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Partial root zone drying alternation frequency effect on yield, biomass production and fruit quality of tomato crop

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ABSTRACT

The objective of the work was to assess the effects of partial rootzone drying (PRD) strategy's alternation frequency on some agronomic responses of a tomato crop cultivated in greenhouse and on a sandy substrate. Three treatments were applied: a control and two PRD treatments. The control (T0) received 100% of water requirements while T3 and T4 were irrigated at 50% of water requirements. Those two treatments were alternated at 20% and 40% of dry side water storage depletion, respectively. The control registered the highest yield but the lowest water use efficiency while T4 produced 15% more than T3. Compared to the control, PRD treatment leaf area was decreased and T4 had 27% higher leaf area than T3. Biomass production reached its higher levels for T3 and root biomass accumulation is greater than stem, leaf and fruits. Total soluble solid concentration and acidity of T3 fruits was 25% as higher as T4 and the control.

Keywords: PRD, yield, leaf area, biomass, fruit quality

INTRODUCTION

Available water resources for agriculture have been decreasing in recent years with the increased demands for irrigation and other non agricultural water uses. New water-saving techniques such as the partial root-zone irrigation (PRI) or partial root-zone drying (PRD) have been proposed as an agronomic practice for more efficient use of the limited water resources ([1],[2]). The PRD is potential water saving irrigation strategy that utilizes plant-to-shoot chemical signaling mechanisms to influence shoot physiology. When the crop is irrigated, soil on only one side of the row receives water while the other is allowed to dry [3]. At each irrigation time, only a part of the rhizosphere is wetted while the other side is kept dry [4].

Regarding the alternation frequency, some researchers demonstrated that prolonged drying of one compartment of the root system eventually diminished the effects of chemical signals on stomatal conductance [5] as water uptake from this compartment contributed proportionally less to the transpiration stream [6]. Other scientists confirmed that prolonged exposure of roots to drying soil may cause anatomical changes in the roots, such as suberization of the epidermis, collapse of the cortex, and loss of succulent secondary roots [7]. Therefore, some of the most important question is: since that alternation period is so important, what would be the effects of different alternation periods on the production and on other agronomic parameters.

In the frame of such reflection and with the goal of answering, even partially, to that question, our experiment was carried out. It had as objective to assess the effect of two alternation frequencies on agronomic parameters of tomato crop cultivated under greenhouse and on soilless. The alternation frequencies were fixed through percentage of water storage depletion within the dry side of roots. Hence, two treatments T3 and T4 were alternated at 20% and 40% of dry side water storage depletion, respectively.

MATERIALS AND METHODS

2.1. Experiment Location

The experiment was carried out in the Agronomic and Veterinary Institute Hassan II- the Horticultural Complex of Agadir in a multi-tunnel greenhouse and on an area of 1322 m^2.

2.2. Plant Material

The used tomato cultivar is '*Pristyla*' that was grafted on 'beaufort'. The crop was planted in 25th November 2010 and was conducted in vertical trellising and on a single stem. Crop cycle lasted for 8 months.

2.3. Soilless System

Soilless system consists of containers (10 m length, 25 cm depth and 40 cm width). Each container is an experimental unit composed of 20 plants. The used substrate is sandy-silty (78% sand, 19% silt and 3% clay). This later was deposed over two drainage layers: 5 cm coarse gravel layer and 5 cm fine gravel layer. As far as the separation between root sides for PRD treatments, each container consists of two juxtaposed substrate filled containers and plants were planted on the juxtaposition line to allow root separation.

2.4. Irrigation

The irrigation was performed using double ramp drip irrigation system with 40 cm spaced emitters that generate a flow of 2l/h/emitter. Concerning PRD treatments, switching was allowed throw small valves that are placed in the beginning of each ramp. Irrigation and fertilization management were made within a fertigation station throw electro-valves. Daily reference evapo-transpiration ETo was calculated using the De Villele formula [8]. Global radiation was measured by a pyranometer (kipp and Zonen model splite). ET0 (mm/j) = 0,0016 x Rg (cal/m2/j)

To avoid water loss, net maximum irrigation dose was determined referring to granulometric properties of the substrate using the following formula:

$$NMD = f \times (Hcc - Hpf) \times Z \times PSH$$

Where, f is the allowed water stock decrease (10%), Hcc and Hpf are, respectively, field capacity and welting point substrate moistures, Z is the root depth and PSH is the percentage of the wetted zone. According to substrate physical properties, calculated NMD was equal to 0.768 mm. Using irrigation system rainfall (4mm/h), each irrigation supply must last 12 mn. As far as irrigation frequencies, they were variable since they depend on the Etc/NMD ratio.

2.5. Experimental Design

A complete randomized design was used. Five treatments were applied. Each treatment consisted of 20 plants and was replicated eight times. Data were analyzed using MINITAB software version 15.1.1.0. Treatment means were separated by Tukey's test at $P \leq 0.05$.

2.6. Adopted Treatments

Besides control treatment (T0) that received 100% of its daily water requirement, two PRD treatments were adopted:

T3: That treatment receives 50% of water requirements and is alternated at 20% of substrate water storage depletion.

T4: It was irrigated at 50% of tomato water requirements and alternated at 40% of substrate water storage depletion.

2.7. Measured Parameters

a) Leaf area: Leaf area measurement was performed on the 20th, 30th and 37th using a leaf area meter.
b) Cumulative yield: 28 harvests were achieved beginning on 27th November 2011. During each harvest, fruits were weighted and counted in order to determine cumulative and total produced yield.
c) Water use efficiency: It was calculated as the ratio between total produced yield and total supplied water volume and expressed as g of fresh yielded fruits /l of supplied water irrigation.
d) Dry matter production: At the end of the crop cycle, two plants per experimental unit (16 plants par treatment) were removed and all plant organs (stem, root, leaf, fruit) were weighted to determine their fresh weight then put in an oven at 65°C. When a constant mass was reached, samples were re-weighted to determine their dry weight. For

each organ, dry matter production or dry biomass production was calculated as the ratio between the dry weight on the fresh one.

- Fruit quality: The fruit quality was assessed through total soluble solids and titratable acidity (%)Titratable acidity: To obtain titratable acidity, a 10 g fresh fruit sample was liquefied with 10 ml of distilled water. A 10ml of aliquot was taken and titrated with NaOH 0.01N, with phenolphthalein as an indicator of pH change. Titratable acidity was calculated as a percentage of citric acid.
- Total soluble solids: Total soluble solids content of fresh undiluted juice was measured using a handheld refractometer and is expressed in °brix.

RESULTS AND DISCUSSION

3.1. Internal greenhouse climate

The greenhouse climate is characterized by a large variation within the time. The end of the first month after planting is characterized by a continuous VPD decrease that lasted for three months. At the end of that period, averaged diurnal VPD reached 3 kPa and began an increase trend during the remaining period of crop cycle. The vapor pressure deficit presented many peaks during high evaporative demand period that started in the 101th day after planting. It reached its maximum level (8 kPa) during the 274th day after planting. Therefore, and according to thermal preferences of tomato crop, it can be deduced that, beginning from the 101st of the crop cycle, climatic conditions were no longer suitable for optimal growth and production ([9], [10]).

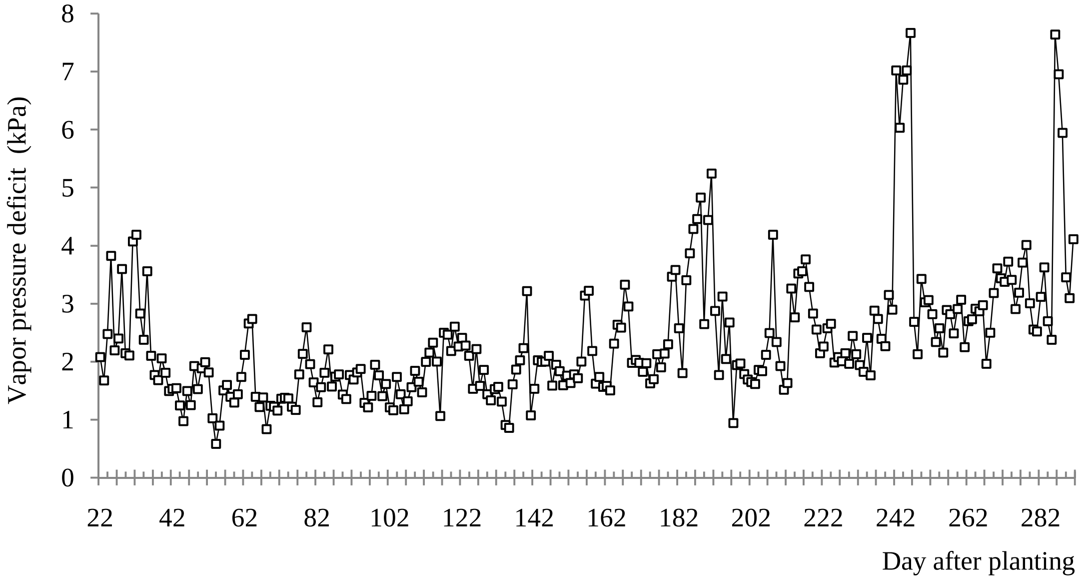


Figure 1. Vapor pressure deficit variation during the crop cycle inside the experimental greenhouse

3.2. Produced Yield and water use efficiency

The Control performed the highest total yield (279 T/ha). Statistically, there was a high significant difference (P = 0,000007 ≤ 0,001) between the control and PRD treatments. Concerning T4 and T3, produced yields were, respectively, 182T/ha and 159T/ha. Hence, the experiment result showed a decrease of PRD treatment yield by 64% compared to the control which is far from some other researches that proved no significant difference between control and PRD treatment production ([11], [12], [13]). That yield decline could be explained by flower abortion that we noticed during the experiment and is a logic consequence of water and nutrient shortage. As far as PRD treatment comparison and despite there is no significant difference, T4 performed 15% higher yield than T3 which could be related to root to shoot chemical signals. In fact, T4 stomatal conductance and maximum daily shrinkage study (results not shown) proved higher water loss restriction than T3 through more strict stomatal closure.

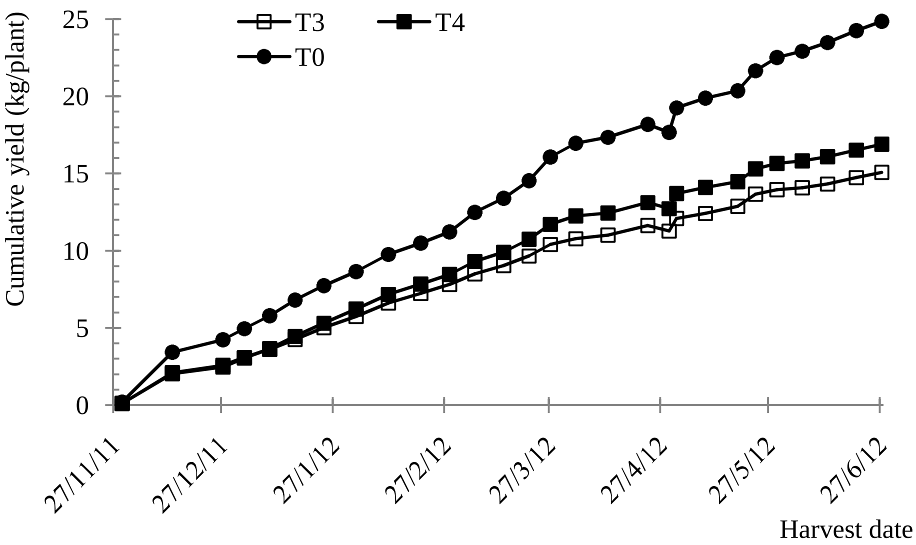


Figure 2. Cumulative produced yield of different treatments: T4 (■), T3 (□) and control (●)

Concerning water use efficiency, it was evaluated in terms of yield and total supplied water volume. The least irrigated treatments (T3 and T4) were the most efficient since they were, respectively, 114% and 130% more efficient than the control. In addition, T4 which is less alternated seems to be more efficient than T3. That result is consistent with many other researches showing that abscissic acid (hormone responsible of stomatal closure) of PRD root increases as soil water content declines and that photosynthesis's decrease is not linearly related to the stomatal conductance one which leads to WUE improvement compared to well watered plants.

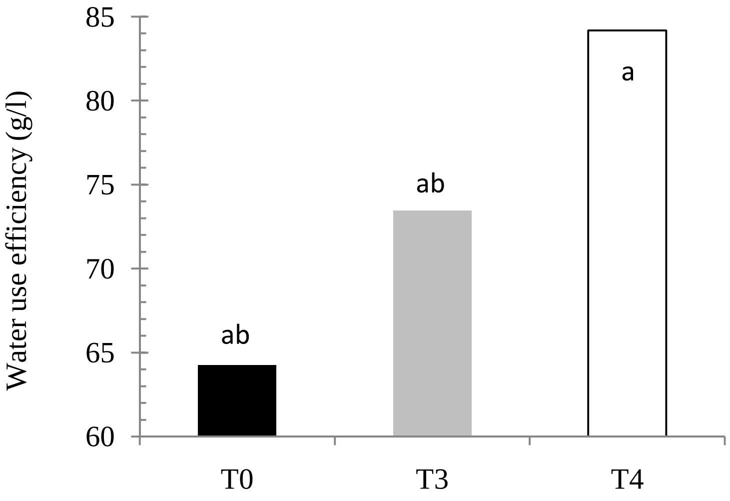


Figure 3. Performed water use efficiency of different treatments

3.3. Plant Growth

a) Plant height: The used cultivar is of undetermined growth type. That's why the height curve is continuously increasing during the crop cycle. As far as height plant comparison, Treatment receiving less water (T3, T4) showed the lowest plant height. Experimental evidence shows that shoot growth can be restricted by mechanisms of root–shoot chemical signaling, even when tissue water potential is constant [14].

b) Leaf area: Leaf area parameter registers significant difference between the control and PRD treatments and seems to be more precise to describe plant growth [15]. The comparison between PRD treatment leaf areas measured in the 263th day after planting indicates that T4 developed 174% larger leaves than T3 since plant leaf number was similar. Thereby, water shortage level influenced plant growth not only when comparing control and PRD treatments but also within PRD treatments which could explain the noticed yield differences. Other reports proved that leaf area decrease is linearly related to stess level such as [11] who confirmed that plant leaf area decreased by 15%, 39%, and 42% for PRD90, PRD70 and PRD50, respectively. That conclusion could prove that T3 plant treatment sense more stress than those of T4 which is consistant with yield parameter previously discussed.

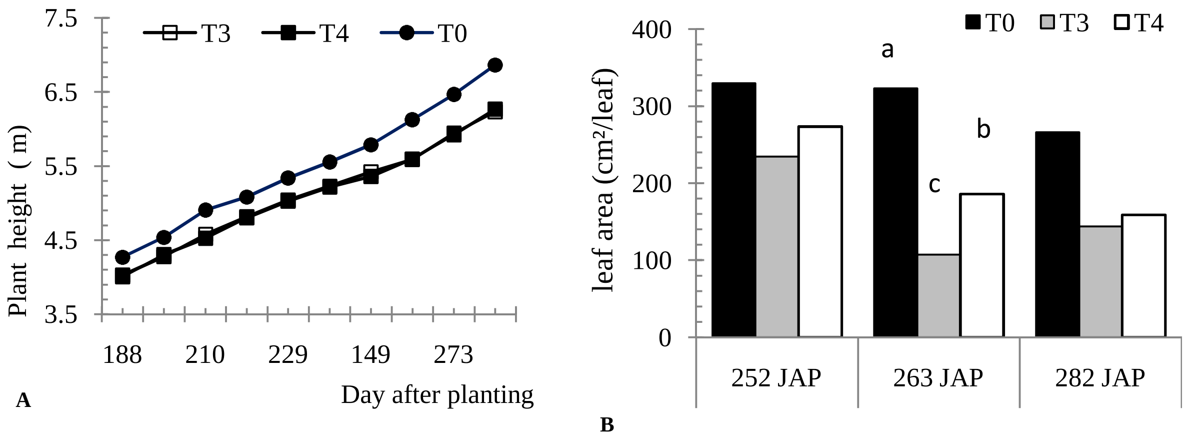


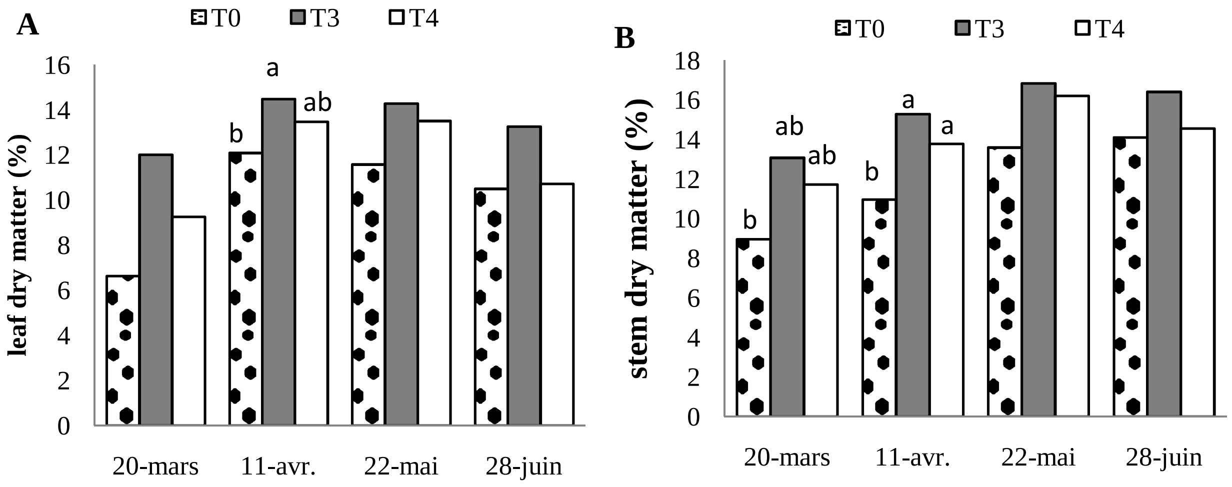
Figure 4. Vegetative growth comparison: height (A) and leaf area (B) of different treatments. Presented values are mean of eight replications and sixteen samples.

3.4. Dry Matter Production

Comparing the general trend of dry matter production within different organs, it can be concluded that it increases similarly for all plant part then declines at the end of the measurement period. That decrease could be attributed, in one hand, to plant age and in the other hand, to internal greenhouse climate (Figure.1) as that period of the crop cycle matches with June month when the vapor pressure deficit reaches its maxima that widely exceeds 2 kPa.

Leaf and stem dry matter variation graph shows the same trends at different date measurement. In fact, for both organs, T3 generated more dry matter than T4 and the control at lower VPD level (2,7 kPa and 1kPa) while that difference was not significant at higher VPD levels (6 kPa). The control is the lowest dry matter productive treatment not only comparing stem and leaf dry matter but also root and fruit one.

As far as root and fruit dry matter partitioning, C and D graphs show that when VPD values were about 2 kPa, T3 accumulated higher amount of dry matter than T4 and the control. Nevertheless, at high VPD levels, T4 fruit and especially root accumulated higher dry matter than T3 and the control which could explain the noticed difference of produced yield between T4 and T3 as previously mentioned. The exposure of roots to soil drying and re-watering seems increasing root growth, which may enhance root biomass production [16]. Besides, [17] confirmed that, even when water stress decrease plant biomass, its allocation to roots remains greater than to other organs. Comparing PRD treatment and the control, fruit dry matter production difference could be attributed to the electrical conductivity increase because of water restriction which stimulates higher dry matter per fruit [18]. While the experiment results shows that the conventional irrigated control treatment generated the lowest dry matter within different plant parts, [19] and several other researches proved that such treatment is the most dry matter productive. Lastly, it is important to notice that the common response was fruit dry matter partitioning that was continuously enhanced although other organ dry matter content decrease especially at the end of the crop cycle.



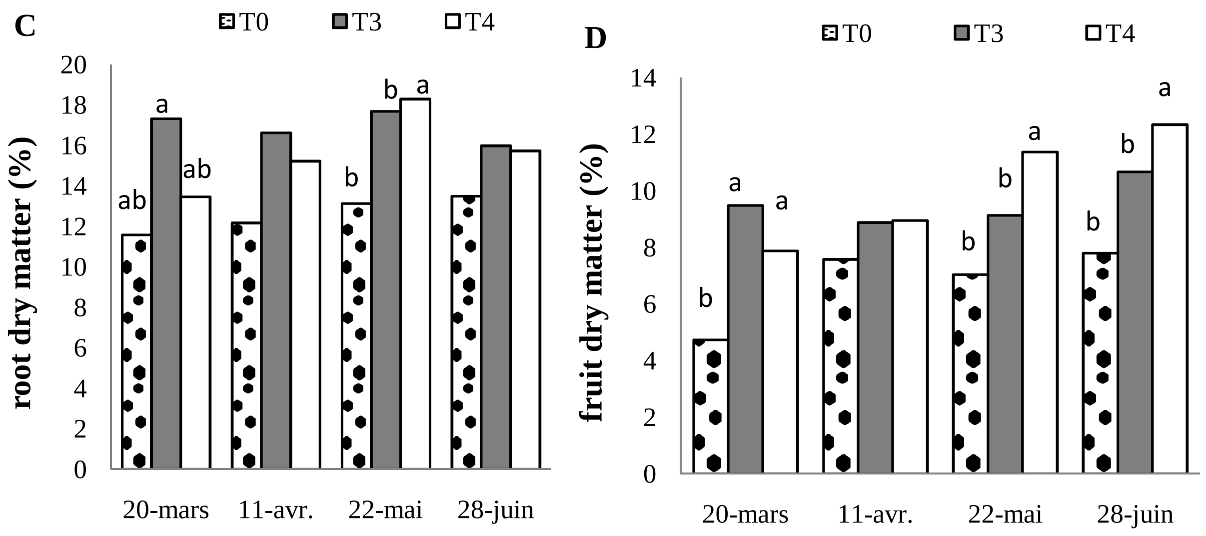


Figure 5. Leaf (A), Stem (B), Root (C) and fruit (D) dry matter content

3.5. Fruit quality

a. Total soluble solids

As shown in the graph below, total soluble solids (TSS) production in T3 fruits is 25% higher than T4 and the control which is consistent with previous reported results ([20] and [21]).Such difference could be explained by additional water shortage applied to T3. In fact, other results of the same experiment (not shown result) proved that T4 resulted in higher water loss restriction than T3 and the control [22]. That excess of water loss leads to phloem water removal and, therefore, to the increase of fruit supplied solute concentration ([23], [24]).

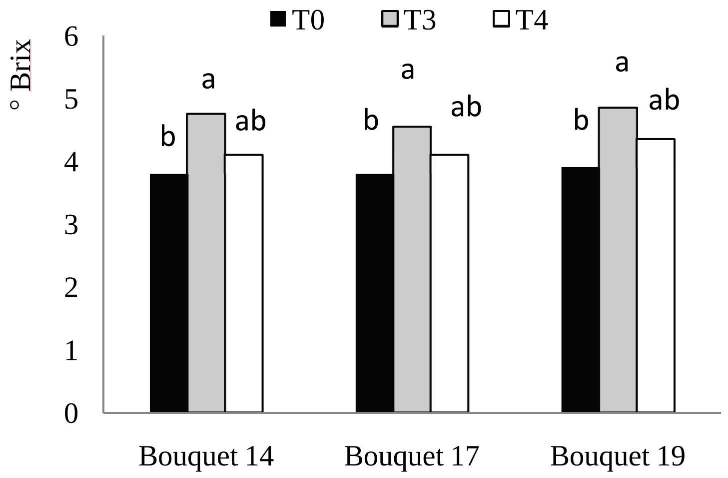


Figure 6. Total soluble solids content of fruit

b. Acidity

According to the graph below, fruit titratable acidity level was not significantly different except that of the 19th truss. Even though, the control produced less acid fruits than other treatments and T3 fruits were more acid than others while T4 produced fruits of medium acidity. According to [11], well watered treatment produces higher acid fruits which is not consistent with our experiment results. [25] pointed out that tomatoes described as ‘‘great taste’’ are characterized by their low level of titratable acidity and high total soluble solids content which could be attributed to T3 fruits.

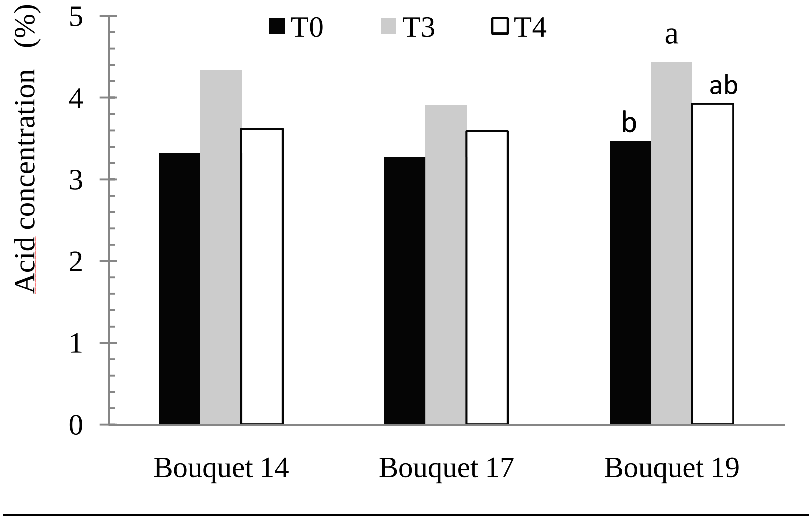


Figure 7. fruit Acidity comparison

CONCLUSION

The trial showed that the variation of alternation frequencies applied with PRD strategy affected the agronomic parameters of tomato crop. In fact, applying 50% of water requirements with alternation at 40% of water storage depletion within the dry side of root enhanced PRD produced yield, leaf area and WUE but negatively affect dry matter production and fruit quality.

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