

Influence of Deficit Irrigation on Water Use Efficiency and Bird Pepper Production (*Capsicum annuum* L.)

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Abstract. An experiment was conducted in indoor lysimeters to study the effect of deficit irrigation on water use efficiency and bird pepper (*Capsicum annuum* L.) production under drip irrigation system. Six-week-old seedlings of hot pepper were transplanted into the lysimeters. Four seedlings spaced 40 cm apart were grown in each lysimeter. Three irrigation treatments were investigated. The first treatment (W1) was 100% of the field capacity as a control. The second and third treatments (W2 and W3) were giving 85% and 70% of the field capacity, respectively, as deficit irrigation treatments. The deficit irrigation practice was applied after 15 days of the transplanting and continued for the whole growth season. The results indicated that the highest yield was obtained from W1 which grew under no stress. Deficit irrigation tends to increase water use efficiency and decrease the fresh fruit yield. Giving 85 % of the field capacity (W2) led to save 41% of the irrigation water and reduce the total yield by 28.9 %. Giving 70% of the field capacity (W3) resulted in 85 % of irrigation water saving but 40% of the total yield was lost. The study indicated that, bird pepper is very sensitive to water stress, however water deficit is a practical technique to save large amounts of irrigation water.

Keywords: Deficit irrigation; Bird pepper production; Drip irrigation.

Introduction

Increasing food production per unit of water is one of the greatest challenges facing the researchers especially in arid and semi-arid areas, which have limited water resources like Egypt, and in tropic and sub-tropics, characterized by hot dry weather during summer like Ishigaki Island, Japan.

Egypt is a country with tremendous land resources but limited water resources. The cultivated area is only 3.3% of geographical area. The main water source for Egypt is Nile River. The total water resources in Egypt are 55.5 billion m³ from Nile River, in addition to 6 billion m³ from groundwater, flash flood and rainfall. The agricultural sector consumes 84% of the water resources, which irrigate 3.3 Mha. The great challenge facing the Egyptian researchers is to expand the irrigated area from 3.3 Mha to 4.68 Mha with the same water resources by the year 2025 (Elarabawy and Tosswell, 1998). Similar conditions of water shortage exist in Ishigaki island, Japan where water stress during hot seasons frequently damages crops. On this island, insufficient water sometimes does not allow for proper irrigation. Thus, practices to increase water productivity and irrigation efficiency like deficit irrigation are greatly required (Ismail and Ozawa, 2007).

Deficit irrigation was proposed long time ago as a technique that irrigates the entire root zone with less evapotranspiration and leads to reduce the irrigation water use with maintaining farmers' net profits (Hoffman, *et al.*, 1990). The decline in water availability for irrigation and the positive results obtained in some fruit tree crops have renewed the interest in developing information on deficit irrigation for a variety of crops (FAO Report, 2002; Dorji, *et al.*, 2005 and Fereres and Soriano, 2007).

Bird pepper is a very pungent variety, suitable for fresh market or dehydration and having a good tolerance to diseases. Hot pepper is a high value cash crop in many countries of the world especially in Egypt. The total world production of this crop has been estimated to be 14 to 15 million tons a year (Weiss, 2002). Hot pepper planting is confined to warm and semi-arid countries where water is often a limiting factor for production. This necessitates the optimization of water management for pepper production because it is considered one of the most susceptible horticultural plants to drought stress for many reasons such as: i) the wide range of transpiring leaf surface and high stomatal conductance (Alvino, *et al.*, 1994), ii) its shallow root system (Dimitrov and Ovtcharova, 1995).

The blossom stage of hot pepper considers the most sensitive period to water stress (Bruce, *et al.*, 1980). For high yields, an adequate water supply and relatively moist soils are required during the total growing period. Reduction in water supply during the growing period in general has an adverse effect on yield, and the greatest reduction in yield occurs when there is a

continuous water shortage until the time of first picking. The period at the beginning of the flowering period is the most sensitive to water shortage, and soil water depletion in the root zone during this period should not exceed 25% (Dimitrov and Ovtcharova, 1995). Water shortage just prior and during early flowering reduces the number of fruits. The effect of water deficit on yield during this period is greater under conditions of high temperature and low humidity.

Kang, *et al.* (2001) conducted a hot pepper study applying water through alternate drip irrigation on partial roots (ADIP), fixed drip irrigation on partial roots (FDIP) and even drip irrigation on whole roots (EDIP). They concluded that ADIP maintained high yield with up to 40% reduction in irrigation compared to the other treatments. Della Costa and Gianquinto (2002) reported that continuous water stress significantly reduced total fresh weight of pepper fruits. Moreover, Antony and Singandhupe (2004) found that the total pepper yield was less at lower levels of irrigation.

Dorji, *et al.* (2005) declared that the deficit irrigation could be feasible irrigation strategy for hot pepper production where the benefit from saving water outweighs the decrease in the total fresh mass of fruit. Gencoglan, *et al.* (2006) also found that deficit irrigation significantly affected the fruit numbers, fruit dry weight and dry yield of hot pepper; the average fruit numbers increased over 3 times with non-stressed compared to water stressed treatments. They added that, when irrigation water is plenty, the red hot pepper can be irrigated at the no stress level, but when water source is scarce, pepper can be irrigated at the lower water level with taking economic conditions into consideration.

Since the amount of water available for agriculture is generally limited overall the world and especially in Egypt, knowledge about the relationship between yield and quality of the product and irrigation regimes is important to maximize the benefit of the available water supply. Therefore, the objectives of this study are: (i) to evaluate the water use efficiency of deficit irrigation for bird pepper (*Capsicum annuum* L.). and (ii) to determine the effect of water stress occurring under drip irrigation system during the whole growing season including the blossom stage on fresh fruit yield of bird pepper.

Materials and Methods

Plant Materials and Experiment Conditions

The experiment was conducted in indoor lysimeters of a greenhouse situated at the Okinawa Subtropical Station (24°23/N, 124°12/E) of the Japan International Research Center for Agricultural Sciences (JIRCAS), Ishigaki, Japan. The size of each indoor lysimeter was 1.25 m in width, 1.55 m in length and 1 m in depth. The soil inside the lysimeters was sandy clay loam and its detailed physical properties are presented in Table 1. All of the lysimeters were equipped with watering systems on the surface and in the bottom, and percolated water collection systems in the bottom. Detailed description of the equipped lysimeters is presented in Ozawa *et al.*, (2005). The weather conditions inside the greenhouse were similar to those outside and if they change, a ventilation system automatically starts to readjust them. Six-week-old seedlings of hot pepper were transplanted into the lysimeters. Four seedlings spaced 40 cm apart were grown in each lysimeter. The plants were fertilized with a Nutriccoat fertilizer containing 14% N, 12% P₂O₅ and 14% K₂O. A dosage of 10g fertilizer was added twice at 30 and 60 days from transplanting, at 10 cm below soil surface in the root area of each plant.

Table 1. Physical characteristics of investigated soils.

| | | | |
|---|-----------------|--------|--------|
| Particle size analysis | Clay % | Silt % | Sand % |
| | 21.4 | 9.2 | 69.4 |
| Texture grade | Sandy clay loam | | |
| Saturation cm ³ /cm ³ | 0.45 | | |
| Field Capacity cm ³ /cm ³ | 0.22 | | |
| Wilting point cm ³ /cm ³ | 0.09 | | |
| Sat. hydraulic Conductivity cm/hr | 0.61 | | |
| Bulk density g/cm ³ | 1.46 | | |
| Organic matter % | 2.8 | | |

Irrigation System, Treatments and Experimental Design

Drip irrigation line was installed on each lysimeter and individual plants were irrigated through one emitter placed on the side of the plant, 0.10 m away from the stem. Fifteen days after transplanting, plants were subjected to the following three irrigation treatments during the whole growing season. A full irrigation treatment (W1) was given 100% of the field capacity and considered as control. The second and third treatments (W2 and W3) were

giving 85% and 70% of the field capacity respectively, and considered deficit irrigation treatments. The irrigation water was supplied every three days. To calculate the required amount of irrigation water for each irrigation, soil water content was measured at 9 a.m. on the day of irrigation and the reduction in soil water content down to 0.3 m depth for the first 6 weeks of the experiment and down to 0.6 m depth for the rest of the growing season for each treatment was compensated by adding water. The experiment had a completely randomized design with three replications for each treatment.

Measurements of Soil Water Content and Leaf Water Potential

Soil water content was measured vertically at 0.3, 0.6 and 0.9 m. soil depth by Time Domain Reflection (TDR) method, where the lysimeters were equipped by CS616 water content reflectometer sensors at the mentioned depths. Soil water content was recorded at a 60 minute interval by CR10X data logger. Leaf water potential (LWP) was determined from two fully exposed mature leaves per plant. Measurements were made at 13:00h for 7 consecutive days (280-286 Julian Days) using a Scholander pressure chamber.

Measurements of Yield and Water Use Efficiency

Fruits were harvested 5 times during the season. The first fruit yield was harvested after 53 days of transplanting. The second, third, fourth and fifth fruit yields were collected after 14, 35, 52 and 85 days of the first harvest, respectively. Fruits were separated to green and red pepper after harvesting. The fresh fruit mass for each type for each individual plant was recorded. Shoots of each individual plant were collected, oven-dried at $71 \pm 1^\circ\text{C}$ and weighed to determine the distribution of plant dry mass. Water use efficiency (WUE) was obtained from dividing the total yield in kg/ha by the total water supply in m^3/ha . Total supplied water and deep percolation below 1 m soil depth were automatically calculated via lysimeter equipments.

The reductions in yield and water saving were calculated from the following equations:

$$\text{Reduction in yield} = 100 - \left(\frac{\text{yield of W2 or W3}}{\text{yield of W1}} \times 100 \right)$$

$$\text{Water saving} = 100 - \left(\frac{\text{water consumption of W2 or W3}}{\text{water consumption of W1}} \times 100 \right)$$

Statistical Analysis

Data were analyzed by statistical software program (StatSoft, 1995). Treatment means were separated by LSD test at $P < 0.05$.

Results and Discussions

Total Water Supply, Soil Water Content and Plant Water Status

Figure 1 shows the results of the total supplied water for all treatments during the whole growing season.

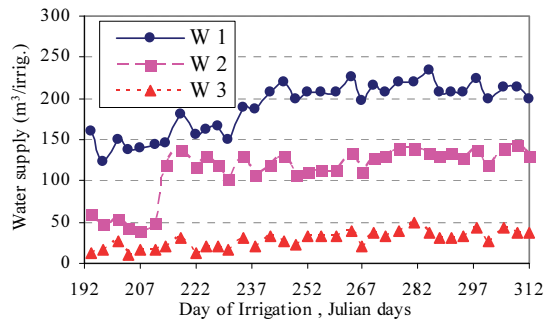


Fig. 1. Total water supply for fully (W1) and deficit irrigation (W2 and W3) treatments along the growing season.

Results revealed that W1 treatment received the highest amount of irrigation water followed by W2 treatment, while the least amount of irrigation water was received by W3 treatment.

The average change in soil water content for all investigated treatments is presented in Figure (2).

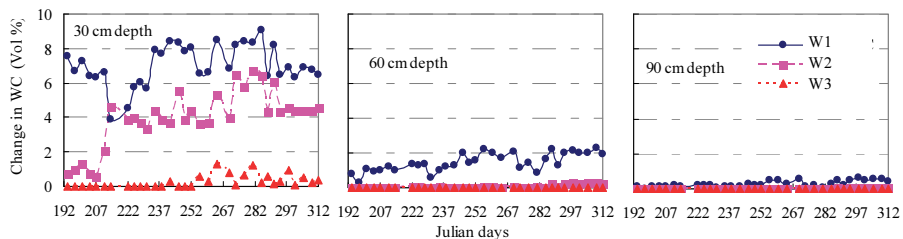


Fig. 2. Changes in volumetric soil water content (WC) in fully (W1) and deficit irrigation (W2 and W3) treatments for different soil depths.

The change in soil water content was calculated by subtracting the measured soil water content before irrigation from the measured soil water content after irrigation for each replication. The average change in soil water content

was obtained by taking the average of all replications for each treatment. The results showed that the majority of the average change in soil water content was in the surface layer (0.3 m depth) for all treatments. The highest change in soil water content was recorded for W1 followed by W2 and W3 treatments. The increase in soil water content at 0.6 m depth was only measured for the W1 compared with W2 and W3 treatments. A little change was measured for W1 at 0.9 m depth but no changes were recorded for W2 and W3 ones.

The distribution of soil water content presented in Fig. 2 reverses the amount of total water supplied found in Fig. 1. For all treatments the highest soil water content was measured at surface layer (0.3 m). Since the supplied amount of water was enough to bring the surface layer (0.3 m) to field capacity in W1 or less than field capacity in W2 and W3, all the supplied water retained on that layer and resulted in a high soil water content. After the first six weeks of transplanting and due to root growth, the targeted deficit irrigation depth increased to be 0.6 m. The water deficit down to the 0.6 m depth was replenished in subsequent irrigations, and then the soil water content started to increase in that layer, but only in the W1 treatment, because the amount of supplied water brought the upper 0.6 m to the field capacity (Fig. 2). Moreover, it led to a little increase in soil water content of the third layer (up to 0.9 m). No change in the soil water content of W2 and W3 at 0.6 and 0.9 m was found because the amount of water supply was less than field capacity and all added water retained in the surface layer (Fig. 2).

Results of leaf water potential (LWP) presented in Fig. 3 showed that the highest value of LWP was measured for W1 followed by W2 and W3 treatments, respectively. The LWP value increased after irrigation and continuously decreased until the next irrigation given.

Leaf water potential decreased markedly in deficit irrigation treatments because fruits are stronger sinks for water than the vegetative parts of plants. Therefore, competition for water from developing reproductive sinks coupled with increased evaporative demand due to rising temperature during the late growing season may have caused the reduction in LWP (Chalmers, 1989).

Dry Matter and Fruit Yield

The average dry matter for all studied treatments is shown in Fig. 4. Decreasing the water supply caused a significant decrease in the total dry

matter. However, the reduction was small. The highest dry matter weight was obtained from W1 followed by W2 and then W3 treatment, respectively (Fig. 4).

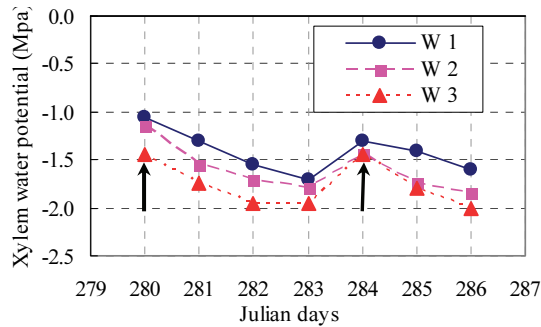


Fig. 3. Change in the leaf water potential measured at 13:00h for 7 consecutive days for all treatments.

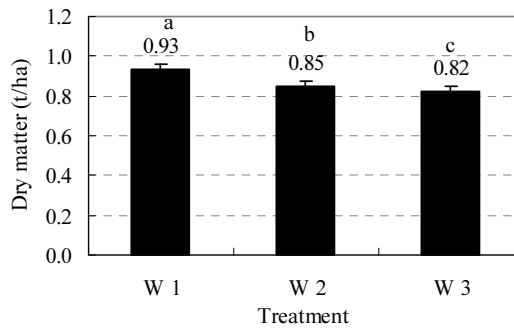


Fig. 4. Dry matter weigh as a response of deficit irrigation treatment (means with different superscripts differ significantly, $P < 0.05$).

Water stress did not strongly affect the dry weight of pepper plants during the first part of its cycle, as stomatal conductance is fairly to moderately resistant to drought, allowing the maintenance of transpiration rate (Delfine, *et al.*, 2001). Moreover, the increase in translocation of dry matter towards reproductive parts might have caused an increase in dry weight of reproductive parts at the lower level of irrigation, where the plants were more dehydrated than other treatments. Fruits harvesting started after 53 days of transplanting. The average amount of each individual harvested fruit yield along the season is presented in Fig. 5. The highest individual fruit yield was obtained from W1 followed by W2 and then W3 treatment. The results also indicate that deficit irrigation treatments (W2 and W3) reached the highest peak of fruit yield after 3.5 months of transplanting, while the

fruit yield along the season continuously increased using the fully irrigation treatment, W1 (Fig. 5).

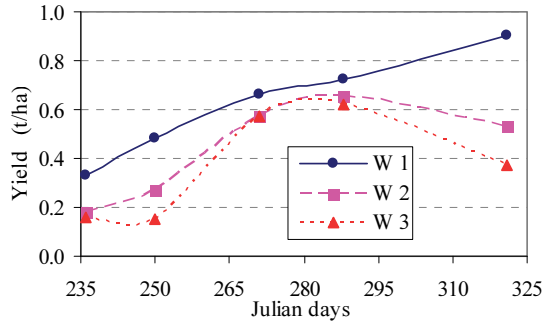


Fig. 5. Fruits yield along the growth season for all irrigation treatments.

The total fresh fruit yield for all treatments is shown in Fig. 6(A). There were significant differences among treatments. The highest total fruit yield was recorded for W1 followed by W2 and W3 treatments; however the difference between W2 and W3 was smaller compared to W1 treatment. The results in Fig. 6(B) reveal that red fruits were almost the same in all treatments and no significant differences were found. This means that there is no relationship between amount of irrigation water and fruit ripening.

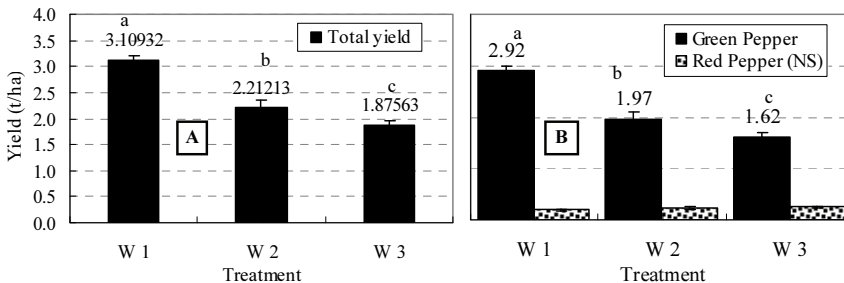


Fig. 6. Total fruit yield (A) as well as total green and red fruit (B) as affected by deficit irrigation treatments (means with different superscripts differ significantly, $P < 0.05$).

Fully water irrigation treatment (W1) gave the highest yield (Fig. 5 and 6(A)) because increasing soil water content led to increasing plant height and number of branches, resulting in an increase in number of fruits and total yield. Similar results were reported by Antony and Singandhupe (2004). It is generally accepted that water deficit reduces pepper yield. For high yields, an adequate water supply and relatively moist soils are required during the entire growing season. The reduction in water supply during the growing period, in general, has an adverse

effect on yield. The greatest reduction in yield occurs when there is a continuous water shortage until the time of first picking (Jaimez, *et al.*, 2000; Delfine, *et al.*, 2001; Della Costa and Gianquinto, 2002; Antony and Singandhupe, 2004; and Sezen, *et al.*, 2006). Figure 6A shows a reduction in the fresh fruit yield of hot pepper due to deficit irrigation because decreasing the soil water content in that soil reduced the fruit size and the total fruit weight of hot pepper. Dry matter transport in dehydrated plants occurred readily but the total yield was less at lower level of irrigation (Westgate and Boyer, 1985). The reduction in fruit yield of hot pepper under deficit irrigation might be due to the reduction in fruit size and numbers, but mainly from fruit size because water deficit may slightly affect fruit number (Fernandez, *et al.*, 2005). The reduction in pepper fruit size appears as the controlling factor for fruit yield. Obviously, the effect of water deficit is much more important when yield is expressed as fruit fresh weight like in the present study (Fig. 6A). Deficit irrigation significantly reduced fresh yield in terms of fresh mass of fruit per plant. However, the total dry mass of fruit per plant may be similar (Dorji, *et al.*, 2005). No significant difference was found in red hot pepper yield among the treatments (Fig. 6(B)) because the water deficit may not have effects on the fruit ripening. Gonzalez, *et al.* (2007) found that water deficit did not hasten ripening but reduced biomass production.

Water Use Efficiency (WUE)

The water use efficiency for fully and deficit irrigation treatments are presented in Fig. 7. There were highly significant differences among irrigation treatments. Increasing the irrigation deficit was met by a high increase in the WUE. The highest value of WUE was obtained from W3 treatment while the lowest one was recorded for W1 treatment. The difference in WUE between W1 and W2 was small compared to that between W2 and W3 treatments, however, these differences were significant.

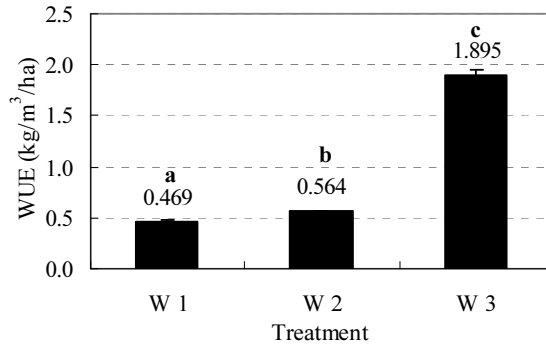


Fig. 7. Water use efficiency (WUE) for irrigation treatments (means with different superscripts differ significantly, $P < 0.05$).

A sharp increase in water use efficiency was obtained by deficit irrigation. The total dry mass of fruit may be slightly affected by deficit irrigation (Dorji, *et al.*, 2005). This indicates that water movement into fruit may have decreased with progressive development of water deficit without affecting the translocation of dry matter into the fruit and resulted in an increase in mass production per unit of water, which led to high water use efficiency (Fig. 7).

The amount of water saving due to deficit irrigation is shown in Table 2. Obviously deficit irrigation saves water but reduces yield. Irrigating hot pepper at 85% of field capacity during the complete growing season reduced the total yield by 28.9 % and saved about 41% of irrigation water. Increasing the deficit irrigation resulted in a severe yield reduction. Giving 70% of the field capacity reduced the fresh fruit yield by 39.7 %, but sharply increased the water saving to be about 85% of irrigation water (Table 2).

Table 2. Irrigation efficiency and water saving in relation irrigation deficit.

| Treatment | Total water supply (m ³ /ha) | Deep percolation (m ³ /ha) | Water consumption (m ³ /ha) | Yield (ton/ha) | Reduction in yield due to deficit irrig. (%) | Water saving due to deficit irrig. (%) |
|--------------------------|---|---------------------------------------|--|----------------|--|--|
| W ₁ (100% FC) | 6630.00 | 1.67 | 6628.33 | 3.109 | 0.0 | 0.0 |
| W ₂ (85 % FC) | 3923.33 | 1.00 | 3922.33 | 2.212 | 28.9 | 40.8 |
| W ₃ (70% FC) | 990.00 | 0.00 | 990.00 | 1.875 | 39.7 | 85.0 |
| LSD _{0.05} | 621.9 | 1.67 | 620.5 | 0.283 | - | - |

Conclusions

From the present study, it is observed that the highest yield was obtained from the treatment grown with no-stress (W1, 100% of FC). Deficit irrigation tended to decrease the fresh fruit yield. Irrigating hot pepper at 85% of the field capacity every three days during the complete growing season led to a reduction of 28.9% from the total fresh fruit yield, while adding water at 70% of the field capacity every three days reduced the fresh fruit yields by 39.7%. The severe reduction in total yield of W3 was due to the low soil moisture during the first picking. Deficit irrigation did not show significant effects on fruit ripening (red color fruits). The amount of saved water sharply increased by deficit irrigation treatments, producing about 60% of total fruit yield led to save 85% of irrigation water, while producing about 71.1 % of the total fruits yield saved about 41% of irrigation water. In conclusion, deficit irrigation could be a feasible irrigation technique for hot pepper production where the benefit from saving large amounts of water outweighs the decrease in total fresh mass of fruit.

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تأثير معدل العجز في كمية مياه الري المضافة على كفاءة استخدام المياه وإنتاج الفلفل الحار (*Capsicum annuum* L.)

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المستخلص. أجريت تجربة ليسيمترات داخل الصوبة الزراعية لدراسة تأثير معدل العجز في مياه الري المضافة على كفاءة استعمال المياه، وإنتاج الفلفل الحار تحت نظام الري بالتنقيط. وفيها تم زراعة شتلات الفلفل الحار وعمرها ستة أسابيع في الليسيمترات بمعدل أربعة شتلات في كل ليسيمتر على مسافات زراعة ٤٠ سنتيمترًا، ثم تم دراسة تأثير ثلاثة معاملات من الري عليها. المعاملة الأولى (W_1) كانت تمثل ١٠٠٪ من السعة الحقلية في التربة، أما المعاملة الثانية والثالثة (W_2 و W_3) كانتا تعطيان ٨٥٪ و ٧٠٪ من السعة الحقلية على التوالي، واعتبرت أنها معاملات عجز في كمية مياه الري المضافة، وتم تنفيذها في الحقل بعد ١٥ يوم من الزراعة، واستمرت طوال فصل النمو.

أشارت النتائج المتحصل عليها أن أعلى محصول نتج من المعاملة (W_1) التي نمت بدون إجهاد مائي طوال موسم النمو. أما كمية العجز في مياه الري المضافة، فقد أدت إلى زيادة كبيرة في كفاءة استعمال المياه، ونقص في محصول الثمار الطازجة في باقي المعاملات. حيث أن إضافة مياه الري بمعدل ٨٥٪ من السعة الحقلية (W_2) أدى إلى توفير ٤١٪ من ماء الري، ونقص

المحصول الكلي بمقدار ٢٨,٩٪. أما إضافة مياه الري بمعدل ٧٠٪ من السعة الحقلية (W_3) أدى إلى توفير ٨٥٪ من ماء الري، لكن أيضاً إلى فقد ٤٠٪ من المحصول الكلي. لذلك يتضح من الدراسة أن نبات الفلفل الحار حساس جداً لمعدل العجز في مياه الري، لذلك فإن معدل العجز في مياه الري المضافة يعتبر تقنية عملية لتوفير كميات كبيرة من مياه الري المستخدمة قد تتفوق اقتصادياً على معدل النقص في المحصول الناتج.

الكلمات الدالة. عجز مياه الري، إنتاجية الفلفل الحار، الري بالتقسيط.