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Full Length Research Paper

Using deficit irrigation approach for evaluating the effects of water restriction on field grown tomato (*Lycopersicon esculentum)*

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This study examined the effects of different irrigation regimes on the growth and development of tomato (*Lycopersicon esculentum* Mill. cv. Taoyuan ASVEG No.20) irrigated under a drip irrigation system. The experiment imposed water deficit at the initial (Trt4); developmental (Trt3); mid-season (Trt2); and the late stage of growth (Trt1) comparing the stages of growth to the fully irrigated control (Control), to indicate the stage most susceptible to water stress. The results showed that plant growth, fruit production and quality were significantly affected under different water applications. The treatments (Trts3 and 4) which underwent water deficit earlier in their growth stage showed a significant reduction in leaf chlorophyll content and plant height as compared to the other treatments. The effect on fruit production and quality as a consequence of a water deficit was apparent among all treatments. The mean number of fully formed fruits on Trts1, 2, 3 and 4 was 5.8, 7.7, 6.8 and 7.5 respectively. All of which were significantly lower than average of 11.6 fully formed fruits found on the Control. The application of the deficit irrigation approach in this study was both useful and appropriate in assessing the response of *L. esculentum* Mill under varying soil moisture.

Key words: Chlorophyll, deficit irrigation, drip irrigation, tomato, growth stage, water restriction.

INTRODUCTION

The earth comprises of three fragile components primarily air, land and water. The quality of human life is directly dependent on how well these resources are managed, water in particular. Matondo (2008) discussed that water is the most important catalyst for human development for it is a major input in almost all sectors of human development. The amount of freshwater on earth is finite, but its distribution have varied considerably, driven mainly by natural cycles of freezing and thawing and the fluctuations in precipitation, water runoffs patterns and evapotranspiration levels (Manning, 1997). This situation has changed because apart from natural causes there are new and continuing human activities which have become one of the primary motivators of the pressure affecting the global water system. Gourbesville (2008) and Wilchens (2002) explained that historically there have been links between economic development and water resources development. There are many studies (Gourbesville, 2008; Lange et al., 2007; Namara et al., 2010; Wilchelns, 2002) which describe how water has contributed to economic development and this development has now lead to an increase in water withdrawal. With the economic development and population growth the demand of water will increase while its availability remains constant (if it not reduced due to climate

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change) (Playan and Mateos, 2006; Savenije and Van der Zaag, 2008). During the past century, while world population tripled, the use of water increased six folds. Presently, agriculture specifically irrigated agriculture accounts for 70% of Global water withdrawals, industry accounts for 20% and municipal 10%. However, a forecast of water withdrawals on a global scale, predict sharp increases in future demand to meet the needs of urban, industrial and environment sectors (Fereres and Soriano, 2007). They noted that the competition for water is increasing rapidly, with irrigated agriculture as a primary user of diverted water globally; reaching a proportion that exceeds 70 to 80% of the total in the arid and semi-arid zones (Wang et al., 2009b).

Water shortage is a worldwide problem for which the only solution is to make efficient use of water in agriculture (Wang et al., 2009a). Even with the high installation and operational cost attached to irrigation development, the common irrigation strategy has been maintained which has been to supply areas under irrigation with sufficient water, so that the crop transpires at their maximum potential and the full evapotranspiration (ET) requirements are met throughout the growing season (Dodd, 2009; Fereres and Soriano, 2007). As previously mentioned, global trend have seen water becoming scarce not only in arid and drought prone areas but also in regions where rainfall is abundant (Pereira et al., 2002; Traore et al., 2008, 2007). So, like agriculture which it serves, irrigation as well is at a crossroad (Turral et al., 2010). To meet these water resource challenges, irrigation need to be adapted to a changing world. Photosynthesis is known as being the ultimate source of all plant growth and since plant get their water from the soil for this chemical process, many of the impacts of climate and soil characteristics are felt by the plants through the filter of soil moisture dynamics (Stephenson, 1990). Under drought or any abiotic stress, there will be a significant decrease in photosynthesis which consequently reduce the amount of metabolites and energy (Kulkarni and Phalke, 2009), which are needed for the proper development of both above and below ground biomass (Dias et al., 2007; Dorji et al., 2005). According to Porporato et al. (2001), the mechanism is initiated in a reduction of soil moisture content during droughts lowers the plant water potential and decreases transpiration; which in turn causes a reduction of cell turgor and relative water content which brings about a sequence of damages of increasing seriousness. Damages which are detrimental to yield and quality of tomatoes grown in the field. This study through the deficit irrigation approach simulated drought conditions a crop may encounter during its various stages of growth.

Deficit irrigation is defined by Fereres and Soriano (2007) as the application of water below a crops ET requirement. This practice although contrary to the reason for irrigation which is to avoid water deficits that would reduce crop production was utilized in this study to evaluate the effect of water restriction on tomato development. There are many ways water stress affects crop growth, most of the response however are negative (Cabelguenne et al., 1999; Cakir, 2004; Flénet et al., 1996; Ghulam et al., 2008; Li et al., 2011), but as they differ in water requirement so does a crop's reaction to water shortage. The specific objectives of this experiment were to apply deficit irrigation to simulate water restriction and thus to analyze the physiological and morphological response of tomato plants to different levels of irrigation at different stages of growth. To determine whether or not the deficit irrigation approach conducted, was suitable to simulate water constraint scenarios, in field grown tomatoes. This would be able to indicate to horticultural producers the feasibility of cropping under water scarce conditions and its general effect on tomato production.

MATERIALS AND METHODS

Experimental site

A field trial was carried out at the irrigation experimental field on the campus of the National Pingtung University of Science and Technology located in Taiwan. The geographical location of this site is 22.39° (N) latitude and 34.95° (E) longitudes and is situated 71 m above sea level.

Cultural methods and treatments

Plants of *Lycopersicon esculentum* Mill (cv. Taoyuan ASVEG No.20) were transplanted on the 23rd of November 2010 at a spacing of 60 cm between plants, 80 cm between rows and 100 cm between treatments of which there were five (Figure 1). From transplanting date to 7 days after transplanting (DAT), the irrigation system presented in Figure 1 provided the crop with its full ETc requirement. The irrigation scheduling for this experiment was formulated based on the crop coefficient for Tomato (Allen et al., 1998) who also highlights the guideline to determine crop water requirement (CWR). The experimental design seen in Figure 1 showed the location of all five treatments. In treatment number one (Trt1), 70% ETc was applied from 8 to 27 DAT after which 100% ETc was applied for the remaining duration of the experiment. In treatment 2 (Trt2), 70% ETc was applied from 28 to 46 DAT after which 100% ETc was applied for the remaining duration of the experiment. In treatment (Trt3), 70% ETc was applied from 47 to 79 DAT after which 100% ETc was applied for the remaining duration of the experiment. In treatment 4 (Trt2), 70% ETc was applied from 80 DAT until final harvest of the crop.

Soil moisture measurement

In irrigation development, even if calculations of crop evapotranspiration are utilized for irrigation scheduling, measuring or monitoring of soil moisture is still recommended. Localized conditions such as soil texture, root depth cause the actual evapotranspiration to differ from the calculated values (George et al., 2000). Therefore, the utilization of a method to measure or monitor soil moisture content may assist in evaluating any effects localize conditions may have on the irrigation schedule. A variety of

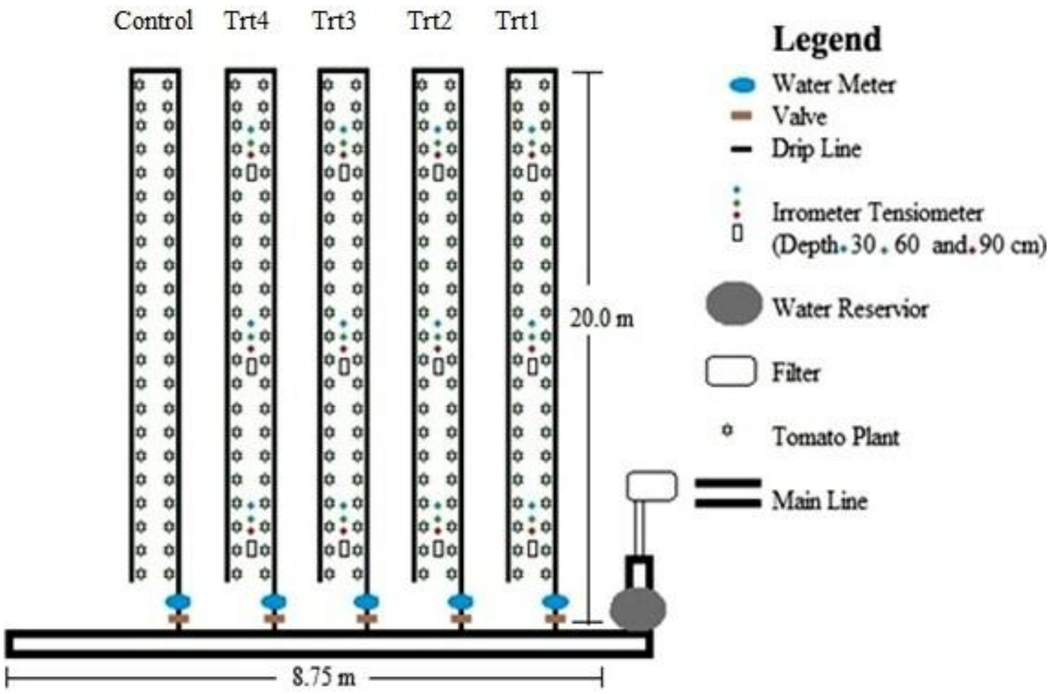

Figure 1. Treatments and field layout.

methods have been used in this field to estimate moisture at different depth within a soil profile which is in relation to the crop rooting depth. These measurement methods may be classified into two categories, one being direct (gravimetric) and the other, indirect (soil moisture sensors). To attain instantaneous soil moisture reading, this study used an indirect non destructive method. This method came in form of IrriWise wireless soil moisture sensory system (Netafim Irrigation Inc.). The components of the system seen in Figure 2 included a receiver (A), tensiometer (B), water meter (C) and a transmitter (D). The tensiometer at their respective depths sends the reading to the transmitter which then relays that information to the receiver through wireless transmission. The information sent to the receiver is converted and then stored on a personal computer at the base station which can be used for data mining. This system was appropriate for this study since 15 min interval of soil moisture condition data collected and stored throughout the cropping cycle of the tomato crop. The real time data of soil moisture conditions at depths of 30, 60 and 90 cm within the soil profile of this experimental plot reduce the chance of deviation from the irrigation regime results of which are illustrated in Figure 3. Figure 3 showed the trend of soil moisture on a daily basis throughout the growing season of the tomato crop.

The irrigation scheduling for this experiment was done using the CROPWAT Program which was developed by Smith (1992). CROPWAT is a globally accepted computer program as use for irrigation planning and management software which estimates crop water use and therefore optimizing irrigation. The basic functions of this software include the calculation of reference evapotranspiration (ETo), crop water requirements (ETc), and crop and scheme irrigation.

Plant measurements and sampling for chlorophyll determination

Growth and development parameters such as plant height, leaf chlorophyll content and reproductive parameters such as the rate of flowering and number of clusters (truss) were collected. Data on the fruit included the number of fruits on the first cluster, sum of fruits on the plant and the fruit size were also collected. The sample size for all parameters was 30 plants per treatment with the exception of fruit size whereby only ten random samples were taken per treatment. The chlorophyll content of the leaf was measured at 25, 33 and 54 DAT between the hours of 1 and 3 p.m. Leaf chlorophyll measurements were made non-destructively using the SPAD-520 chlorophyll meter (Minolta, Osaka, Japan). This device measured the absorption at 650 and 940 nm wavelengths to estimate chlorophyll levels (Mercado-Luna et al., 2010). At 60 DAT, the chlorophyll content was measured by layers to establish if there is a variation in the accumulation chlorophyll content by the layers of the plant as shown in Figure 4. Several studies have reported conflicting results on the exact location on a leaf which may indicate a representative value of its chlorophyll content. So, as not to assume a location on the leaf which represents the chlorophyll content of the entire leaf, a test was carried out whereby the spad value of seven leaflets of the leaf (Figure 5) was compared to average spad value of the leaf.

Results in Figure 6 showed that there was no significant difference between the 7 sampling positions and that of the average leaf spad value. Therefore it was decided that position 3 on the leaf would be used as the location at which the leaf chlorophyll content would be measured. Since position 3 mean spad value of 45.02±2.12 was closest to the average leaf spad value of 45.90±2.24.

Statistical analysis

The SPSS software for windows was used to statistically analyze the data first by using the Levene’s equation. ANOVA was then performed at $\alpha = 0.05$ level of significance to determine if significant differences existed among regimes. To determine significant

Figure 2. Wireless soil moisture sensory system (Netafim Irrigation Inc.).

effects, multiple comparisons were made using the least significant difference (LSD) test at α = 0.05.

RESULTS AND DISCUSSION

Chlorophyll

Leaf chlorophyll content provides valuable information about the physiological status of plants (Gitelson et al., 2003). A close relationship exists between a plants photosynthetic capacity and its nutrition. Pinkard et al (2006) in their study reported that if a plant is grown under optimal conditions, photosynthesis needed for the plants development would only be hindered by the nutrient elements available. In this study, less than optimum moisture was simulated, to observe that even with a soil environment well supplied with nutrients, would there be a variation in the rate of photosynthesis. Usually, the first symptoms produced by a shortage of any mineral element is a loss of chlorophyll (chlorosis) (Fernández-Falcón et al., 2006), which result in an alteration of the chloroplast structure. There have been studies (Fontes and de Araujo, 2006; Wang et al., 2004) proven that spad readings are correlated with the amount of chlorophyll present in the leaf and chlorophyll content is positively correlated with leaf nitrogen content. Spad readings would therefore also be correlated with the amount of nitrogen present in

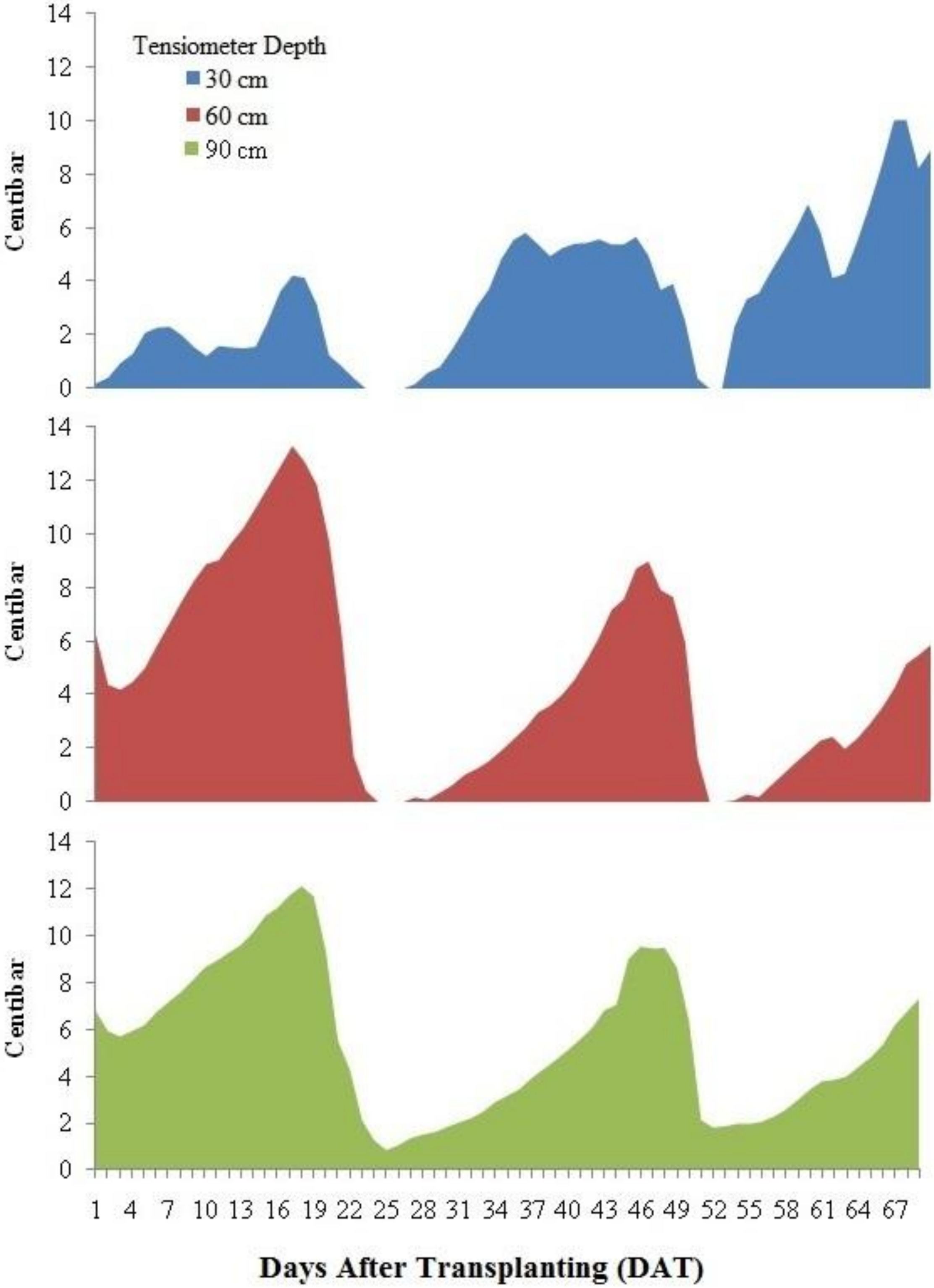

Figure 3. Trend of soil moisture in field during experimentation period.

the leaf of a tomato plant (Fontes and de Araujo, 2006). Evident in the spad reading of the plants not subjected to water deficit earlier in their growth cycle. Results of this experiment have shown that all treatment were significantly lower than the control at 25 DAT, with treatment 4 (Trt4) having the lowest spad value (38.2±3.3) of the five

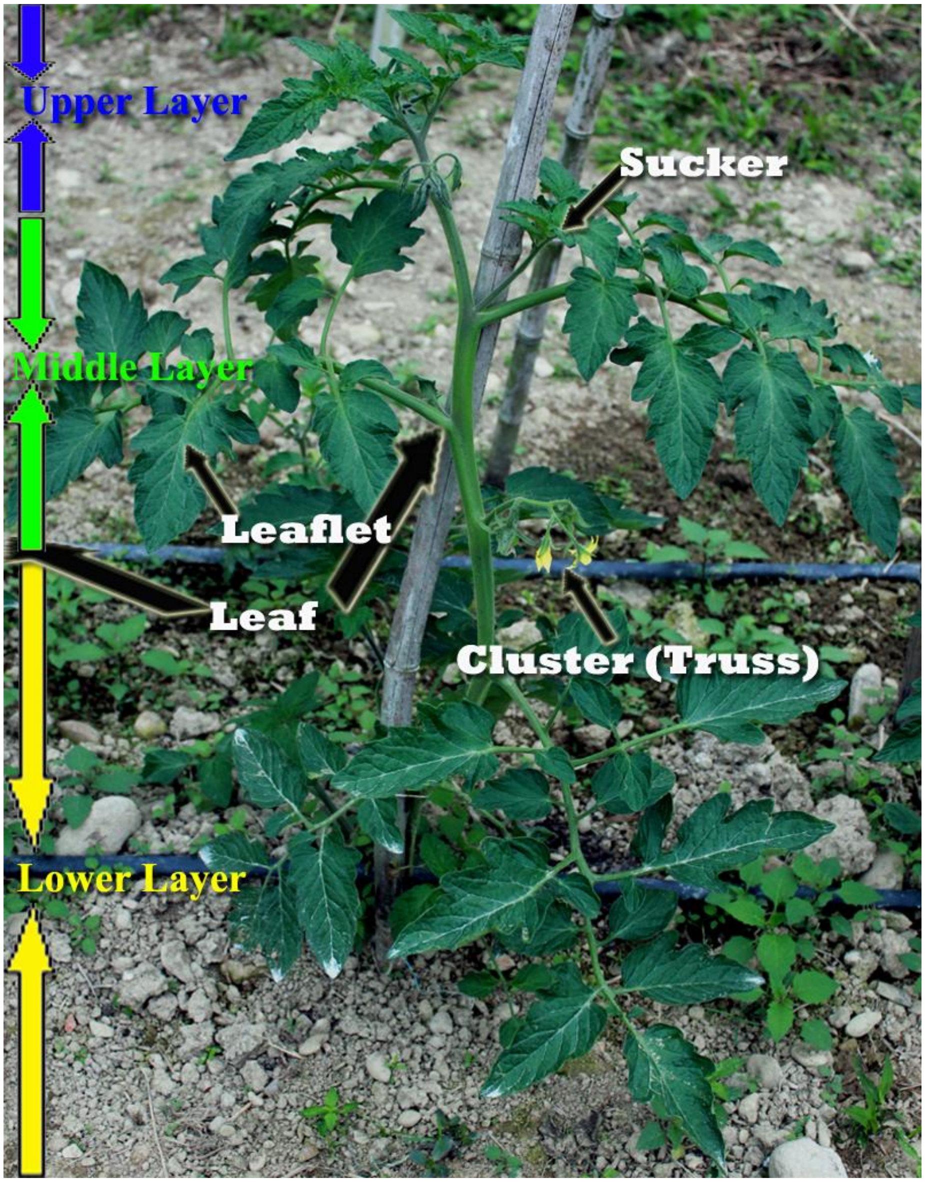

Figure 4. Morphology of tomato plant.

treatments. At 33 DAT, the control still recorded the highest spad value whereas Trt3 although not significantly different from Trt1, 2 and 4, it recorded spad value of 43.1±2.86 which was the lowest of the treatments.

The trend of a lower leaf chlorophyll content, due to water restriction in the previous stages of growth Trt1 (initial stage) and Trt2 (vegetative or developmental stage) was not continued in the mid season stage, only the control had the highest spad value within these respective stages. The trend in the previous stages of growth was not observed at 54 DAT. Sibley et al (1996) discouraged the use of the spad meter stating that it was not a suitable substitute for chemical N determination. The results of this experiment are in agreement with previous studies (Fontes and de Araujo, 2006; Richardson et al., 2002; Wang et al., 2004) which showed under field conditions the environmental factors and cultural practices may interfere with the reading. A positive association could be observed between chlorophyll content and crop development, where under well irrigated conditions the improvement of nitrogen uptake efficiency as measured indirectly by chlorophyll determination (spad value) which is essential for the performance of the tomato plant. In Figures 7 and 9, it noted that both the leaf chlorophyll content and the height of the plant increased as the tomato plant developed and made the transition through the various growth stages. At 60 DAT, there was no significant difference between treatments; however, there was a significant difference in

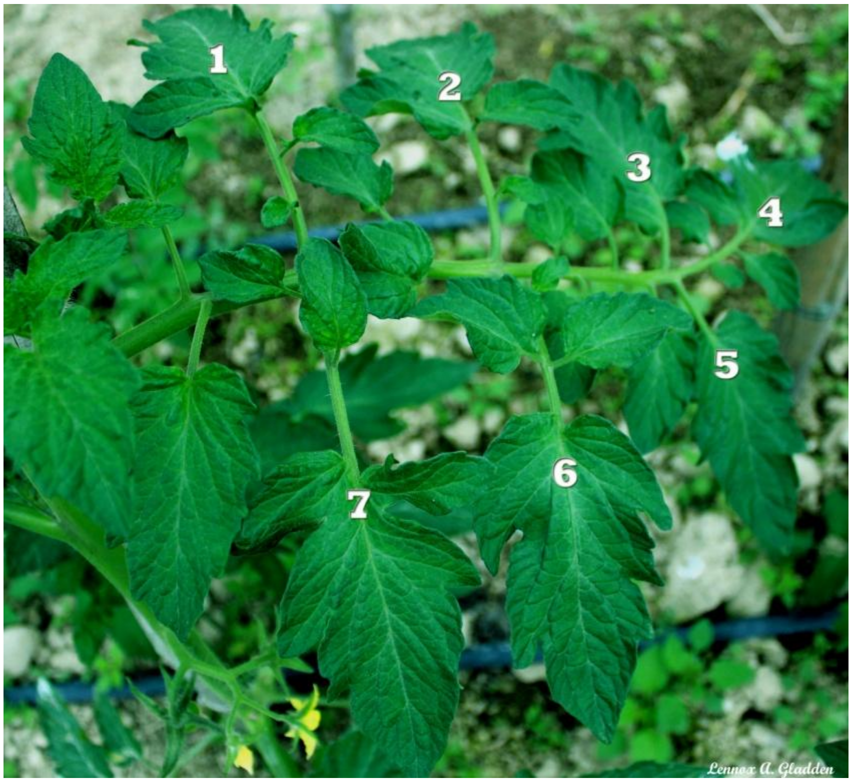

Figure 5. Foliar sampling of tomato plant.

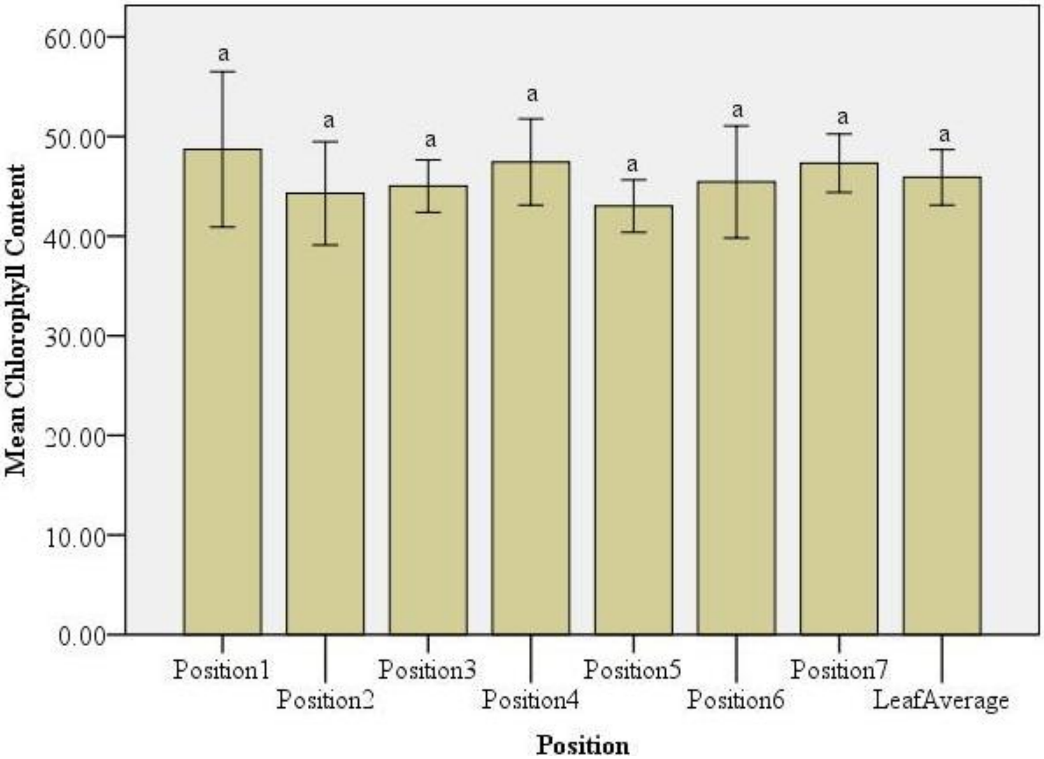

Figure 6. Mean chlorophyll content of sampling positions on tomato leaf. Means followed by the same letter are not significantly different as determined by LSD analysis ($P \leq 0.05$). While the vertical bars represent SD of means.

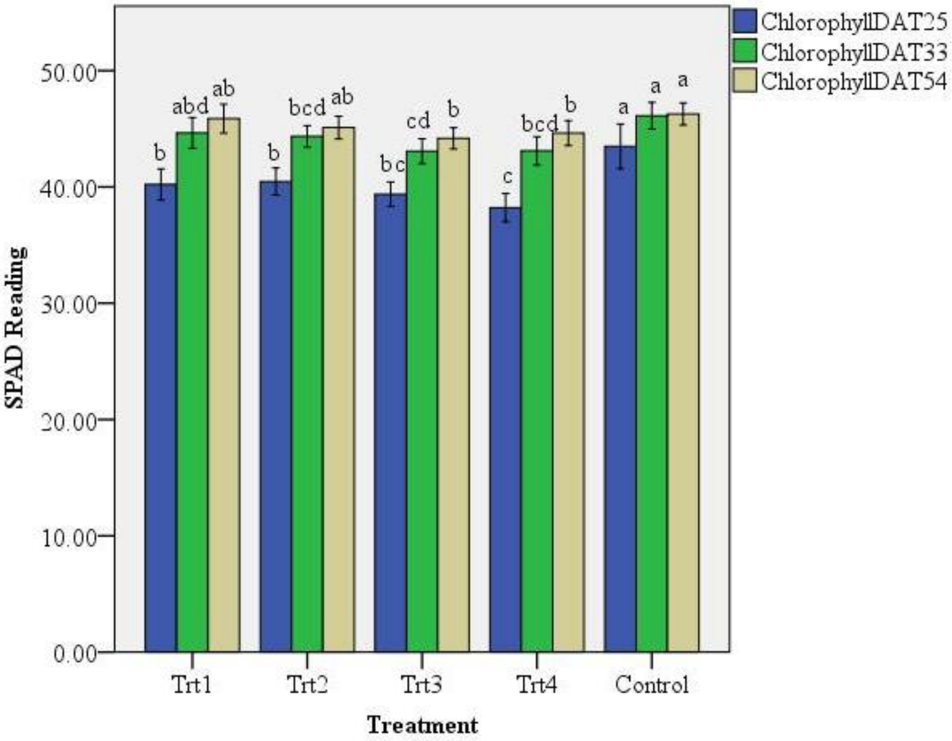

Figure 7. Effect of water restriction on chlorophyll content of tomato leaf. Columns represent mean ±SD (n = 30) and the difference between means were compared by least-significant difference test (LSD; P = 0.05).

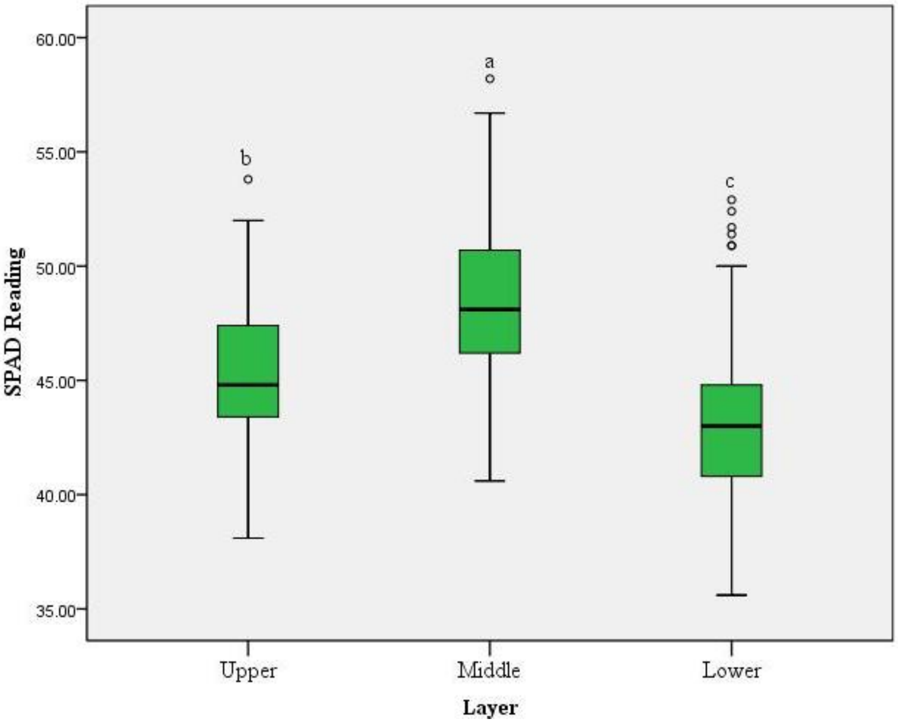

Figure 8. Leaf chlorophyll content measured by layers. Each plot represent mean ±SD (n = 30) and the difference between means were compared by least-significant difference test (LSD; P = 0.05).

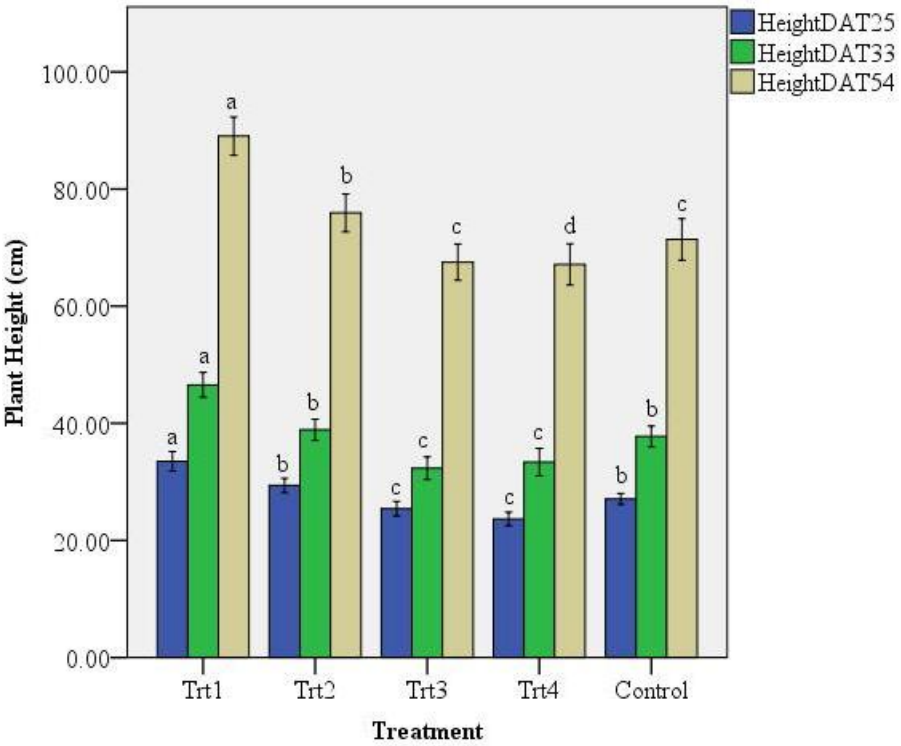

Figure 9. Effect of water restriction on plant height. Columns represent mean ±S.D (n = 30) and the difference between means were compared by least-significant difference test (LSD; P = 0.05).

the leaf chlorophyll content within the respective layers (Figure 8). It could be observed that the highest average spad value was concentrated in the middle layer followed by the second highest reading within the upper layer and the lowest reading being recorded in the lower layer of the plant. This according to Buchanan-Wollaston (1997) is a natural phenomenon in a plant's development, whereby leaf chlorophyll content is known to be lower in both the newly developed leaves and older leaves of the plant.

Buchanan-Wollaston (1997) described leaf senescence as the sequential degradation process that leads to a massive mobilization and export of nitrogen and eventually plant death. This description along with insight from Grover (1993) and Lu et al. (2001) mentioned that the disassembly of the photosynthetic apparatus within chloroplast caused by aging leaves (leaf senescence) result in a concomitant decrease in photosynthetic activity. Aforementioned discussions verified the reason for the low spad value in the lower layer of the tomato plant.

Plant growth characteristics

The cumulative trends of the plant height were similar in the different irrigation treatments as indicated in Figure 9. The approach to calculate plant height growth rate was used by Zeng et al (2009). They defined plant height growth rate as the ratio of the plant net growth amount for the adjacent measurement values and the former plant height values, and the former height value is the reference (100%). It was determined that the plant growth rate of Trts1, 2, 3, 4 and Control from 25 to 33 DAT were 39.0, 32.3, 27.2, 40 and 39.5% respectively. The plant growth rates from 33 to 54 DAT were 90.9, 95.1 108, 100.9 and 88.8% respectively. A common factor which may have contributed to both Trts4 and 3 having the highest growth rate in their respective stage is re-watering. Torrecillas et al (1995) in their research showed that after re-watering to full ETc vegetative growth of a stressed tomato plants can recover which indicated a reversibility of morphological changes promoted by water stress. Figure 9 shows the relationship between control and treatments 1 through 4. Where at 25 DAT, it was observed that both Trts1 and 2 had a significantly higher plant height than that of the control and Trt4 had a significantly lower plant height. At 33 DAT, the plant height in Trt1 was still significantly different than that of the control whereas at this stage, both Trt3 and 4 showed a significantly lower plant height. When measurements were taken at 54 DAT, the only treatment which had a significant difference was Trt1. Under field conditions where all treatments are exposed to equal amount of

Table 1. Growth performance between field grown tomato and tomato grown under different water deficit treatments.

Treatment	Plant height (cm)		Leaf chlorophyll content (spad value)	
	DAT 25	DAT 33	DAT 25	DAT 33
Shade	47.2 ± 3.42^{a}	64.4 ± 3.43^{a}	45.6 ± 2.09^{a}	45.5 ± 2.49^{ab}
Trt1	36.5 ± 4.32^{b}	45.9 ± 2.81^{b}	35.0 ± 5.78^{b}	48.5 ± 6.33^{a}
Trt2	31.5 ± 2.45^{c}	44.8 ± 2.07^{b}	28.8 ± 2.26^{c}	41.2 ± 4.40^{bce}
Trt3	27.1 ± 2.25^{d}	45.4 ± 1.66^{b}	26.3 ± 2.89^{cd}	33.6 ± 5.94^{cd}
Trt4	22.3 ± 2.74^{e}	44.8 ± 2.45^{b}	24.1 ± 3.23^{d}	37.5 ± 5.28^{cde}
Control	27.9 ± 4.26^{d}	45.9 ± 3.42^{b}	27.9 ± 3.29^{c}	40.4 ± 5.76^{ce}

Means followed by different letters within each column showed significant differences (p<0.05. L.S.D.).

Table 2. The effect of deficit irrigation on the reproductive performance of tomato.

Parameter	Treatments					
	DAT	Trt1	Trt2	Trt3	Trt4	Control
Clusters on plant	45	2.6 ± 0.49^{a}	2.4 ± 0.67^{a}	1.8 ± 0.61^{b}	1.7 ± 0.53^{b}	2.4 ± 0.56^{a}
	54	3.5 ± 0.57^{a}	3.0 ± 0.61^{b}	2.9 ± 0.51^{b}	3.0 ± 0.49^{b}	3.1 ± 0.64^{b}
	68	4.9 ± 0.51^{a}	4.3 ± 1.02^{b}	4.1 ± 0.49^{bc}	3.9 ± 0.69^{c}	4.2 ± 0.57^{bc}
Blossoms	45	5.8 ± 0.81^{a}	5.7 ± 0.99^{a}	4.9 ± 1.01^{b}	4.9 ± 0.94^{b}	5.8 ± 0.97^{a}
Fruits on first cluster	54	4.5 ± 1.74^{a}	2.2 ± 1.44^{b}	1.4 ± 1.22^{c}	1.5 ± 1.11^{c}	3.9 ± 1.03^{a}
Fruits on plant	68	5.8 ± 0.81^{c}	7.7 ± 3.25^{b}	6.8 ± 2.23^{bc}	7.5 ± 2.19^{b}	11.6 ± 3.44^{a}
Fruit size (cm)	71	5.3 ± 0.40^{a}	4.8 ± 0.75^{b}	4.3 ± 1.08^{c}	4.7 ± 0.61^{bc}	5.2 ± 0.34^{ab}
Yield Estimation Index	71	31.2 ± 4.6^{c}	44.4 ± 11.4^{b}	25.5 ± 9.06^{c}	31.2 ± 7.43^{c}	71.1 ± 11.7^{a}

Means followed by different letters within each row showed significant differences (p<0.05. L.S.D.).

environment factors, the response of the plant to water restriction should have been similar to reaction seen in Trt4 at 25 DAT and Trt3 at 33 DAT. It was assumed that the shadow cast on a portion of the experimental field would not have influenced the results. However, the results seen here have shown that shade even if only partial shade has an influence on plant development in particular the plant height also observed by Sandri et al. (2003).

To verify the effect of shade on plant development, plant height and leaf chlorophyll data was compared to an adjacent experiment which was being conducted under a net house with 30% shade, results of which can be seen in Table 1. Although, less samples were collected for this analysis, an adequate comparison was still performed which revealed that the height of tomato plants grown under continuous shade was significantly higher than those cropped in open field. The response of tomato under these conditions was also observed by Sandri et al. (2003). Also, in this study, it was documented that an increase in height is not positively related to fruit establishment or yield.

Plant reproductive performance

In this experiment, treatment which underwent a deficit in water supply at early stages of their growth produced less clusters than those which underwent the deficit treatment later in their growth stage, when a cluster count was conducted at 45 DAT. However, when a cluster count was conducted nine days later it was observed that Trt3 and 4 did not show any significant difference from the number of clusters found on the Control. The development however was still affected; this was indicated by the number of buds of these two treatments which were significantly lower and more poorly formed in comparison to the treatments, the treatment not subjected to water stress earlier in their growth. In Table 2, it could be observed that Trts3 and 4 did recover the development

Figure 10. Comparison of fruit development between control (B) and treatments subjected to water deficit (A).

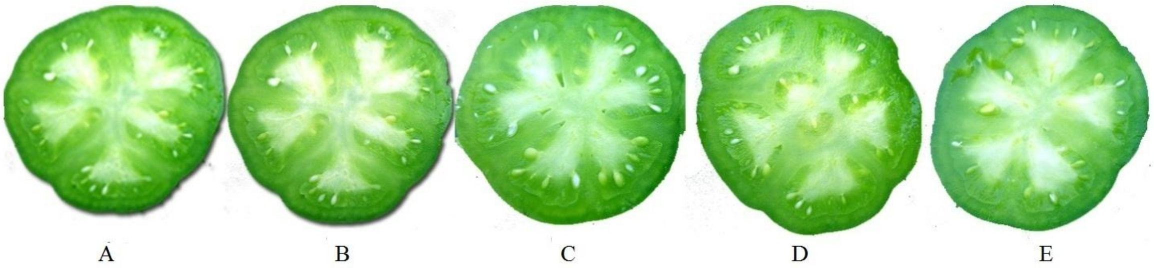

Figure 11. Transverse section of tomato fruit.

however, was still affected; this was indicated by the number of buds of these two treatments which were significantly lower and poorly formed in comparison to the other treatments as illustrated in Figure 10. This figure represents an observed trend in the fruits which are found in these two treatments where it was observed that although they produced similar quantity of fruit buds, the size were much smaller than those found in the other treatments. The deficit water at mid season significantly affected the quantity of fully formed fruits on the first cluster of the plant. However, the yield estimation index has determined that apart from the Control, Trt2 performed best amongst the treatments subjected to drought scenarios. Visual observation showed all treatments had healthy developing seeds with properly formed pericarp (which includes the inner wall, columella; the radial wall, septa; and the outer wall). The pericarp and the placenta showed no deformities as illustrated in Figure 11 and the only difference amongst these treatments would have been the fruit size (Table 2). Also, comparing results from Figure 9 and Table 2 showed that there was no relationship between the plant's height and the number of fruits it bears. Rather there were positive association between the fruits and the amount of water applied. As seen in the control, where although the plants were shorter in stature due to its crop water requirement being met it was able to have more optimum production of the tomato fruit.

Conclusions

Results of the study indicated that the different irrigation regimes had a significant influence on responses of field grown tomatoes where vegetative growth and reproductive was closely linked to the amount of water applied. Water deficit in the earlier stages of growth (Trts3 and 4) not only diminished the leaf chlorophyll content and rate at which plant grew, but it reduced rate of cluster formation; a reduction that affected the number of fully formed fruits on plants within these treatments. During this experiment, it was observed that the Control performed best among the five treatments which indicated tomatoes sensitivity to water deficit. Although, water was saved in the other treatments if the goal is to optimize the production under water scarce scenarios either the deficit irrigation approach should not be utilized or the percentage of water being restricted revised. The water restriction percentage in this experiment was 30%, as a recommendation it would be prudent to decrease this percentage by 5 to 10% amongst all the treatments. We conclude that there is a positive relationship between the water application and the sum of fully developed fruits and not with the height of the plant. This would further verify the statement of the plant being more sensitive to water deficit earlier in their growth stage rather than later.

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