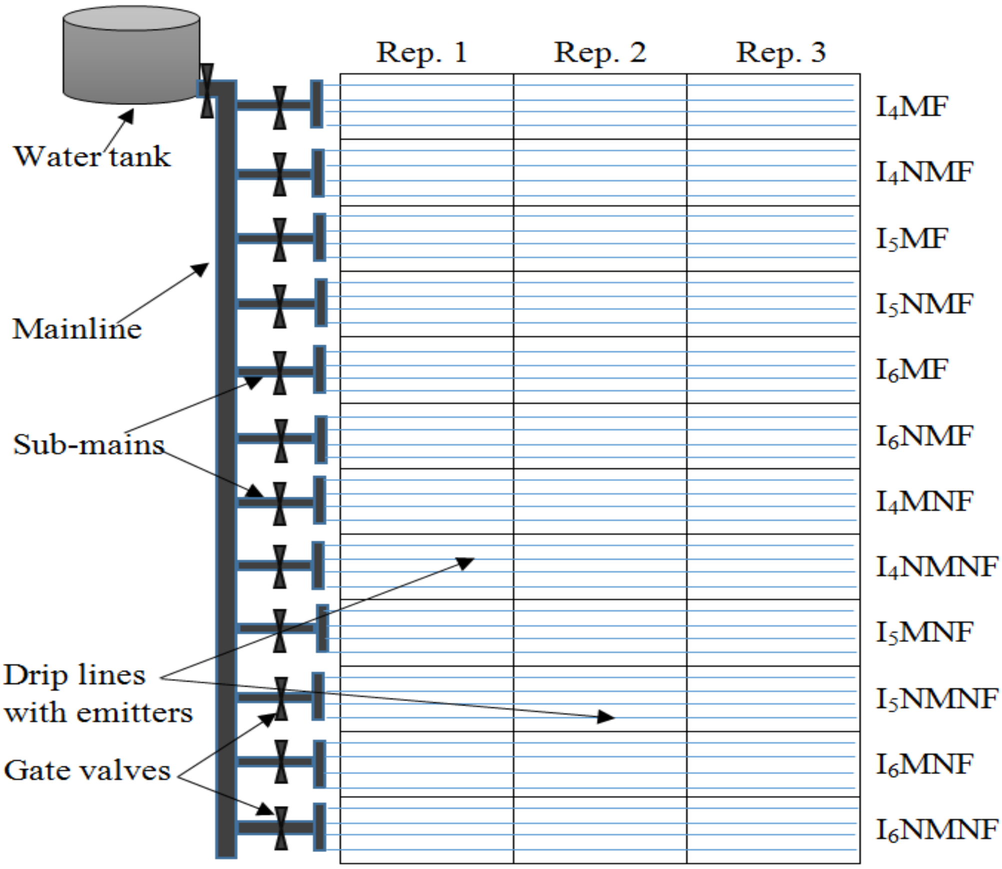
The field experiment was conducted between January and March, 2018 and 2019 at the Irrigation and Research Farm, Federal University Oye-Ekiti, Southwestern Nigeria. The site is located at longitude N 07° 48.357' and latitude E 05° 29.722'. It has a humid tropical climate characteristics with distinct dry and wet seasons and moderate mean annual rainfall of about 200 mm while temperature is almost uniform throughout the year with little deviation from a mean of was 27 °C. The soil at the study site belongs to the broad group of ultisols (Soil Survey Staff, 2014) with top sandy loam. The results for the physical and chemical properties of the top 0–15 cm of soil in the experimental plot before the commencement of the experiment are shown in Table 1; meteorological data on Ikole-Ekiti during the experimental period are given in Table 2. According to the cropping history of the land, it had been used previously for the cultivation of *Citrullus lunatus* (watermelon), *Cucumis sativus* L. (cucumber) and *Abelmoschus esculentus* (okra) for 5 years before commencement of the study.

2.2. Experimental Design and Treatment

The experiment was a three-factional lay out in a randomized complete block design (RCBD) with a split-plot arrangement and three replications. Irrigation constituted the main factor, with three different regimes: I_4, applied twice per week; I_5, applied three times per week; and I_6, applied four times per week. The sub-plot was N-fertilization: N_0, control (no fertilizer application) and N_{180}, 180 kg/ha N, in the form of urea. The third treatment was mulching (M, mulch and NM, no mulch).

2.3. Land Preparation, Field Layout, and Installation of Drip Irrigation System

The experimental site was prepared by plowing and harrowing, with unburied grasses properly removed to ensure a clean field. In the field layout there were three plots of 2 x 5 m in each of the 12 blocks, giving a total area of 360 m². The drip irrigation system adopted from Awe, Fasina, Shittu, and Omotoso (2017) consisted of a 3000-l tank, 25-mm main pipe, sub-mains end plugs, T-joint plugs, rubber hose, gum, gate valve, lateral cum drippers, and pipe nipples. The mainline delivered water from the tank to the sub-mains and further into the drip lines, while the emitters delivered water to the field at the rate of 4 l/h. The field and part of the drip irrigation set up are shown in Figure 1.



I_4, I_5, and I_6: irrigation frequency twice, thrice and four times per week;
F: fertilization at 180 kg/ha as urea; NF, no fertilizer;
M, mulch; NM, no mulch.

Figure-1. Installation of drip irrigation setup and field layout.

2.4.Sowing and Field Management

Cucumber seeds were sown on 19 and 23 January; 2018 and 2019, respectively, on the prepared plots. Two to three seeds of cucumber (variety Ashley) were sown at a spacing of 60 x 60 cm and sowing depth of about 5 cm. One week after sowing, excess seedlings were thinned to two plants per stand, giving a plant population of 55,555 /ha. The soil was irrigated to field capacity for crop emergence and establishment. After crop establishment, irrigation, mulch, and nitrogen fertilizer treatment were applied. The fertilizer treatment of 180 kg/ha N urea was applied by hand two weeks after sowing (WAS). Weed control was done manually three times, and other cultural practices including crop protection were also carried out.

2.5. Soil Sampling and Analysis

Prior to sowing and irrigation, soil samples were randomly collected from 0-15 cm depth from three representative locations and were mixed to obtain a composite sample, which was air-dried, ground with a mortar and pestle and passed through a 2-mm sieve for determination of soil physical and chemical properties. The IITA (1979) method of soil analysis was used for all soil properties.

2.6. Fruit Yield, WUE and NUE

Mature cucumber fruits were harvested periodically from an area 1 x 1 m from each plot prior to irrigation, and weighed with a sensitive scale. Total fruit yields were obtained from the sum of the various harvests and were then converted to kg/ha. Irrigation WUE recorded during the growing period was calculated according to the FAO (1982) equation below:

WUE (kg/ha/ mm) = fruit yield (kg/ha)/irrigation water (mm)

The IAEA (1971) method for measurement of ^{15}N in the field was adopted where the use of labelled material was employed as a tracer for quantitative determination of the fate of specific nutrient elements in a specific component or the whole soil–plant system. Samples were collected from the field and were sent to The National Center for Energy and Nuclear Science and Technology (CNESTEN) in Morocco for ^{15}N analysis. NUE or coefficient of utilization of the added fertilizer was determined according to IAEA (2001) using the formula:

NUE (%) = (amount of N in the fertilized plant/amount of N fertilizer applied) x 100.

2.7. Data Analysis

Data collected were subjected to statistical analysis of variance (ANOVA) and means were separated by Fisher's least significant difference (LSD) test at the 5% level of probability. Pearson correlation was carried out among yield, WUE and NUE. All analyses were performed using SPSS software (IBM version 2.0).

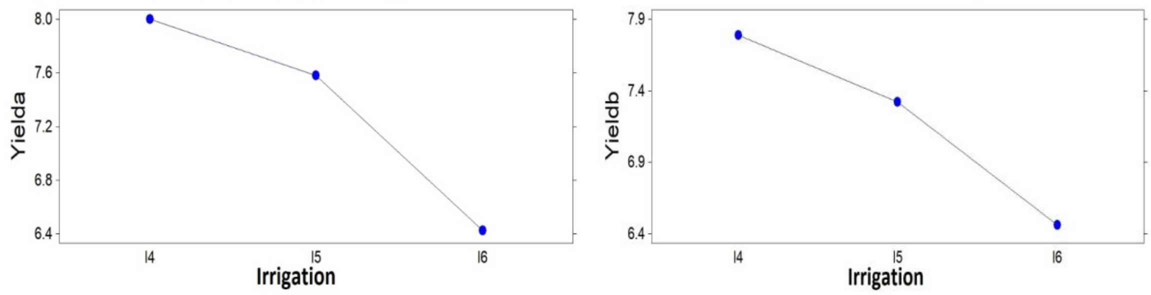
3. RESULTS AND DISCUSSION

3.1. Irrigation Water Applied

Before planting, 25 mm of irrigation water was applied to all treatments to bring the soil water content up to field capacity within 0–60 cm soil depth. The total amount of water applied to plants was 623.5 mm for treatment I_4, 779.4 mm for treatment I_5, and 935.3 mm for I_6 in both study years.

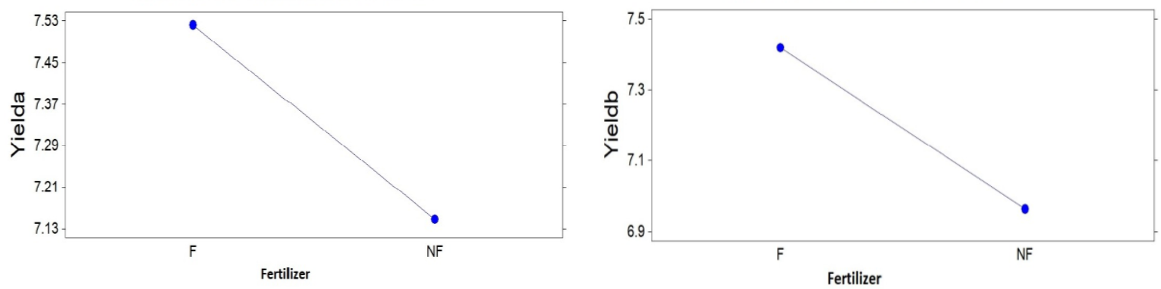
3.2. Effect of Drip Irrigation, N- Fertilization and Mulching on Cucumber Yield

The results of the effect of drip irrigation frequency, N-fertilization, and mulching on fresh yield are shown in Table 3 and Figures 2, 3, and 4. Irrigation frequency had a significant (P<0.05) effect on fruit yield for both planting seasons, but not fertilizer application and soil mulching. The highest marketable cucumber yield was obtained with the treatment combination of I_4MF for 2018 (8.39 t/ha) and 2019 (8.51 t/ha), while the lowest yield was obtained from treatment I_6MF (5.81 and 5.79 t/ha, respectively). It was observed that cucumber yield decreased with increased water application (Table 3). The trend of results obtained for fruit yield was consistent for both study years. Similar results was obtained by Tomasz et al. (2010), who found no significant difference in levels of total and marketable yields of fruits in both mulched and unmulched soils. Irrigation water application was better utilized on mulched than on unmulched land, with yield obtained from the former being higher. Other studies (Ibarra-Jiménez, Zermeño-González, Munguia-Lopez, Rosario Quezada-Martín, & De La Rosa-Ibarra, 2008) have all reported higher cucumber yields from plants cultivated in soil mulched with black polyethylene in comparison with those from plants cultivated in soil without mulching.



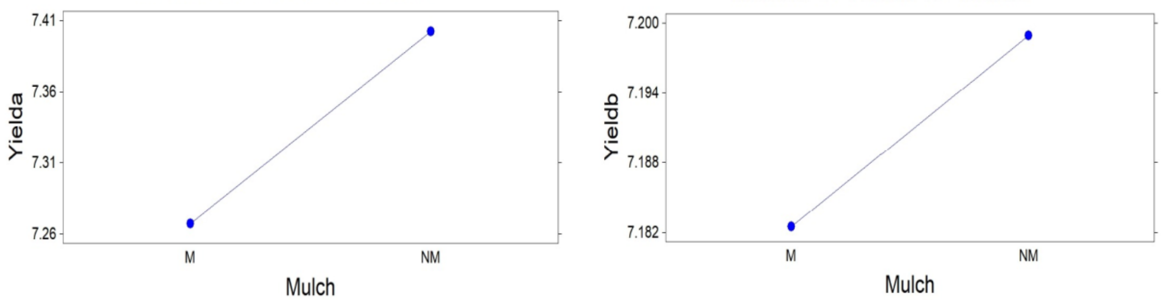
a) b)

Figure-2. Relationship between irrigation water (mm) applied and yield (t/ha) of cucumber for (a) 2018 and (b) 2019.



a) b)

Figure-3. Relationship between fertilizer application (kg/ha) and yield (t/ha) of cucumber for (a) 2018 and (b) 2019.



a) b)

Figure-4. Relationship between mulching and yield (t/ha) of cucumber for (a) 2018 and (b) 2019.

Table-1. Physiochemical properties of the soil of the experimental site.

pH	TOC	OM	TN	Avail. P	Ca	Mg	K	Na	Sand	Silt	Clay	Textural
(H_2O)	(%)			(mg/kg)	(cmol/kg)				(%)			Class
5.8	2.41	4.15	0.25	32.40	6.18	2.41	0.24	0.78	85.2	9.4	5.4	LS

Note: TOC: Total organic carbon; OM: organic matter; TN:total nitrogen; LS: loamy sand.

In this study, drip irrigation and mulching interaction was significant (P<0.05) with reference to cucumber yield (Table 3). Al-Omran and Louki (2011) concluded in their study that reduced irrigation (80% of crop evapotranspiration, ETc) was more effective for good marketable yield and water saving compared to 100% ETc. In that study, it was observed that irrigating cucumber with twice-weekly mulching gave better yield (Table 3). Statistically, irrigation and N-fertilizer application significantly influenced (P<0.05) average cucumber yield. The highest yield of cucumber (8.31 and 8.18 t/ha for the respective seasons) obtained from the application of 180 kg/ha u urea with watering twice per week (F + I_4) was significantly (P<0.05) different from all other treatments (Table 3 and Figure 2a, b). Similar results were obtained by Ayas and Demirtas (2009). The yield advantage obtained with drip irrigation in that study may be related to the fact that application of water and nutrients was more frequent and in close proximity to the shallow root system of the cucumber plants.

3.3. WUE, NUE, and Yield

WUE) and NUE were determined to evaluate the productivity of irrigation and nitrogen in the treatments. The results are presented in Table 3 and Figure 5a, b. The highest WUE, 13.45 and 13.66 kg/ha/mm in 2018 and 2019, respectively, was obtained from the combination of twice-weekly water application with mulching and fertilizer (I_4MF) while the lowest was from four-times weekly watering with mulching and fertilizer (I_4MF), for both seasons. Some researchers have also reported maximal WUE values for cucumber under reduced irrigation conditions (Abdul Hakkim & Jisha Chand, 2014; Hashem, Medany, Abd El- Moniem, & Abdallah, 2011; Kirnak & Demirtas, 2006). The results from the present study also confirmed that water productivity under a mulching/-water-saving strategy was higher under lower irrigation (I_4) than with full or excess water application. For the respective years, the highest WUE (13.45 and 13.66 kg/ha/mm) was obtained from I_4MF: in both years this consumed about 45 and 40% less water than I_5 and I_6, respectively, and also produced the best yield (8.39 and 8.51 t/ha). The lowest WUE (6.22 and 6.19 kg/ha/mm) realized for I_6 can be attributed to the fact that more excess water (four times weekly) was applied with this treatment than with the others (I_5 and I_4), and this actually affected the yield output of these treatments. Treatment I_4, which produced the highest yield (8.39 t/ha) was 59.08% greater than the lowest yield from I_6 with excess water. These results are also in agreement with those obtained by other researchers (Kirnak & Demirtas, 2006; Seyfi & Rashidi, 2007).

The correlation between WUE and yield was positive (r=0.87* and 0.85*) for both years of study (Table 4). This result showed that WUE was increased by reduced application of water, also corresponding to increase in marketable cucumber yield. Hence; it can be concluded that the treatment combination (I_4MF) efficiently improved WUE, and this is also consistent with results obtained by Wang and Xing (2016). The data analysis results obtained in Table 3 show that irrigation, mulching, and fertilization for all treatment combinations significantly (P<0.05) affected WUE. WUE with treatments I_4MF and I_4NMF was found to be significantly different from that of other treatments. In this study we have observed that WUE increased with decreasing levels of irrigation, irrespective of mulching (Table 3). The use of controlled irrigation allows plants to use water and nutrients efficiently and reduces nitrogen leaching. The results obtained in this study suggest WUE as a good criterion for evaluating the effectiveness of irrigation.

Table-2. Meteorological data of Ikole-Ekiti during the experimental period.

Year	Month	Rainfall (mm/day)	Wind speed (m/s)	Relative humidity (%)	Temperature (°C)
2018	January	0.05	1.55	48.52	23.53
	February	2.53	1.96	68.35	26.34
	March	1.18	2.39	72.69	27.15
	Mean	1.25	1.97	63.18	25.67
2019	January	0.42	1.60	64.32	24.91
	February	0.73	1.69	65.62	25.59
	March	0.89	2.10	73.07	27.16
	Mean	0.68	1.80	67.67	25.89

Source: National Aeronautics and Space Agency (NASA), 2019.

The relationship between irrigation water application (mm) and WUE (kg/m^3) represents a close linear form (Figure 5a, b) for both years of the study. The highest value of WUE was obtained at 13.35 and 13.66 kg/ha/mm with treatment I_4MF (twice-weekly water application with mulch and fertilizer) with water application at 623.5 mm, whereas the lowest value was obtained at 6.22 and 6.19 kg/ha/mm from treatment I_6MF (four-times weekly water application with mulch and fertilizer) with water at 935.3 mm. Other studies (Al-Omran & Louki, 2011; Zhang, Chi, Wang, Fang, & Fang, 2011) reported that reduced irrigation led to increased WUE.

Table-3. Effect of drip irrigation frequency, mulching, and N-fertilization on yield, NUE, and WUE of cucumber.

Treatment	Yield (t/ha)		NUE (%)		WUE (kg/ha/mm)	
	2018	**2019**	**2018**	**2019**	**2018**	**2019**
Irrigation						
I_4	7.99a	7.79a	74.98a	80.55a	12.83a	12.49a
I_5	7.58ab	7.32ab	59.21b	79.93ab	9.73b	9.39b
I_6	6.43b	6.46b	54.60b	61.77b	6.78c	6.83c
LSD $_{p<0.05}$	1.39	1.00	15.61	18.35	1.82	1.34
Fertilizer						
N_0	7.52	7.42	-	-	9.51	9.23
N_{180}	7.15	6.96	-	-	10.05	9.90
LSD $_{p<0.05}$	NS	NS	-	-	NS	NS
Mulch						
NM	7.40	7.19	65.30	74.14	9.78	9.47
M	7.27	7.13	60.56	74.02	9.78	9.67
LSD $_{p<0.05}$	NS	NS	NS	NS	NS	NS
Fertilizer + mulch						
NFM	7.49	7.34	-	-	10.04	9.83
NFNM	6.80	6.59	-	-	8.98	8.64
FNM	8.00	7.81	-	-	10.58	10.30
FM	7.04	7.02	-	-	9.52	9.51
LSD $_{p<0.05}$	NS	NS			NS	NS
Fertilizer + irrigation						
NFI_4	7.69ab	7.39ab	-	-	12.32ab	11.85a
NFI_5	7.79ab	7.42ab	-	-	9.99bc	9.52b
NFI_6	5.97b	6.08b	-	-	6.20d	6.33c
FI_4	8.31a	8.18a	-	-	13.33a	13.12a
FI_5	7.37ab	7.22ab	-	-	9.46cd	9.26b
FI_6	6.88ab	6.85ab	-	-	7.36d	7.32c
LSD $_{p<0.05}$	1.96	1.41	-	-	2.57	1.89
Mulch + irrigation						
NMI_4	7.91a	7.44a	82.92a	87.94a	12.68ab	11.93a
NMI_5	7.22ab	7.02ab	43.93c	85.82ab	9.27c	9.01bc
NMI_6	7.08ab	7.14a	54.84bc	74.04ab	7.39cd	7.46cd
MI_4	8.09a	8.14a	67.05ab	73.15ab	12.97a	13.05a
MI_5	7.94a	7.62a	74.49ab	63.08ab	10.19bc	9.78b
MI_6	5.77b	5.79b	54.37bc	60.45b	6.17d	6.19d
LSD $_{p<0.05}$	1.83	1.32	22.36	25.95	2.41	1.77
Irrigation + fertilizer + mulch						
I_4MF	8.39a	8.51a	82.92a	87.94a	13.45a	13.66a
I_5MF	6.92a	6.76abc	43.93d	74.04b	8.88b	8.68b
I_6MF	5.81bc	5.79c	54.84c	60.46c	6.22c	6.19c
I_4NMF	8.23a	7.85ab	67.05b	73.15b	13.20a	12.59a
I_5NMF	7.82a	6.68bc	74.49ab	85.83a	10.04ab	9.85b
I_6NMF	7.95a	7.90ab	54.37c	63.08bc	8.50b	8.45b
LSD $_{p<0.05}$	2.80	1.78	8.46	11.82	3.43	2.18

Note: F: fertilization at 180 kg/ha as urea, no fertilizer; M, mulch; NM, no mulch; means in a column followed by different letters differed significantly at the 5% level of probability by LSD test; NS, not significant.

Table-4. Correlation matrix between yield, WUE, and NUE of cucumber.

Parameter	NUE_a	NUE_b	WUE_a	WUE_b	$Yield_a$	$Yield_b$
NUE_a	-					
NUE_b	0.9306	-				
WUE_a	0.3433	0.3433	-			
WUE_b	0.2142	0.4243	0.9683	-		
$Yield_a$	-0.0347	0.2921	0.8658**	0.7947*	-	
$Yield_b$	0.0559	0.6271	0.8428*	0.8502*	0.9491	-

Note: $_a$ and $_b$, 2018 and 2019 season, respectively.

Optimal NUE (82.92 and 87.94%) was also obtained with I_4MF treatment. This means that, with the right quantity of irrigation water applied, cucumber can make effective use of the nutrients applied in the field. The reason for the low NUE value obtained from I_6MF treatment (54.84 and 60.46%) is probably due to the effect of excess water (935.3 mm) applied which may have leached some of the applied nutrient from the soil leading to significant differences (*P*<0.05) in NUE obtained for the different treatment combinations; this trend was also similar to that of WUE (Table 3).

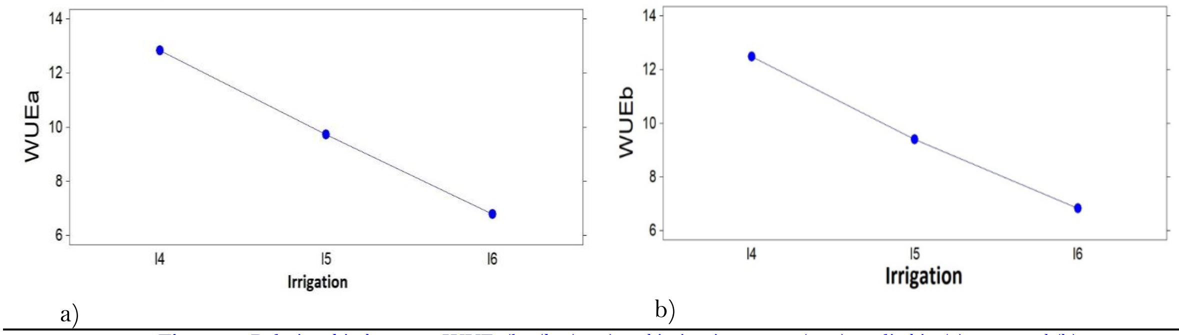


Figure-5. Relationship between WUE; (kg/ha/mm) and irrigation water (mm) applied in (a) 2018 and (b) 2019.

4. CONCLUSION

Increasing water demand and scarcity have prompted the optimization of irrigation water use for higher-yield output. The treatment I_4MF resulted in higher cucumber yields, the optimal WUE and NUE with lowest values obtained in treatments with higher irrigation frequency (I_6) for the respective seasons. The results further confirmed the efficiency of the drip irrigation system, supplying water and nutrients in close proximity to the root zone. However, lower irrigation frequency should be investigated in regards to optimal irrigation quantity as indicated in this work.

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