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Deficit irrigation affects on physiological and biochemical parameters of hot pepper grown in soilless culture

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Abstract

There are limited available data about the effect of deficit irrigation on Hot pepper, therefore this study investigated the effect of deficit irrigation on some physiological and biochemical parameters in leaves of Hot pepper (*Capsicum annuum* cv. Battle) during plant growth to evaluate the critical period of irrigation for this cultivar for good growth. The plants were grown in a 1:1 v/v sand-to-cotton stalk compost and subjected to four irrigation treatments: 100% of water holding capacity (control), 85%, 70% and 55% of water holding capacity which were considered deficit irrigation treatments. All treatments were given to the plants at the first day of transplanting and continued during the whole growing season. Our results demonstrated that deficit irrigation had a negative effect on physiological parameters. Increasing irrigation deficiency exhibited a reduction in chlorophyll content and net photosynthetic rate, the maximum values were obtained at 30 and 40 days after transplanting respectively. And a corresponding increases in the activity of antioxidant enzymes. The maximum activity of SOD and CAT enzymes was obtained at 30 and 40 days after transplanting respectively, while the maximum activity of POD was obtained at 45 and 60 days after transplanting. The root activity also increased as deficit irrigation was increased. Lipid peroxidation membrane (MDA) had lower values at 30 and 40 days after transplanting. We concluded that 'Battle' hot pepper is sensitive to deficit irrigation and the period from 30 to 45 days after transplanting is considered critical period of irrigation this cultivar under our condition.

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Introduction

Hot pepper (*Capsicum annuum* L.) is one of the vegetable crops commonly grown in the greenhouse and consumed in China, USA, East Indies, Korea, and many other countries, for the nutritional value fruit contents, which are an excellent source of antioxidant compounds and natural colors, like carotenoids and vitamin C (Howard *et al.*, 2000; Russo and Howard, 2002; Navarro *et al.*, 2006; Shao *et al.*, 2008). In the greenhouse, water availability is an important factor affecting plant growth and yield, because hot pepper is considered one of the most susceptible horticultural crops to water stress (Shao *et al.*, 2010). The physiological and biochemical responses to water stress may vary considerably among species. In general, strategies of drought-avoidance or drought tolerance can be recognized; both involving diverse plant mechanisms that allow plants to respond and survive water deficit.

Deficit irrigation is a strategy that allows a crop to sustain some degree of water deficit in order to reduce costs and potentially increase income. Deficit water is one of the major environmental factors that can limit the growth, and physiological characteristics of plants and recent global climate change has made this situation more serious (Martínez *et al.*, 2003; Ren *et al.*, 2007; Tadina *et al.*, 2007; Wu *et al.*, 2009). Plants usually experience a fluctuating water supply during their life cycle due to continuously changing climatic factors. Deficit water induces several physiological, biochemical and molecular responses in several Crop plants, which would help them to adapt to such limiting environmental conditions (Arora *et al.*, 2002; Chaves *et al.*, 2003). Water deficit induces oxidative damage leading in the formation of active (AOS) and reactive oxygen species (ROS) (Farooq *et al.*, 2009 a, b). Production of these species is started with reduction of O_2 leading in the synthesis of singlet oxygen ($^1O_2$), superoxide (O^{2-}), hydroxyl radical (OH^-) or hydrogen peroxide (H_2O_2) (Wu *et al.*, 2008). Production of these species at higher level may damage cellular membranes and other vital substances like chlorophyll, DNA, proteins and lipids (Blokhina *et al.*, 2003).

The final product of lipid peroxidation in the cellular membranes, malondialdehyde (MDA) is taken as an index of oxidative membrane damage (Ozkur *et al.*, 2009). Plants resist to stress-induced production of active and reactive oxygen species through induction of enzymatic and non-enzymatic antioxidant defense enzymes, which protect the membranes and other vital substances (Ali *et al.*, 2008). Among the enzymatic components, superoxide dismutase (SOD) plays the key role in antioxidant defense system as it scavenges O^{2-} free radicals converting them into H_2O_2. The H_2O_2 is then further scavenged by catalase (CAT) and peroxidase (POD) into H_2O and O_2 (Farooq *et al.*, 2009 a).

The activities of antioxidant enzymes and the amount of antioxidants increase under drought; however the extent of increase varies among the plant species and cultivars of the same species.

Photosynthesis is an essential process to maintain crop growth and development, and it is well known that photosynthetic systems in higher plants are most sensitive to water deficit (Falk *et al.*, 1996).

Chlorophyll is one of the major chloroplast components for photosynthesis, and relative chlorophyll content has a positive relationship with photosynthetic rate (Guo and Li, 1996). The effect of water deficit on photosynthesis varies among the plant species and cultivars of the same species (Akhkha *et al.*, 2011**)**.

Several investigators have reported a negative effect of water stress on chlorophyll content in leaves such as (Kirnak *et al.*, 2001**)** on eggplant; (Zhang *et al.*, 2007) on soybean; (Li *et al.*, 2008) on cucumber; (Sikuku *et al.*, 2010) on rice; (Bettaieb *et al.*, 2011) on *Salvia officinalis* L; (Ebrahimian and Bybordi, 2012) on sunflower; (Sayyari and Ghanbari, 2012) on hot pepper. On the contrary, (Khamssi *et al.*, 2010) found that chlorophyll content of three chickpea (*Cicer arietinum* L.) cultivars showed no significant differences among deficit irrigation and well irrigation treatments**.**

Also, many investigators have reported a negative effect of water stress on net photosynthetic rate in leaves such as (Kauser *et al.*, 2006) on canola (*Brassica napus* L.); (Zhang *et al.*, 2007) on soybean; (Jaleel *et al.*, 2008 a) on *Catharanthus roseus*. On the contrary (Akhkha *et al.*, 2011) observed that a reduction in photosynthesis rates of wheat cultivars (Hab-ahmar and Sindy-2) due to water stress but no decrease in cultivars, (Al-gaimi and Sindy-1).

The effects of water deficit on antioxidative responses have been studied in a number of plant species such as, (Sairam and Srivastava, 2001) on wheat; (Lima *et al.*, 2002) on *Coffea_canephora;* (Sofo *et al.,* 2004, 2005) on olive; (Yong *et al.*, 2006) on *Radix Astragali* ; (Ge *et al.*, 2006) on maize; (Zhang *et al.*, 2007) on soybean; (Jaleel *et al.*, 2008 b) on *Catharanthus roseus;* (Pourtaghi *et al.*, 2011) on sunflower; (Anjum *et al.*, 2012) on hot pepper. These studies indicate that the antioxidative response is well correlated with sensitivity and tolerance of the cultivars under investigation.

Few studies have been reported on physiological and biochemical parameters of hot pepper under deficit irrigation during plant growth. This study was conducted to investigate the effect of deficit irrigation on some physiological and biochemical parameters in leaves of 'Battle' hot pepper during plant growth to evaluate the critical period of irrigation for this cultivar for good growth.

Materials and methods

A greenhouse experiment was conducted at the Soilless Culture Department, Vegetables and Flowers Institute (VFI), Chinese Academy of Agricultural Sciences (CAAS), Beijing, China from May to August 2012.

Growing media and plant materials

A sand-to-cotton stalk compost (1:1 v/v) was used as a growing media; seven litters were used per pot. The physical and chemical properties of the growing media used in this study are presented in Table 1. The seedlings of hot pepper (*Capsicum annuum* cv. Battle) were transplanted at eight- leaf stage, one plant per pot.

Irrigation treatments and experimental design

Four irrigation treatments; 100%, 85%, 70% and 55% of water holding capacity (WHC) of growing media were used during the whole growing season, which will be referred to in the text as T1, T2, T3 and T4, respectively. A full irrigation treatment (T1) was considered as a control. The second, third and the fourth treatments (T2, T3 and T4) were considered as deficit irrigation treatments. All water treatments were given to the plants on the same day of transplanting. The desired moisture contents of pots were daily monitored by HH2 moisture meter version 4.0 (Delta- T Devices Ltd. UK) and maintained through water application, if required. The experiment was organized in a completely randomized design (CRD) with three replications per treatment; each replication had seven plants (twenty one plants per treatment).

Measurements

Physiological parameters

Chlorophyll content and net photosynthetic rate (Pn) of the fully expanded leaves were measured at 15, 30, 45, 60 and 75 days after transplanting. Chlorophyll content was measured using a chlorophyll meter (SPAD-502, Konica Minolta Sensing Inc, Japan). Net Photosynthetic rate was measured with LI 6400 (Li-Cor Inc, Lincoln NE, USA) under a saturating photosynthetic photon flux density of 800 µmol m^{-2} s^{-1} provided by an external halogen lamp. Measurements of chlorophyll content and net photosynthetic rate were taken between 09:00 and 11:00 am, five plants of each treatment and triplicate reading at random locations in the leaf were recorded for each plant and the average used for the analysis.

Biochemical parameters

Leaves were sampled at 15, 30, 45, 60 and 75 days after transplanting. The segments (0.3 g**)** of the fully expanded leaf from each plant was detached (three leaves per pot and five pots per treatment) and immediately frozen in liquid nitrogen and then stored at - 80 °c till used.

Antioxidant enzymes assay

For the enzymes assay, 0.3 g of frozen leaf segments was ground with 3 ml ice-cold 50 mM phosphate buffer (PBS pH 7.8) containing 0.2 mM EDTA and 2 mM ascorbic acid (AsA). The homogenates were centrifuged at 4 °C for 20 min. at 12,000 g, and the supernatants were used for the determination of the enzymatic activities. Superoxide dismutase (SOD) activity was assayed according to (Stewart and Bewley, 1980) on the basis of its ability to inhibit the photochemical reduction of nitro blue tetrazolium (NBT). Catalase (CAT) ctivity was assayed according to (Chandlee and Scandalios, 1984). Peroxidase (POD) activity was determined as described by (Upadhyaya *et al.*, 1985).

Lipid peroxidation

The degree of lipid peroxidation was assessed as malondialdehyde (MDA) contents according to the TBA method (Hodges *et al.*, 1999).

Root activity

Measurement of root activity was performed according to the TTC method (Wang *et al.*, 2010). The roots sampled after second harvesting, the substrate was removed from the root using tweezers, and then the roots were washed with sterile water. The surface liquid of roots was blotted with tissue paper and their fresh weights were measured. Roots with weights 0.5 g were placed in tubes and filled with 5 ml of 0.4% TTC and 5 ml phosphate buffer (0.06 $mol.l^{-1}$, pH 7.0). Control treatment (blank runs) was always carried out using the same procedure, but adding 2 ml of 1$mol.l^{-1}$ sulfuric acid first. The tubes were incubated at 37 °C for up to 4 hr. The chemical reaction was stopped by adding 2ml of 1 $mol.l^{-1}$ sulfuric acid into the tubes. This step was followed by extraction with 10 ml of 95% ethanol for 24 h., which consisted of taking the root in a new tube. The optical density (OD) values were recorded at 485 nm.

Statistical analysis

Data were analyzed statistically using Statistix version 8.1 software. Differences between means were determined using the Least Significant Difference (LSD) test at $P < 0.05$. The analyzed data were then presented as mean ± standard deviation (SD) of the mean.

Results

Physiological parameters

Chlorophyll content

Data presented in Fig. 1 demonstrate that the chlorophyll content in leaves was affected by irrigation treatments during plant growth.

In our study, chlorophyll content increased sharply from 15 days after transplanting and reached to the peak at 30 days after transplanting, then declined slightly at 45 days after transplanting and continued to decline till 75 days after transplanting, for all irrigation treatments.

Table 1. Physical and chemical properties of growing media.

Properties	Physical Properties					Chemical Properties				
	BD[a] g/cm^3	AS[b] %	WHC[c] %	TP[d] %	EC[e] mS/cm	pH	TOC[f] g/kg	TN[g] g/kg	OM[h] g/kg	C/N[i] ratio
Values	1.04	14.34	40.11	54.45	1.18	7.86	84.42	8.41	145.55	10.05

[a]bulk density; [b] air space; [c] water holding capacity; [d] total porosity; [e] electrical conductivity; [f] total organic carbon; [g]total nitrogen; [h] organic matter; [i] carbon to nitrogen ratio.

Moreover, deficit irrigation showed a significant reduction in chlorophyll content of leaves. The reduction was increased with increase in the intensity of deficit. The lowest reduction in chlorophyll content was 30.98% followed by 18.91 and 13.67 for T4, T3 and T2, respectively, at 30 days after transplanting, as compared with the control. Meanwhile, the highest reduction at 45 days after transplanting was 34.00% followed by 19.90 and 13.08 for T4, T3 and T2, respectively, as compared with the control.

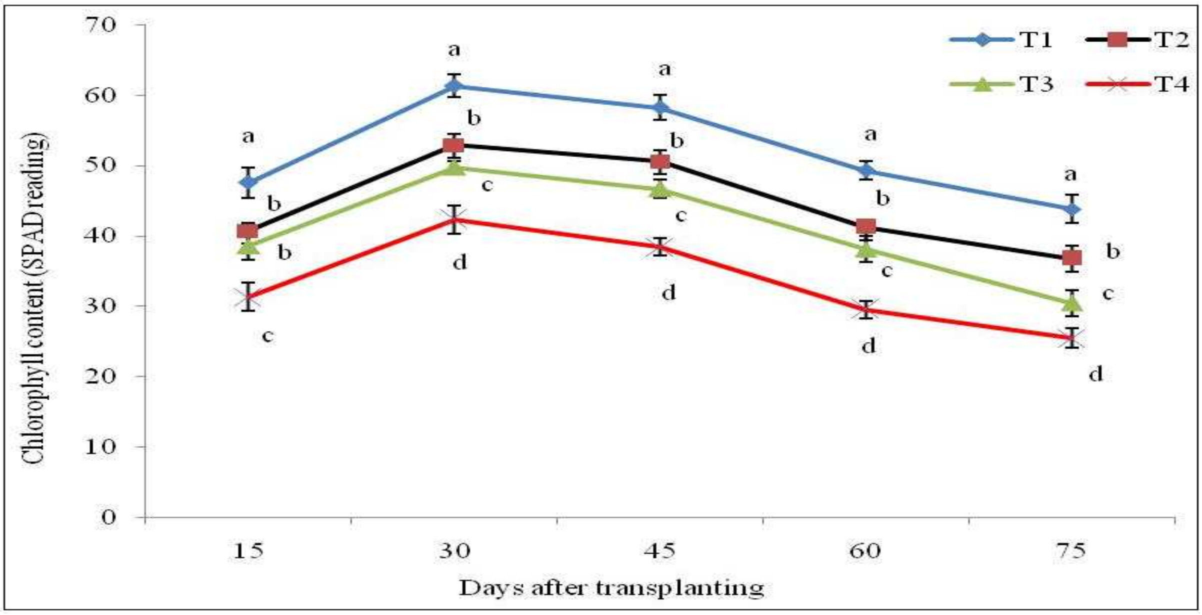

Fig. 1. Effect of deficit irrigation on chlorophyll content of leaves during different times (days after transplanting) of hot pepper. [T1, 100% of water holding capacity; T2, 85% of water holding capacity; T3, 70% of water holding capacity; T4, 55% of water holding capacity]. Lines in figure that are denoted with the same letter in each group separately are not significantly different. The values are means ± SD (n= 3).

Net photosynthetic rate

Data illustrated in Fig. 2 reveal that photosynthetic rate in leaves was changed during plant growth under irrigation treatments. Net photosynthesis rat rose sharply from 15 days after transplanting, reached to the peak at 30 days after transplanting,, then decreased slightly till 45 days after transplanting. Afterwards, declined sharply at 60 days after transplanting.

Thereafter, continued to decline sharply till 75 days after transplanting for T1. Meanwhile, net photosynthesis rat in T2, T3 and T4 declined slightly (nearly constant) until 75 days after transplanting.

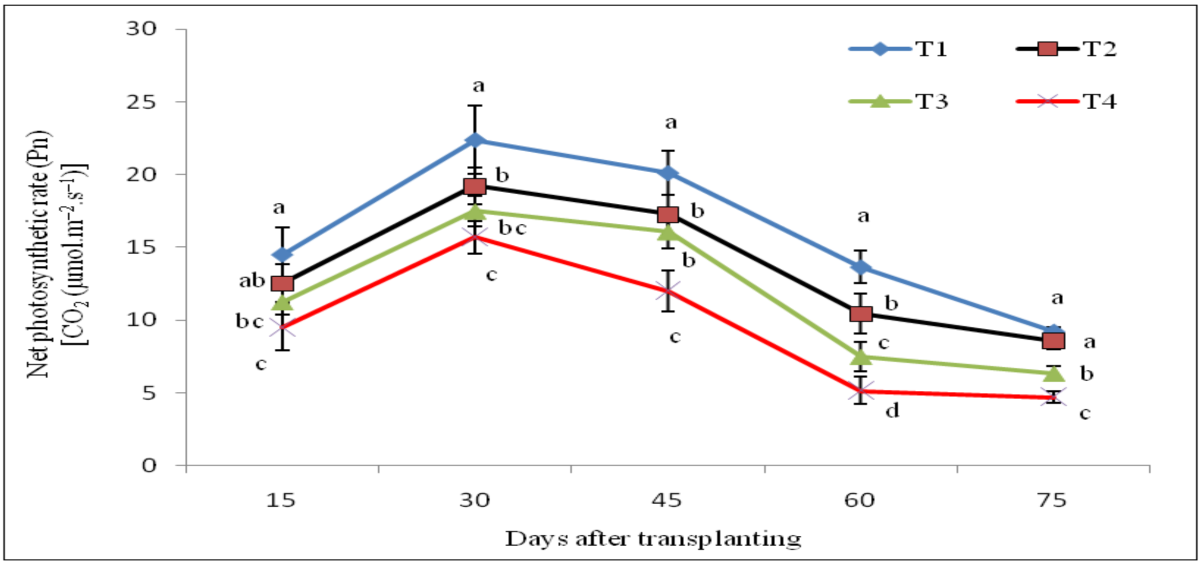

Fig. 2. Effect of deficit irrigation on net photosynthetic rate of leaves during different times (days after transplanting) of hot pepper. [T1, 100% of water holding capacity; T2, 85% of water holding capacity; T3, 70% of water holding capacity; T4, 55% of water holding capacity]. Lines in figure that are denoted with the same letter in each group separately are not significantly different. The values are means ± SD (n= 3).

Furthermore, net photosynthetic rate was significantly affected by deficit irrigation treatments, during plant growth. Deficit irrigation caused a significant decrease in net photosynthetic rate as compared with the control. The maximum reduction in net photosynthetic rate was 29.85% followed by 21.91% and 14.15% for T4, T3 and T2, respectively, which obtained at 30 days after transplanting. While, the maximum reduction in net photosynthetic rate at 45 days after transplanting was 40.39% followed by 20.12% and 14.26% for T4, T3 and T2, respectively, as compared with the control.

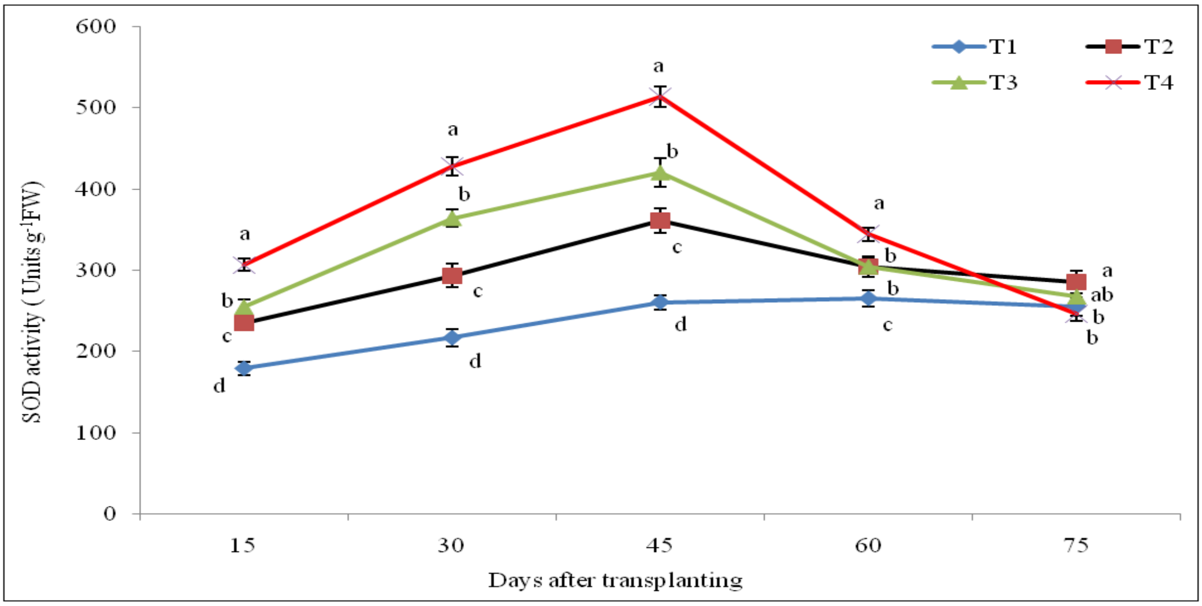

Fig. 3. Effect of deficit irrigation on superoxide dismutase (SOD) activity of leaves during different times (days after transplanting) of hot pepper. [T1, 100% of water holding capacity; T2, 85% of water holding capacity; T3, 70% of water holding capacity; T4, 55% of water holding capacity]. Lines in figure that are denoted with the same letter in each group separately are not significantly different. The values are means ± SD (n= 3).

Biochemical parameters

Antioxidant enzyme activities

Superoxide dismutase (SOD) activity

The effect of deficit irrigation treatments on the activity of superoxide dismutase during plant growth is presented in Fig. 3 Data clear that under control (100% of WHC), SOD activity in leaves of hot pepper plant increased slightly from 15 days after transplanting and continued to slightly increase till 60 days after transplanting.

Afterwards, started to slightly decline till 75 days after transplanting. However, under deficit irrigation treatments, superoxide dismutase activity rapidly increased from 15 days and continued to increase, it's reached to the peak at 45 days after transplanting. Thereafter, decreased sharply and reached to level lower than the control at 75 days after transplanting for T4. However, in T2 and T3, the activity of SOD declined after 45 days and continued slightly decline till 75 days after transplanting.

On the other hand, the activity of SOD enzyme was affected by deficit irrigation treatments during plant growth. Deficit irrigation caused a significant increase in activity of SOD. The highest increment in SOD activity was 97.03% followed by 61.59% and 38.56% for T4, T3 and T2, respectively, as compared with control at 45 days after transplanting.

Catalase (CAT) activity

Catalase activity (CAT) exhibited a similar trend to SOD activity as illustrated in Fig. 4 The data demonstrate that, catalase activity un- obviously increased in leaves of plant under control treatment (T1), from 15 till 60 days after transplanting, then, un-obviously decreased at 75 days after transplanting. Under deficit irrigation treatments, the activity of catalase enzyme rapidly increased from 15 days after transplanting and continued to increase, it's reached to the peak at 45 days after transplanting. Thereafter, rapidly declined till 60 days and continued to decline till 75 days after transplanting.

Moreover, the activity of catalase enzyme in leaves of pepper plant was affected by deficit irrigation. Deficit irrigation caused a significant increase in catalase activity in leaves with compare with non-deficit. The increment in the activity was increased as a result of increasing deficit irrigation.

The maximum activity of catalase enzyme was 88.99% followed by 64.29% and 48.49% for T4, T3 and T2, respectively, at 45 days after transplanting relative with the control.

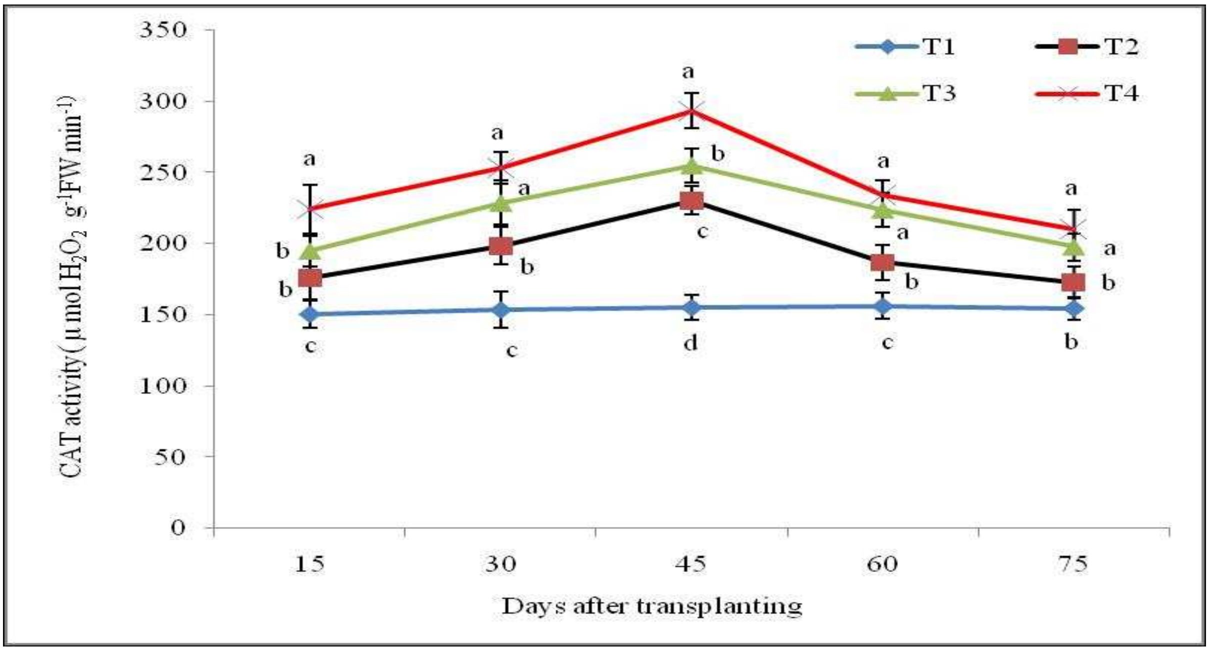

Fig. 4. Effect of deficit irrigation on catalase (CAT) activity of leaves during different times (days after transplanting) of hot pepper. [T1, 100% of water holding capacity; T2, 85% of water holding capacity; T3, 70% of water holding capacity; T4, 55% of water holding capacity]. Lines in figure that are denoted with the same letter in each group separately are not significantly different. The values are means ± SD (n= 4).

Peroxidise (POD) activity

Data presented in Fig. 5 demonstrate that, the activity of peroxidase (POD) enzyme affected by deficit irrigation treatments during plant growth. Data clear that, under deficit irrigation the activity of enzyme started slightly increase from 15 days after transplanting and continued to increase till 45 days after transplanting, then tended to rapidly increase its reached to the maximum activity at 60 days after transplanting.

Thereafter, the activity of enzyme rapidly decreased till 75 days after transplanting for T3 and T4. However, the activity of POD enzyme slightly decreased till 75 days after transplanting for T2.

Under control irrigation treatment, a very slightly increased for POD activity observed from 15 to 60 days after transplanting, then also very slightly decreased at 75 days after transplanting.

Furthermore, the activity of POD enzyme was influenced by deficit irrigation. Increasing deficit irrigation caused a significant increase in activity of POD enzyme. The increment of activity was increased with increase in the severity of deficit.

The highest activity of peroxidise enzyme was 163.96% followed by 111.69% and 59.10% for T4, T3 and T2, respectively, at 60 days after transplanting as compared with the control.

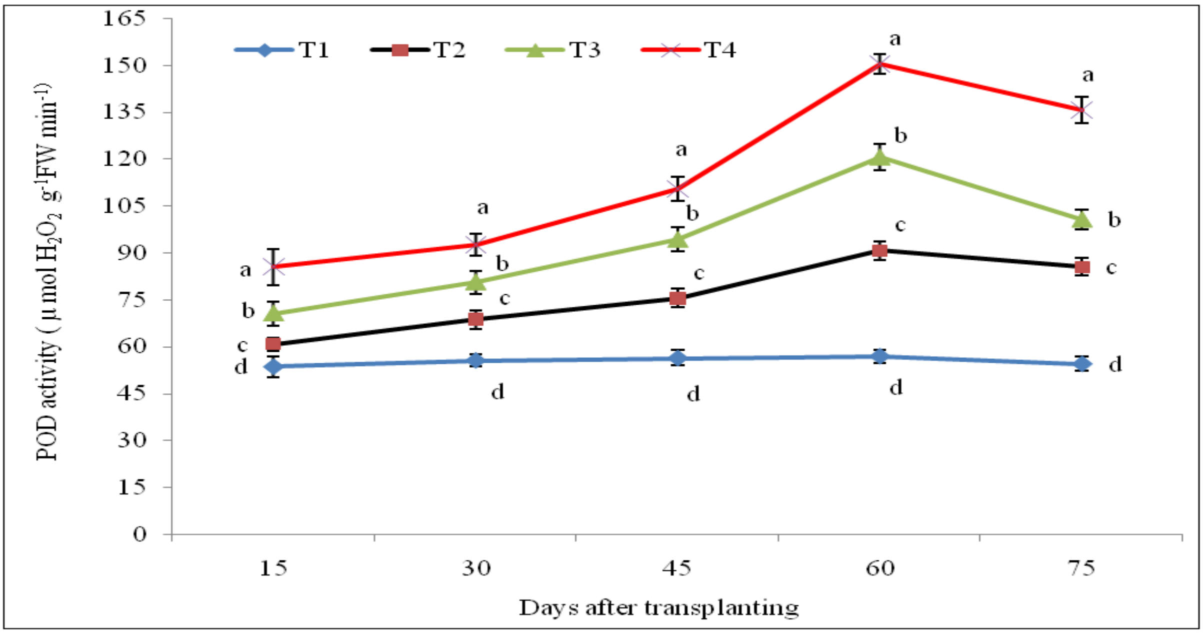

Fig. 5. Effect of deficit irrigation on peroxidase (POD) activity of leaves during different times (days after transplanting) of hot pepper. [T1, 100% of water holding capacity; T2, 85% of water holding capacity; T3, 70% of water holding capacity; T4, 55% of water holding capacity]. Lines in figure that are denoted with the same letter in each group separately are not significantly different. The values are means ± SD (n= 5).

Malondialdehyde (MDA) contents

Data presented in Fig. 6 clear that malondialdehyde contents showed a similar trend to POD activity from 15 until 60 days after transplanting. After that, the malondialdehyde contents showed an opposite trend to POD activity. Also the Data clear that under full irrigation treatment (T1), the MDA contents started to slightly increase at 15 days after transplanting and continued to increase to maximum contents at 75 days after transplanting. However, under deficit irrigation treatments, the MDA contents slightly increased at 15 until 45 days after transplanting then tended to rapidly increase till 60 days after transplanting, then continued to slightly increase till reached to highest contents at 75 days after transplanting.

Likewise, malondialdehyde (MDA) contents significantly affected by deficit irrigation treatments. Deficit irrigation treatments led to a significant increase in malondialdehyde (MDA) contents as compared with the control.

The increment in malondialdehyde (MDA) contents was increased with increase in the intensity of deficit. The maximum content of MDA was 38.65% followed by 75.22% and 120.85% for T4, T3 and T2, respectively, at 75 days after transplanting. Meanwhile, the maximum content of MDA was 126.40% followed by 82.71% and 33.29% for T4, T3 and T2, respectively, at 60 days after transplanting relative with the control.

Root activity

The effect of deficit irrigation treatments on root activity of pepper plant presented in Fig. 7 The data show that, root activity was affected by deficit irrigation. Increasing deficit irrigation caused a significant increase in root activity as compared with the non-deficit. The increment in root activity was increased with increased in the severity of deficit. The maximum activity of root was 126.70% followed by 86.87% and 47.22% for T4, T3 and T2, respectively, as compared with the control.

Discussion

Physiological parameters

Water deficit is considered as a disturbing factor in plant physiology affects growth parameters and the quality. The results of this study showed that deficit irrigation had a considerable effect on physiological parameters. As a result of increased deficit irrigation, chlorophyll content was reduced. This reduction could be attributed to an increase of production of free oxygen radicals in the cell. These free radicals cause peroxidation and disintegration and by reduction of chlorophyll, considerable changes are produced in the plants (Schutz and Fangmir, 2001).

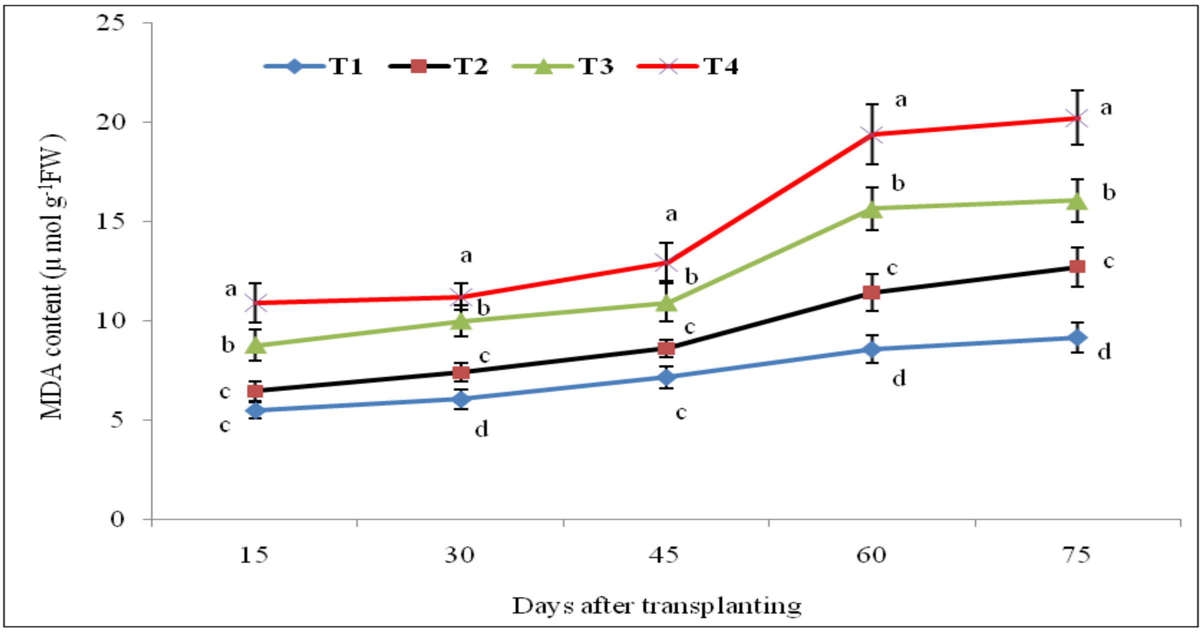

Fig. 6. Effect of deficit irrigation on malondialdehyde (MDA) contents of leaves during different times (days after transplanting) of hot pepper. [T1, 100% of water holding capacity; T2, 85% of water holding capacity; T3, 70% of water holding capacity; T4, 55% of water holding capacity]. Lines in figure that are denoted with the same letter in each group separately are not significantly different. The values are means ± SD (n =3).

Furthermore, the reduction in chlorophyll content can be attributed to of the sensitivity of this pigment to increasing environmental stresses, especially water deficit, which has been reported by several researchers (Moran *et al.*, 1994; Younis *et al.*, 2000; Mekliche *et al.*, 2003). Our results are also in agreement with the findings of (Sayyari and Ghanbari, 2012) who found that by increasing drought stress, content of chlorophyll in leaf of hot pepper was reduced. Similarly, many researchers such as (Zhang *et al.*, 2007; Li *et al.*, 2008; Sikuku *et al.*, 2010; Bettaieb *et al.*, 2011; Ebrahimian and Bybordi, 2012) all those have found reduction in chlorophyll content of leaf as a result of water deficit.

Our experiment identified a positive relationship between net photosynthetic rate and chlorophyll content. As a result of increased deficit irrigation caused a reduction in net photosynthetic rate. A decrease of the photosynthesis rate under water deficit condition can be attributed to both stomatal and non-stomatal limitations (Shangguan *et al.*, 1999). Non-stomatal photosynthesis limitation has been attributed to the reduced carboxylation efficiency (Jia and Gary, 2004), reduce ribulose-1,5-bisphospate (RuBP) regeneration, reduced amount of functional Rubisco (Kanechi *et al.*, 1995), or to the inhibited functional activity of photosystemII (PSII). Similar results were obtained by (Guang-cheng *et al.*, 2011) who observed that water deficit reduced photosynthetic rate of pepper leaves as compared with the control. (Jaleel *et al.*, 2008 a) who demonstrated that a significant reduction in the photosynthetic pigment contents in both varieties of Catharanthus roseus due to water deficit. Similar results obtained by (Kauser *et al.*, 2006) and (Zhang *et al.*, 2007).

Moreover, we observed the maximum values of chlorophyll content and net photosynthetic rate were obtained at 30 and 40 days after transplanting respectively, for all irrigation treatments and the different between these values at 30 and 40 days after transplanting were small, this indicated that this period from 30 and 40 days after transplanting is considered critical period of irrigation. Activation of antioxidant system helps the plants to stress induced damages (Noctor *et al.*, 2000).

Biochemical parameters

In this study a negative correlation between physiological and biochemical parameters was observed. The activity of SOD enzyme increased with increasing deficit irrigation. This increase could be suggested as an adaptive mechanism to scavenge O^{2-} free radicals converting them into H_2O_2 and offer protection against oxidative damage. The activities of POD and CAT enzymes also increased with increasing deficit irrigation. This increment might be suggested as an adaptive mechanism to reduce the H_2O_2 and offer protection against oxidative damage.

The period for high activity of SOD and CAT enzymes was 30 and 45 days after transplanting while for POD activity was 45 and 60 days after transplanting this indicated that POD enzyme continued to scavenge H_2O_2. On the other hand, MDA contents increased with increasing deficit irrigation but this increment was slightly a corresponding with high activity of antioxidant enzymes. In period from 30 to 45 days after transplanting MDA had a lower values, this has been confirmed by higher activities of antioxidant enzymes.

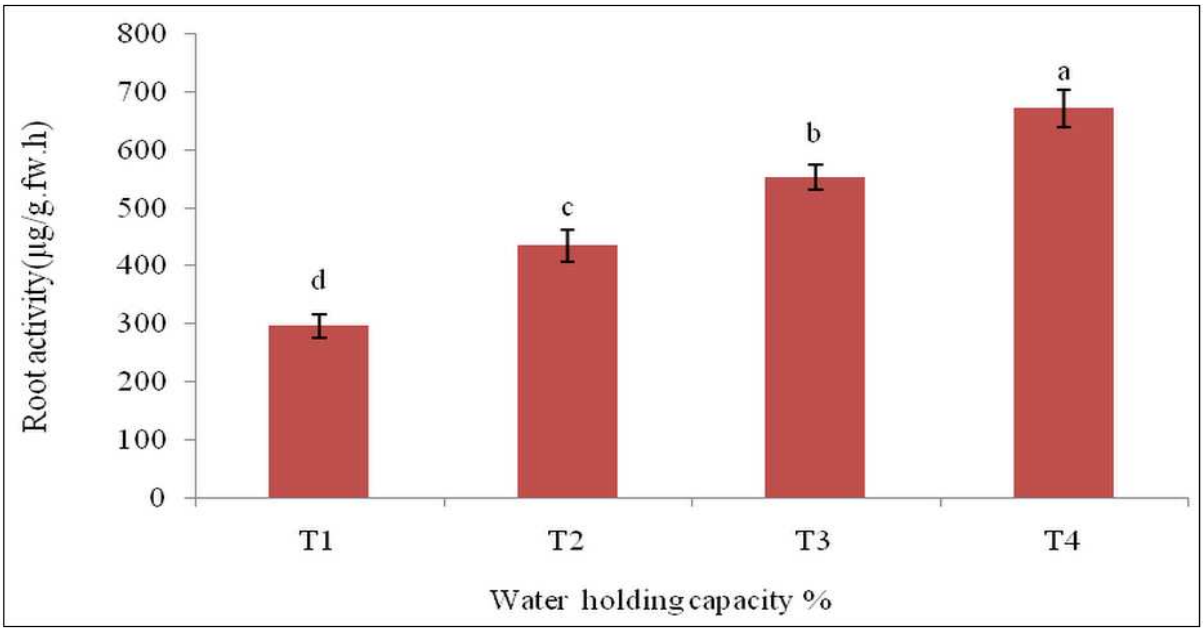

Fig. 7. Effect of deficit irrigation on root activity of hot pepper. [T1, 100% of water holding capacity; T2, 85% of water holding capacity; T3, 70% of water holding capacity; T4, 55% of water holding capacity]. Columns in figure that are headed with the different letter are significantly different. The values are means ± SD (n= 3).

The activity of all antioxidants increased at start of water deficit but decreased with progression of stress indicating that prolonged drought may result in decrease in antioxidant activities (Sairam and Srivastava, 2001; Feng *et al.*, 2004; Simova-Stoilova *et al.*, 2008). With increase in severity and duration of stress, synthesis of active and reactive oxygen species possibly exceeded the capacity of the enzyme protective system, and resulted in an extensive membrane lipid peroxidation and the decrease of the protective enzyme activities (Chen and Zhang, 2000). This could be an explanation for the reduction in the activity of antioxidant enzymes with a corresponding increase in MDA content with progression of water deficit. Our results are in agreement with those obtained by (Anjum *et al.*, 2012) who demonstrated that, the progression in drought enhanced the activities of catalase (CAT), peroxidase (POD) and superoxide dismutase (SOD) as well as MDA contents in leaves of hot pepper initially, which were then decreased with increasing in MDA contents. Pourtaghi *et al.* (2011) who noticed that water deficit, significantly increased the activity of antioxidant enzymes in leaves of sunflower such as Superoxide dismutase (SOD) and Catalase (CAT) compared to full irrigation. Ge *et al.* (2006**)** who found that, under water stress the activities of protective enzymes including superoxide dismutase (SOD), catalase (CAT) and peroxidase (POD) in leaves of maize were increased sharply at prophase and metaphase growth stages, but then declined towards the physiological maturity.

The content of malondialdehyde (MDA) increased according to the severity of water stress. Our results established that, root activity was increased with increased in the severity of deficit.

This increment in root activity may be an adaptive mechanism to severe water stress, which could facilitate drought resistance by maintaining active respiration processes (Huang *et al*., 1997).

Finally, we observed there was an opposite relationship between physiological and biochemical parameters of hot pepper cultivar Battle under deficit irrigation. The period from 30 to 45 days after transplanting is considered critical period of irrigation this cultivar under our condition.

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