Response of Okra (Abelmoschus Esculentus L. Yalova Akköy-41) to Different Irrigation and Fertigation Levels

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A B S T R A C T
This study was carried out in the greenhouses of Bursa Uludag University Yenisehir Ibrahim Orhan Vocational School in 2014-2015 to determine the effects of five different irrigation levels (T1: 100% (full irrigation), T2: 75%, T3: 50%, T4: 25%, T5: 0% (non-irrigated)) and two different fertigation levels (F1.0: 100% (100:100:100 NPK) fertigation and F0.5: 50% (50:50:50 NPK) fertigation) on yield and quality parameters of okra grown under unheated greenhouse conditions. In 2014 and 2015, the amount of irrigation water in the study was applied as 0.0-380.0 mm and 0.0-360.0 mm for the 100% (100:100:100 NPK) fertigation and 50% (50:50:50 NPK) fertigation treatments, respectively. Evapotranspiration values were realized as 200.0-410.0 mm and 130.0-400.0 mm for 100% (100:100:100 NPK) and 50% (50:50:50 NPK) fertigation treatments in 2014, 185.0-425.0 mm and 200.0-450.0 mm in 2015, respectively. It was observed that irrigation water levels significantly affected the yield, fruit diameter, fruit length, 10 fruit weight, and number of fruits per plant and dry matter of okra. The highest yield average for both years were obtained from T1:F1.0 and T1:F0.5 treatments were found to be 14.6-17.8 tons’ ha-1 and 16.8-15.7 tons’ ha-1 in 2014 and 2015, respectively. Crop response factors (k1) of okra were found as 1.38-1.26 and 1.26-1.41 for 100% (100:100:100 NPK) fertigation and 50% (50:50:50 NPK) fertigation treatments in 2014 and 2015, respectively. The highest water use efficiency (WUE) and irrigation water use efficiency (IWUE) values were calculated as 0.036-0.038 kg m-3 and 0.045-0.049 kg m-3 from T1:F1.0 and T1:F0.5 treatments in 2014 and 0.040-0.047 kg m-3 and 0.035-0.046 kg m-3 from same treatments (T1:F1.0 and T1:F0.5) in 2015, respectively. The highest T1:F1.0 and T1:F0.5 values were the closest values were obtained from T1:F1.0 and T1:F0.5 treatments therefore T1:F1.0 and T1:F0.5 treatments can be recommended for okra.

Keywords: Irrigation, Fertigation, Yield and quality of okra, Okra cultivation, Bursa

Introduction
Okra production has an important place in world agriculture. Okra (Abelmoschus esculentus L. Moench), is an important vegetable crop, also known as lady’s finger or bhendi belongs to family Malvaceae (Nagegowda et al., 2020). Okra productions in the world and in Turkey are 7 915 533 tons and 51 611 tons, respectively. Turkey is among the world ranks 30th in 47 countries producing okra (TUİK, 2018). Okra is one of the important fruits produced in Marmara region of Turkey. In Bursa province of Marmara Region, annual okra production is about 887 tons of fruit from 240 ha (TUİK, 2016). While okra is produced as amateur in most of the regions of Turkey, it is cultivated as commercially in Aegean, Marmara, Mediterranean and Central Anatolian regions of the country and utilized freshly, frozen, dried and salted. Düzyaman (1997) states that okra cultures are spreading on the tropic, subtopical and Mediterranean climate belt. The countries that make commercial okra production are West African countries, Asian countries out of India and South East Asia, USA, Brazil, Australia and Turkey (Vural, 2000). Growing population and ever-increasing urbanization have intensely increased vegetable cultivation in peripheral urban areas. Therefore, it is essential to ensure a supply of quality vegetable seeds. Water and fertilizers, which are important inputs in agriculture, are the most important factors affecting yield. Therefore, applying the most efficient irrigation and fertilizer management is important in the crop production system (Nagegowda et al., 2020).

Water is more effective than other factors on the distribution and development of vegetation on earth. Vegetation develops very well in regions where rainfall is abundant and rainfall regime is good. The total amount of...
precipitation per region and its distribution by months is one of the most important factors that determine the plants growing in that region. The amount of water used by plants according to their development periods is also different. While plants consume less water in early development periods, they need the most water during flowering. The total water consumption of each plant variety is different. Total plant water consumption has a significant effect on yield (Falah and Fehem-Yasir, 2020). Total plant water consumption increases as yield increases. Thus, the irrigation influences the quality and quantity of product in agriculture (Tonkaz et al., 2019). In recent years, with the increasing strategic importance of water, efforts have been increasing towards the rapid development of water resources. The first of these efforts is the application of irrigation techniques to save water (Gökmen, 2011). Irrigation planning is called as long as it determines how much irrigation water will be applied per irrigation and when to give water to the plant. An appropriate irrigation schedule should be planned for the efficient use of water, energy and fertilizer included in the production inputs (Nagegowda et al., 2020).

Most plant nutrients can be applied through irrigation systems. The application of nutrients with the irrigation system is called fertigation (Kaur et al., 2017). Application of N, P and K with irrigation system can significantly increase yield by reducing the loss of nutrients. Macro elements are very important nutrients for plant growth and development. The formation of amino acids, nucleoproteins, amino sugars and other organic compounds in the plant occurs due to nitrogen. In addition, nitrogen contributes to all vital processes of the plant. In order for the plant cells perform well, various nitrogen components must be supplied to the plant. The two most important forms of nitrogen taken by plants are ammonium (NH₄⁺) and nitrate (NO₃⁻) ions (Kılıç and Korkmaz, 2012). In fertigation, the most appropriate nitrogen forms or nitrogen forms suitable for each plant should be researched and applied (Çetin and Tolay, 2009). Phosphorus plays a vital role in the formation of new cells and photosynthesis. Phosphorus is also a component of various nucleoproteins and lipids. In fertigation applications, phosphoric acid (H₃PO₄) and ammonium phosphate fertilizers are widely used in the application of phosphorus fertilizers with drip irrigation systems (Çetin and Tolay, 2009). Fertilization of phosphorus with drip irrigation systems gives very effective results. Activator function in enzyme systems takes place thanks to potassium. It is known that potassium contributes significantly to transpiration, respiration and water delivery in plant cells. It also promotes root division and development in plants. (Yazıcı ve Korkmaz, 2020). Potassium nitrate (KNO₃) is used as a source of both K (potassium) and N (nitrogen) (Vijay, 2017).

Many studies have been carried out in the world and in Turkey on the irrigation of okras (Ünlükara et al., 2008; Ulu et al., 2016; Deveci et al., 2017; Ünlükara and Cemek, 2019). Previous studies have clearly shown that okra yield, fruit diameter, fruit length and 10 fruit weight, number of fruits per plant, and dry matter ratio are highly correlated with the amount of irrigation water. The previous studies on okra in Turkey were carried out in different irrigation levels. Unlike from previous studies, the effect of different fertigation levels as well as the different irrigation levels on okra were also investigated in our study. There are very few studies on okra related to the different fertigation levels as well as the different irrigation levels. The aim of this study is to determine the effect of different irrigation and fertigation levels on okra yield and some quality parameters.

**Materials and Methods**

The research was carried out in plastic covered greenhouse conditions in 2014 and 2015 years. Bursa-Yenişehir region was chosen as the study area and 8x40 m² dimensional greenhouse was placed in the North-South direction. While the summer months are hot and dry, the winter months are cold and rainy in Yenişehir province. The average annual rainfall and temperature values for the region where the greenhouse experiments were made in 2014 and 2015 were 620.8 – 784.4 mm and 14.0 – 13.3°C respectively (Anonymous, 2011a). The maximum and minimum temperature values of greenhouse inner air in June-July-August months, which are considered as the plant growing period (92 days) were measured. Maximum and minimum temperature values were 38-38°C and 0.9-3.3°C, respectively in 2014-2015 years (Figure 1 and 2). The average relative humidity values for 2014 and 2015 were 75.8 -76.8%. The highest and lowest relative humidity values in greenhouse in 2014 and 2015 years were found as 88-87% and 39-40%, respectively (Figure 3). In addition, the highest and lowest radiation values in greenhouse in 2014-2015 years were measured as 1974-1725 W/m² and 589-797 W/m², respectively (Figure. 4) (Anonymous, 2011b).
The soil of the trial site was sandy-clay and the soil reaction (pH) value vary between 7.90 to 8.08. Some of the physical and chemical properties of the soil of the experiment site are presented in Table 1.

Yalova Akköy-41 okra variety was developed with selective breeding of sultani type. Selection of this variety was completed in 1986 year. The fruits of the okra variety are bright green-yellowish and have a size of 0.8 x 6.0 cm. The fruits of this variety, which are of high quality, are also suitable making or selling canned food. The average yield of Yalova Akköy-41 variety is 1200 kg per decare. The estimated ripening period of the Yalova Akköy okra variety is 100-110 days.

Mankozeb and Endosulfan were used as chemical drugs against okra diseases and insects. In addition, 10 l ha⁻¹ chlorophyll-ethyl was sprayed against the insects. 100 kg ha⁻¹ potassium nitrate (13% N and 46% K₂O) and 100 kg ha⁻¹ phosphoric acid (61% P₂O₅) in treatments which is applied as 100% (100:100:100 NPK) fertigation as base dressing were applied to the soil two weeks before planting seedling process. In treatments which is applied as 50% (50:50:50 NPK) fertigation were applied 50 kg ha⁻¹ potassium nitrate (13% N and 46% K₂O) and 50 kg ha⁻¹ phosphoric acid (61% P₂O₅) as base dressing. 40 kg ha⁻¹ potassium nitrate (13% N and 46% K₂O) and 20 l ha⁻¹ phosphoric acid (61% P₂O₅) in treatments which is applied as %100 (100:100:100 NPK) fertigation were applied to the soil six weeks after planting seedling process. In treatments which is applied as %50 (50:50:50 NPK) fertigation were applied 20 kg ha⁻¹ potassium nitrate (13% N and 46% K₂O) and 10 kg ha⁻¹ phosphoric acid (61% P₂O₅). 50 kg ha⁻¹ potassium nitrate (13% N and 46% K₂O) and 20 l ha⁻¹ phosphoric acid (61% P₂O₅) in treatments which is applied as 100% (100:100:100 NPK) fertigation were applied to the soil eight weeks after planting seedling process. In treatments which is applied as 50% (50:50:50 NPK) fertigation were applied 25 kg ha⁻¹ potassium nitrate (13% N and 46% K₂O) and 10 kg ha⁻¹ phosphoric acid (61% P₂O₅). In addition, 30 kg ha⁻¹ urea fertilizer (45%-46% N) which is applied as 100% (100:100:100 NPK) fertigation and 15 kg ha⁻¹ urea fertilizer (45%-46% N) which is applied as 50% (50:50:50 NPK) fertigation were applied to the soil. Potassium nitrate, phosphoric acid and urea fertilizer treatments were applied through the drip irrigation system.

Okra seedlings was planted on June 01 in 2014 and in 2015. The plant and row spacing applied in the experiment was 0.35 m and 0.35 m, respectively. Each parcel involved 66 seedlings of okra. From the middle of each parcel were harvested 14 plants as sample plants, considering that water would leak from adjacent parcels. The fruit size of the okras taken as an example were measured with a calliper tool and the average values was measured. The dry matter ratio of the fruits was specified by drying the samples (at 65°C in a drying oven). The dry matter ratio was found by using (AOAC, 2000). The detail of the experimental plot is shown in Figure 5.

The experimental design was determined as a 3-replicate and two-factor random block design. 5 different irrigation levels (T₁: 100% (full irrigation), T₂: 75%, T₃: 50%, T₄: 25%, T₅: 0% (non-irrigated)) and two different fertilizer treatments (F₁: 100% (100:100:100 NPK) fertigation and F₂: 50% (50:50:50 NPK) fertigation were distributed randomly to each block. All treatments are formed as follows: T₁F₁: 100% irrigation and 100% (100:100:100 NPK) fertigation, T₁F₁: 75% irrigation and 100% (100:100:100 NPK) fertigation, T₁F₁: 50% irrigation and 100% (100:100:100 NPK) fertigation, T₁F₁: 25% irrigation and 100% (100:100:100 NPK) fertigation, T₁F₁: 0% irrigation and 100% (100:100:100 NPK) fertigation, T₁F₁: 75% irrigation and 100% (100:100:100 NPK) fertigation, T₁F₁: 50% irrigation and 100% (100:100:100 NPK) fertigation, T₁F₁: 25% irrigation and 100% (100:100:100 NPK) fertigation, T₁F₁: 0% irrigation and 100% (100:100:100 NPK) fertigation, T₁F₁: 75% irrigation and 100% (100:100:100 NPK) fertigation, T₁F₁: 50% irrigation and 100% (100:100:100 NPK) fertigation, T₁F₁: 25% irrigation and 100% (100:100:100 NPK) fertigation, T₁F₁: 0% irrigation and 100% (100:100:100 NPK) fertigation.
Figure 5. The detail of a plot

Figure 6 (a) Drip irrigation system, (b) Main and lateral pipes

Table 2. Specific properties of irrigation water

| Water source | Deep well |
|--------------|-----------|
| EC<sub>25x(10<sup>6</sup>)</sub> | 723 |
| Na<sup>+</sup> (me L<sup>-1</sup>) | 2.5 |
| K<sup>+</sup> (me L<sup>-1</sup>) | 2.67 |
| Ca<sup>2+</sup> (me L<sup>-1</sup>) | 9.55 |
| Mg<sup>2+</sup> (me L<sup>-1</sup>) | 5.8 |
| pH | 7.17 |
| Class | C<sub>2</sub>S<sub>1</sub> |
| SAR | 0.85 |

The drip irrigation equipment in greenhouse used in the study was given in Figure 6.

Drip irrigation method was used in the trial. Irrigation water amount was calculated by placing flow measurement devices per parcel. The need for watering of the okra is provided by a deep well (3 l s<sup>-1</sup>) located in the greenhouse area. The depth of the well is 18 meters. Chemical composition of irrigation water were presented in Table-2. Groundwater composition of Yenişehir province is generally alkaline. The irrigation water applied in the experimental research was analysed and was determined to be in the C<sub>2</sub>S<sub>1</sub> class with low sodium risk and medium EC value. The water of the C<sub>2</sub>S<sub>1</sub> quality class has low sodium risk and medium electrical conductivity (EC). The irrigation of water of this quality class is used for plants with medium and highly salinity resistant. In addition, C<sub>2</sub>S<sub>1</sub> quality class water can be used in all plants and soils without creating a risk of alkalinity. C<sub>2</sub>S<sub>1</sub> quality class water was applied in a study on tomato plants (Ashraf and Ewees, 2008).

Soil moisture between 30-120 cm before and after irrigation was monitored by gravimetric method. Evapotranspiration (ET) was calculated by means of the water balance equation (Eq. 1).

\[
ET = I + P - Rf - Dp \pm AS
\]  
(Eq. 1)

Where the evapotranspiration states with ET, the irrigation water amount is indicated by the I symbol, the total precipitation symbol is P, the surface flow amount is Rf (mm), the deep drainage is shown by Dp (mm) and the soil water content at the beginning and end of the growth period states with S (mm 120 cm<sup>-1</sup>) symbol. Irrigation water was applied to the crop by the drip irrigation method before planting seedlings. Total precipitation (P) and surface flow (Rf) were neglected in water requirements and consumption calculations in greenhouse. Soil water values in soil profiles deeper than 120 cm were accepted as deep drainage (Dp) and these values were neglected. The row spacing and intra row intervals in the experimental research were taken equally. Therefore, wetted area of dripper was calculated by the equation as follows (Eq. 2).

\[
P = \frac{Sd}{Sl} \times 100
\]  
(Eq. 2)

Where the percentage of wetted area states with P, the interval of dripper and the intervals of lateral are indicated by Sd and Sl symbols, respectively. Irrigation water amount applied in each irrigation was obtained from the equation (Eq.3) given below.

\[
dn = \frac{(FC - WP)}{\gamma D} \times 100 \times \frac{P}{100}
\]  
(Eq.3)

Where the amount of irrigation water applied in each irrigation states with dn, field capacity and wilting point are indicated by FC and WP, respectively. Soil bulk density, wetted soil depth and the percentage of wetted area are shown as $\gamma$, D and P, respectively. Steward Model (Eq.4) helps to describe the relationship between yield and ET in this experimental research (Stewart et al., 1975; Doorenbos and Kassam, 1979). The equation can be given as:

\[
\left(1 - \frac{Ya}{Ym}\right) = ky \left(1 - \frac{ETa}{ETm}\right)
\]  
(Eq. 4)

Where the maximal and actual yield are shown as Ym (t ha<sup>-1</sup>) and Ya (t ha<sup>-1</sup>), respectively. The maximal and actual evapotranspiration are shown as ETm (mm) and ETA (mm), respectively. ky symbol states the yield response factor, the assessment of irrigation efficiency is determined by WUE values. WUE and IWUE terms contributes to the efficient use of irrigation water in plant production stages (Bos, 1980). By dividing the fruit yield into seasonal evapotranspiration (ET), WUE was calculated. IWUE was predicted as (Zhang et al., 1999):
Results

Before planting, each plots were given irrigation water to bring the soil moisture level up to field capacity (that is, 0-60 cm soil depth moisture level). After a week from planting okra seedlings, the first irrigation water treatment was applied. The maximum and minimum irrigation water amounts for 2014 and 2015 years were obtained from T1F1.0-T1F0.5 and T1F1.0-T1F0.5 treatments were 380-0 mm and 360-0 mm, respectively. The amounts of other irrigation water applied during the experiment years ranged between 285-90 mm and 270-85 mm, respectively. Seasonal evaporation (ETa) increased in parallel with the increase in the amount of applied irrigation water. The actual evapotranspiration values for T1F1.0-T1F0.5 and T1F1.0-T1F0.5 treatments in the first year varied between 410-400 mm and 200-130 mm, respectively. These values in the second year varied between 400-450 mm and 130-200 mm, respectively (Tables 3, 4 and 5).

Table 3. Applied water and ET values according to irrigation and fertigation treatments in 2014 and 2015 years

| Fertilization | IT  | T   | AW 2014 | AW 2015 | CE 2014 | CE 2015 |
|---------------|-----|-----|---------|---------|---------|---------|
| % 100         | T1  | T1F1.0 | 380.0 | 360.0 | 410.0 | 425.0 |
| Fertilization | (F1.0% 100%) | T1F1.0 | 285.0 | 270.0 | 300.0 | 320.0 |
| NPK           | T1  | T1F1.0 | 190.0 | 200.0 | 250.0 | 235.0 |
| % 50          | T1  | T1F0.5 | 360.0 | 340.0 | 400.0 | 450.0 |
| Fertilization | (F0.5% 50%) | T1F0.5 | 270.0 | 260.0 | 280.0 | 320.0 |
| NPK           | T1  | T1F0.5 | 180.0 | 170.0 | 250.0 | 300.0 |

Table 4. Relationship between yield and yield response factor (ky) with the decrease in water use, for okra in 2014 year.

| Treatments | Yield (t ha⁻¹) | Applied Water (mm) | ETa (mm) | ETa/ETm | Ya/Ym | 1-(ETa/ETm) | 1-(Ya/Ym) | Ky |
|------------|---------------|------------------|----------|---------|-------|-------------|-----------|-----|
| T1F1.0     | 14.6          | 380.0            | 410.0    | 1.00    | 1.00  | 0.00        | 0.00      | 0.00|
| T2F1.0     | 10.5          | 285.0            | 300.0    | 0.732   | 0.719 | 0.268       | 0.281     | 1.047|
| T3F1.0     | 7.0           | 190.0            | 250.0    | 0.610   | 0.479 | 0.390       | 0.521     | 1.334|
| T4F1.0     | 3.5           | 95.0             | 210.0    | 0.512   | 0.240 | 0.488       | 0.760     | 1.559|
| T5F1.0     | 2.8           | 0.0              | 200.0    | 0.488   | 0.192 | 0.512       | 0.808     | 1.578|
| T1F0.5     | 17.8          | 360.0            | 400.0    | 1.00    | 1.00  | 0.00        | 0.00      | 0.00|
| T2F0.5     | 12.4          | 270.0            | 280.0    | 0.700   | 0.697 | 0.300       | 0.303     | 1.011|
| T3F0.5     | 8.7           | 180.0            | 250.0    | 0.625   | 0.489 | 0.375       | 0.511     | 1.363|
| T4F0.5     | 2.8           | 90.0             | 150.0    | 0.375   | 0.157 | 0.625       | 0.843     | 1.348|
| T5F0.5     | 2.0           | 0.0              | 130.0    | 0.325   | 0.112 | 0.675       | 0.888     | 1.315|

Table 5. Relationship between yield and yield response factor (ky) with the decrease in water use, for okra in 2015 year.

| Treatments | Yield (t ha⁻¹) | Applied Water (mm) | ETa (mm) | ETa/ETm | Ya/Ym | 1-(ETa/ETm) | 1-(Ya/Ym) | Ky |
|------------|---------------|------------------|----------|---------|-------|-------------|-----------|-----|
| T1F1.0     | 16.8          | 360.0            | 425.0    | 1.00    | 1.00  | 0.00        | 0.00      | 0.00|
| T2F1.0     | 12.6          | 270.0            | 320.0    | 0.753   | 0.750 | 0.247       | 0.250     | 1.012|
| T3F1.0     | 9.2           | 200.0            | 235.0    | 0.553   | 0.548 | 0.447       | 0.452     | 1.012|
| T4F1.0     | 4.0           | 90.0             | 210.0    | 0.494   | 0.238 | 0.506       | 0.762     | 1.506|
| T5F1.0     | 2.4           | 0.0              | 185.0    | 0.435   | 0.143 | 0.565       | 0.857     | 1.518|
| T1F0.5     | 15.7          | 340.0            | 450.0    | 1.00    | 1.00  | 0.00        | 0.00      | 0.00|
| T2F0.5     | 11.3          | 260.0            | 320.0    | 0.711   | 0.720 | 0.289       | 0.280     | 0.970|
| T3F0.5     | 7.7           | 170.0            | 300.0    | 0.667   | 0.490 | 0.333       | 0.510     | 1.529|
| T4F0.5     | 3.0           | 85.0             | 220.0    | 0.489   | 0.191 | 0.511       | 0.809     | 1.583|
| T5F0.5     | 1.8           | 0.0              | 200.0    | 0.444   | 0.115 | 0.556       | 0.885     | 1.594|
**Figure 7.** The relationship between irrigation water (IW) with yield (Ya) for 2014 and 2015 years. (The errors bars are SE of 14 plants)

**Figure 8.** The relationship between ETC with yield (Ya) for 2014 and 2015 years. (The errors bars are SE of 14 plants)

**Table 6.** Effects of irrigation treatments on yield and quality parameters of okra in 2014 year.

| Fertilization       | T   | Y   | FL  | FD  | FW  | NFP | DM  |
|---------------------|-----|-----|-----|-----|-----|-----|-----|
| (F1.0: %100, 100:100:100 NPK) | T<sub>F,1,0</sub> | 14.6<sup>a</sup> | 7.2<sup>a</sup> | 1.5<sup>f</sup> | 55.0<sup>b</sup> | 15.0<sup>a</sup> | 7.0<sup>b</sup> |
| T<sub>F,1,0</sub> | 10.5<sup>c</sup> | 6.8<sup>c</sup> | 1.4<sup>abcd</sup> | 42.0<sup>abc</sup> | 14.6<sup>b</sup> | 8.0<sup>c</sup> |
| T<sub>F,1,0</sub> | 7.0<sup>f</sup> | 5.8<sup>f</sup> | 1.2<sup>bcd</sup> | 30.0<sup>d</sup> | 13.4<sup>bc</sup> | 9.5<sup>d</sup> |
| T<sub>F,1,0</sub> | 3.5<sup>f</sup> | 4.2<sup>f</sup> | 1.0<sup>def</sup> | 27.0<sup>d</sup> | 12.5<sup>f</sup> | 11.0<sup>f</sup> |
| T<sub>F,1,0</sub> | 2.8<sup>f</sup> | 3.6<sup>f</sup> | 0.8<sup>ef</sup> | 12.0<sup>f</sup> | 9.5<sup>f</sup> | 12.5<sup>ab</sup> |
| **Treatments**     | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** |
| **Blocks**         | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** |

| (F2.0: %50, 50:50:50 NPK) | T<sub>F,0,5</sub> | 17.8<sup>b</sup> | 7.1<sup>ab</sup> | 1.4<sup>ab</sup> | 58.0<sup>b</sup> | 14.5<sup>ab</sup> | 8.0<sup>b</sup> |
| T<sub>F,0,5</sub> | 12.4<sup>c</sup> | 6.9<sup>c</sup> | 1.3<sup>abc</sup> | 44.0<sup>c</sup> | 14.2<sup>ab</sup> | 9.5<sup>d</sup> |
| T<sub>F,0,5</sub> | 8.7<sup>c</sup> | 6.0<sup>c</sup> | 1.1<sup>dec</sup> | 31.0<sup>e</sup> | 13.2<sup>c</sup> | 10.5<sup>c</sup> |
| T<sub>F,0,5</sub> | 2.8<sup>f</sup> | 5.0<sup>f</sup> | 0.9<sup>efg</sup> | 25.0<sup>d</sup> | 12.3<sup>d</sup> | 12.0<sup>b</sup> |
| T<sub>F,0,5</sub> | 2.0<sup>f</sup> | 4.2<sup>f</sup> | 0.7<sup>e</sup> | 14.0<sup>f</sup> | 10.8<sup>d</sup> | 13.0<sup>e</sup> |
| **Treatments**     | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** |
| **Blocks**         | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** |

T: Treatments, Y: Yield (t/ha), FL: Fruit Length (cm), FD: Fruit Diameter (cm), FW: 10 Fruit Weight (g), NFP: Number of Fruits Per Plant, DM: Dry Matter (%)

**Table 7.** Effects of irrigation treatments on yield and quality parameters of okra in 2015 year.

| Fertilization       | T   | Y   | FL  | FD  | FW  | NFP | DM  |
|---------------------|-----|-----|-----|-----|-----|-----|-----|
| (F1.0: %100, 100:100:100 NPK) | T<sub>F,1,0</sub> | 16.8<sup>a</sup> | 7.0<sup>a</sup> | 1.6<sup>c</sup> | 60.0<sup>a</sup> | 14.0<sup>b</sup> | 8.5<sup>f</sup> |
| T<sub>F,1,0</sub> | 12.6<sup>c</sup> | 6.7<sup>a</sup> | 1.6<sup>c</sup> | 48.0<sup>b</sup> | 13.5<sup>b</sup> | 10.0<sup>f</sup> |
| T<sub>F,1,0</sub> | 9.2<sup>c</sup> | 6.0<sup>b</sup> | 1.4<sup>ab</sup> | 40.0<sup>c</sup> | 12.5<sup>c</sup> | 11.0<sup>d</sup> |
| T<sub>F,1,0</sub> | 4.0<sup>f</sup> | 5.0<sup>c</sup> | 1.3<sup>abc</sup> | 29.0<sup>d</sup> | 11.5<sup>c</sup> | 11.5<sup>c</sup> |
| T<sub>F,1,0</sub> | 2.4<sup>f</sup> | 4.2<sup>d</sup> | 1.0<sup>c</sup> | 15.0<sup>e</sup> | 10.0<sup>d</sup> | 13.0<sup>de</sup> |
| **Treatments**     | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** |
| **Blocks**         | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** |

| (F2.0: %50, 50:50:50 NPK) | T<sub>F,0,5</sub> | 15.7<sup>b</sup> | 6.9<sup>a</sup> | 1.5<sup>c</sup> | 58.0<sup>a</sup> | 13.5<sup>ab</sup> | 9.0<sup>d</sup> |
| T<sub>F,0,5</sub> | 11.3<sup>d</sup> | 6.6<sup>a</sup> | 1.5<sup>c</sup> | 50.0<sup>b</sup> | 13.0<sup>b</sup> | 10.0<sup>f</sup> |
| T<sub>F,0,5</sub> | 7.7<sup>c</sup> | 5.9<sup>b</sup> | 1.4<sup>ab</sup> | 42.0<sup>c</sup> | 11.5<sup>c</sup> | 11.5<sup>c</sup> |
| T<sub>F,0,5</sub> | 3.0<sup>b</sup> | 5.0<sup>c</sup> | 1.3<sup>abc</sup> | 33.0<sup>d</sup> | 10.0<sup>d</sup> | 12.5<sup>b</sup> |
| T<sub>F,0,5</sub> | 1.8<sup>f</sup> | 3.9<sup>d</sup> | 1.1<sup>bc</sup> | 18.0<sup>e</sup> | 8.0<sup>f</sup> | 13.0<sup>e</sup> |
| **Treatments**     | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** |
| **Blocks**         | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** |

T: Treatments, Y: Yield (t/ha), FL: Fruit Length (cm), FD: Fruit Diameter (cm), FW: 10 Fruit Weight (g), NFP: Number of Fruits Per Plant, DM: Dry Matter (%)
Figure 9. Relationship between applied of irrigation water and fruit length (9.a.I-9.a.II), diameter (9.b.I-9.b.II), fruit weight (9.c.I-9.c.II), number of fruits per plant (9.d.I-9.d.II) and dry matter ratio (9.e.I-9.e.II).
The highest yield values in treatments which is applied as 100% (100:100:100 NPK) fertigation and 50% (50:50:50 NPK) fertigation for the 2014-2015 years were obtained from T₁F₁₀ and T₂F₀₅ treatments and found as 14.6-17.8 t ha⁻¹ and 16.8-15.7 t ha⁻¹, respectively. T₁F₁₀ treatments in both trial years were followed by T₂F₀₅, T₃F₁₀ and T₂F₀₅, T₃F₀₅ treatments and yield values for 2014 and 2015 years were 10.5, 7.0, 3.5 – 12.4, 8.7, 2.8 t ha⁻¹ and 12.6, 9.7, 4.0 – 11.3, 7.7, 3.0 t ha⁻¹, respectively. As expected, minimum yield values for 2014 and 2015 years were found from control T₂F₁₀ and T₂F₀₅ treatments (2.8–2.0 and 2.4 – 1.8 t ha⁻¹), in which irrigation was not applied. During the 2014 and 2015 testing years, the product yield of the untreated T₁F₁₀ and T₂F₀₅ treatments were lower by 421.4-790.0% and 600.0-772.2.0% compared to the T₁F₁₀ and T₂F₀₅ treatments. In addition, compared to the first year T₁F₁₀ and T₂F₀₅ treatments, T₂F₁₀, T₂F₁₀ and T₂F₀₃, T₁F₀₅, T₂F₀₅ treatments achieved 39.1%, 108.6%, 317.1% - 43.6%, 104.6%, 535.7 % and 33.3%, 82.6%, 320.0% - 38.9%, 103.9%, 423.3%, lower product yields in the second year, respectively. (Table 6 and 7). Yield and quality have been particularly affected by deficit irrigation and all treatments were situated in a different statistical group.

In the first year of the experiment, all yield averages were affected by different deficit irrigation treatments and all treatments were found in a different statistical group. The quality parameters such as fruit length, fruit diameter, and number of fruits per plant were affected by deficit irrigation and each of the treatments were almost situated in a different statistical group. There was a negative linear relationship between dry matter and applied water (IW). The amount of dry matter decreases as the water content in the tuber increases.

In the second year of the experiment, all yield averages were affected by different deficit irrigation treatments and all treatments were found in a different statistical group. Table 8 shows the WUE and IWUE values for drip-irrigated okra at the treatments of different irrigation and fertigation levels for 2014 year. In the experimental years was calculated as 1.38-1.26 and 1.26-1.41, respectively (Fig. 10). Except T₁F₁₀ and T₂F₀₅ treatments, kᵢ values increased parallel to the increase of water amount.

### Table 8. WUE and IWUE values for drip-irrigated okra at the treatments of different irrigation and fertigation levels for 2014 year.

| Treatments | Yield (t ha⁻¹) | Applied Water (mm) | ETa (mm) | WUE (kg m⁻³) | IWUE (kg m⁻³) |
|------------|---------------|-------------------|----------|--------------|--------------|
| T₁F₁₀      | 14.6          | 380.0             | 410.0    | 0.036        | 0.038        |
| T₂F₁₀      | 10.5          | 285.0             | 300.0    | 0.035        | 0.037        |
| T₃F₁₀      | 7.0           | 190.0             | 250.0    | 0.028        | 0.037        |
| T₁F₀₅      | 3.5           | 95.0              | 210.0    | 0.017        | 0.037        |
| T₂F₁₀      | 2.8           | 0.0               | 200.0    | 0.014        | 0.000        |
| T₁F₀₅      | 17.8          | 360.0             | 400.0    | 0.045        | 0.049        |
| T₂F₀₅      | 12.4          | 270.0             | 280.0    | 0.044        | 0.046        |
| T₃F₀₅      | 8.7           | 180.0             | 250.0    | 0.035        | 0.048        |
| T₁₀F₀₅     | 2.8           | 90.0              | 150.0    | 0.019        | 0.031        |
| T₂₀F₀₅     | 2.0           | 0.0               | 130.0    | 0.015        | 0.000        |

**Figure 10.** The relationship between relative yield decrease and relative evapotranspiration deficit for the experimental years (2014 and 2015)
Water-Use Efficiency

During the experimental years, when the irrigation water amount decreased, the WUE and IWUE values also decreased. The highest WUE values of both years were obtained from T1,F1.0, T3,F0.5, T1,F1.0 and T3,F0.5 treatments were calculated as 0.036, 0.045, 0.035, 0.044 – 0.040, 0.035, 0.039, 0.035 kg m⁻³, respectively. The highest IWUE values of both years were similarly obtained from T1,F1.0 and T3,F0.5 treatments and were calculated as 0.038, 0.049, 0.037, 0.046 – 0.047-0.046, 0.047, 0.043 kg m⁻³, respectively. The WUE and IWUE values of T1,F0.5 and T2,F0.5 treatments in 2014 were found to be higher than the other treatments such as T3,F1.0, T2,F1.0, T1,F1.0, T4,F1.0, T5,F0.5, T6,F0.5, T3,F0.5, T5,F0.5, T6,F0.5, respectively. The WUE and IWUE values of T1,F1.0 treatment in 2015 were found to be higher than the other treatments such as T3,F1.0, T4,F1.0, T1,F1.0, T5,F0.5, T1,F0.5, T3,F0.5, T2,F0.5, T3,F0.5, respectively (Table 8 and 9).

Discussion

In our study years, the amount of water applied ranged between 0.0 – 380.0 mm and 0.0 – 360.0 mm while the actual evapotranspiration ranged between 130.0 – 410.0 mm and 185.0 – 450.0 mm. Bahadur et al. (2009) reported that the total water applied for I₁, I₂, I₃, and I₄ were 628, 575, 255 and 180 mm, respectively. In mulched plot, the estimated total water applied was 278, mm and 395 mm in “no mulch”. Aliku and Oshunsanya (2016) reported that daily crop evapotranspiration values for DS1, DS2 and HF applications range from 1.16 to 3.36, 1.17 to 3.64 and 1.2 to 3.38 mm day⁻¹, respectively. Ünlükara and Cemek (2019) specified that the water consumption and fresh fruit production were found 664.0 mm and 28690 kg ha⁻¹, 596.0 mm and 24691.0 kg ha⁻¹ and 506.0 mm and 20554.0 kg ha⁻¹ for I100, I15 and I50 treatments, respectively. Sharma and Kaushal (2015) determined that drip irrigation in okra saves 20% to 61% of water, increases yield by 13% to 76%, fertilizer saving from 15% to 30% as compared with traditional method. Nagegowda et al. (2020) indicated that the application of water soluble fertilizer T4- 150:75:150 NPK kg ha⁻¹ through fertigation either with mulch (14.05 q ha⁻¹) or non-mulch (11.83 q ha⁻¹) recorded significantly higher seed yield than fertilization through soil application (9.92 q ha⁻¹). These results were consistent with water and water consumption values found from previous studies (Anu et al., 2014; Sharma and Kaushal 2015; Aliku and Oshunsanya, 2016; Sindhu et al., 2016; Deveci et al., 2017; Kadam et al., 2017; Adejumo et al., 2018; Ünlükara and Cemek, 2019; Nagegowda et al., 2020).

The okra yield for 2014-2015 trial years hanged between 8640.0-500.0 kg ha⁻¹ and 8320.0-900.0 kg ha⁻¹. According to the conclusions of this trial, it is observed that limited irrigation has an important effect on the yield of the fruit. This result is in agreement with (Soomro et al., 2012, Sharma et al., 2016; Ulu et al., 2016; Deveci et al., 2017; Ünlükara and Cemek, 2019; Nagegowda et al., 2020). Similar results were obtained in previous irrigation regimes (Sharma and Kaushal, 2015; Sharma et al., 2016; Deveci et al., 2017; Ünlükara and Cemek, 2019; Nagegowda et al., 2020). As the irrigation water amounts decreased, the yield decreased significantly as well. The quality parameters of okra showed a same reaction to limited irrigation as beheld in the yield. The whole irrigation applications had higher values than the T3,F1.0 and T3,F0.5 treatments in which water is not used. These values show similarities with (Haris et al., 2014; Deveci et al., 2017; Adejumo et al., 2018; dos Santos Farias et al., 2019). The fruit weight values of T1,F1.0 and T1,F0.5 treatments were higher compared to other irrigation treatments. In years of the trial, the maximum dry matter rate was observed in T3,F1.0 and T3,F0.5 treatments, while the minimum dry matter rate was found from T1,F1.0 and T1,F0.5 applications. With the obtained data, it can be decided that with the decrease in irrigation water deficit, there will be significant increase in the amount of dry matter. These results are consistent with those of (Bahadur et al., 2009; Sharma et al., 2016; Deveci et al., 2017; Adejumo et al., 2018; dos Santos Farias et al., 2019).

The highest WUE and IWUE values for 2014 and 2015 years found as 0.036-0.045, 0.040-0.035 kg m⁻³ and 0.038-0.049, 0.047-0.046 kg m⁻³, respectively. T1,F1.0, T3,F0.5, T2,F1.0, T3,F1.0, T1,F1.0 and T3,F0.5, T3,F0.5, T3,F0.5, T3,F0.5, T3,F0.5, T3,F0.5 respectively (Table 8 and 9).
Conclusions

According to the results of the study, irrigation water were applied 380.0 and 360.0 mm in T_{F1,0} treatment in 2014 and 2015 years. The plant water consumptions of okra were determined as 410.0-400.0 mm and 325.0-450.0 mm for T_{F1,0} and T_{F0,5} treatments in 2014 and 2015 years. The factors of k_{p} for the different treatments (T_{F1,0} and T_{F0,5} treatments) in 2014 and 2015 years were calculated as 1.38-1.26 and 1.26-1.41 for okra, respectively. The factors of k_{p} (1.38-1.26 and 1.26-1.41) values are bigger than 1.00 showed that the okra was susceptible to water. The highest yield decreases in all treatments were in T_{F1,0} and T_{F0,5} treatments, while the lowest yield decreases were in T_{F1,0} and T_{F0,5}treatments. In our study, it was studied out that irrigation treatments considerable influences yield, fruit length, 10 fruit weight, fruit diameter, number of fruits per plant and dry matter ratio.

In this study, it was studied out that irrigation applications considerably influences yield, 10 fruit weight, fruit diameter, fruit length, number of fruits per plant and dry matter. In both years of the study, the highest yields were 14.6-17.8 t h^{-1} and 16.8-15.7 t h^{-1} and it was observed in T_{F1,0} and T_{F0,5} treatments. The lowest yield was observed as 2.8-2.0 t h^{-1} and 2.4-1.8 t h^{-1} in T_{F1,0} and T_{F0,5}treatments. Yield decreased considerably as a result of the diminishment in the water amount. It is necessary to carefully plan different irrigation and fertigation levels in arid or semi-arid regions where precipitation is insufficient. However, it is possible to say that different irrigation and fertigation levels and timing are significantly effective on okra yield. If a different irrigation and fertigation levels is obligatory, water deficiency should be planned only for T_{F1,0} and T_{F0,5} treatments of okra. Compared with other treatments, it seems more reasonable to apply different irrigation and fertigation levels in these two treatments. It can be recommended that T_{F1,0} and T_{F0,5}treatments are most suitable periods for the different irrigation and fertigation levels practices for okra irrigation by drip irrigation.

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