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Full Length Research Paper

Effect of irrigation and nitrogen on yield, yield components and water use efficiency of eggplant

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The effects of irrigation interval and nitrogen fertilizer on eggplant (*Solanum melongena* L.) in a field trial at Astaneh Ashrafiyeh, Guilan, Iran during 2009 were studied. Experiment was conducted in split plot based on randomized complete block design with three replications. Irrigation levels were the main-plots consist of three irrigation intervals (no irrigation, 6 days interval and 12 days interval). Nitrogen fertilization which included four levels (0, 60, 120 and 180 kg ha^{-1}) was assigned to sub-plots. The results of this study show that among irrigation treatments, the highest amounts of all studied traits of eggplant included plant height, fruit length, fruit diameter, number of leave per m^2, number of fruit per m^2, water use efficiency (WUE) and fruit yield were observed in 6 days interval irrigation with total water use of 441 (mm). On the other hand, water stress resulted in significant decreases in these characteristics. Results also illustrated that plants that received 120 kg N ha^{-1} produced the highest fruit yield and yield-determining traits than those in the control treatment. In addition, regarding the interaction effects between irrigation intervals and nitrogen fertilizer, it could be concluded that irrigation of eggplants every 6 days and application of 120 kg N ha^{-1} resulted in the highest yield and yield attributes. In addition, results of interaction effects comparison indicated that WUE varied from 4.36 to 11.6 kg m^{-3} and the highest amount of WUE was recorded in plants irrigated every 6 days and received 120 kg nitrogen per hectare.

Key words: Eggplant, fertilizer, Iran, irrigation interval.

INTRODUCTION

Existing water resources are at risk of near depletion and being heavily degraded. It should further be noted that there are strong evidences for climate change which would result in even further decrease of annual rainfall year by year (Kimura, 2007).Drought stress (water deficit or low water availability) is a major problem that widely distributed worldwide over 1.2 billion ha in rain fed agricultural land (Passioura, 2007). These reasons emphasize on developing methods of irrigation that minimize water use or maximize the water use efficiency. This has led to irrigation scheduling which is conventionally aimed to achieve an optimum water supply for productivity, with soil water content being maintained close to field capacity (Boamah et al., 2011).

Plant reactions are affected by the amount of soil water directly or indirectly. All physiological processes like photosynthesis, transpiration, cell turgidity, cell and tissue growth in plants are directly affected by water availability (Reddi and Reddi, 1995; Sarker et al., 2005). Yield losses up to 60 to100% are reported due to long spell of drought stress in different crop species (Singh et al., 2002).

Drainage and evaporation play an important part in water loss. It is clear that much of the water used in plant irrigation is lost due to transpiration alone (Mengel and Kirkby, 1987). Therefore, it is suggested to find ways by which available water could be economically utilized. One way to achieve this goal is to reduce the transpiration rate; consequently, irrigation water could be minimized substantially (Bafeel and Moftah, 2008).

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To achieve high yield, an adequate water supply is required during the growing season. The period at the beginning of the flowering stage is most sensitive to water shortage, while maximum yield was obtained with full irrigation; almost the maximum yield was generally obtained when irrigation was made to provide adequate water during flowering and fruit formation periods (Blum, 2005).

Kirnak et al. (2001) evaluated the effects of irrigation regime (100, 80, 60 and 40% of pot capacity (PC)) on eggplant and concluded that water stress resulted in significant decreases in chlorophyll content, leaf relative water content (LRWC) and vegetative growth. Severe water stress (40% of PC) slightly reduced plant height, stem diameter, total dry weight, and relative leaf expansion rate. They also concluded that the plants grown under severe water stress had less fruit yield and quality than those in the control treatment.

Abd El-Aal et al. (2008) investigated the effects of irrigation interval (irrigation at 10 and 21 days intervals) on eggplant traits and found that the better vigor plant growth, the heavier total yield and the better physical and chemical properties of fruits were recorded when eggplant was irrigated at 10 days intervals.

Candido et al. (1999) found that water application positively influenced tomato productivity. The supplementary irrigation increased 284% of the marketable yield, and this value reached 578 and 1327% with the 50 and 100% of maximum crop evapotranspiration replenished.

Randall and Locasio (1988) reported that fruit yield of cucumber reduced due to decreasing amounts of water applied.

Plant nutrition is one of the most important factors that increase plant production. Nitrogen is one of the major elements for plants growth and development that has an important role in plant nutrition and therefore is the yield-limiting factor for plant growth in many areas especially in low organic soils (NajafvaandDirekvandi et al., 2008). Moreover, nitrogen is the main constituent of all amino acids in proteins and lipids acting as structural compounds of the chloroplast (Basela and Mahadeen, 2008).

Under dry land conditions, soil moisture often limits yield. Nitrogen only increase yield to the extent limits imposed by the moisture supply. Increased moisture supply increased the yield potential of the crop and increased the amount of N required for optimum yield (Grant and Bailey, 1993).

Rosati et al. (2001) indicated that by increasing nitrogen supply, leaf area index, light interception and dry matter production of eggplant increased. Akbari et al. (2003) also found that N fertilizer influenced leaf number per plant, plant height, fruit number per plant, fruit mean weight, and total yield per plant in tomato crops. Karic et al. (2005) applied four nitrogen levels (0, 50, 100, and 200 kg N ha^{-1}) to leek culture and observed that the application of 200 kg N ha^{-1} resulted in the highest number of leaves per plant. Pal et al. (2002) reported that eggplant fruit yield increased with increase in N up to187.5 kg N ha^{-1}. Sat and Saimbhi (2003) observed that increasing the nitrogen significantly delayed flowering of eggplant and increased the number of days taken to fruit setting of eggplant. Akanbi et al. (2007) reported that nitrogen fertilizer affected seed number, fruit pH, crude protein, total solid and ascorbic acid of eggplant and nitrogen deficiencies reduced both physical and chemical properties. Wange and Kale (2004) observed significant improvement in plant height, number of leaves and fruit yield of eggplant over recommended rate of nitrogen fertilizer. Devi et al. (2002) found better fruit girth, fruit weight and fruit yield of eggplant with the application of 120 kg nitrogen per hectare. Aminifard et al. (2010) evaluated the effect of four rates of nitrogen fertilizer on growth and yield of eggplant and found that plant height, lateral stem number, leaf chlorophyll content, flower number, fruit weight and fruit yield were all affected by nitrogen fertilizer. They also observed that nitrogen fertilizer affected flower number and the days to first flowering.

This study aimed to evaluate the effect of irrigation intervals and nitrogen fertilization on the yield, yield attributes and WUE of eggplant (*Solanum melongena* L.).

MATERIALS AND METHODS

This experiment was conducted at the experimental field at Astaneh Ashrafiyeh, Guilan province, Iran (37° 16′ N, 49 56′ E; 3 m above sea level) in 2009 growing season. Mean precipitation during growing season was 166 mm. The experiment was performed as split plot randomized complete block design with three replications. The treatments comprised of three irrigation intervals (no irrigation or rain fed, 6 days interval and 12 days interval) in main plots and four levels of N fertilizer (0, 60, 120 and 180 kg ha^{-1}) in sub plots. The soil texture of experimental site was loam with pH = 7.5. The meteorological data and soil characteristics of experimental site are presented in Tables 1 and 2, respectively. The experimental plots consisted of 4 rows, each of 4 m length and 80 cm apart, and 50 cm between plants. Sowing was performed in April 2009. Irrigation method in this experiment was furrow irrigation and required water for irrigation provided from precipitation and irrigation. In plots irrigated at 6 and 12 days interval, irrigation was carried out 4 and 8 times with 441 and 242 mm total irrigation water through growing season, respectively.

To measuring the total fruit yield, mature fruits of eggplant in two centre rows of each experimental plot were hand-harvested 7 times and then weighted using digital balance. Furthermore, at the end of growing season, eggplant traits such as plant height, leave number per m^{-2}, fruit number per m^{-2}, length and diameter of fruit were measured.

WUE was calculated as described by the equation of Wright et al. (1996) as follows:

$$WUE = [\text{total yield (kg)}] / [\text{water used } (m^3)] \times 100$$

The data collected were statically analyzed for variance using MSTAT-C software. The means were compared by applying

Table1. Some meteorological data of region during the growing season.

Month	Evaporation from pan (mm day^{-1})	Min. R. H (%)	Max. R. H (%)	Average wind speed (m s^{-1})	Rainfall (mm)	Average sunshine duration (h)	Min. temp (°C)	Max. temp (°C)
April	2.0	63.4	94.8	1.0	45.5	4.5	12.3	21.7
May	4.1	58.9	92.0	1.2	39.5	6.5	17.3	27.3
June	6.3	49.0	85.9	0.9	0	8.5	20	41.9
July	2.5	66.9	93.4	0.3	70	9.3	18.8	29.5
August	3.4	63.8	91.3	0.9	11	4.4	18.5	28.4

Table 2. Physical and chemical characteristics of soil.

EC (ds m-^{1})	O. C (%)	Total N (%)	Available P (ppm)	Available K (ppm)	Clay (%)	Silt (%)	Sand (%)	Depth (cm)
0.631	0.68	0.084	0.07	239	19	32	49	0 - 20
0.656	0.66	0.065	2.17	191	19	32	49	20 - 40

Table 3. Analysis of variance of selected parameters of eggplant as affected by irrigation and N fertilizer treatments.

SOV	df	Fruit yield	Plant height	Leaf number (m^{-2})	Fruit number (m^{-2})	Fruit length	Fruit diameter	WUE
Irrigation (A)	2	1562.3**	1413.51**	3616.02**	14.58*	504.82**	8.15**	24.74**
Error (A)	4	3.845	8.161	13.99	2.08	1.06	0.06	0.35
N fertilizer (B)	3	306.15**	374.27**	453.95**	6.94*	54. 76**	0.739**	26. 06**
Interaction (A×B)	6	146.01**	95.57 **	162.84**	0.69ns	12.79**	0.098 ns	7.05**
Error (B)	18	1.098	1.114	2.574	2.08	0.88	0.053	0.136
CV (%)		4.81	1.05	1.74	9.12	4.65	5.54	5.05

Ns = Non significant; * and ** = Significant at 5% and 1% probability level, respectively.

Duncan Multiple Range Test at P≤0.05. Correlation coefficient between yield and yield-determining parameters was determined using the SPSS software. STATISTICA5.5 software was used for calculating the production function coefficients.

RESULTS AND DISCUSSION

Fruit yield

Data cited in Table 3 shows a significant effect of irrigation and nitrogen fertilizer on the fruit yield of eggplant. The yield of plants that were irrigated every 6 days was 150% higher than plants that were not irrigated (Figure 1). Abd El-Aal et al. (2008) also found similar results and reported that better fruit yield was obtained when eggplant was irrigated at shorter period. In addition, Salisbury and Ross (1992) reported that low water availability adversely affects hormonal balance, plant development and assimilate translocation. In the case of the effect of nitrogen levels on fruit yield, results of mean comparisons (Figure 2) show that the highest value (27.62 ton ha^{-1}) was obtained from the application of 120 kg N ha^{-1}, while the lowest value (14.82 ton ha^{-1}) was related to the lack of nitrogen application. The positive effect of nitrogen on yield might be due to the stimulating effect of nitrogen on the vegetative growth characters which form the base for flowering and fruiting (Aminifard et al., 2010). Similar results have been reported in experiments on eggplant conducted by Pal et al. (2002) and Devi et al. (2002). Interaction effect between irrigation and nitrogen fertilizer treatments on fruit yield was significant (Table 5). Among all treatments, irrigation in 6 days interval and application of 120 kg N ha^{-1} had the highest fruit yield (51.12 ton ha^{-1}). These results coincide with that obtained by Aujla et al. (2007) who found that fruit yield of eggplant had a positive response to the increase of nitrogen fertilizer under different irrigation levels.

Plant height

Results presented in Table 3 indicate that irrigation and nitrogen fertilizer significantly affected the plant height of

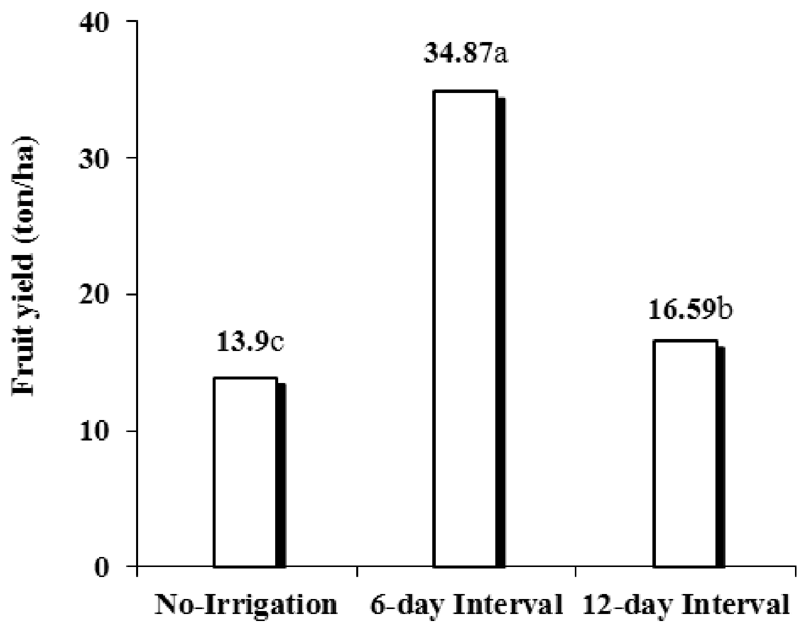

Figure 1. Fruit yield of eggplant under irrigation regimes.

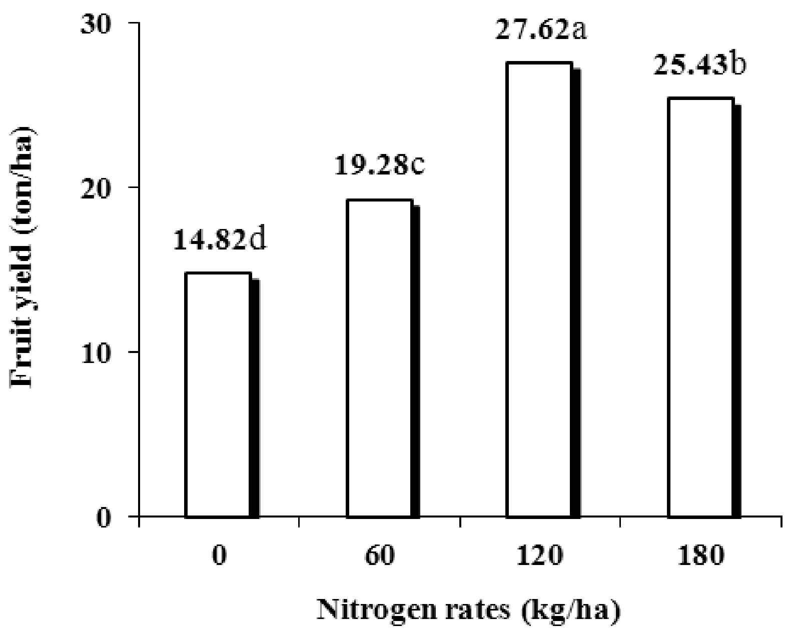

Figure 2. Fruit yield of eggplant under nitrogen rates.

eggplant. Among irrigation regimes, the highest plant height was observed (produced) in 6 days interval and was 6.3% higher compared with no-irrigation treatment (Table 4). Kirnak et al. (2001) also concluded that drought stress resulted in more significant reduction in plant height of eggplant than control treatment. Moreover, it was noticed that the highest plant height was recorded with plants which received 120 kg N ha^{-1}, and eggplants that did not receive nitrogen fertilizer had the lowest value (Table 4). Pervez et al. (2004) noted that soil nutrients are very important for the plants height. Wange and Kale (2004) and Aminifard et al. (2010) also reported significant improvement in plant height of eggplant due to the application of nitrogen fertilizer. The interaction effects between irrigation interval and N fertilizer on the height of eggplant were statistically significant at 0.05 probability

Table 4. Mean comparison of the main effects of irrigation and N fertilizer treatments on selected parameters of eggplant.

Treatment	Plant height (cm)	Leaf number (m^{-2})	Fruit Number (m^{-2})	Fruit Length (cm)	Fruit diameter (cm)	WUE (kg m^{-3})
Irrigation						
No irrigation	91.4 ^{c}	81.25^{b}	15.4^{b}	14.3^{c}	3.4^{c}	8.35^{a}
6 days interval	112.4^{a}	112^{a}	17.1^{a}	27.1^{a}	5.5^{a}	7.92^{a}
12 days interval	97.2^{b}	82.67^{b}	15^{b}	19.0^{b}	3.9^{b}	5.68^{b}
Nitrogen fertilizer						
No fertilization	92.3^{c}	82.4^{c}	14.7^{b}	17.3^{d}	3.7^{c}	5.31^{c}
60 kg N ha^{-1}	98^{b}	90.6^{b}	15.5^{ab}	19.0^{c}	4.0^{b}	6.51^{b}
120 kg N ha^{-1}	105.9^{a}	97.1^{a}	16.3^{a}	22.7^{a}	4.3^{a}	8.71^{a}
180 kg N ha^{-1}	105.2^{a}	97.6^{a}	16.6^{a}	21.6^{b}	4.3^{a}	8.75^{a}

Mean followed by similar letters superscripted in each column, are not significantly different at the 5% level.

Table 5. Mean comparisons of interaction (irrigation ×N fertilizer) effects on fruit yield, plant height, leave number per m^2, fruit length and WUE of eggplant.

Treatment (kg N ha^{-1})		Fruit yield (ton ha^{-1})	Plant height (cm)	Leaf number (m^{-2})	Fruit length (cm)	WUE (kg m^{-3})
No irrigation	No fertilization	11.13^{g}	87.4^{i}	78^{i}	13.0^{h}	6.70^{de}
	60	12.14^{g}	89.2^{i}	79h^{i}	13.8^{gh}	7.30^{d}
	120	14.24^{f}	93.7g^{h}	83^{fg}	14.2^{gh}	8.56^{c}
	180	18.09^{d}	95.4^{fg}	85^{ef}	16.2^{ef}	10.87^{b}
6-day interval	No fertilization	19.13^{d}	96.3^{f}	90.3^{d}	23.8^{c}	4.36^{i}
	60	29.83^{c}	109.1^{c}	112^{c}	25.7^{b}	6.76^{de}
	120	51.12^{a}	125.6^{a}	124.7^{a}	32.4^{a}	11.60^{a}
	180	39.41^{b}	118.7^{b}	121^{b}	26.6^{b}	8.96^{c}
12-day interval	No fertilization	14.20^{f}	93.2^{h}	79^{hi}	15.0^{fg}	4.86^{hi}
	60	15.89^{ef}	95.7^{f}	81^{gh}	17.5^{e}	5.46^{gh}
	120	17.49^{de}	98.3^{e}	83.6fg	21.5^{d}	5.96^{fg}
	180	18.78^{d}	101.5^{d}	87^{e}	22^{d}	6.43^{ef}

Mean followed by similar letters superscripted in each column, are not significantly different at the 5% level.

level as shown in Table 3. It was clear from data in Table 5 that the tallest plants (125.6 cm) were observed in plots irrigated at 6 days interval and fertilized by 120 kg N ha^{-1}.

Number of leaves per m^2

Data shown in Table 3 indicates that the numbers of leaves per m^2 were significantly influenced by different irrigation intervals. It is obvious that irrigation at shorter period that is 6 days interval resulted in obtaining the highest value (112 leaves per m^2). On the contrary, the lowest value (81.25 leaves per m^2) was observed in no irrigation treatment (Table 4). However, the difference between it and 12 days interval did not reach the level of significance. The results obtained are in good harmony with those of Byari and Rabighis (1996) who found that the increasing of irrigation frequency caused an increase in number of leaves of eggplant. The statistical analysis of the data obtained in Table 3 showed that the differences among nitrogen rates regarding the number of leaves per m^2 were significant at 1% level. The data presented in Table 4 clearly indicates that by increasing N rate, the number of leaves per m^2 gradually increased

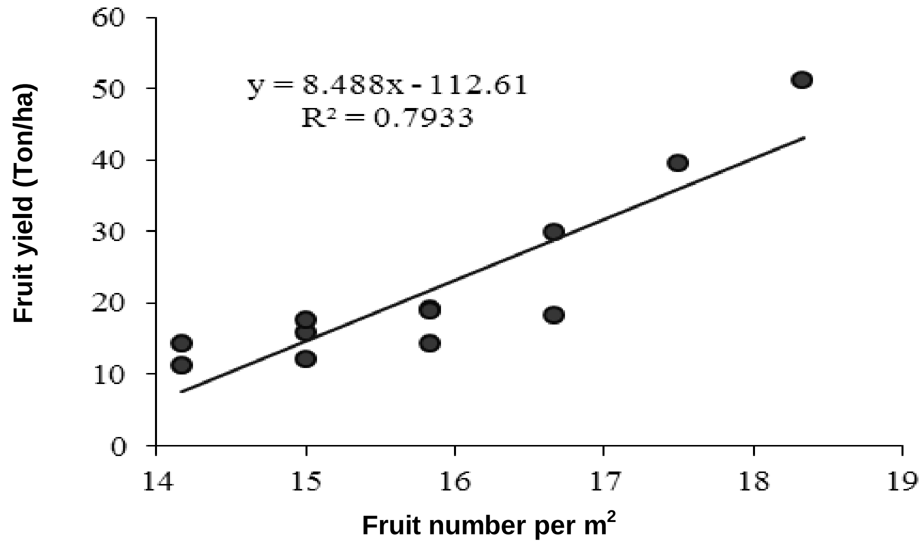

Figure 3. The relationship between the number of fruit per square meter and fruit yield.

to reach its highest value, while, the difference between application of 120 and 180 kg N ha^{-1} was not statistically significant. These results are in conformity with the findings of Wange and Kale (2004) and Oloniruha (2009). The effects of interaction between irrigation intervals and nitrogen levels were significant regarding its effects on the number of leaves per m^2 as shown in Table 3. It could be concluded that the highest value was recorded in plants irrigated at shorter interval (6 days) and supplied 120 kg N ha^{-1} followed by 6 days interval and 180 kg N ha^{-1}. The lowest value was found in no irrigation and without nitrogen application (Table 5). This might be due to the availability of nitrogen and could be due to the improvement of soil water holding capacity (Roe and Cornforth, 2000).

Fruit number per m^2

The statistical analysis of the obtained data indicated the differences of the effects of irrigation and nitrogen fertilizer treatments on fruit number per m^2 were significant at 5% level. Data presented in Table 4 reveals that among irrigation interval treatments, the highest amount of this parameter (17.1) was recorded from 6 days interval. Bafeel and Moftah, (2008) suggested that the negative effect of drought stress on the yield and its components may be related to the decrease in vegetative growth. Chartzoulakis and Drosos (1997) found that fruit number per plant in pepper was affected by the amount of water applied. Fruit number per m^2 had a significant and positive correlation with fruit yield as shown in Figure 3. Similar results were obtained by Hidaytullah et al. (2008) in tomato. Our results also showed that by increasing nitrogen fertilizer level, fruit number per m^2 increased to reach its highest level (Table 4). Similar results have been reported in investigations conducted by Aujla et al. (2007).

Fruit length and fruit diameter

Fruit length and fruit diameter were significantly affected ($p \leq 0.01$) by irrigation and N fertilizer treatments applied as shown in Table 3. At 6 days interval treatment, fruit length and fruit diameter were increased by 27.1% and 5.5% compared with the no-irrigation treatment, respectively (Table 4). The findings obtained by Abd El-Aal et al. (2008) support our results.

In the case of fertilizer treatment, results obtained (Table 4) indicated that the highest values of fruit length (22.7 cm) and fruit diameter (4.3 cm) were recorded from application of 120 kg N ha^{-1}. Aujla et al. (2007) also found that increasing the rate of N fertilizers increased the fruit size of eggplants. Data on Table 3 exhibits that the interaction between irrigation intervals and N application had a significant effect ($p \leq 0.01$) on the fruit length; however, the interaction effects between these two factors were not significant in the case of fruit diameter. The highest value of fruit length (32.4 cm) was obtained in plants that received 120 kg N ha^{-1}. Moreover, significant correlations ($p \leq 0.01$) were obtained between fruit diameter and yield or fruit length and yield presented in Figures 4 and 5, respectively.

Water use efficiency (WUE)

Experimental treatments affected WUE of eggplant significantly at 5% probability level (Table 3). The best

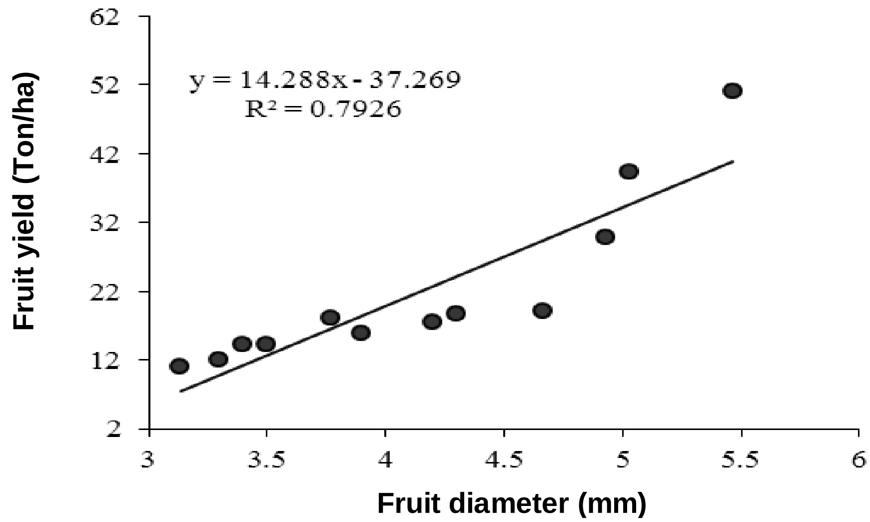

Figure 4. The relationship between the fruit diameter and fruit yield.

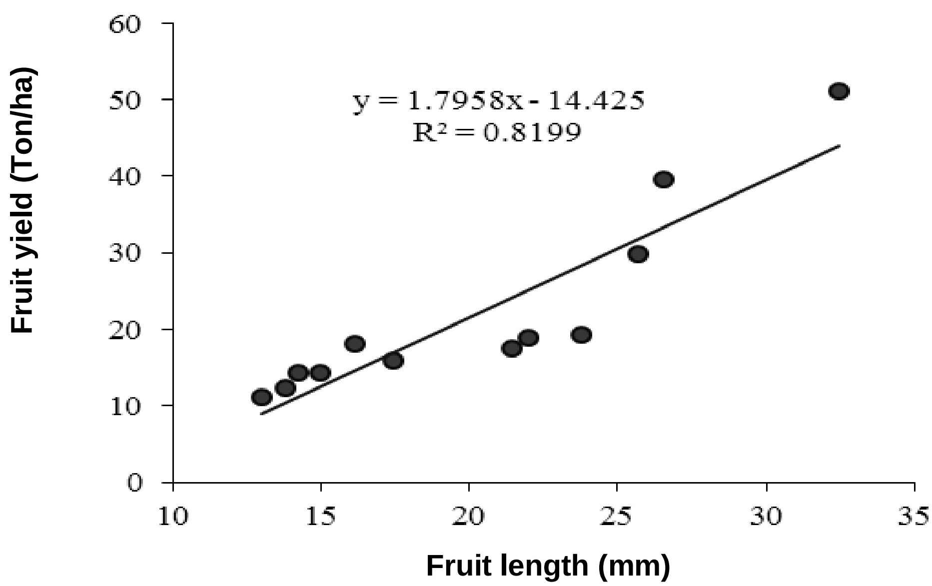

Figure 5. The relationship between the fruit length and fruit yield

treatment towards the WUE of eggplant was no-irrigation (rain fed) treatment which produced WUE of 8.35 kg m^{-3}; however, the difference between it and 6 days interval was not statistically significant. The 12 days interval treatment showed the lowest WUE of 5.8 kg m^{-3} among the three irrigation treatments (Table 4). Teare et al. (1973) stated that plants grown under optimum conditions may use water efficiently but high yielding crops may range widely in WUE and these variations may be due to the differences in irrigation methods. Aujla et al. (2007) examined the effects of irrigation and N on eggplant and reported the maximum WUE of 11.99 kg m^{-3} and concluded that the improvement of WUE could be due to the increase of crop yield. Results presented in Table 4 indicate that among fertilizer treatments, the highest value of WUE was related to application of 120 kg N ha^{-1} which produced WUE of 8.71 kg m^{-3}. The lowest value (5.31 kg m^{-3}) was observed in without N fertilizer treatment. Interaction effect between irrigation and fertilezer treatments had a significant influence ($p \leq 0.01$) on WUE of eggplant, as appears in Table 3. Among all treatments, irrigation in 6 days interval and application of 120 kg N ha^{-1} had the highest value (Table 5). The results of this study generally agreed with the observations of

Table 6. Simple correlation coefficients between yield and yield-determining traits.

Trait	Plant height	Leaf number (m^{-2})	Fruit number (m^{-2})	Fruit length	Fruit diameter	Fruit yield	WUE
Plant height	1						
Leaves number (m^{-2})	0.949**	1					
Fruit number (m^{-2})	0.671**	0.718**	1				
Fruit length	0.673**	0.768**	0.598**	1			
Fruit diameter	0.678**	0.779**	0.673**	0.970**	1		
Fruit yield	0.724**	0.845**	0.664**	0.900**	0.869**	1	
WUE	0.375*	0.430**	0.562**	0.299	0.279	0.588**	1

* and ** significant at p ≤ 0.05 and 0.01, respectively.

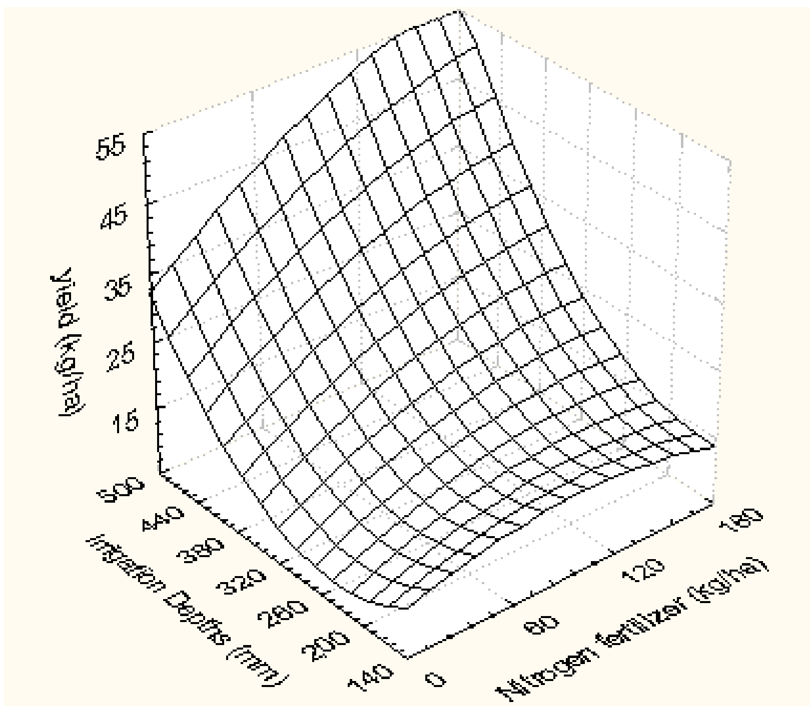

Figure 6. Relationship of irrigation depths and nitrogen fertilizer on fruit yield

Olsen et al. (1964) that reported that N fertilization increases WUE on N-deficient soils where water is adequate.

Regarding the correlation coefficients between yield and its components, it is obvious that correlation between fruit yield and its attributes were significant at 1% probability level (Table 6). The highest correlation coefficients were observed between fruit length (R^2 = 0.90) and fruit diameter (R^2 = 0.87) with fruit yield. Tiwari and Upadhyay (2011) found a positive correlation between fruit yield and fruit diameter in tomato. Ertek et al. (2007) also reported that fruit length of green pepper (*Capsicum annuum* L.) had a positive correlation with fruit yield. They concluded that increase in fruit length increased fruit yield more than that of in fruit diameter. In our experiment, similar result was obtained. WUE was positively and significantly correlated with fruit yield (R^2 = 0.59). By contrast, WUE did not show significant association with fruit size (fruit length and fruit diameter).

Yield function

Figures 6 and 7 show the relationships between amounts of irrigation water totally supplied and N fertilizer on fruit yield and WUE, respectively. Water-fertilizer production

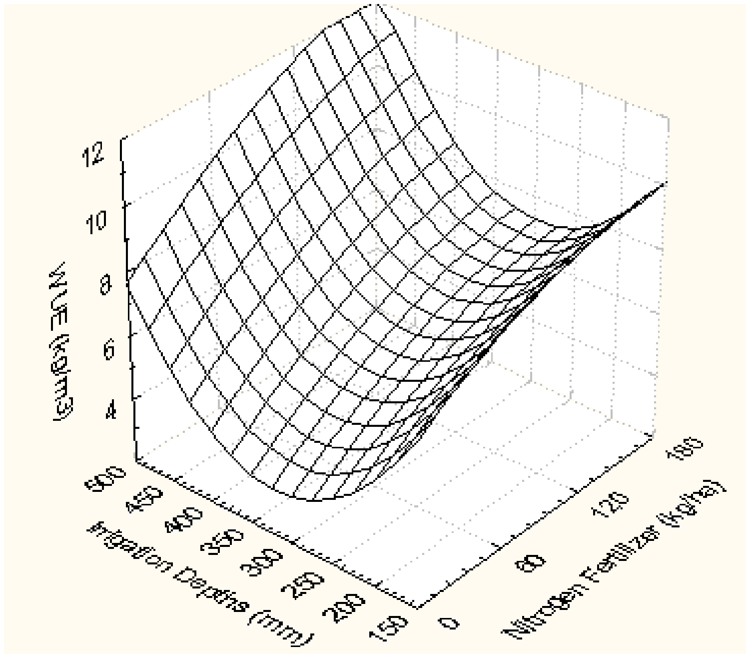

Figure 7. Relationship of irrigation depths and nitrogen fertilizer on water use efficiency (WUE).

function is presented as follows:

$$Y = 30.581 + 0.039N - 0.181I - 0.0004619N^2 + 0.00037NI + 0.0003695I^2$$

$$WUE = 16.994 + 0.025N + 0.025I - 0.00008025N^2 + 0.00003303NI + 0.0001318I^2$$

Where, Y = Fruit yield (ton ha^{-1}); WUE = water use efficiency (kg m^{-3}); I = applied water and N = applied N fertilizer (kg N ha^{-1}).

Influence of irrigation on fruit yield was found significant and higher than the influence of N fertilization. No increase was observed in fruit yield of eggplant over the application of 450 mm irrigation water during growing season.

In all irrigation water used, application of N rate over the 120 kg ha^{-1} had no significant influence on fruit yield and WUE of eggplant. Thus, the optimum rate of irrigation interval and N fertilizer under conditions of this study is 6 days interval and application of 120 kg N ha^{-1}.

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