*International Journal of Applied Agricultural Sciences*
2025, Vol. 11, No. 4, pp. 120-125
https://doi.org/10.11648/j.ijaas.20251104.12

Research Article

# Using Roma Tomato to Study the Limits of Deficit Irrigation

**Niharika Gadde[1], Ambrose Anoruo[1, *], Benjamin Tuner[1], Paul Holland[2], Shad Nelson[3]**

[1]Department of Agriculture, Agribusiness & Environmental Sciences, Texas A&M University, Kingsville, USA
[2]Department of Animal Science & Veterinary Technology, Texas A&M University, Kingsville, USA
[3]Dick and Mary Lewis Kleberg College of Agriculture & Natural Resources, Texas A&M University, Kingsville, USA

## Abstract

A greenhouse study of deficit irrigation was conducted to understand the fraction of optimum evapotranspiration water requirement that limits growth and development of Roma tomato. Seedlings of the crop were germinated and transplanted into 20 cm diameter pots in a mixture of 2: 1 topsoil and perlite. The 200 seedlings were arranged in a randomized complete block replicated five times such that each block contained 40 seedlings. Deficit irrigation treatments included 100% (control), 75%, 50%, and 25% of the amount of control freshwater. Crop growth and development parameters studied include relative growth rate, fresh and dry vegetative biomass accumulation, chlorophyll content, leaf area, stomatal conductance, and number of flower buds and flowers as a consequence of deficit irrigation. Results of the study indicate a two-tier effect of deficit irrigation on the crop with no growth loss at the vegetative growth phase even at 50% irrigation, but a significant reduction in flower bud initiation and flowering even at the 75% irrigation. Based on these results, it is recommended that deficit irrigation up to 50% of optimum evapotranspiration requirement of Roma tomato be adopted as a water conservation strategy at the vegetative growth phase, and a return to the full evapotranspiration water requirement at the onset of flower bud initiation.

## Keywords

Cultivation, Chlorophyll Content, Stomatal Conductance, Relative Growth, Evapotranspiration, Freshwater, Conservation, *Solanum lycopersicum*

## 1. Introduction

Traditional irrigation methods intended to supply all the water necessary for crop growth and development are becoming unsustainable in many parts of the world due to water scarcity. As a result, research into alternate irrigation techniques that reduce water consumption without compromising crop yield has increased [1-4]. Deficit irrigation (DI), an alternative irrigation technique, has been defined as the practice of applying lower amounts of water than the general crop evapotranspiration requirement to increase water use efficiency of the crop without reduction in its yield [1, 5].

Deficit irrigation has been applied to many crops including grapes, olives, citrus, and many others that have responded well with improved water use efficiency and a minimal reduction in yield [6]. One of the most abundantly grown and economically most important crops worldwide is tomato (*Solanum lycopersicum*) [7-9]. Tomatoes are famous for their versatility and nutritional value and are essential to food in the diets of people all over the world whether eaten fresh or

*Corresponding author: kuaoa001@tamuk.edu (Ambrose Anoruo), ambrose.anoruo@tamuk.edu (Ambrose Anoruo)

**Received:** 4 June 2025; **Accepted:** 18 June 2025; **Published:** 21 July 2025

processed. Roma tomato has dense fleshy meso- and endocarps, low water content, and more robust flavor hence its preference for use in sauces, pastes and canning compared to the other tomato varieties [10]. Given the global demand for tomato, optimization of its cultivation in the era of global freshwater scarcity is vital to ensure food production and financial stability of tomato farmers [11] and this requires the development of novel irrigation techniques for *Solanum* species. Some studies [1, 2, 4, 6, 10, 12] have applied various techniques, and forms of modified freshwater irrigation in crop production, and achieved growth, development and yield results comparable to the full evapotranspiration needs of the crop species. For example, bell pepper suffered no loss of yield when grown at 75% of its evapotranspiration freshwater requirement [10].

Although positive results of growing crops with reduced or modified freshwater requirement of some agricultural crops have been reported, there are still problems associated with deficit irrigation [13]. For example, water stress can cause poor fruit set, blossom end rot, and undersized fruit in tomato if the crop's specific water requirements and irrigation reduction time are not adhered in its growing cycle. Also, excessive DI impacts tomato fruit color and flavor, and reduces fruit quality, quantity and yield [14, 15]. Additionally, Van et al. [13] warned that DI must be carefully timed and regulated to prevent negative effects such as blossom end rot, poor fruit set, and reduced marketability.

While there is abundant evidence in support of or against DI, there is a lack of sufficient studies to determine the limit of DI that supports evapotranspiration water needs of major food crops. There are suggestions gleaned from DI studies but none has been designed to study specifically the deficit fraction of the optimum evapotranspiration requirement of a crop that induces reduction in growth and development of the crop. We report the results of a study of the fraction of optimum evapotranspiration water requirement of Roma tomato at which growth and development of this important food crop is compromised. The purpose is to achieve optimum production with less water as a conservation strategy for freshwater resource in the context of increasing water shortage in agriculture due to human population pressure and climate change.

## 2. Materials and Methods

### 2.1. Study Location and Experimentation

Seeds of *Solanum lycopersicum* of the Ferry Morse Roma variety were germinated in a mixture of topsoil and perlite (1: 1) at the Texas A&M University-Kingsville greenhouse located 27°31′ 50.3″ N and 97°53′ 13.8″ W in mid June, 2024 at an average day and night temperatures of 29.4 ℃ and 21 ℃ respectively. The seedlings were transplanted into celled trays filled with 2: 1 topsoil: perlite and fertilized with 3.44 $gL^{-1}$ NPK 30: 10: 10. The seedlings were further transplanted into 20 cm diameter pot filled with the same topsoil and perlite mixture (2: 1) after three weeks. The transplants were watered thoroughly and 200 pots were randomly selected for the study. The average pH of the potting mixture was 7.05 as measured at each watering throughout the study.

The plants were arranged on greenhouse tables in five randomized blocks such that each block contained 40 plants. The study included four treatments of 100% (control), 75%, 50%, and 25% deficit irrigation. The treatments were randomly assigned such that 10 plants per block received a treatment, thus the four treatments were represented in each block and replicated five times. Irrigation treatments were conducted only when the control treatment (100%) started showing early signs of leaf limp (droop/wilting). Irrigation water at 100% treatment was measured so the amount of water to attain potting soil capacity was recorded, and fractions of 75%, 50% and 25% of the control were used as deficit irrigation treatments.

### 2.2. Morphological and Physiological Growth Parameters Studied

The morphological and physiological growth parameters studied include plant relative growth rate (RGR), leaf area (LA), fresh biomass (FB), dry biomass (DB), number of flower buds (NFB), number of flowers (NF), chlorophyll content (CC), and stomatal conductance (SC).

Plant height was measured weekly in cm from the soil line at crown to the shoot tip, and used to compute relative growth rate according to Lebaka et al [3]. Leaf area (LA) was measured with the CI-202 Portable Laser Leaf Area meter manufactured by CID Bio-Science, Washington, U.S.A. Fresh biomass of the experimental plants was harvested in October 2024, four months after seed germination, and weighed to obtain the weight of fresh plant biomass. The fresh biomass was dried at air temperature in the greenhouse until constant weight before weighing to obtain the dry weight of the plants under the different treatments. The number of flower buds, and flowers was visually counted weekly from the onset of bud initiation through the end of the study in October 2024.

Chlorophyll content was measured once every week using SPAD-502 Plus chlorophyll meter (manufactured by Konica Minolta Inc., Japan) in SPAD Units. Randomly selected topmost fully expanded leaves of each plant, often the third leaf plastochron from the stem apex, were selected for CC and SC measurements. Stomatal conductance was measured using the leaf porometer manufactured by Decagon Devices, Washington, USA.

## 3. Results

Two separate statistics were adopted to explore information obtained from the parameters studied (Table 1). We used ANOVA to compare the means of the treatment groups, and unpaired t-test to compare means of any two treatments. The purpose of the later analysis was to determine the limit of deficit irrigation at which the detrimental effects of water shortage began to impact growth and development of the crop.

***Table 1.*** *Summary of parameter values due to deficit irrigation.*

| Treatment (% water) | RGR (cm day$^{-1}$) | LA (cm$^2$) | FB (g) | DB (g) | NFB (No.) | NF (No.) | CC (SPAD) | SC (mmol/m$^2$s) |
|---|---|---|---|---|---|---|---|---|
| 25 | 0.07 $^b$ | 315.16 $^c$ | 5.78$^b$ | 0.32 $^a$ | 0.00$^*$ | 0.00$^*$ | 32.07 $^b$ | 189.91 $^c$ |
| 50 | 0.17 $^a$ | 336.44 $^b$ | 7.50 $^a$ | 0.35 $^a$ | 0.80$^*$ | 0.00$^*$ | 26.42 $^a$ | 250.73 $^b$ |
| 75 | 0.12 $^a$ | 347.91 $^b$ | 7.88 $^a$ | 0.41 $^a$ | 2.80$^*$ | 0.00$^*$ | 23.73 $^a$ | 282.81 $^a$ |
| 100 | 0.20 $^a$ | 369.67 $^a$ | 8.66 $^a$ | 0.52 $^a$ | 10.60$^*$ | 0.40 $^*$ | 23.17 $^a$ | 340.34 $^a$ |

Means with the same letter superscripts are not statistically significantly different.

$^*$Irrigation treatment effect was severe on flower bud initiation that it was needless continuing the study on the effects of deficit irrigation on flowering and fruiting of Roma tomato.

## 3.1. Relative Growth Rate of Roma Tomato

The ANOVA results indicate that freshwater irrigation at 100%. 75%. 50%, and 25% has significant effect on the growth rate of Roma tomato (P = 0.0259). The unpaired t-test analysis indicates that difference exists between the 100%, 75%, and 50% on one hand compared to the 25% irrigation on the other (P = 0.0095, P = 0.0074, and P = 0.0037 respectively). However, no significant difference in growth rate exists between the 100%, 75%, and 50% irrigation treatments. Detailed discussion about the results of this study will be in the discussion section but it is important to point out here that plant height growth is statistically similar up to 50% reduction in irrigation water. Figure 1 shows the growth rate of Roma tomato due to the different water irrigation levels.

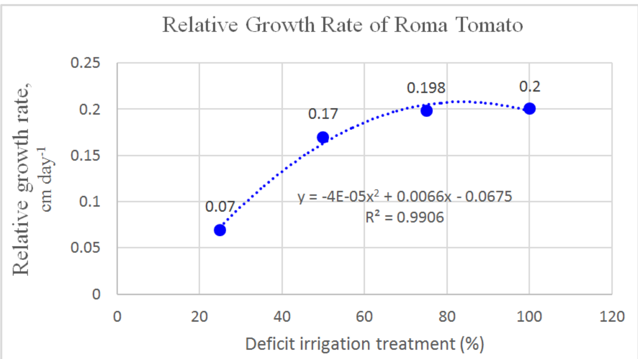


***Figure 1.*** *Daily growth rate of Roma tomato at different freshwater irrigation levels. Each point on the graph is the average of 50 measurements.*

## 3.2. Leaf Area

The ANOVA analysis indicates a significant difference between means of the treatments (P < 0.0001). This result is supported by the unpaired t-test analysis except for the 75% and 50% treatments (P = 0.0921). These results indicate a loss of leaf area due to reduced water irrigation, an indication that leaf area decreases with increasing reduction of evapotranspiration needs of the crop (Figure 2), and reduction in irrigation water up to 50% has a similar effect as 75% reduction (Table 1).

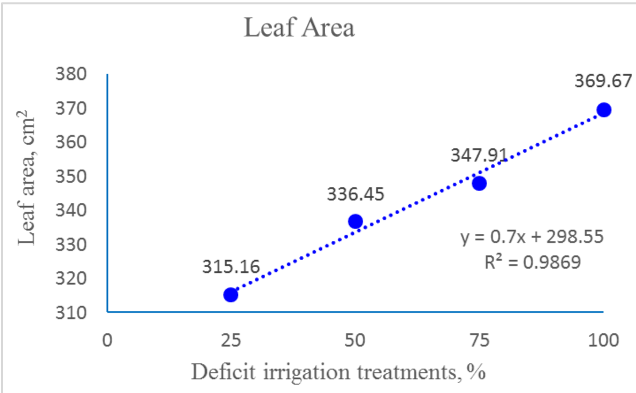


***Figure 2.*** *Leaf area of Roma tomato showing a reduction in leaf growth with increasing water deficit. Each point on the graph is the average of 50 measurements.*

## 3.3. Biomass Accumulation

Fresh biomass accumulation due to the treatments is significantly different (P = 0.0227). However, this difference disappears when the treatments are compared one-on-one except at the 25% deficit irrigation, indicating that the source of the difference picked up in the ANOVA analysis (Table 1) came from the most severe irrigation deficit. The ANOVA and unpaired t-test analyses of air-dried vegetative biomass indicate no significant difference in dry biomass of deficit irrigated Roma tomato. This result indicates higher biomass moisture with increasing irrigation water and consequently more water loss in drying by the 100%, 75% and 50% irrigation treatments compared to the 25% deficit irrigation (Table 1).

### 3.4. Flower and Flower Bud

The irrigation treatment effects on flower bud initiation and flowering were severe that there was no information to continue with deficit irrigation studies on flower bud initiation, flowering and fruiting of the crop. This information led to the two-tier effect of irrigation water reduction on the growth and development of Roma tomato crop (see discussion).

### 3.5. Chlorophyll Content (CC)

ANOVA analysis shows that deficit irrigation has a reverse and highly significant effect on chlorophyll content of Roma tomato (P = 0.0002). While the unpaired t-test analysis shows no difference between 100%, 75% and 50% treatments, CC of the crop increases significantly with increase in irrigation shortage at 25% treatment (Table 1). There seems to be a negative relationship between irrigation water and CC in Roma tomato such that increased irrigation water results to decreasing CC in the crop (Figure 3).

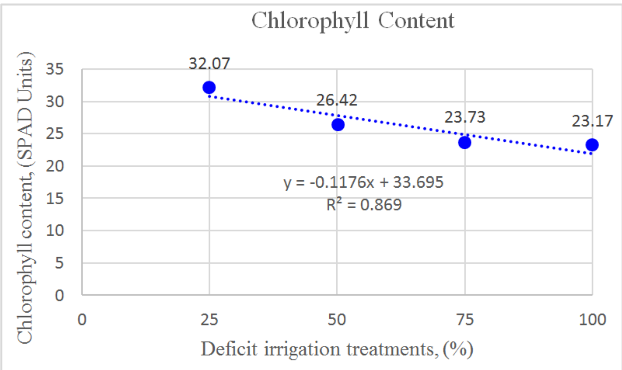


***Figure 3.*** *Negative relationship between irrigation water and CC in Roma tomato. Each point on the graph is the average of 50 measurements.*

### 3.6. Stomatal Conductance (SC)

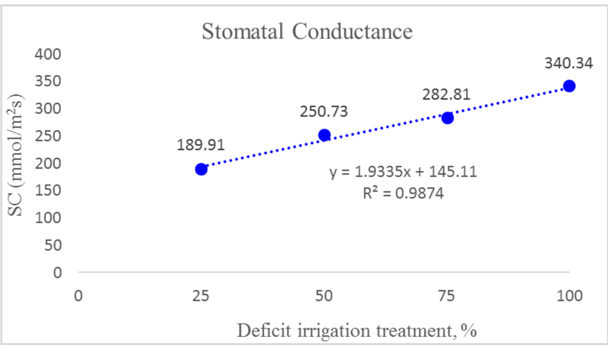


***Figure 4.*** *Stomatal conductance of deficit irrigated Roma tomato. Each point on the graph is the average of 50 measurements.*

ANOVA analysis indicates a significant difference between SC due to deficit irrigation treatment (P < 0.0001). However, the unpaired t-test analysis shows that the differences are due to the 50% and 25% treatments (Table 1). No significant difference exists between the 100% and 75% treatments so stomatal activity increases with increase in irrigation water availability (Figure 4).

## 4. Discussion

Deficit irrigation is an important freshwater conservation technique in agriculture for long term sustainability of this important natural resource. The practice is even more important in arid and semi-arid agriculture in which water sources are restrained [5]. Mild water stress is thought to improve the flavor and nutritional content of tomato by concentrating sugars as well as other beneficial compounds in the fruit, although some studies indicate it can also weaken the crop and cause undesirable effects like tough fruit skin and reduced juiciness, which may negatively impact consumer preference [16]. Water stress can cause changes in plant anatomical development and this in turn affects the physiological processes which manifest in the overall growth and development of the plant species.

Deficit irrigation seems to have a two-tier effect on Roma tomato crop. Results of this study indicate an overall non-serious detrimental effect due to deficit irrigation up to 50% water reduction during the vegetative growth phase. The crop showed no loss in RGR, FB, DB, and CC even when water was reduced to 50% evapotranspiration requirement of the crop. This is an indication of significant freshwater conservation at the vegetative growth phase of the crop. It further shows that the crop can be grown at 50% of its optimum water use without comprising any vegetative growth and development.

Loss of stomatal activity at 25% and 50% irrigation compared to those at 100% and 75% is an indication that Roma tomato is an isohydric crop. The loss in stomatal activity at these irrigation levels may be due to an effort by the crop to maintain a *stable leaf water potential*, a common adaptation of isohydric plant species. The higher CC at 25% compared to 100%, 75%, and 50%, and complete loss of bud initiation and flower at 50% and 25% indicate that water stress has a more adverse effect on the physiology of Roma tomato. Irrigation at 25% and 50%, and to a less extent 75% severely impacted bud initiation and consequently flowering hence there was no information to continue with the study on the effects of deficit irrigation on Roma tomato bud initiation, flowering and fruiting. The higher CC of leaves at 25% irrigation could be attributable to the reduced LA per unit of chlorophyll, and less cellular cytoplasmic fluid resulting to higher concentration of chlorophyll per unit area of cell. It could also be due to inefficient acropetal translocation of reabsorbed nutrients [19-22], especially nitrogen, from older leaves although we tried to minimize this plant physiological process by measuring CC and SC from fully expanded young leaves of the third plastochron from stem apex. Conversely, CC in the 100%, 75%, and 50% was probably less due in part to dilution, larger LA per unit if chlorophyll, and efficient reabsorption of nutrients for acropetal translocation to leaf and bud primordia.

Plants have adaptive mechanisms to tolerate stress conditions including increased root-proliferation, osmotic adjustments and enhanced water-use efficiency [17]. The physiological response of plants to water stress varies. Some studies suggest that mild deficit irrigation can stimulate root growth which enhances the plant's ability to absorb moisture from deeper soil layers [18]. This adaptation is crucial for sustained growth and fruit production under limited water conditions. Atilgan and Van [6, 13] suggested that deficit irrigation during the flowering and fruiting stages should be watched carefully to prevent poor fruit set and avoid yield reduction. Our study shows that deficit irrigation as a technique to supply the evapotranspiration water requirement of Roma tomato should be restricted to the vegetative growth phase of the crop only. In fact, based on our observations, up to 50% of the evapotranspiration requirement of the crop can be adopted at the vegetative growth phase to conserve freshwater, but full evapotranspiration water requirement must be returned at the inception of flower bud initiation. We do not even recommend 75% of the optimum evapotranspiration water needs of the crop at this growth stage.

Deficit irrigation as a water conservation strategy in agriculture is not recommended for all environments because its successful implementation depends on a myriad of extraneous conditions. Climatic and edaphic conditions, and crop factor (variety) are some of the conditions that must be well understood for a successful deficit irrigation program. These environmental and crop factor effects create the difficulty to widely adopt any successful DI program even for different crop varieties of the same species. Location and crop variety knowledge are required for a successful deficit irrigation program. Despite these conditions, DI remains one of the major freshwater conservation strategies especially when the competition for freshwater between crop production and human population is increasing by the day.

## 5. Conclusion

Considering the findings of this study, we conclude that deficit irrigation is feasible in Roma tomato production without compromise in yield. Deficit irrigation has a two-tier effect on Roma tomato crop variety and based on the results of the study, we recommend adoption of DI up to 50% of the evapotranspiration requirement of the crop at the vegetative growth phase, and a return to full evapotranspiration requirement of the crop at the onset of flower bud initiation. We do not recommend even a 75% deficit irrigation at onset of flower bud initiation through crop harvest.

## Abbreviations

| | |
|---|---|
| DI | Deficit Irrigation |
| RGR | Relative Growth Rate |
| LA | Leaf Area |
| FB | Fresh Biomass |
| DB | Dry Biomass |
| NFB | Number of Flower Buds |
| NF | Number of Flowers |
| CC | Chlorophyll Content |
| SC | Stomatal Conductance |

## Acknowledgments

Funding for this study was provided by the Welhausen Family Student Scholarship fund, and the NSF-CREST Sustainable Water Use grant, Award No. 1914745. One of us, Ms. Niharika Gadde, acknowledges her friends for their help in greenhouse work and data collection.

## Author Contributions

**Niharika Gadde:** Data curation, Formal Analysis, Investigation, Methodology, Writing - original draft

**Ambrose Anoruo:** Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Supervision, Validation, Writing - review & editing

**Benjamin Turner:** Supervision, Validation, Writing - review & editing

**Paul Holland:** Supervision, Writing - review & editing

**Shad Nelson:** Funding acquisition, Resources, Writing - review & editing

## Conflict of Interest

The authors declare no conflicts of interest.

## References

[1] Morgan, E. I., Zamora, E., Nelson, S. D., Donato-Molina, M. C., and Anoruo, A. (2024). Effects of Deficit Irrigation in Pepper Plants (*Capsicum annuum*) Grown Under Greenhouse Conditions. *World Journal of Agriculture and Soil Science, 9(2): 1-7.*

[2] Anoruo, A. O., Turner, B. L., Garcia, M. R. Nelson, S. D. and Donato-Molina, M. C. (2024). Morphological and anatomical development of *Solanum lycopersicum* seedlings grown with non-conventional water. *International Journal on Agriculture Research and Environmental Sciences, 5(1): 1-4.*

[3] Lebaka, R., Turner, B., Nelson, S., and Anoruo, A. (2023). Studies on production of Anaheim pepper in greenhouse media supplemented with organic and inorganic nutrient sources, and water conservation. *Journal of Horticultural Sciences, 18(2): 357 - 362.*

[4] Nelson, S. D., Enciso, J. M., Perea, H., Sétamou, M., Beniken, L., Young, M. and Williams, C. F. 2013. Alternative flood irrigation strategies that improve water conservation in citrus. *Subtropical Plant Science*, 65: 15-23.

[5] Monforte, A. J., Diaz, A., Caño-Delgado, A., and Van Der Knaap, E. (2013). The genetic basis of fruit morphology in horticultural crops: lessons from tomato and melon. *Journal of Experimental Botany, 65(16): 4625-4637.*

[6] Atilgan, A., Rolbiecki, R., Saltuk, B., Jagosz, B., Arslan, F., Erdal, I., and Aktas, H. (2022). Deficit irrigation stabilizes fruit yield and alters leaf macro and micronutrient concentration in tomato cultivation in greenhouses: a case study in Turkey. *Agronomy, 12: 2950*.

[7] Yesdhanulla, S., Aparna, B. (2018). Marketing channels and price spread of tomato in Chittoor district of Andhra Pradesh. *J. Pharmacogn. Phytochem. 7: 873-876.*

[8] Kumbasarŏglu, H.; Emine, A.; Dăgdemir, V. (2021). Economic analysis of tomato in Turkey, *Mediterr. Agric. Sci. 34: 47-54.*

[9] Martínez-Damián, M. T.; Cano-Hernández, R.; Moreno-Pérez, E. C.; Sánchez-del Castillo, F.; Cruz-Álvarez, O. (2019). Effect of preharvest growth bioregulators on physicochemical quality of saladette tomato. *Rev. Chapingo Ser. Hortic. 25: 29-43.*

[10] Mahmoud, M. M. A., and Fayad, A. M. (2022). The effect of deficit irrigation, partial root drying and mulching on tomato yield, and water and energy saving. *Irrigation and Drainage, 71(2), 295 -309.*

[11] Van der Knaap, E., and Tanksley, S. D. (2003). The making of a bell pepper-shaped tomato fruit: identification of loci controlling fruit morphology in Yellow Stuffer tomato. *Theoretical and Applied Genetics*, *107: 139-147.*

[12] Sadeghi, Z., Shamshiri, M. H., Soroush, F., and Karimi, H. R. (2023). Evaluation of growth, yield and elements uptake of grafted tomatoes on several Solanaceous rootstocks exposed to deficit irrigation. *Journal of Plant Nutrition, 46(17): 4326-4339.*

[13] Van der Burg, W. J., Aartse, J. W., Van Zwol, R. A., Jalink, H., & Bino, R. J. (1994). Predicting tomato seedling morphology by X-ray analysis of seeds. J. Amer. Soc. Hort. Sci., 119(2): 258-263.

[14] Wu, Y., Yan, S., Fan, J., Zhang, F., Xiang, Y., Zheng, J., and Guo, J. 2021. Responses of growth, fruit yield, quality and water productivity of greenhouse tomato to deficit drip irrigation. *Scientia Horticulturae, 275, id 109710.*

[15] Liava, V., Chaski, C., Añibarro-Ortega, M., Pereira, A., Pinela, J., Barros, L., and Petropoulos, S. A. (2023). The effect of biostimulants on fruit quality of processing tomato grown under deficit irrigation. *Horticulturae, 9(11): 1184.*

[16] He, Y., Wang, J., Yang, J., Bai, P., and Wu, Y. 2024. Enhancement of tomato fruit quality through moderate water deficit. *Foods*, 13(22): 3540. https://doi.org/10.3390/foods13223540

[17] Alves, F. M., Joshi, M., Djidonou, D., Joshi, V., Gomes, C. N., & Leskovar, D. I. (2021). Physiological and biochemical responses of tomato plants grafted onto *Solanum pennellii* and *Solanum peruvianum* under water-deficit conditions. *Plants,* 10(11): 2236.

[18] Geilfus, C. M., Zorb, C., Jones, J., Wimmer, M. A., and Schmockel, S. M. 2024. Water for agriculture: more crop per drop. *Plant Biology*, 26: 499-507. https://doi.org/10.1111/plb.13652

[19] Li, W., Zhang, H., Li, X., Zhang, F., Liu, C., Du, Y., Gao, X., Zhang, Z., Zhang, X., Hou, Z., Zhou, H., Sheng, X., Wang, G., and Guo, Y. 2017. Integrative metabolomic and transcriptomic analyses unveil nutrient remobilization events in leaf senescence of tobacco. *Sci. Rep*., 7: 12126. https://doi.org/10.1038/s41598-017-11615-0

[20] Lu, L., Tian, S., Zhang, J., Yang, X., Labavitch, J. M., Webb, S. M., Latimer, M and Brown, P. H. 2013. Efficient xylem transport and phloem remobilization of Zn in the hyperaccumulator plant species *Sedum alfredii*. *New Phytologist*, 198: 721-731 721.

[21] Bausenwein, U., Millard, P. and Raven, J. A. 2001. Remobilized old-leaf nitrogen predominates for spring growth in two temperate grasses. *New Phytologist*, 152: 283-290. https://doi.org/10.1046/j.0028-646X.2001.00262.x

[22] Kolb, K. J. and R. D. Evans, R. D. 2002. Implications of leaf nitrogen recycling on the nitrogenisotope composition of deciduous plant tissues. *New Phytologist*, 156: 57-64. https://doi.org/10.1046/j.1469-8137.2002.00490.x