EFFECT OF IRRIGATION INTERVAL ON GROWTH CHARACTERISTICS, PLANT WATER STRESS TOLERANCE AND WATER USE EFFICIENCY FOR CHILE PEPPER

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ABSTRACT

Container experiments were carried out to study the effect of irrigation interval on root development, yield and water use efficiency for Chile pepper. Each containers has a size of 31 x 15 x 60 cm with one transparent side for the visual view of the root development. Sandy clay loam soil was packed in each container to a 50 cm height. One seedling of Chile pepper (*Takano tsu me*) was transplanted in the middle of each container on the 15th of February, 2005. Three irrigation intervals, (1, 3 and 5 day) with four replications were investigated. The soil water content in each container was kept at field capacity by compensating the loss in weight by adding water.

The results indicated that increasing the water supply caused increases in the root biomass. The 1-day irrigation interval produced the highest root biomass while the 5-day resulted in the least root biomass. The 3-day irrigation interval showed remarkable roots development in the bottom of the containers, resulting in 12 % water saving compared to other treatments. The increasing in the irrigation interval induced an increase in the xylem water potential but it caused a reduction in leaf growth. Generally, the proper irrigation interval increases the plant water stress tolerance by developing the root in lower layers where high soil moisture content is present.

Keywords: irrigation interval – Pepper – root development

1. INTRODUCTION

In the arid and semi arid as well as sub-tropical regions, water shortage is a normal phenomenon and seriously limits the agricultural potential. Therefore, under irrigation or rain-fed conditions, it is important for the available water to be used in the most efficient way. The proper irrigation interval can play a major role in increasing the water use efficiency and the productivity by applying the required amount of water when it is needed. On the other hand, the poor irrigation interval can lead to the development of crop water deficit and result in a reduced yield due to water and nutrient deficiency. Early in the season when plants are small, it is beneficial to encourage the roots to explore as much of the soil profile as possible. This maximizes nutrient uptake and stress tolerance later in the season. Hartz, (1999) showed that the best approach to early season irrigation is to began with a full soil profile to encourage deep rooting by non routine watering instead of waiting until the 20% depletion of available water to reach the appropriate monitoring depth. This means waiting from 5 to 7 days or longer between irrigations depending on the weather. Soil profile should be filled with water at each irrigation. Frequent light irrigations result in plants with shallow root systems that suffering from water stress even with short periods of water deficit (Sanders, 1997). The soil in the early growth root zone during germination process should be moist at the time of planting. So, irrigation should take place to wet this zone. As the plant grows, a moist soil becomes necessary for proper root development, because roots will not grow through a dry layer of a soil. A dry soil layer produces a shallower rooting depth than is desirable (Wright, 2002). Leskovar (1998) pointed out that irrigation method, rate, timing and interval may influence the physical and chemical properties of the growing media and thereby, affecting root initiation, elongation, branching, development and dry matter partitioning between roots and shoots. Both root mass and length were reported to decrease significantly with water stress (Snyman, 2004). Reduced root dry weight, basal root number, basal root diameter and shoot growth were obtained from pepper transplants exposed to mild drought stress when compared with well water seedlings (Leskovar and Cantliffe 1992). Chile pepper (*Takano tsu me*) is a very pungent variety; it is suitable for the fresh market or dehydration; it has a good tolerance to diseases. Chile pepper is also a high value cash crop in many countries of the world. The total world production of this crop has been estimated to be 14 to15 million tons a year (Weiss, 2002). Chile pepper is a good indicator for measuring water stress for several reasons: i) Hot pepper planting is confined to warm and semi-arid countries where water is often a limiting factor for production, ii) It is considered one of the most susceptible horticultural plants to drought stress, and iii) it has a shallow root system (Dimitrov and Ovtcharrow, 1995; Kang et al., 2001).

The objectives of this study are to i) show out the best irrigation interval which maximizes root development, crop production and water use efficiency for chile pepper, and ii) estimate the amount of water that can be saved at the early growth stages of this plant

2. MATERIALS AND METHODS

2.1. Irrigation Interval Experiment

A container experiment was carried out in a greenhouse situated at Japan International Research Center for Agricultural Science (JIRCAS), Okinawa Subtropical Station, Ishigaki, Japan to study the effect of irrigation interval on root development, growth characteristics, plant water stress tolerance and water use efficiency for chile pepper. The container size was 31 x 15 x 60 cm with one transparent side for the visual view of the root development. A container with this size makes the obtained results are comparable to the field data because it enables the plants to grow in an area similar to that of the actual field. Moreover, the soil depth inside each container is 50 cm which is considered a suitable for most plants; especially those have small root depth like chile pepper. In addition, growing the plants in containers enables to collect all plant roots after washing the soil by water. Sandy clay loam soil taken from the surrounding area with bulk density of 1.5 g/cm3 mixed with CaCO3 and Phosphorus fertilizers were packed in each container to 50 cm height. One seedling of chile pepper (Takano tsu me) was transplanted in the middle of each container on the 15th of February, 2005. Three irrigation intervals, (1, 3 and 5 day) with four replications were investigated. These irrigation intervals are frequently used by farmers under drip irrigation system in open fields of the surrounding areas. Before starting the treatments, the containers were saturated with water and then, they were kept at the field capacity during the growth period. The development of roots was observed from the transparent side of the container. The plants received the last watering on March 24 to adjust the water content of all treatments to the field capacity, and then the soil surface was covered by transparent plastic mulch to prevent evaporation in order to study the effect of root development on the plant water stress tolerance. The leaf area index was measured every two days for all treatments. When the water stress symptoms appeared on the plants, xylem water potential was determined from two fully exposed mature leaves per plant. The measurements were made at 1:00 pm for the last 5 consecutive days before harvest using a Scholander pressure chamber. It was difficult to measure the xylem water potential along the growth period of the experiment because two matured leaves must be killed every day for collecting the measurements.

The weight of the aboveground biomass was recorded after drying at 70 ºC. The roots for each 10 cm depth were collected separately and washed and weighted after drying at 70 ºC to study the roots mass over depth for each irrigation interval. Analyzing the results of the conducted experiment revealed that 3 day irrigation interval was the best due to the developed roots at the bottom of the container (40-50 cm depth). To confirm our obtained results, another experiment was conducted aimed to restrict the horizontal root growth for certain depths, while the vertical root growth was unrestricted to show whether the enhancement at the 3 day irrigation interval was due to the developed roots in lower soil layers or not.

2.2. Root Restriction Experiment

Another experiment was carried out in the same containers explained previously with the same lay-out except for the treatments. Three different lengths, (10, 20 and 40 cm) of PVC pipe with a diameter of 14 cm were installed in the containers to constitute three horizontal root restriction treatments with three replications. Chile seedlings were transplanted on July 1st in the middle of the pipes. The root growth was restricted within the pipe in the upper 10 cm of container for the first treatment (T10), the upper 20 cm depth for the second treatment (T20) and the upper 40 cm depth for the third treatment (T40). The containers were kept at the field capacity during the growth period by compensating the loss in weight by adding water every three days. The irrigation water was added on the soil surface to maintain homogeneously distributed inside and outside the pipes. Shoot weight was recorded after the drying at 70 ºC. The roots in each 10 cm depth were also collected separately, washed and weighted after drying at 70 ºC. Collecting and recording the yield three times with 10 days interval during the growth period and analyzing the total green chile pepper per plant were also preformed. The plants were harvested on October 3rd after the roots reached to the bottom of the containers. The data were analyzed by statisica software program (StatSoft Inc, 1995). Treatment means were compared using the LSD test at $P < 0.05$

3. RESULTS

3.1. Irrigation Frequency Experiment

3.1.1. Shoot and Root Dry Weights

The average shoot and root dry weights as influenced by irrigation intervals are illustrated in Figure 1. The results indicated that the highest shoot dry weight was obtained using 3-day followed by 1 and 5 day irrigation interval, although the differences between treatments were not significant. The least root dry weight was recorded from 5 day irrigation interval while no differences were found between 1 and 3 days irrigation intervals.

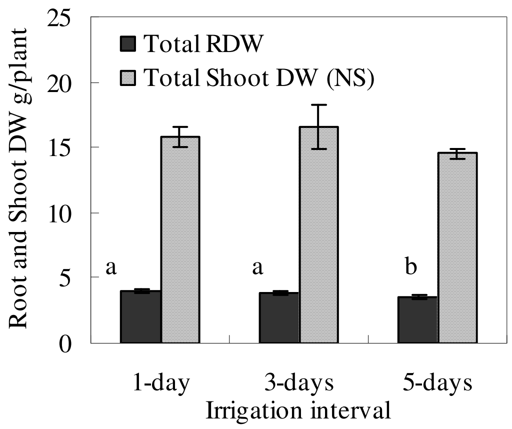

Figure1: Effect of irrigation interval on root and shoot dry weights (Means with different superscripts differ significantly (P<0.05) while NS is not significant)

The distribution of root dry weight ratio over 0-50 cm soil depth in relation to the total root dry weight revealed that 50 % to 60 % of the roots dry weight were found in the 0-10 cm layer for all irrigation intervals (Fig. 2). Increasing the irrigation interval decreased root ratios in this layer. The highest root ratio was obtained from 1-day followed by 3 and 5 days irrigation interval. On the contrary, the root ratios in 20-30, 30-40 and 40-50 cm depth were significantly increased with increasing the irrigation interval except for 40-50 cm depth where the highest root ratio was obtained from 3-day irrigation interval.

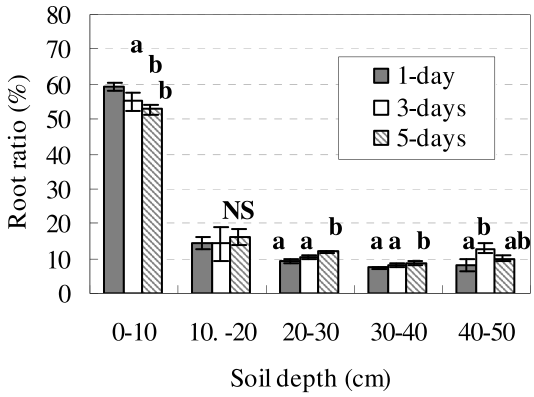

Figure 2: Root ratio distribution at 50 cm soil depth relative to total root dry weight under different irrigation intervals (Means with different superscripts differ significantly (P<0.05) while NS is not significant)

3.1.2. Leaf Area Index (LAI) and Change in LAI

The results of LAI and the change in LAI are shown in Figure 3. The results indicated that no significant differences were found in LAI between 1 and 3 day irrigation intervals while 5-day interval had the lowest LAI (Fig. 3a). At the last 10 days of the experiment, the LAI of the 5-day irrigation interval increased rapidly compared to other two intervals. The highest increase in the change of LAI during the last 10 days was obtained from the 5-day followed by 1 and 3 day irrigation interval, (Fig. 3b).

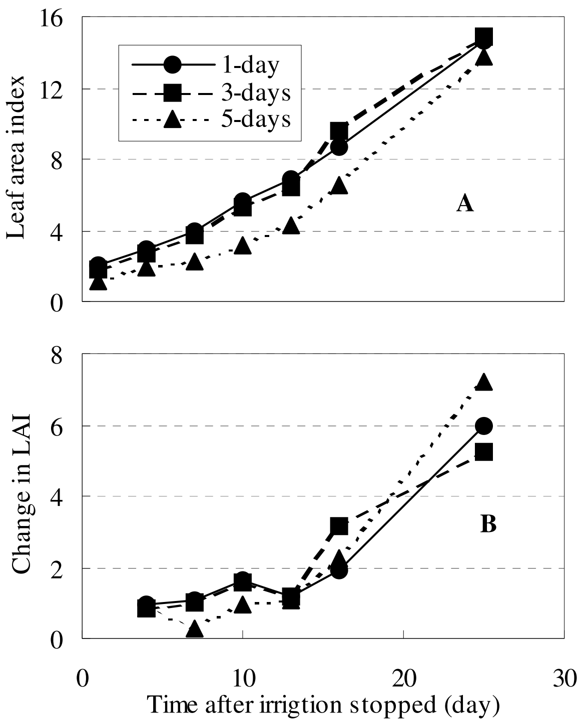

Figure 3: Leaf area index (LAI) and change in LAI after irrigation stopped

3.1.3. Xylem water potential and soil water content

The xylem water potential result is shown in Figure 4. The results revealed that the highest xylem water potential was for the 5-day irrigation interval while the xylem water potential for 1 and 3 day intervals was same. The soil water content measured on the harvest day was higher for 5-day than for 1 or 3 day irrigation interval while no differences was found between 1 and 3 day irrigation interval (Fig. 5).

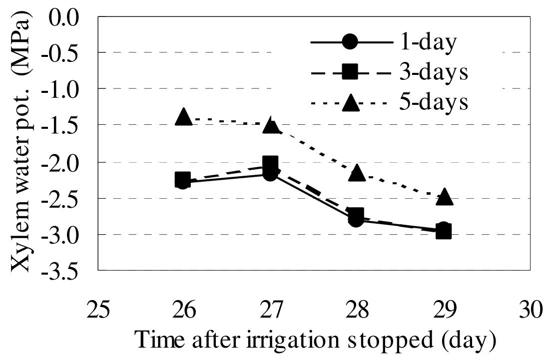

Figure 4: Xylem water potential in chile pepper after irrigation stopped

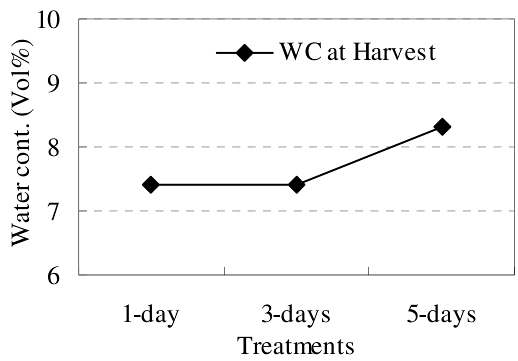

Figure 5: Soil water content measured on harvest day for different irrigation intervals

3.1.4. Water consumption and water use efficiency

Increasing the irrigation interval reduced plant water consumption. However, the reduction in water consumption was not significant (Fig. 6a). The amount of water used to produce 1 g of chile pepper dry matter as influenced by the irrigation intervals is illustrated in Figure 6b. The lower the amount of water use, the higher the water use efficiency. The highest water use efficiency was obtained from the 3-day irrigation interval while no significant differences were found between 1 and 5 day irrigation interval.

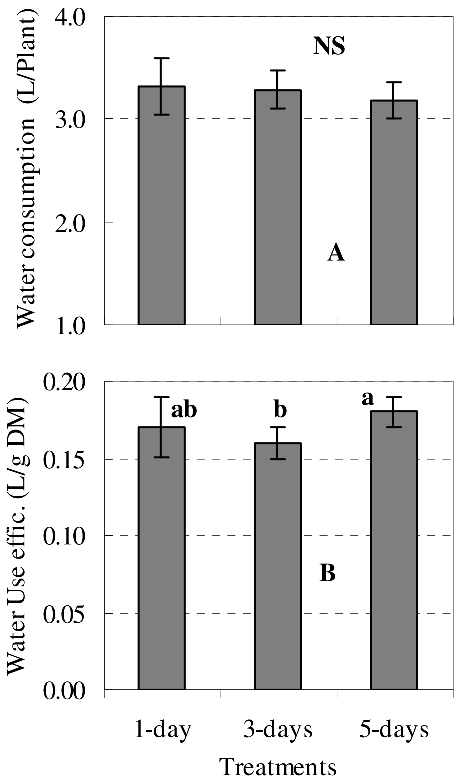

Figure 6: Effect of irrigation interval on water consumption (A) and water use efficiency (B) (Means with different superscripts differ significantly ($P<0.05$) while NS is not significant)

3.2. Root restriction experiment

The results of irrigation frequency experiment explained previously revealed some improvement in shoot dry weight and water use efficiency for the 3-day irrigation interval compared to the other intervals. These enhancements may be attributed to the high root ratio in the 40-50 cm soil layer (Fig. 2). To confirm our results and expectation, the root restriction was carried-out to restrict the horizontal root development for certain depths, while encouraging the vertical root development. The obtained results will be discussed as follow:

3.2.1. Root and shoot dry weights

The results of root and shoot dry weights are shown in Figure 7. The highest root dry weight was recorded in T40 followed by T10 and T20 although there were no significant differences between T10 and T20. The highest shoot dry weight was obtained in T40 while the least one was in T10 (Fig 7a). Increasing the restriction depth resulted in increases in the root dry weight inside the pipes. The highest root dry weight inside the pipes was recorded in T40 followed by T20 and T10. However, the development of the root outside of the restricted depth followed an opposite order. The highest root dry weight outside of the pipes was recorded in T10 while no significant differences were recorded between T20 and T40 (Fig. 7b). The results of root dry matter distribution in 0-50 cm depth revealed that there was a significant differences distribution between the treatments in 0-10 and 40-50 cm layers, (Fig. 8). The highest root dry weight was recorded in T40 followed by T10 and T20 for both layers. The other layers (10-20, 20-30 and 30-40 cm depth) did not show any significant difference between treatments.

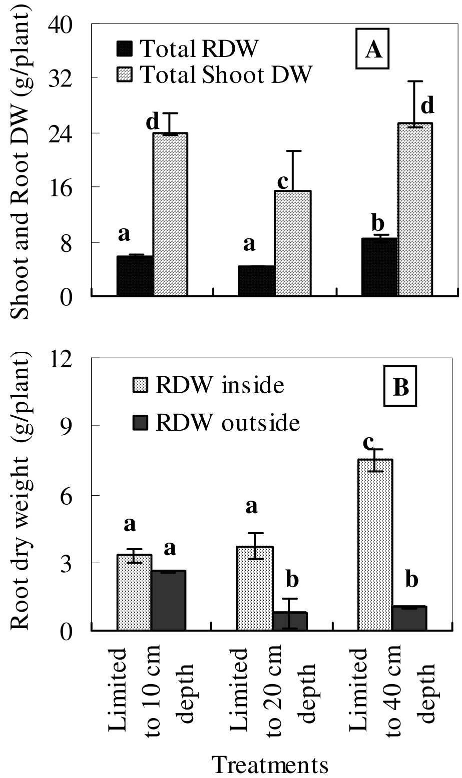

Figure 7: Effect of root restriction on root and shoot dry weights, inside and outside root dry weights (Means with different superscripts differ significantly (P<0.05) while NS is not significant)

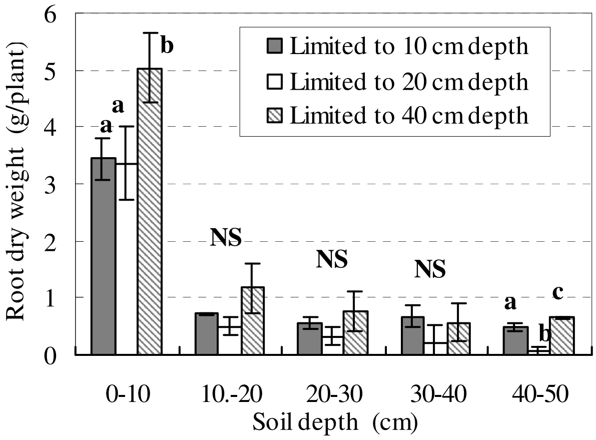

Figure 8: Root dry weights distribution at 50 cm soil depth under different degrees of root restriction (Means with different superscripts differ significantly (P<0.05) while NS is not significant)

3.2.2. Yield, water consumption and water use efficiency

The results of green chile pepper fruit shown in Figure 9 revealed that there was a significant difference between treatments. The highest fruit yield was measured in T40 followed by T20 and T10. The highest water consumption was used by T40 while, the differences between this treatment and other ones were not significant (Fig. 10a). Significant differences in water use efficiency (the amount of water used to produce 1 g of green chile pepper) were found between treatments (Fig. 10b). The least water use efficiency was recorded in T10 while for T20 and T40 they were similar.

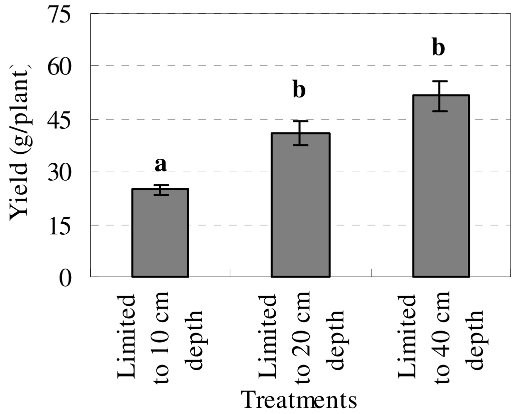

Figure 9: Effect of root restriction on chile pepper yield (Means with different superscripts differ significantly (P<0.05) while NS is not significant)

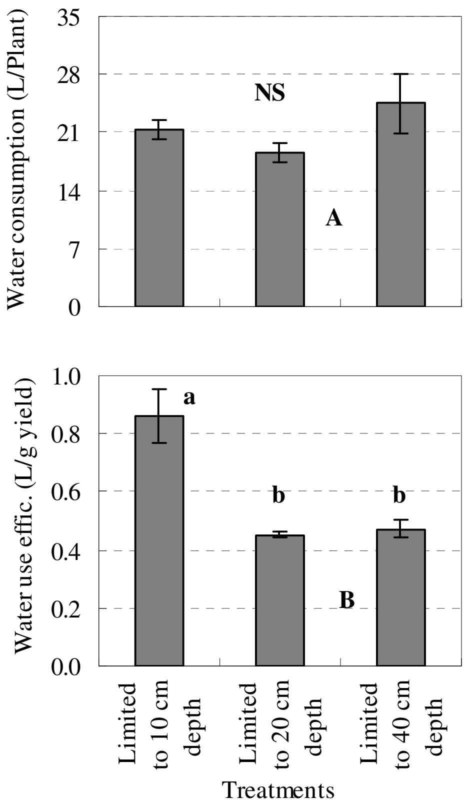

Figure 10: Effect of root restriction on water consumption and water use efficiency (Means with different superscripts differ significantly (P<0.05) while NS is not significant) (P<0.05) while NS is not significant)

4. DISCUSSION

4.1. Root development

Water stressed plants generally exhibit a small root system configuration and the reduction in root system size is directly proportional to the magnitude of water shortage as indicated by the result presented in Figure 1, in which increasing the irrigation interval causes a decrease in the root dry weight because the pattern of root distribution was similar to that of the moisture distribution (Levin et al., 1979; Kramer 1995). A similar trend was confirmed from the result of root restriction experiment (Fig. 7) where the highest root dry weight obtained from T40, which consumed the highest amount of irrigation water (Fig. 10a). Decreasing the root system due to water stress leads to a decrease in shoot dry weight (Figs. 1 and 7) because the maintenance of a proper balance between them is required; if either is too limited or too great in extent, the other will not thrive. The roots grew rapidly downward (40-50 cm depth in 3 and 5 days treatments) to a high soil moisture content resulting in a higher root ratio than for the 1-day interval (Fig. 2). Water stress alters the root system structure by promoting the production of long lateral roots that emerged from the basal portion of the taproot and thus making the direction elongation of these lateral roots more downward (Wright, 2002).

4.2. Leaf area, soil water content and xylem water potential

The differences in LAI (Fig. 3a) were due to the root development and/or the water stress conditions. During the first two weeks after watering is stopped, the LAI was higher in the treatments of 1 and 3 day irrigation interval than in 5-day interval due to root development because increasing the root development increased the leaf growth and consequently leaf area. Similar results declared by Ismail and Davies (1998) who found that the root restriction reduces the leaf growth. During the last 10 days of the experiment the water stress become sever, so that the change in LAI increased slowly in 1 and 3 day irrigation intervals while increased rapidly in the 5-day irrigation interval (Fig. 3b). The results were due to the high soil water content in the 5-day irrigation interval (Fig. 5), which relieved water stress effects and increased LAI compared to 1 and 3 day intervals.

Xylem water potential varied with water supply and therefore, it may be quite effective to monitor moisture stress in plants (Katerji et al., 1987). The results presented in Figure 4 indicated that the highest xylem water potential was for the 5-day irrigation interval, which also had the highest soil water content (Fig. 5). Increasing the soil water stress decreases leaf water potential. Using the 5-day irrigation interval the plants were adopted to grow under water stress conditions and to consumed less water resulting in a higher soil water content and higher plant water stress tolerance compared to 1 or 3 day irrigation interval.

4.3. Water use efficiency

The higher water use efficiency in root container experiment was obtained from 5 and 3 days irrigation intervals. The water use efficiency obtained from the amount of water used to produce 1 g of dry matter. The 3-day irrigation interval for chile pepper saves 6 % and 12 % of irrigation water compared to 1 and 5 day intervals, respectively. In root restriction experiment, the water use efficiency obtained from the amount of water used to produce 1 g of green chile pepper fruit. The T20 and T40 treatments had similar results and each one saved about 45 % of irrigation water compared to T10 treatment.

5. CONCLUSIONS

Increasing the irrigation interval causes decreases in both shoot and root dry weights. The proper irrigation interval saves more water at the early growing stage of the plants. High water use efficiency was obtained from the 3-day irrigation interval compared to the other irrigation intervals. The highest shoot dry weights, root dry weights, root biomass at the bottom of the containers, yield and water use efficiency were obtained from the (T40) treatment. In conclusion, the proper irrigation interval which encourages root development in lower soil layers at the early growth stages is a practical tool to increase water use efficiency and to save more water.

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