**The Effect of Different Levels of Irrigation and Nitrogen Fertilizer on Onions Yield and Efficiency, and Determination of Production Function**

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**Abstract**

The effect of different levels of irrigation, nitrogen fertilizer and irrigation methods on the yield and yield components of onions was examined using a split plot factorial experiment conducted in the form of a randomized complete block design with three replications and for two years, at a research field in Zahak. Seedlings were planted in 2015 and 2016 and irrigation was carried out in the following forms: surface furrow irrigation, surface drip irrigation and subsurface drip irrigation. To determine the optimized depth of water and fertilizer, the best function of onion production was selected from four production functions (linear, logarithmic, quadratic and transcendental) for all three irrigation methods. The results showed that the effect of amount of irrigation water, nitrogen fertilizer and irrigation method on the parameters measured was significant at 1% probability level. There was no significant effect of the planting year on the measured parameters. The highest yield and efficiency level was obtained from the subsurface drip irrigation system (28.42 t / ha and 5.9 kg / m³ / ha) and the lowest level was obtained from surface furrow irrigation (19 t ha-2 and 2.33 kg / m³/ ha). A reduction in the amount of nitrogen fertilizer to less than the plant requirement caused significant reduction in the yield of bulb and efficiency of onions. The highest yield and efficiency was observed in 100% nitrogen fertilizer treatment (31.59 t / ha and 4.75 kg / m³ / ha) and the lowest was in 25% nitrogen fertilizer treatment (16.12 t / ha and 2.67 kg / m³/ha). The effect of irrigation water on onion bulb yield and efficiency showed that a reduction in the depth of irrigation water to less than the plant water requirement caused a reduction in yield and corresponding increase in efficiency, but in this regard, no significant effect was observed between 100% of the plant water requirement and 75% the plant water requirement treatments. In all three irrigation methods, the quadratic function was selected as the superior production function. Therefore, according to the obtained results and lack of water in the region, irrigation of this plant can be done with 75% of the plant's water requirement, without having a significant effect on the production yield, and the storage water can be used elsewhere. Also, due to the high production potential in subsurface drip irrigation and reduction of evapotranspiration this irrigation method was used to plant onions in the region and it is the best treatment for the use of 100% nitrogen fertilizer, especially under water stress conditions.

**Keywords:** Subsurface Drip Irrigation; Onion Bulb; Efficiency; Yield Components

**1. Introduction**

Onion is one of the oldest vegetables in Iran, which has had a long history of oral and medicinal intake. Some scholars attribute its origins to Iran and Afghanistan. According to the statistics of World Food and Agriculture Organization in 2012, Iran is the fourth onion producer in the world, with an average of 71,000 hectares under cultivation and an average yield of 32 tons per hectare; more than 2.26 million tons of this product is produced annually (FAO, 2012). The production areas of this product in Iran are divided into three regions: long day, mean day and short day. In latitudes below 32°C or tropic, short day cultivars are planted, in geographical latitudes, 32-38°C, mean day cultivars are planted and in geographical latitudes more than 38°C, long day cultivars are planted (Darani et al., 2014). Onion is a cool season plant that grows well in a wide range of temperatures and responds to the day long in terms of the bulb formation (Ombodi et al., 2016). Due to the different reactions to the day long to form and bulk the onions, this product can be cultivated in northeastern, north and south provinces, respectively, in early spring, winter and autumn. Sistan and Baluchistan province, after the provinces of East Azarbaijan, Isfahan and Fars, ranks fourth for onion production in the country. The average annual onion production in this province is 4,000 hectares per year. Sistan region in Sistan and Baluchestan province are two of the important areas for development of onions in the country. Water shortage in Sistan plain is a serious and important issue. The only source of water in the region is Hirmand River, which originates from the mountains of Baba Yagmah, Afghanistan. The water crisis in the region is due to water shortage in the river, so that the lack of supply by the Hirmand River has adversely affected agriculture in ​​the region. In many parts of the world, the growth and production of plants have been limited due to water shortage, and especially in recent decades such shortcomings have caused changes in the world's agriculture. Consequently, several studies have been conducted in different countries to better utilize water in the agricultural sector. According to a report by Houman (2001), among all the irrigation methods, a method that provides plants with timely water will have the best economic yield for onions (Human and Grobler, 1989). Hassan (2001) reported that acceptable economic yield was obtained when water and fertilizer use was saved but at the same time the plant was provided with different methods of irrigation (Hassan, 1983). From a study conducted by Chang (1989) in Sudan, by using four different irrigation periods (7, 10 and 14 days, as well as whenever the plant needs water) and nitrogen fertilizer application at three levels (no fertilizer use, 90 and 180 kg nitrogen fertilizer per hectare), the best onion yield was produced in 7-10 days irrigation treatment. Also, due to increasing water consumption and shortening of the distance between irrigation intervals, the percentage of bolting (unwanted flowering) was reduced, but the number of multiple growing bulbs was increased. In their report, Rastegar et al. (2007) stated that by using water drip irrigation method, water use efficiency was 54% higher than plot irrigation method. Also, the results of this study showed that at the soil stage, for the seed emergence, about 500 cubic meters of water per hectare was used when the plot and groove irrigation method was adopted compared to the drip method (Rastegar et al., 2008). Hanson and Mie (2004) reported no significant difference between drip irrigation and sprinkler irrigation method, but more water was provided by drip irrigation in the onion root zone (Hanson and May, 2004). Shok et al. (2005) reported that when onion sweet spinach cultivar was cultured on two lines at a distance of three inches and spacing of 44 inches from each other, with a density of 150,000 seeds at the end of March, and then irrigated by drip irrigation method with spacing of each 12-inch dropper,, the best germination percentage and therefore the highest bulb yield was obtained (Shock et al., 2005). Rastgar and Baghani (2013) examined the effect of different irrigation methods on the bulb yield of onion cultivars. From the results of this study, drip irrigation method increased the yield of onion bulb compared to other methods. The efficiency of irrigation water used in drip irrigation method was 28% and 52%, respectively, more than the plot and groove irrigation method (J and J, 2013). Taheri et al. (2015) in order to examine the effect of different irrigation regimes and planting methods on yield, yield components, morphological traits and storage characteristics of local population of GholiGhese cultivar conducted a factorial split plot experiment in a complete randomized block design in four replications for three years at ZanjanKheirabad Research Station. The results of their research showed that planting methods were significant on water use efficiency at level 5 and the highest water use efficiency was obtained with 10/295 kg / m³ water by seedling planting method. Water use efficiency due to lack of water resources in the region and 70 millimeter cumulative evaporation due to reduced water consumption is more suitable than irrigation treatment with 40 millimeter cumulative evaporation (Taheri et al., 2015). Aminpoor and Mousavi (2006) examined the effect of three irrigation regimes after 50, 70 and 90 millimeter cumulative evaporation of the culture of class A on onion seed yield of Texas Early Grano during a two-year experiment in Isfahan. In this experiment, the maximum water use efficiency was related to the treatments of 50 and 70 millimeter, and irrigation after 70 millimeters (Aminpour and Mousavi, 2006). The study results of Mohammad and Ashok (2014) showed that the application of potassium fertilizer can compensate for part of the water stress on the plant (Hussein and Alva, 2014). The present study aims to determine the most suitable method for irrigation of onions and determine the appropriate amount of nitrogen fertilizer and water intake in Sistan region during two crop years.

**2. Materials and methods**

This research was conducted in 2015 and 2016 at the Agricultural Research Field located in Zahak in Sistan region, Sistan and Baluchestan province at 61° 67 minutes east longitude, 30° and 89 minutes northern latitude and 480 meters above the sea. The study area has a warm and arid climate, with a rainfall of less than 60 mm per year. In order to determine the physical and chemical properties of the soil before the land preparation stages, soil samples were taken from depths of 0-30 and 30-60 cm, and some of their physical and chemical properties were determined (Table 1). With the determination of fertilizer requirement before planting based on the soil test, phosphorous fertilizer of triple superphosphate and potassium (potassium sulfate) in concentrations 100 and 80 kg / ha, respectively, was provided for the plant at planting time. The amount of nitrogen fertilizer required was calculated as 130 kg based on the requirement of fertilizer, which was used as nitrogen fertilizer at three stages and based on the treatments mentioned before providing the plant with the bulb.

The average values ​​of some irrigation water characteristics in different treatments are given in Table 2.

In order to achieve the desired objectives, the present study was carried out in a factorial split plot design. The treatments were performed including four nitrogen levels (N1, N2, N3 and N4 equal to 25, 50, 75 and 100% N fertilizer requirement, respectively), four levels of irrigation water depth (I1, I2, I3 and I4 equal to 50, 75, 100 and 120% of onion water requirement, respectively) and three irrigation methods (surface furrow irrigation, drip irrigation and subsurface drip irrigation) in three replications. The dimensions of the plots were 3 × 3 (m / m) and the plots were 1 meter apart. The seedlings were planted in rows with spacing of 30 cm and bush spacing of 7 cm apart. The seeds were planted in early August in the Treasure and Seed Planting was on October 15th. Surface irrigation was carried out using the stream method with furrow width of 30 cm apart. In drip irrigation, for each row, a drip irrigation pipe with a diameter of 16 mm was used, with droppers at a distance of 30 cm and irrigation of 4 liters per hour in one meter. For each cultivation row, a subsurface water pipe was installed with a diameter of 16 mm, a dropper inside it and irrigation of 3.41 liters per hour, with a distance of 30 cm apart at a depth of 30 cm.

**Determination of plant irrigation interval and water requirement**

The irrigation interval for onion according to the soil texture, water holding capacity in the soil, and local investigations was considered in three days for surface and subsurface drip irrigation and seven days for furrow irrigation. An evaporation pan was used to determine the water requirement of the plant. The data related to the class A evaporation pan was obtained from Zabol Water Organization, which was studied at the Agricultural Research Center of Zahak, adjacent to the land, and the amount of irrigation water used was calculated on the basis of the plant potential evapotranspiration loss (ETc) over a 3-day interval (irrigation interval) using the following equation:

Where V: Irrigation water volume (cubic meters), I: Plot length (m), s: Plot width (m), Kp: pan coefficient (0.7), kr: shadow factor and kc: Vegetation factor.

With regard to the graph, the coefficient of plant variation was determined during the growing season for irrigation intervals using FAO publication instruction No. 56.

The amount of shadow factor depends on the vegetation percentage (relative to the total area of the field) and its value was obtained from the following equation based on suggestions by Keller and Karmeli (Alizadeh, 2001):

(2)

ETp: pan evaporation (m)

Ea: system efficiency (90% for subsurface drip irrigation and 85% for drip irrigation).

In order to determine the volume of water required for furrow irrigation by 7-day irrigation interval, the above Equation was used without considering the shadow factor.

The volume of irrigation water was measured using the installed meters on each water supply pipe. The volume of water for other treatments was determined and applied based on this volume.

**Irrigation Water Use Efficiency (IWUE)**

This is the ratio of the product produced to irrigation water and it is obtained from Equation (4). (Payero et al., 2006)

IWUE: Irrigation water use efficiency, Y: Harvested product (forage) (kg / ha) LR: Irrigation water amount (cubic meter).

**Plant sampling**

The plots were harvested when 30% of the bushes became yellow and fell. The harvesting operations were performed by removing half a meter from the top and bottom of each plot and removing the marginal lines from each side of the plot. Four samples were selected from each plot, and traits such as bulb yield, multiple growing percentage, bulb diameter and water use efficiency were measured.

Finally, the measured data were analyzed using SAS software and the means were compared by Duncan's test.

**Production functions**

The production function is the relation between input and output in a system. In this study, the bulb yield was considered as the output and different amounts of irrigation water and nitrogen fertilizer were considered as input parameters. The general form of the production function is expressed as follows.

(2)Y = f (I, N)

In this equation, Y is the function of the onion bulb (ton per hectare), which is a function of the amount of irrigation water (cm) and the amount of nitrogen fertilizer (kg / ha).

The forms of functions of yield - irrigation water – fertilizer were simple linear, logarithmic, quadratic and transcendental for each irrigation method, separately.

Simple Linearity:

Logarithmic model:

(4)

Quadratic model:

Transcendental model:

In these equations, I: the amount of irrigation water (cm) N: the amount of nitrogen fertilizer (kg / ha), α: constant value, β: the regression parameters that should be calculated and Y: the value of the bulb yield.

After determining the required coefficients, in order to compare and evaluate these models, five statistical indexes including root mean square error (RMSE), model efficiency (EF), maximum error (ME), residual coefficient (CRM), and coefficient of explanation (R2) obtained from the following equations were used (5).

*(7)*

(8)(9)

(10)

In these equations, O and P are, respectively observed and predicted yield values, and n is the number of observations.

**3. Results and discussion**

The results of variance analysis of measured traits of onions in different treatments are presented in Table 3. As can be seen, the results of analysis of variance showed that the effect of irrigation water, nitrogen fertilizer and irrigation methods on the parameters measured was significant at 1% probability level. The planting year did not have a significant effect on the measured parameters and the reason was the uniform conditions of the weather in the region for successive years. The effect of repetition on measured traits was not significant, indicating the uniform conditions of the test for all repetitions (Table 3).

**The bulb diameter**

The irrigation water had a significant effect on the bulb diameter. By reducing the amount of irrigation water to less than the plant water requirement, the bulb diameter was reduced, but no significant difference was observed between the treatments of 100 and 75% of the water requirement of the plant. Also, increasing the irrigation water more than the water requirement of the plant also reduced the bulb diameter. The highest bulb diameter was obtained from the treatment of 100% plant water requirement (4.9 cm) and the lowest was obtained in 50% water requirement (2.93 cm). The effect of amount of nitrogen fertilizer was reduced by reducing the amount of nitrogen consumed by the bulb diameter. In this regard, a significant difference was observed at the 5% probability level between the treatments (Table 4). The effect of irrigation method showed that subsurface drip irrigation reduced the bulb diameter (Table 4).

The interactive effect of irrigation method and amount of irrigation water in all three irrigation methods showed that by reducing depth of irrigation water the bulb diameter was reduced. Also, increasing the depth of irrigation water more than the water requirement of the plant also reduced the bulb diameter (Table 5). The interactive effect of irrigation methods and nitrogen fertilizer showed that by reducing the depth of irrigation water and reducing the amount of nitrogen consumed, the bulb diameter was reduced. The highest amount was obtained from the treatment of 100% water requirement of the plant and 100% nitrogen fertilizer (6.1 cm) and the lowest was in 50% water requirement and 25% nitrogen fertilizer (2.19 cm) (Table 6). The interactive effect of irrigation methods and nitrogen fertilizer showed that in all three irrigation methods used, by reducing the amount of nitrogen consumed the bulb diameter was reduced (Table 7).

**Multiple growing percentage**

The amount of irrigation water had a significant effect on the multiple growing percentage at the level of 5%. By reducing the depth of irrigation water, the multiple growing percentage was increased. However, no significant effect was observed between irrigation treatments with 120 and 75% water requirement of the plant. The highest multiple growing percentage (6.92%) was found in the treatment of 50% of plant water requirement and the lowest (5.19%) was in 100% water requirement of the plant (Table 4). Chang (1989) in his research showed that the number of multiple growing onions was increased by increasing water consumption and shortening the distance between irrigation intervals (Chung, 1989). Almoshilla (2007) in his study on onion bulbs observed that different levels of irrigation by drip irrigation method did not affect the multiple growing percentage of the bulb (Al-Moshileh, 2007). The effect of nitrogen fertilizer level showed that by reducing nitrogen level, multiple growing percentage was increased, but no significant difference was observed between the treatments of 100 and 75 nitrogen fertilizers. The lowest multiple growing percentage was obtained from the treatment of 100% nitrogen fertilizer (4.65%) and the highest percentage was in the treatment of 25% nitrogen fertilizer (7.6%) (Table 4). The effect of irrigation method on the multiple growing percentage was significant at 5% level. Surface furrow irrigation significantly increased the multiple growing percentage of onion bulb. Surface drip irrigation had the lowest multiple growing percentage (5.45%), but no significant difference was observed between surface and subsurface drip irrigation. Surface irrigation (furrow) had the highest multiple growing percentage (6.5%) (Table 4). Bagali (2012) in his research on the effect of irrigation methods on onion yield and characteristics concluded that the multiple growing percentage in surface irrigation methods was higher than that of drip irrigation, which was consistent with the results of this research (Bagali et al., 2012). Interactive effects of nitrogen fertilizer, irrigation method and amount of irrigation water did not have a significant effect on multiple growing percentage (Table 3).

**Bulb yield (ton per hectare)**

The effect of amount of irrigation water on the yield of onion bulb showed a reduction in yield when depth of irrigation water was less than the plant water requirement, but in this regard, no significant effect was observed between the treatments of 100% water requirement and 75% water requirement of the plant. Also, increasing the amount of irrigation water more than the water requirement of the plant reduced the yield of bulb onion, but did not have a significant effect on irrigation treatment. Ensiso et al. (2009) examined the quantitative and qualitative yield of onions at different levels of stress in subsurface drip irrigation (Enciso et al., 2009). From the results of the study, no significant difference was observed between the amount of onion yield in the treatments of 100% and 75% water requirement of the plant and the pressure of 20 and 30 kPascal. No significant difference was also observed between different levels of irrigation of bulb onion. Plater et al. (2004) in their study concluded that reducing irrigation levels in each stage of onion growth would reduce its yield (Pelter et al., 2004). The difference in yield in different irrigation methods was significant at 5% level. The highest yield was observed in the subsurface drip irrigation system (28.42 t ha-1) and the lowest was in furrow irrigation (19 ton / ha) (Table 4). Onion irrigation based on evapotranspiration of the region caused increasing bulb yield in the subsurface drip method compared to other methods. Bagali et al. (2012) found similar results in their research on the effect of drip irrigation method on onions yield and efficiency(Bagali et al., 2012). The reduction in nitrogen fertilizer amount to less than the requirements of the plant reduced the bulb yield. The highest yield was observed in the treatment of 100% nitrogen fertilizer (31.59 ton / ha) and the lowest was in the treatment with 25% nitrogen fertilizer (16.12 ton/ha) (Table 4). In their research, Hushmand et al. (2017) concluded that reducing nitrogen consumption directly by reducing the amount of photosynthesis and the production of nutrients, as well as reducing the leaf durability and plant growth period, caused a reduction in the amount of dry matter during the plant growth period (Houshmand et al., 1970). The interactive effect of amount of irrigation water and irrigation method showed that in all three irrigation methods, by reducing and increasing the depth of irrigation water more than the water requirement of the plant, the amount of the bulb yield was reduced and the highest yield was obtained from subsurface drip irrigation (Table 5). The interactive effect of irrigation water and nitrogen fertilizer showed that by reducing the depth of irrigation water and reducing nitrogen levels, the amount of the bulb yield was reduced. The highest amount of the bulb yield was obtained from the treatment of 100% water requirement and 100 nitrogen fertilizer amount (Table 6). The interactive effect of irrigation method and nitrogen fertilizer showed that the highest yield was obtained from subsurface drip irrigation and 100% nitrogen fertilization treatment (Table 7). In all three methods, the amount of yield was reduced by reducing the amount of nitrogen fertilizer.

**Efficiency of irrigation water (kg / m³ / ha)**

The effect of amount of irrigation water on irrigation water efficiency was significant at 5% probability level. Reducing the depth of irrigation water from 100% of the water requirement of the plant to 75% of the water requirement of the plant increased the efficiency, no significant difference was observed between the two treatments in this regard. Increasing irrigation water from 100% to 120% of water requirement of the plant reduced efficiency. The highest amount of efficiency was obtained from the treatment of 75% water requirement of the plant (4.47 kg / m³ / ha) and the lowest was in the treatment of 120% water requirement of the plant (2.78 kg / m³ / ha) (Table 4). Garrity et al. (1983) stated that the occurrence of aqua stress, although affected the numerator of the fraction of WUE (efficiency) i.e. the yield, but by the osmotic adjustment mechanism activity of the plant, the denominator was reduced more and efficiency was increased to some extent. In the treatment of 50%, it can be said that although the yield level (the numerator of the fraction) was significantly reduced, the efficiency has been reduced(Garrity et al., 1982). Abat et al. (2004) also found the above results of water use efficiency and stated that increased water use efficiency is higher in low irrigation. Also, the results indicate a reduction in water use efficiency by increasing the intensity of aqua stress (Abbate et al., 2004). For example, in a study on different cultivars of strawberries, the reduction in water use efficiency by increasing aqua stress was reported in the cultivar Salot. But results from other studies suggested increased water use efficiency associated with an increase in aqua stress (Zegada-Lizarazu and Iijima, 2005). The effect of nitrogen fertilizer levels indicated that reducing the amount of nitrogen fertilizer consumed reduced the efficiency (Table 4). The effect of irrigation method showed that the highest level of efficiency was observed in the treatment of subsurface drip irrigation (5.19 kg / ha), and the treatment of furrow irrigation reduced the efficiency of irrigation water by 55% (Table 4). Rastegar and Baghani (2013) stated that due to the application of drip irrigation method for onion cultivation, water use efficiency was 54% higher than furrow irrigation. The interactive effect of irrigation and nitrogen fertilizer at 5% level had a significant effect on irrigation water efficiency (J and J, 2013). Efficiency in all three irrigation methods was reduced by reducing the amount of nitrogen fertilizer used (Table 7). Hall et al. (2008) in their study concluded that in onion cultivation, water use efficiency and nitrogen efficiency used in drip irrigation were more than furrow irrigation and economically more cost-effective (Halvorson et al., 2008).

**Superior production function**

As shown in Table 8, based on the final ranking, the quadratic function was considered as superior to other functions in all three irrigation methods. Transcendental, logarithmic and linear functions were ranked second to fourth, respectively. Given the larger ME values, it indicates the weaker yield of the model in estimating the yield of the product, so it can be seen from the Table that a quadratic function with the lowest ME had the best estimate of product yield. The minimum numerical value of the RMSE index is also related to the quadratic function, indicating that this function with the least difference has estimated the yield against its real value. Also, the high values ​​of the coefficient of determination of R² (0.94) and the efficiency of the EF model (0.84) express the high degree of certainty and efficiency of the quadratic function in estimating the desired values. Therefore, regarding the above results and taking into account the final rank, it can be said that the quadratic function can be introduced as the superior function under mixed conditions of fertilizer and irrigation water levels in the Sistan region. Many researchers have described the quadratic function as the superior function for determining the relationship between salinity parameters, irrigation water and yield. In examining aqua stress on forage product, Yazdani et al. (2014) in evaluating the yield of rape in comparison with salinity and irrigation water in Mashhad, considered the quadratic function with the highest coefficient of determination and the lowest error rate as the superior function (YAZDANI et al., 2015).

**4. Conclusion**  
Based on the results of this research, no significant difference was found between the treatments for supplying 75 and 100% of the water requirement of the plant in terms of bulb yield and efficiency. Hence, the amount of water given to the plant can be reduced to 75% of the plant's water requirement, and with proper management less water can be used without any significant reduction in yield, while saving water consumption. Also, it can be said that due to changes in irrigation water, nitrogen fertilizer and irrigation method, the quadratic function is a better estimator of onion bulb yield compared to other functions. The effect of increasing the depth of irrigation water and nitrogen fertilizer on the yield of onion bulb in subsurface drip irrigation was more compared to the other two irrigation methods. In order not to reduce the amount of yield by reducing the depth of irrigation water, the amount of nitrogen consumed should be increased. Due to the inappropriateness of the spatial and temporal dispersion of atmospheric precipitation in Iran and the low irrigation efficiency in agriculture, water is one of the most limiting factors in agricultural production. Hence, reduction of irrigation water consumption, optimum cultivation model and application of pressurized irrigation system (drip superficial and subsurface) are recommended in developing the cultivation model in onion fields. Also, considering the contamination of groundwater due to the excessive nitrogen fertilizer application and the prevention of nitrate accumulation in the bulbs, it seems that the use of drip irrigation allows the management of nitrogen fertilizers use.

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Tables:

Table 1- Some Physical and Chemical Characteristics of the Soil of the Research Field

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Organic carbon | Absorbed phosphorus | Absorbed potassium | EC | Wilt point | Crop percentage | pH | Soil texture | Clay percentage | Sand percentage | Silt percentage | Sampling depth | Year |
| .78 | 3.4 | 145 | 1.1 | 9 | 21 | 8 | Loam sand | 8 | 61 | 29 | 0-30 | 1 |
| .68 | 3.1 | 151 | 1.3 | 11 | 25 | 7.8 | Loam sand | 11 | 53 | 34 | 30-60 |
| .84 | 3.8 | 148 | 1.3 | 10 | 22 | 8.3 | Loam sand | 8 | 61 | 29 | 0-30 | 2 |
| .75 | 3.6 | 155 | 1.4 | 11.5 | 26 | 8.1 | Loam sand | 11 | 53 | 34 | 30-60 |

Table 2- Chemical properties'values of irrigation water

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Anion | | | Cation | | | | SAR | EC | pH | Water sample |
| So4⁻ | Cl | HCo³⁻ | K | Na | Mg | Ca |
| 1.1 | .9 | 2.9 | .03 | 2.2 | 1.17 | 1.5 | 1.9 | .4 | 7.8 | S1 |

Table 3- The results of variance analysis (mean squares and degrees of freedom) of measured onion traits

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Change source | Freedom degree | Bulb diameter | Multiple growing percentage | Bulb yield | Irrigation water efficiency |
| Year (Y) | 1 | .23 ns | 5.54 ns | .25 ns | .13 ns |
| Replication (Year) | 4 | .01 ns | 10.71 ns | 1.34 ns | .29 ns |
| Irrigation method(A) | 2 | 47.43 \*\* | 29.21\* | 2217.42 \*\* | 87.34 \*\* |
| Y × A | 2 | 0.013 ns | 7.94ns | 0.98ns | 6.78ns |
| Main Error | 8 | 0.08 | 6.42 | 1.02 | 2.31 |
| Irrigation water amount(B) | 3 | 52.95 \*\* | 39.95\*\* | 1429.18\*\* | 35.45\*\* |
| Y × B | 3 | 0.012ns | 8.15ns | 0.89ns | 0.07ns |
| B × A | 6 | 0.95\*\* | 8.42ns | 68.84\*\* | 2.03ns |
| Y × B × A | 6 | 0.014ns | 8.78ns | 0.76ns | 0.08ns |
| Nitrogen fertilizer amount(C) | 3 | 53.16 \*\* | 115.1\*\* | 3399.89\*\* | 63.03\*\* |
| Y × C | 3 | 0.015ns | 8.03ns | 0.88ns | 0.08ns |
| C × A | 6 | 0.27\*\* | 7.78ns | 78.37\*\* | 9.46\*\* |
| C× B | 9 | 0.57\*\* | 8.78ns | 58.58\*\* | 0.66ns |
| C × B × A | 18 | 0.07\*\* | 8.64ns | 7.88\*\* | 1.4ns |
| Y × C × B | 9 | 0.011ns | 8.92ns | 0.94ns | 0.02ns |
| Y × C × A | 6 | 0.007ns | 8.88ns | 0.92ns | 0.76ns |
| Y× C×B× A | 24 | 0.012ns | 8.75ns | 0.85ns | 0.36ns |
| Sub Error | 180 | 0.02 | 8.75 | 1.05 | 1.25 |

\*and \*\*: significance at the probability level of 5% and 1%, ns: insignificance.

The results of the comparison of the mean of measured traits in different treatments are presented in Tables 4 and 5.

Table 4- Comparison of the measured onion traits

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Experimental treatments | | Bulb diameter | Multiple growing percentage | Bulb yield | Irrigation water efficiency |
| Irrigation water amount | 120% of water requirement | 4.2 b | 5.54 b | 25.76 a | 2.78 c |
| 100% of water requirement | 4.9 a | 5.19 b | 27.61 a | 3.58 a |
| 75% of water requirement | 4.6 a | 5.8 b | 25.21 a | 4.47 a |
| 50% of water requirement | 2.93 c | 6.92 a | 17.38 b | 3.16 b |
| Nitrogen fertilizer amount | 100% | 5.2 a | 4.65 c | 31.59 a | 4.75 a |
| 75% | 4.4 b | 5.3 c | 27.29 b | 4.33 b |
| 50% | 3.76 c | 5.91 b | 20.65 c | 3.4 c |
| 25% | 3.2 d | 7.6 a | 16.12 d | 2.67 d |
| Irrigation method | Surface | 3.5 c | 6.5 a | 19 c | 2.33 c |
| Drip | 4.03 b | 5.45 b | 24.56 b | 3.87 b |
| Subsurface drip | 4.9 a | 5.65 b | 28.42 a | 5.19 a |

The mean of the same letters based on Duncan test is not significantly different at 5% probability level.

Table 5- Comparison of the mean interactions of irrigation water and irrigation methods (A× C)

|  |  |  |  |
| --- | --- | --- | --- |
| Irrigation method | Irrigation water amount | Bulb diameter | Bulb yield |
| Surface | 120% of water requirement | 3.9 g | 20.43 h |
| 100% of water requirement | 4.11 f | 20.76 g |
| 75% of water requirement | 3.67 h | 19.62 i |
| 50% of water requirement | 2.41 k | 14.9 k |
| Drip | 120% of water requirement | 4.4 e | 25.73 e |
| 100% of water requirement | 4.93 c | 28.8 d |
| 75% of water requirement | 3.92 g | 25.59 f |
| 50% of water requirement | 3.01 j | 17.89 j |
| Subsurface drip | 120% of water requirement | 5.44 b | 31.09 a |
| 100% of water requirement | 5.78 a | 32.59 b |
| 75% of water requirement | 4.78 d | 30.3 c |
| 50% of water requirement | 3.43 i | 19.6 i |

The mean of the same letters based on Duncan test is not significantly different at 5% probability level.

Table 6- Comparison of the mean interactions between irrigation water and nitrogen fertilizer (A× B)

|  |  |  |  |
| --- | --- | --- | --- |
| Irrigation water amount | Nitrogen fertilizer amount | Bulb diameter | Bulb yield |
| 120% of water requirement | 100% | 5.76 b | 33.96 b |
| 75% | 4.9 d | 30.04 e |
| 50% | 4.08 g | 21.79 i |
| 25% | 3.57 j | 17.21 m |
| 100% of water requirement | 100% | 6.1 a | 36.12 a |
| 75% | 5.25 c | 31.45 d |
| 50% | 4.63 e | 24.96 g |
| 25% | 3.66 i | 17.65 l |
| 75% of water requirement | 100% | 5.27 c | 33.57 c |
| 75% | 4.31 f | 29.25 f |
| 50% | 3.82 h | 21.45 j |
| 25% | 3.29 k | 16.41 n |
| 50% of water requirement | 100% | 3.68 i | 22.72 h |
| 75% | 3.13 l | 18.43 k |
| 50% | 2.7 m | 15.92 o |
| 25% | 2.19 n | 12.35 p |

The mean of the same letters based on Duncan test is not significantly different at 5% probability level.

Table 7: Comparison of the mean interactions between irrigation method and nitrogen fertilizer (B × C)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Irrigation method | Nitrogen fertilizer amount | Bulb diameter | Bulb yield | Irrigation water efficiency |
| Surface | 100% | 4.52 e | 24.09 f | 3.52 de |
| 75% | 3.88 h | 21.34 g | 2.9 gf |
| 50% | 3 j | 16.13 k | 2.47 gf |
| 25% | 2.6 k | 13.29 l | 2.3 g |
| Drip | 100% | 5.17 b | 33.06 b | 4.7 c |
| 75% | 4.24 f | 28.34 d | 3.94 d |
| 50% | 3.7 i | 20.59 f | 3.1 ef |
| 25% | 2.96 j | 16.38 j | 3.05 ef |
| Subsurface drip | 100% | 5.92 a | 37.62 a | 6.51 a |
| 75% | 5.07 c | 32.2 c | 5.52 b |
| 50% | 4.59 d | 24.8 e | 4.18 cd |
| 25% | 4.01 g | 18.95 i | 3.23 e |

The mean of the same letters based on Duncan test is not significantly different at 5% probability level.

Table 8- Statistical parameters calculated to evaluate the validity of water-fertilizer-yield functions

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Final rank | Mean rank | R2 | CRM | ME | EF | RMSE | Function type | Irrigation method |
| 4 | 3.6 | .76 | -.45 | 14.9 | -2.53 | 48.96 | Linear | Furrow |
| 3 | 3 | .75 | -.33 | 12.4 | -1.08 | 37.61 | Logarithmic |
| 2 | 2.4 | .72 | -.17 | 10.6 | .04 | 25.48 | Transcendental |
| 1 | 1 | .94 | -.14 | 4.5 | .65 | 15.25 | Quadratic |
| 4 | 4 | .67 | -.24 | 14.8 | 0.1- | 33.49 | Linear | Surface drip |
| 3 | 3 | .7 | -.03 | 11.2 | .55 | 21.2 | Logarithmic |
| 2 | 2.6 | .71 | .02 | 13.4 | .54 | 21.42 | Transcendental |
| 1 | 1 | .89 | .009 | 8.7 | .85 | 12.53 | Quadratic |
| 4 | 3.2 | .65 | -.15 | 16.6 | .19 | 115.02 | Linear | Subsurface drip |
| 3 | 1.8 | .7 | .017 | 16.6 | .52 | 67.49 | Logarithmic |
| 2 | 2.8 | .7 | -.08 | 19.1 | .48 | 73.51 | Transcendental |
| 1 | 1 | .83 | -.004 | 17.8 | .77 | 32.86 | Quadratic |