INFLUENCE OF GREENHOUSE SHADING AND DIFFERENT NUTRIENT MANAGEMENT PRACTICES ON ALLEVIATING HEAT STRESS, IMPROVING PLANT NUTRIENTS STATUS, FLOWERING GROWTH AND YIELD OF TOMATO

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ABSTRACT

The experiment was conducted in a greenhouse during 2017 and 2018 growing seasons to evaluate the impact of the shading and various nutrition programs on mitigating heat stress, reducing the use of chemical minerals, improving the reproductive growth and yield of tomato plant. Split-plot within Randomized Complete Block Design (RCBD) with three replications was conducted in this study. Shading factor was allocated in the main plots and the nutrition programs distributed randomly in the subplots. Results indicate that shading resulted in the decrease of daytime temperature by 5.7°C as an average for both seasons; thus a significant increasing was found in leaf contents of macro nutrients (Nitrogen, Phosphorous, and Potassium), and micro nutrients (Iron, Zinc and Boron), except the Iron content in 2018 growing season. Furthermore, shading improved significantly the reproductive growth and tomato yield. Among the plant nutrition programs, the integrated nutrient management (INM) including the application of organic substances, bio inoculum of AMF and 50% of the recommended dose of chemical fertilizers; lead to the enhancement of nutrients content, reproductive characteristics and plant yield. Generally, combination of both shading and INM showed positive effects on plants nutrient status and persisting balance on tomato flowering growth and fruits yield.

Keywords: reproductive growth, pollen grain, fruit set, biotimulants, mycorrhizae
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تأثير تظليل البيوت البلاستيكية وبرامج التسميد المختلفة في تقليل الاجهاد الحراري وتعزيز الحالة الغذائية للنبات والنمو الزهري والحاصل لمحصول الطماطة

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المستخلص

اجريت التجربة في أحد البيوت المحمية التابعة لقسم البستنة، كلية علوم الهندسة الزراعية، جامعة السليمانية للموسمين 2017 و 2018 لدراسة تاثير كل من التظليل وبرامج تسميد مختلفة في تخفيف تأثير الاجهاد الحراري وتقليل استخدام الاسمدة الكيمياوية وتعزيز النمو الزهري والثمري لمحصول الطماطة. نفذت التجربة حسب تصميم القطع المنشقة وبثلاث مكررات، اذ تمثل عامل التظليل قطع رئيسية وبرامج التسميد المختلفة تمثل القطع الثانوية. أظهرت النتائج ان التظليل أدى الى خفض درجات الحرارة في النهار بمعدل 5.7°م للموسمين على حد سواء. حققت التظليل زيادة معنوية في النسبة المئوية لعناصر الكبرى (النيتروجين، الفسفور والبوتاسيوم) وتركيز العناصر الصغرى (الحديد، الزنك والبورون) في الاوراق في كلا الموسمين ماعدا عنصر الحديد في موسم 2018. وقد اثرت عملية التظليل معنويا في تحسين الصفات الزهرية مما ادى الى زيادة الانتاج . كذلك أظهرت النتائج التفوق المعنوي لمعاملة INM والتي هي معاملة التداخل الثلاثي بين معاملة التسميد العضوي واللقاح المايكورايزي و50% من التوصية السمادية في صفات محتوى المغذيات في اوراق النبات والصفات الزهرية وكمية الحاصل. وقد أكدت النتائج ان التداخل بين معاملة التظليل وINM أثرت ايجابيا في مستوى العناصر الغذائية وفي توازن النمو الزهري والانتاج في النبات.

الكلمات المفتاحية: النمو الزهري، حبوب اللقاح، عقد الثمار، المحفزات الحيوية، مايكورايزا
جزء من اطروحة الدكتوراه للباحث الاول

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INTRODUCTION

Heat accumulation inside the greenhouses in late spring and summer seasons due to high and long duration of solar radiation leads to expose cultivated plants to heat stress. Many literatures indicated that heat stress causes various negative effects on plant growth, development, physiological aspects and productivity in terms of quantity and quality (30). Tomato (*Solanum lycopersicum* L.) is one of the most popular and versatile vegetable crops worldwide which is very sensitive to high temperatures, especially in their reproductive stages (33, 34). Several researchers confirm that heat stress reduces tomato yield through its effect on pollen viability, flower abortion, blossoms drop, fruit sets limit and the reduction in fruit weight (12, 21). Several techniques are used to mitigate the effects of heat stress such as the decrease of light intensity by shading, which is one of the simplest, non-chemical, inexpensive and sustainable approaches to modify the greenhouses environmental conditions in hot seasons. Many studies assured that greenhouses shading is very useful in reducing the negative effects of heat stress leading to the improvement of plants nutrient status, reproductive growth and plant yield (14, 17). Furthermore, proper nutrient management practices play a major role in alleviating heat stress and optimizing plant performance (16, 31, 32). It is evident that using chemical fertilizers in appropriate quantities at the right time plays a significant role in all crop life cycles. However, excessive use of chemical fertilizers by many farmers causes numerous problems such as increasing environmental pollution, hurting human health and wasting a tremendous amount of money annually. In the last decade, several modern methods were invented to enhance the sustainability of the production systems through the reduction of chemical fertilizers and the usage of organic substances and biofertilizers as plant biostimulants. Poultry manure has a significant role on soil fertility and structure through acting on chemical, physical and biological properties of soils; thereafter, these improve root architecture and increase nutrient uptake by plants (10). Previous studies reported that a variety of biostimulant substances (i.e., humic and fulvic acids, hdrolysed proteins and amino acids containing products) and microbial inoculants (i.e., mycorrhizal fungi) have been introduced as efficient, safe, and sustainable tools to optimize root system, boosting crop performance, improving nutrient use efficiency as well as enhancing tolerance to heat stress (4, 5, 8). Plant response to nutrition can be more efficient under shade conditions. Consequently, the combination of shading and nutrient management is essential to optimize crop productivity, and avoiding excessive application of inorganic fertilizers. Considering the above-mentioned facts, it is possible to attenuate the symptoms of heat stress, improve the reproductive growth and productivity of tomato as well as reduce using synthetic fertilizers; by applying chemical fertilizers in combination with organic substances and biofertilizers. Therefore, the aims of this study were to examine the influence of shading and different nutrition programs including chemical, organic substances and bio fertilizers as a biostimulants, alone or in combinations on mitigating heat stress, reducing the use of inorganic fertilizers, improving reproducive growth and yield of tomato under uncontrolled greenhouse conditions.

MATERIALS AND METHODS

Experimental site and soil analysis

The experiment was carried out during 2017 and 2018 growing seasons at the research farm belongs to the department of Horticulture, College of Agricultural Engineering Sciences, Sulaimani University, Sulaimani, Iraq (35º 32' 9.6" N, 45º 21' 54" E) with an altitude 741 masl, in a greenhouse (40 m length, 11 m width, 3.9 m height) covered with 200µm thick polyethylene plastic film. Soil samples were taken at (0-30 cm) depth in order to determine the baseline soil properties. Samples were air dried and passed via a 2mm sieve prior to analysis. Results of some chemical and physical properties of the soil are shown in (Table 1).

Table 1. Some physical and chemical properties of the experiment soil

Texture	Sand	Silt	Clay	pH	EC	$CaCO_3$	O.M	Total N	Soluble K	Available P	Available Fe
	g kg-1				dS m^{-1}	g kg^{-1}				mg kg^{-1}	
Silty Clay	97.9	439.5	462.6	7.97	1.04	267	10.9	13.7	56.4	6.6	2.91

Plant materials, seedling production and transplanting

An indeterminate F1-hybrid tomato cultivar (Newton-F1) produced by Syngenta® was used in this study. Seeds were sown on 15th February 2017 and 2018 in 54-well seedling trays, which filled with sterilized peat-moss (TS 1, Klasmann- Deilmann GmbH). The seeds were sown under glasshouse conditions, and maintained at 23/18 ± 2˚C day/night temperature, 14/10 h light/dark photoperiod and a relative humidity of 65 ± 10%. After reaching at 4-5 true-leaf stage, the seedlings were transplanted to the experimental units. The area of each unit was 3.74 m^2 (2.2m × 1.7m), which consisted of two cultivation lines; space between plants within a line was 0.4m. Each experimental unit contained 10 plants which cultivated in zigzag pattern resulting in a plant density of 2.674 plants m^{-2}.

Experimental design and treatments detail

Split-plot within Randomized Complete Block Design (RCBD) with three replications was conducted in this study. Shading factor was allocated in the main plots and the nutrition programs distributed randomly in the subplots. The greenhouse was divided into two longitudinal halves that one half was covered with the shade net above the plastic cover to reduce the light intensity by relatively 40%. While the other half was free of the shade net covering. The shading process was implemented in the middle of May, when the weather temperature started to warm up. Regarding the nutrition treatments, eight nutrition programs were arranged randomly as a sub plots within each replicate in the main plots as the following: *T1*: Absolute control; *T2:* Full recommended dose of chemical fertilizer (100% RDCF). The application included macro and micro nutrients and applied in two methods: soil and foliar application (Table 2). This treatment was implemented after four weeks of transplanting; *T3:* Organic nutrition program (ONP); the locally produced poultry manure (SHAMAL) was added at a rate of (5 t ha^{-1}) to the soil during the field preparation time. The following two liquid organic fertilizers as a biostimulants were also added: (i) HUMATE, which contains 25% humic and fulvic acids, 4% N, 4% K and 1% Fe, was applied (2L ha^{-1}) to the soil 6 times during the growing seasons, the first application was conducted after four weeks of transplanting and the others at 10 days intervals. (ii) VEGEAMINO, which contains 24.8% w/v free amino acids was added by foliar spraying (1ml L^{-1}), which applied once every three weeks from transplanting for 4 times. *T4:* the microbial biostimulant of arbuscular mycorrhizal fungi (AMF), *Glomus mosseae*, was conducted by applying 25g of the inoculum per plant into the planting holes during the transplanting time in case which most of the seedling roots were attached the inoculum. Each gram of the inoculum contains approximately 47 spores of the fungus. The inoculum obtained from the Al-Zaefaraniya Agricultural Research Center, Ministry of Sciences and Technology, Baghdad. *T5:* ONP+AMF; *T6*: ONP+50% RDCF; *T7:* AMF+50% RDCF; *T8:* Integrated Nutrient Management (INM), which included (ONP+AMF+50% RDCF).

Growth conditions

During the experimental period, the air temperatures inside the greenhouse compartments were measured by using data logger device (Model: Perfect-Prime TH0160) with fifteen-minute intervals. One device was placed in the center of each compartment at 1.5m above the soil surface. Maximum, minimum and average of air temperatures during the growing seasons inside the greenhouse were summarized in (Table 3).

Statistical data analysis

Data were submitted to the analysis of variance (Two-way ANOVA) using JMP 7.0.1 statistical analysis software. Least Significant Difference (LSD) test at $P \leq 0.05$ was used to compare the means.

Table 2. Applied full recommended dose of chemical fertilizers (100% RDCF)

Weeks after transplanting	Chemical fertilizers types (1) (Soil application)	Dosages (g plant^{-1})	Chemical fertilizers types (Foliar application)	Dosages (g L^{-1} or ml L^{-1})
5th	NPK 15-30-15	1.5	NPK(2) 12-48-8 + CALMAX (3)	2
6th		2.5	NPK 12-48-8 + CALMAX	2
7th		3	NPK 12-48-8 + CALMAX	2
8th	NPK 20-20-20	3	NPK 20-20-20 + CALMAX	2
9th	Calmag+Zn N-P-K-CaO-MgO-Zn 13-0-0-16-6-0.2	3	NPK 20-20-20 + CALMAX	2
10th	NPK 15-30-15+ 20-20-20 (1:1)	3	NPK 20-20-20 + CALMAX	2
11th		3	NPK 9-15-30 + CALMAX	2.5
12th	Calmag+Zn N-P-K-CaO-MgO-Zn 13-0-0-16-6-0.2	3	NPK 20-20-20 + CALMAX	2.5
13th	NPK 20-20-20 + 12-8-40 (1:1)	3	NPK 9-15-30 + CALMAX	2.5
14th		3	NPK 20-20-20 + CALMAX	2.5
15th	NPK 12-8-40	3.5	NPK 9-15-30 + CALMAX	2.5
16th		3.5	NPK 9-15-30 + CALMAX	2.5
17th		3.5	NPK 9-15-30 + CALMAX	2.5

1- SANGRAL™ fertilizers (SQM lberian SA, Barcelona, Spain) were used for soil application.
2- NUTRI-LEAF® fertilizers (NPK) manufactured by (Miller chemical & fertilizer, LLC, Hanover) were used for foliar application.
3- The chemical composition of the foliar liquid fertilizer CALMAX (Omex, UK) in (w/v) units is as follows: Total Nitrogen (N) 15%, Calcium (CaO) 22.5%, Magnesium (MgO) 3%, Manganese (Mn EDTA) 0.15%, Iron (Fe EDTA) 0.75%, Boron (B) 0.75%, Copper (Cu EDTA) 0.06%, Zinc (Zn EDTA) 0.03%.

Table 3. Monthly maximum, minimum and average air temperature (˚C) inside the greenhouse compartments during both growing seasons 2017 and 2018

Months	2017						2018					
	Without shading			With shading			Without shading			With shading		
	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.
May	37.2	14.9	29.5	32.2	14.6	25.1	34.1	15.2	27.3	28.1	16.3	26.3
June	42.4	17.4	32.8	37.2	17.1	29.4	40.4	18.1	30.8	34.8	17.9	28.2
July	46.1	22.5	36.1	39.8	22.3	32.2	43.9	21.4	32.8	38.2	20.8	30.6
August	49.3	22.8	37.2	42.1	20.7	33.7	46.4	20.8	33.9	39.9	20.3	31.2
September	43.6	20.3	33.8	38.9	19.4	30.9	44.1	20.1	31.7	39.2	19.1	30.3

Leaf nutrients analysis

The fourth leaf from the growing point of five randomly selected plants for each experimental unit was collected to determinate the concentrations of some of the significant macro and micro nutrients. The selected leaves were oven dried at 70˚C for 48 hours and then grinded with grinder. The samples were digested by taking 200mg of the grinded leaf samples and digested with concentrated sulfuric acid and perchloric acid solutions (5:3) according to the method proposed by Cresser and Parsons (6). After the digestion process; Nitrogen (N) was estimated by evaporation and distillation process with Micro- Kjeldahl. Phosphorous (P) estimated by Spectrophotometer at 882 nm wavelength. Potassium (K) was determined by using Flame photometer. Micro nutrients (Fe, Zn and B) were evaluated by using Atomic Absorption Spectrophotometer. All nutrient concentrations were expressed on a dry mass basis (15, 23).

Tomato reproductive growth and fruit yield parameters

Four plants from the middle of each experimental unit were labelled and the means were calculated for the following parameters: number of clusters per plant, number of flowers per plant, number of aborted flower per plant, fruit set (%) and plant yield (kg plant^{-1}). The harvesting process started in 10th June and ended in 1st September in 2017 growing season. While in 2018 the fruits harvesting started in 5th June and continued till 15th September.

RESULTS AND DISCUSSION

Effects of shading on air temperature reduction, plant nutrients content, reproductive growth and fruits yield

Shading had significant impact on reducing daytime air temperature inside the greenhouse from the middle of the May to the middle of the September for two consecutive growing seasons 2017 and 2018. The greenhouse shading decreased the average of the maximum air temperature by 5, 5.2, 6.3, 7.2 and 4.7 ˚C in 2017 and 6, 5.6, 5.7, 6.5 and 4.9 ˚C in 2018 for the months of May, June, July, August and September, respectively. The overall reduction of the air temperature in daytime for the both seasons was 5.7 ˚C (Table 3 and Fig. 2).

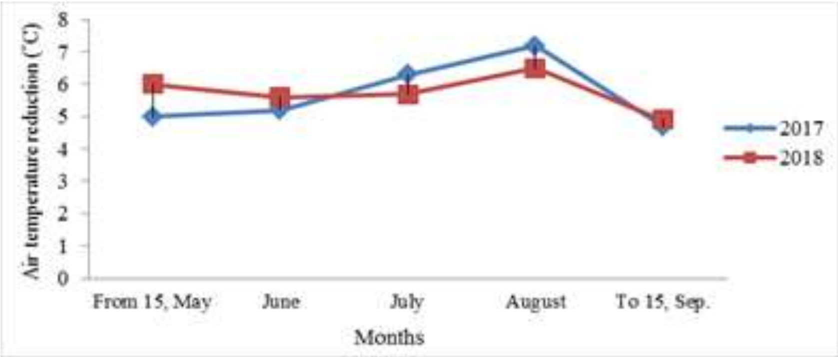

Figure 2. Effect of greenhouse shading on the air daytime temperature reduction during 2017 and 2018 growing seasons

The influences of the greenhouse shading on tomato leaves content of nutrients are presented in (Table 4). It can be noticed that shading seriously improved the tomato leaves content of macro nutrients (N, P and K) and micro nutrients (Fe, Zn and B) in both growing seasons, with exception of the Fe content in the second season (2018), which increasing the content of this nutrient did not reach the significant level due to the shading factor compared to non-shade conditions. The impacts of greenhouse shading on reproductive growth and tomato yield characteristics are shown in (Table 5). Based on the outcomes, the shading factor results in a substantial rise in the number of clusters and flowers per plant. Also, a significant reduction of the aborted flowers per plant, improving the fruit set percentage, and plant yield were enhanced in both growing seasons under shade conditions. While, the number of aborted flowers in the first season (2017) was not affected significantly by shading treatment.

Table 4. Effects of greenhouse shading on nutrients content in tomato leaves in 2017 and 2018 growing seasons

Effect of shading	N (%)	P (%)	K (%)	Fe (mg kg^{-1})	Zn (mg kg^{-1})	B (mg kg^{-1})
First season (2017)						
Without shading	**2.19 b**	**0.24 b**	**1.89 b**	**66.64 b**	**51.71 b**	**36.71 b**
With shading	**2.92 a**	**0.29 a**	**2.22 a**	**77.75 a**	**62.82 a**	**41.93 a**
LSD $_{P\leq 0.05}$	**0.098**	**0.033**	**0.180**	**8.128**	**6.956**	**3.383**
Second season (2018)						
Without shading	**2.34 b**	**0.28 b**	**2.46 b**	**85.68 a**	**53.10 b**	**41.34 b**
With shading	**2.97 a**	**0.31 a**	**2.91 a**	**95.34 a**	**64.07 a**	**49.14 a**
LSD $_{P\leq 0.05}$	**0.376**	**0.014**	**0.388**	**n.s**	**10.125**	**7.703**

Table 5. Effects of greenhouse shading on reproductive growth and tomato yield in 2017 and 2018 growing seasons

Effect of shading	No. of cluster plant^{-1}	No. of flower plant^{-1}	Aborted flower plant^{-1}	Fruit set (%)	Yield (kg plant^{-1})
First season (2017)					
Without shading	8.76 b	51.84 b	11.32 a	77.51 b	4.244 b
With shading	10.24 a	64.30 a	11.58 a	81.53 a	5.973 a
LSD $_{P\leq 0.05}$	0.428	3.115	n.s	3.652	0.279
Second season (2018)					
Without shading	9.91 b	64.67 b	17.88 b	71.59 b	5.688 b
With shading	10.67 a	70.06 a	14.71 a	78.31 a	7.269 a
LSD $_{P\leq 0.05}$	0.367	4.248	2.322	1.805	0.743

Effects of different nutrition programs on plant nutrients content, reproductive growth and tomato fruits yield

In general, it can be observed that application of each the chemical, organic nutrition program and biofertilizer of AMF were separately increased the levels of all measured nutrients in the tomato leaves in the both growing seasons if compared to the control treatment. In addition, interactions between them were more effective (Table 6A and 6B). In the first growing season, the nutrition program (INM) recorded the highest content of N (2.85%), P (0.30%), K (2.44%) and Fe (95.75 mg kg^{-1}); and significantly superior to all nutrition programs in Fe content, and the majority of the other nutrition treatments for other mentioned nutrients content. The (ONP+AMF) treatment recorded the highest content on Zn (71.05 mg kg^{-1}) and was substantially overcome the other nutrition programs. While, the highest content of B (48.17 mg kg^{-1}) was registered by the nutrition program (ONP+50%RDCF) which was not different with the (INM and ONP+50% RDCF) of the nutrition programs (Table 6A).

Table 6A. Effects of different nutrition programs on nutrients content in tomato leaves in 2017 growing season

Nutrition programs	N (%)	P (%)	K (%)	Fe (mg kg^{-1})	Zn (mg kg^{-1})	B (mg kg^{-1})
Control	2.04 d	0.21 e	1.41 e	49.53 f	45.57 d	18.63 e
100% RDCF	2.85 a	0.28 bc	2.02 cd	70.80 cd	54.78 bc	38.00 cd
ONP	2.79 a	0.27 c	2.12 c	75.75 c	55.62 bc	41.71 bc
AMF	2.17 d	0.24 d	1.82 d	68.30 d	51.37 cd	34.21 d
ONP + AMF	2.43 c	0.29 ab	2.04 cd	70.68 d	71.05 a	42.63 b
ONP + 50% RDCF	2.73 ab	0.28 bc	2.19 bc	86.02 b	60.72 b	48.17 a
AMF + 50% RDCF	2.57 bc	0.25 d	2.37 ab	60.70 e	56.93 bc	45.58 ab
INM	2.85 a	0.30 a	2.44 a	95.75 a	62.08 b	45.63 ab
LSD $_{P\leq 0.05}$	0.188	0.022	0.222	4.987	7.348	4.136

Furthermore, similar results were achieved in the second season (2018) about the effects of each kind of the used fertilizers individually on the improving the nutrient contents in the tomato leaves (Table 6B). No significant variations were noticed between the nutrition programs (100% RDCF and INM) in the contents of N, K, Zn and B; which they recorded (3.04 and 3.06% for N), (3.24 and 3.38% for K), (70.16 and 70.83 mg kg^{-1} for Zn), as well as (56.00 and 55.39 mg kg^{-1} for B) respectively for the both treatments. These treatments were significantly superior to all the other nutrition programs in K and Zn contents; and the majority of the nutrition treatments in the contents of N and B. The highest concentration of P (0.38%) and Fe (119.54 mg kg^{-1}) was found due to the application of the INM, which was significantly varied with the control treatment and all the other nutrition programs. In the both growing seasons, the control treatment gave the lowest content of all the measured macro and micronutrients in the tomato leaf tissues (Table 6A and 6B).

Table 6B. Effects of different nutrition programs on nutrients content in tomato leaves in 2018 growing season

Nutrition programs	N (%)	P (%)	K (%)	Fe (mg kg^{-1})	Zn (mg kg^{-1})	B (mg kg^{-1})
Control	1.82 d	0.21 g	1.70 e	60.37 e	36.98 d	16.70 d
100% RDCF	3.04 a	0.30 de	3.24 a	98.65 b	70.16 a	56.00 a
ONP	2.53 c	0.28 e	2.45 d	88.65 bcd	55.62 c	44.85 c
AMF	2.41 c	0.25 f	2.34 d	80.12 d	54.96 c	41.49 c
ONP + AMF	2.73 b	0.33 b	2.72 c	84.31 cd	63.41 b	44.09 c
ONP+50% RDCF	2.97 a	0.33 bc	3.04 b	96.88 b	59.69 bc	50.15 b
AMF+50% RDCF	2.69 b	0.30 cd	2.64 c	95.58 bc	57.04 c	53.24 ab
INM	3.06 a	0.38 a	3.38 a	119.54 a	70.83 a	55.39 a
LSD $_{P\leq 0.05}$	0.161	0.022	0.175	11.662	5.300	6.585

Table 7A and 7B show clear influences of different nutrition programs on reproductive growth and tomato yield. At the first season (2017), the nutrition program (INM) recorded the highest number of clusters per plant (10.88), flowers per plant (69.88), as well as lowest number of aborted flowers per plant (9.42), maximun fruit set (86.22%) and plant yield (6.98 kg $plant^{-1}$). This treatment was superior significantly to the majority of the nutrition programs (Table 7A). In the second season (2018), the (INM) has more affected on the repoductive growth and tomato yield parameters. Also, it was registered the highest number of clusters per plant (12.08) and number of flowers per plant (79.25) which significantly dominates all the other nutrition programs. Furthermore, due to applying the INM, the minimum number of aborted flowers was obtained (12.50). Therefore, the INM treatment recorded the maximum fruit set (84.15%) and plant yield (8.80 kg $plant^{-1}$) (Table 7B). The control treatment negatively influenced the reproductive growth and plant yield parameters in both seasons, which was recorded the lowest number of clusters and flowers per palnt as well as registered the minimum percentage of fruit set and plant yield. While the highest number of aborted flowers per plant was registered by plants that colonized with AMF in the first season and by control treatment in the second season (Table 7A and 7B).

Table 7A. Effects of different nutrition programs on reproductive growth and tomato yield in 2017 growing season

Nutrition programs	No. of cluster $plant^{-1}$	No. of flower $plant^{-1}$	Aborted flower $plant^{-1}$	Fruit set (%)	Yield (kg $plant^{-1}$)
Control	7.46 d	43.71 e	12.46 bc	71.06 d	2.78 f
100% RDCF	9.75 b	60.25 b	13.38 c	77.74 c	5.67 bc
ONP	9.08 bc	54.38 cd	10.46 ab	80.87 bc	4.56 de
AMF	8.88 c	51.58 d	13.83 c	72.92 d	4.02 e
ONP + AMF	9.79 b	60.63 b	10.17 ab	82.93 ab	5.56 bc
ONP + 50% RDCF	10.75 a	66.42 a	11.67 abc	82.45 ab	6.11 b
AMF + 50% RDCF	9.42 bc	57.75 bc	10.25 ab	81.96 b	5.19 cd
INM	10.88 a	69.88 a	9.42 a	86.22 a	6.98 a
LSD $_{P\leq 0.05}$	0.751	4.993	2.570	3.863	0.679

Table 7B. Effects of different nutrition programs on reproductive growth and tomato yield in 2018 growing season

Nutrition programs	No. of cluster $plant^{-1}$	No. of flower $plant^{-1}$	Aborted flower $plant^{-1}$	Fruit set (%)	Yield (kg $plant^{-1}$)
Control	8.21 f	53.46 f	20.46 e	61.65 f	3.86 f
100% RDCF	10.79 c	72.46 b	18.00 d	75.07 d	7.22 c
ONP	9.33 e	62.04 d	18.17 d	70.68 e	5.49 e
AMF	9.13 e	58.50 e	17.13 cd	70.61 e	5.00 e
ONP + AMF	10.17 d	65.63 c	15.25 bc	76.61 cd	6.37 d
ONP + 50% RDCF	11.42 b	73.88 b	15.25 bc	79.36 bc	7.85 b
AMF + 50% RDCF	11.17 bc	73.71 b	13.58 ab	81.50 ab	7.24 c
INM	12.08 a	79.25 a	12.50 a	84.15 a	8.80 a
LSD $_{P\leq 0.05}$	0.461	3.331	2.082	2.935	0.529

Combination effects between greenhouse shading and different nutrition programs on plant nutrients content, reproductive growth and tomato fruits yield:

Nutrients content in tomato leaves were affected significantly by combinations between greenhouse shading and nutrition programs in both seasons (Table 8A and 8B). In the first season (2017), it can be found that the maximum content of N was recorded by plants that cultivated under shade conditions and treated with the nutrition programs (100%RDCF, ONP and INM); which they registered (3.47, 3.43 and 3.47%) respectively; and they superior significantly to the other interaction treatments. The treatment combination (Shade × INM) gave the highest value of P and Fe content (0.34% and 120.50 mg kg^{-1} respectively) and it was substantially different with the other treatment combinations, except (Shade × ONP+AMF) in P content. The maximum concentration of K (2.48 %) was found due to the application of the INM under non-shade conditions (Non-shade × INM), which was significantly varied with some other combinations. In addition, the highest contents of Zn and B (74.93 and 54.50 mg kg^{-1}, respectively) were observed in (Shade × ONP+50%RDCF) which was significantly excessed some of the other combinations (Table 8A). The minimum content of N (1.58%) was registered by plants that colonized with AMF under non-shade conditions (Non-shade × AMF). Whereas, the lowest contents of P (0.18%), K (1.30%), Fe (47.87 mg kg^{-1}), Zn (43.83 mg kg^{-1}) and B (17.17 mg kg^{-1}) were obtained from plants without shading and fertilization treatments (Non-shade × control) (Table 8A).

Table 8A. Combination effects between greenhouses shading and different nutrition programs on nutrients content in tomato leaves in 2017 growing season

Effect of shading	Nutrition programs	N (%)	P (%)	K (%)	Fe (mg kg^{-1})	Zn (mg kg^{-1})	B (mg kg^{-1})
Without shading	Control	1.71 g	0.18 e	1.30 g	47.87 e	43.83 g	17.17 f
	100% RDCF	2.24 ef	0.24 cd	1.74 ef	70.70 d	53.30 defg	38.25 bcde
	ONP	2.16 f	0.24 cd	1.78 ef	80.50 c	46.30 fg	40.50 bcd
	AMF	1.58 g	0.22 d	1.34 g	70.60 d	45.93 fg	33.50 e
	ONP + AMF	2.24 ef	0.27 c	1.92 de	70.37 d	73.83 a	41.42 bc
	ONP + 50% RDCF	2.45 de	0.25 c	2.11 cd	71.37 d	46.50 efg	41.83 bc
	AMF +50% RDCF	2.90 b	0.24 cd	2.42 abc	50.70 e	53.60 defg	40.92 bc
	INM	2.24 ef	0.27 c	2.48 a	71.00 d	50.40 defg	40.08 bcd
With shading	Control	2.37 def	0.24 cd	1.52 fg	51.20 e	47.30 efg	20.08 f
	100% RDCF	3.47 a	0.31 b	2.30 abc	70.90 d	56.27 cdef	37.75 cde
	ONP	3.43 a	0.30 b	2.46 ab	71.00 d	64.93 abc	42.92 bc
	AMF	2.76 bc	0.26 c	2.30 abc	66.00 d	56.80 cde	34.92 de
	ONP + AMF	2.63 cd	0.32 ab	2.16 bcd	71.00 d	68.27 ab	43.83 b
	ONP +50% RDCF	3.02 b	0.30 b	2.26 abc	100.67 b	74.93 a	54.50 a
	AMF +50% RDCF	2.24 ef	0.25 cd	2.33 abc	70.70 d	60.27 bcd	50.25 a
	INM	3.47 a	0.34 a	2.40 abc	120.50 a	73.77 a	51.17 a
LSD $_{P\leq 0.05}$		0.265	0.032	0.313	7.052	10.391	5.849

Whereas, in the second growing season (2018). The treatment combination (Shade × ONP+50%RDCF) gave the highest content of N (3.42%), while it was not different markedly with the nutrition programs 100%RDCF and INM under the same circumstances (Shade × 100%RDCF) and (Shade × INM). The nutrition program (INM) under shade conditions (Shade × INM) recorded the maximum values of P content (0.41%) and Fe content (127.88 mg kg^{-1}); this treatment showed extremely important distinctions with all the other treatment combinations. As for the contents of K and B, the treatment combination (Shade × INM) gave the highest values, in which recorded (3.53% and 62.43 mg kg^{-1} respectively); although it did not differ with some other treatments including (Shade × 100%RDCF). Tomato plants that fertilized with 100%RDCF and grown in shade compartment (Shade × 100%RDCF) gave the maximum content of Zn (78.08 mg kg^{-1}) which was significantly superior over the other interactions, except the (Shade × INM). The minimum contents of all measured nutrients (N, P, K, Fe, Zn, and B) were registered from plants without applying any kinds of fertilizers in non-shade conditions (Non-shade × control). This treatment recorded (1.66, 0.19 and 1.54%) for N, P, and K contents respectively; and recorded (54.77, 31.46 and 16.07 mg kg^{-1}) respectively for Fe, Zn and B contents (Table 8B).

Table 8B. Combination effects between greenhouses shading and different nutrition programs on nutrients content in tomato leaves in 2018 growing season

Effect of shading	Nutrition programs	N (%)	P (%)	K (%)	Fe (mg kg^{-1})	Zn (mg kg^{-1})	B (mg kg^{-1})
Without shading	Control	1.66 i	0.19 j	1.54 k	54.77 g	31.46 h	16.07 f
	100% RDCF	2.84 cd	0.28 efg	3.02 cd	92.03 cde	62.24 bc	49.66 bc
	ONP	2.15 gh	0.26 gh	2.17 hi	83.48 de	52.45 ef	39.85 e
	AMF	2.03 h	0.24 hi	2.08 ij	80.34 def	49.35 fg	39.64 e
	ONP + AMF	2.43 f	0.31 de	2.47 g	79.59 ef	58.83 cde	45.30 bcde
	ONP + 50% RDCF	2.51 ef	0.32 cd	2.83 def	89.67 cde	53.76 def	43.10 cde
	AMF +50% RDCF	2.36 fg	0.31 cde	2.36 gh	94.40 cde	51.06 f	48.72 bcd
	INM	2.71 de	0.34 bc	3.23 bc	111.20 b	65.65 bc	48.36 bcd
With shading	Control	1.98 h	0.22 i	1.85 j	65.97 fg	42.49 g	17.33 f
	100% RDCF	3.24 ab	0.32 cd	3.46 ab	105.26 bc	78.08 a	62.33 a
	ONP	2.91 cd	0.30 def	2.72 ef	93.82 cde	58.79 cde	49.85 b
	AMF	2.79 d	0.27 fg	2.60 fg	79.91 ef	60.57 bcd	43.33 bcde
	ONP + AMF	3.03 bc	0.36 b	2.96 de	89.04 cde	67.99 b	42.88 de
	ONP +50% RDCF	3.42 a	0.33 cd	3.25 bc	104.10 bc	65.61 bc	57.20 a
	AMF +50% RDCF	3.02 bc	0.30 def	2.92 de	96.76 bcd	63.02 bc	57.76 a
	INM	3.40 a	0.41 a	3.53 a	127.88 a	76.01 a	62.43 a
LSD $_{P\leq 0.05}$		0.227	0.031	0.248	16.492	7.495	6.585

Results in (Table 9A and 9B) illustrate that the treatment combination between the greenhouse shading and the INM (shade × INM) offered the highest values of the clusters per plant (11.83) and flowers per plant (77.33); also it was recorded the minimum number of aborted flowers (8.75). For this reason, the highest percentage of fruits set (88.69%) and the maximum plant yield (8.409 kg $plant^{-1}$) was registered by this combination (Table 9A). Similar results were recorded in the second growing season (2018), which the highest number of clusters (13.08) and flowers (85.75); as well as the highest percentage of fruits set (85.32%) and plant yield (10.039 kg $plant^{-1}$) were recorded by appyling the treatment combination (shade × INM).Whereas the minimum number of aborted flowers was recorded through implementing the AMF+50%RDCF under shade condition which was recorded (11.50 aborted flower plant^{-1}) (Table 9B). In the both growing seasons, the minimum number of clusters and flowers per plant, as well as the lowest percentage of fruit set and plant yield were recorded by plants that grown without shade conditions and without applying any kinds of fertilizers (Without shade × Control). While, the highest number of aborted flowers was registered by the combination (Non-shade × 100%RDCF) in 2017 and by (Non-shade × ONP) in 2018 growing season (Table 9A and 9B).

Table 9A. Combination effects between greenhouses shading and different nutrition programs on reproductive growth and tomato yield in 2017 growing season

Effect of shading	Nutrition programs	No. of cluster plant^{-1}	No. of flower plant^{-1}	Aborted flower plant^{-1}	Fruit set (%)	Yield (kg plant^{-1})
Without shading	Control	6.50 i	38.25 j	12.50 bcde	67.35 g	2.009 h
	100% RDCF	9.00 fgh	56.00 efg	13.92 e	75.06 def	4.991 de
	ONP	8.42 gh	47.92 hi	9.00 ab	81.22 bc	4.025 fg
	AMF	8.17 h	44.42 ij	13.50 de	69.95 fg	3.149 g
	ONP + AMF	9.33 efg	54.83 fgh	10.58 abcde	80.79 bc	4.564 ef
	ONP + 50% RDCF	10.67 bc	62.83 cde	11.50 abcde	81.70 b	5.733 bcd
	AMF + 50% RDCF	8.08 h	48.08 hi	9.50 abc	80.25 bcd	3.938 fg
	INM	9.92 bcdef	62.42 cde	10.08 abcd	83.75 ab	5.543 cd
With shading	Control	8.42 gh	49.17 ghi	12.42 bcde	74.76 ef	3.541 g
	100% RDCF	10.50 bcd	64.50 bcd	12.83 cde	80.42 bcd	6.355 bc
	ONP	9.75 cdef	60.83 cdef	11.92 abcde	80.53 bc	5.101 de
	AMF	9.58 def	58.75 def	14.17 e	75.89 cde	4.897 def
	ONP + AMF	10.25 bcde	66.42 bc	9.75 abc	85.06 ab	6.562 b
	ONP + 50% RDCF	10.83 ab	70.00 b	11.83 abcde	83.19 b	6.477 bc
	AMF + 50% RDCF	10.75 bc	67.42 bc	11.00 abcde	83.68 ab	6.444 bc
	INM	11.83 a	77.33 a	8.75 a	88.69 a	8.409 a
LSD $_{P< 0.05}$		1.062	7.062	3.635	5.463	0.960

Table 9B. Combination effects between greenhouses shading and different nutrition programs on reproductive growth and tomato yield in 2018 growing season

Effect of shading	Nutrition programs	No. of cluster plant^{-1}	No. of flower plant^{-1}	Aborted flower plant^{-1}	Fruit set (%)	Yield (kg plant^{-1})
Without shading	Control	7.67 i	51.92 h	21.58 fg	58.44 f	3.411 i
	100% RDCF	10.33 de	69.50 d	19.42 ef	72.14 d	6.315 fg
	ONP	9.08 gh	61.83 ef	23.08 g	62.66 e	4.770 h
	AMF	9.00 gh	57.25 fg	19.67 f	65.61 e	4.386 h
	ONP + AMF	10.00 ef	62.83 e	16.50 de	73.75 d	5.619 g
	ONP + 50% RDCF	11.25 bc	69.67 d	14.67 bcd	79.01 bc	6.899 def
	AMF + 50% RDCF	10.83 cd	71.58 cd	15.67 cd	78.15 c	6.541 ef
	INM	11.08 bc	72.75 cd	12.42 ab	82.99 ab	7.562 cd
With shading	Control	8.75 h	55.00 gh	19.33 ef	64.87 e	4.300 h
	100% RDCF	11.25 bc	75.42 bc	16.58 de	78.00 c	8.120 bc
	ONP	9.58 fg	62.25 e	13.25 abc	78.70 c	6.208 fg
	AMF	9.25 gh	59.75 ef	14.58 bcd	75.61 cd	5.624 g
	ONP + AMF	10.33 de	68.42 d	14.00 abcd	79.47 bc	7.116 de
	ONP + 50% RDCF	11.58 b	78.08 b	15.83 cd	79.70 bc	8.803 b
	AMF + 50% RDCF	11.50 b	75.83 bc	11.50 a	84.85 a	7.939 c
	INM	13.08 a	85.75 a	12.58 ab	85.32 a	10.039 a
LSD $_{P\leq 0.05}$		0.652	4.710	2.945	4.150	0.748

Heat stress is one of the most significant problems in many areas around the world (29). In general, temperatures between 18.3 and 32.2°C are considered to be optimal for tomato production during the entire growing season, and the temperature stress begins at 35˚C (24, 28). The plants in our research conditions were under heat stress even in shading or non-shading compartments as the temperature were high particularly during late spring and summer (Table 3). On the other hand, the plants grew better under shading because of the general decrease of daytime temperature by 5.7˚C as an average for 2017 and 2018 seasons (Fig. 2), such decrease in temperature resulted an alleviation of heat stress on the plants. As a result of mitigating heat stress due to the greenhouse shading, the tomato leaves content of macro nutrients (N, P and K) and micro nutrients (Fe, Zn and B) were improved (Table 4). Also, the reproductive traits like pollen grains viability (data not shown), number of clusters and total flowers per plant were increased, as well as significant reduction of aborted flowers was observed by shading treatment . All mentioned changes were lead to improve the fruit set% , thereby the tomato yield was increased significantly (Table 5). Similar approach is used as a common agro-technological method and has a significant role in improving the nutrients content, flowering growth and productivity of tomatoes (2, 9, 14, 17). Studies reported that heat stress induced flower abscission due to the decrease of the transporting capacity of indole-3-acetic acid (IAA) in the reproductive organs (13). Several researchers found that stigma tube elongation, poor pollen germination, poor pollen tube growth and carbohydrate stress are the main reasons for poor fruit set at high temperature in tomato (18, 27). In addition, Pressman (21) reported that a major effect of heat stress on pollen development is a decrease in starch content three days before flowering period, which resulted in a decreased sugar content in the mature pollen grains, which might contribute in decreasing pollen viability in tomato. All these disturbances induced by high temperature in reproductive growth of tomato plants caused to decline the fruit set and finally the components that related to the plant yield. Also, proper plant nutrient management is another approach to alleviate the adverse effects of heat stresses in plants (16, 31). Generally, in our study the plants that treated separately with each of chemical, organic substances and bio-fertilizer caused the increase in the contents of measured macro and micro nutrients (N, P, K, Fe, Zn and B). The combined effects of the three mentioned fertilizers in the constitution of INM could be the reason for its superiority to the control and the majority of the other nutrition programs in both seasons (Table 6A and 6B). Furthermore, the (INM) also improved AMF roots colonization, the plant roots architecture, vegetative growth of plants, total chlorophyll contents (data not shown). So, this nutrition program led to significant increase in the reprductive characteristics and plant yield in the both season (Table 7A and 7B). All the above mentioned changes indicated that the INM enhanced tomato plants to resist heat stress conditions. Results are in accordance with previous studies that related to the effect of chemical fertilizers, organic manure and variety of biostimulant substances such as humic substances free amino acids as well as mycorrhizal fungi symbiosis on enhancing the nutrients content, improving the reproductive stage as well as boosting plants yield (1, 3, 10). Amino acids are the most important organic compounds. They play a significant biological role as building blocks of proteins, enzymes, nucleic acids, hormones, pigments, antioxidants and other components. Plants are capable of self-synthesis of amino acids, but this process needs much time and energy. Therefore, the application of these compounds as biostimulants may save energy and improve dynamics of plant development (22). Several studies have reported that the biostimulation action of humic substances on soil mineral availability and acquisition has been attributed to several mechanisms affecting soil properties and plant physiology including: (i) improving soil structure, (ii) increasing cation exchange capacity (CEC) and neutralizing soil pH, (iii) increasing population and activity of beneficial soil microorganisms, (iv) increasing solubility of phosphorous by interfering with Ca-phosphate precipitation and also by improving the availability of micronutrients by preventing leaching, (v) improving lateral root induction and hair growth due to the auxin-like activity, which triggers plasma membrane H+-ATPase activity, and (vi) stimulating nitrate assimilation through the upregulation of the target enzymes (NR, GDH, and GER) involved in this process (20, 25). The AMF symbiosis is able to create a network of external hyphae effective of extending the surface area (up to 40 times) as well as the explorable soil volume for mineral uptake, throughout the generation of enzymes and/or secretions of organic substances (11). Besides, hyphae thicknesses are much smaller compared to those of fine root hairs (3–7 μm versus 5-20 μm). However, the hyphal densities are ten-hundred times higher than root densities (7). Furthermore, the AM hyphal- length values obtained in field soil vary between 2 and 85 m g^{-1} soil, whereas in artificial growth systems (like pot cultures), the values are typically ranged between 2-20 m g^{-1} soil (19). Consequently, the absorption surfaces of the host plant are increased significantly, which enhances the ability of the host plant to acquisition nutrients beyond the depletion zones of plant rhizosphere and thereby improves the whole plant growth (26). According to our results, lower air temperature in shade compartment conditions and the (INM) among the nutrition programs led to improving the nutrients uptake, flowering and fruit growth of the tomato plants. For this reason plants that fertilized with (INM) and grown under shade conditions increased these mentioned parameters in tomato plants (Tables 8A, 8B, 9A and 9B), this may be due to the effects of each treatment individually on alleviating negative effects of heat stress on the plants and enhancing nutrients uptake as well as improving whole plant growth as mentioned previously. Three important points could be concluded in this study: (i) each greenhouse shading and proper plant nutrition is the most important strategy to improve the plants nutrients status, reproductive growth and plant yield. (ii) it is possible to reduce the use of chemical fertilizers to 50% with increasing productivity through the INM, which includes integrated reduced chemical fertilizers with applying organic manure and using bio stimulators such as humic and fulvic acid, free amino acids and mycorrhizal inoculum. (iii) plants response to nutrition programs can be more efficient under shade circumstances.

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