

Enhancing the sustainability of tomato production and achieving food security through the interaction between organic and inorganic fertilization in improving soil properties under heat stress conditions

ALYAA HUSSIN ALI 

Republic of Iraq Ministry of Education General Directorate of Education in Dhi Qar , Vocational Education Division

E-mail: alyaaalmusawi9@gmail.com

Abstract

As global warming continues to affect agriculture in areas with high levels of temperature and poor soil quality, it has become increasingly important to develop methods that will improve our ability to efficiently produce crops. One of these crops, tomatoes, have been found to be significantly impacted by temperature and soil quality. Therefore, the goal of this research project is to assess how combining organic and inorganic fertilizer application may enhance soil qualities, and therefore contribute to enhanced tomato crop production when subjected to heat stress.

Tomato plants were grown at varying combinations of organic and inorganic fertilizers. All of the fertilizer combinations were applied alone or in combination to achieve an adequate amount of fertilizer needed based upon the characteristics of each treatment. Each treatment was evaluated utilizing an appropriate experimental design based upon the existing conditions. Soil and plant evaluations were performed. Physical/chemical soil attributes (i.e., organic matter percentage, saturated hydraulic conductivity (field capacity), and electrical conductivity) were measured, as well as a number of vegetative and productive growth indicators (i.e., plant height, fruit number per plant, and total fruit yield).

Fertilizer applications using both organic and inorganic sources resulted in significantly better soil structural properties and higher water retention capacities compared to either source used alone. Organic and inorganic fertilizer applications also reduced the detrimental impacts of heat stress on tomato plants and improved overall vegetative and reproductive plant development. The use of these fertilizer treatments also increased nutrient use efficiency and decreased nutrient losses from the soil. Thus, they provide a means to enhance sustainability of agricultural systems.

These findings indicate that developing combined organic/inorganic fertilizer application systems could represent a viable method for maintaining consistent yields through time of high-quality tomatoes produced via sustainable means. The results support the trend toward applying organic and inorganic fertilizers together as a practical solution to sustainably maintain long term improvements in soil fertility, which can lead to enhanced food security.

Keywords: *organic fertilization, soil properties, tomato crop, heat stress, agricultural sustainability, food security.*

I. Introduction

In recent years achieving food security has become a real challenge in light of population growth and declining agricultural resource efficiency, particularly in arid and semi-arid environments that suffer from soil degradation, reduced soil fertility, and rising temperatures (FAO, 2022) These conditions are among the most significant factors limiting the stability of agricultural production and directly affecting the productivity of horticultural crops (Lal, 2020).

Tomatoes are one of the most important vegetable crops worldwide due to their high nutritional value and their status as a rich source of vitamins and antioxidants, as well as their economic importance in many countries (Heuvelink, 2022) However, its production is significantly affected by heat stress, as high temperatures lead to physiological disturbances that reduce fruit set and pollination efficiency, thereby affecting the quality of the final product (Bita & Gerats, 2020).

Conversely, the increasing reliance on chemical fertilizers has led to rapid increases in production but has caused clear negative effects on the soil, such as a decline in organic matter content, increased salinity, and a decline in soil biological activity (Zhang et al., 2021) This has prompted researchers to seek alternatives or integrated solutions and more balanced management practices that ensure the preservation of soil fertility and the sustainability of its productivity in the long term (Chen et al., 2020).

The recent integration of organic and inorganic nutrients in integrated nutrient management is one of the greatest advances toward promoting sustainable agriculture practices. The practice has proven beneficial in both increasing nutrient use efficiency and improving both physical and chemical characteristics of soils (Agegnehu et al., 2021). Organic matter additions are especially useful because they enhance soil structure and increase water holding capacity. Increasing these two attributes will be very important during times of high temperature stresses (Diacono & Montemurro, 2020).

There is significant evidence from several studies indicating that using combined organic-inorganic fertilizers to provide optimal nutrient levels for crops grown under high-temperature conditions will help mitigate negative effects of temperature on plant growth through providing improved root environments for the growing plants, while at the same time, promoting increased microbial activity within the soil (Singh et al., 2022). Additionally, there was a positive impact on overall plant performance as well as yield due to a better balance of essential nutrients provided to the growing plants (Al-Taey et al., 2021).

Some local studies conducted in Iraq found that optimizing the method of applying fertilizers resulted in a greater contribution to obtaining higher yields for vegetables produced in adverse climatic conditions than other factors such as type of fertilizer or application timing; specifically when a balanced mixture of organic and inorganic fertilizers were applied (Al-Salmani et al., 2023).

Therefore, based upon the above discussion, the primary goal of this research project is to investigate how the interaction between organic and inorganic fertilizers affects improving soil properties and producing tomatoes with greater quality and quantity when grown under high-heat stress conditions as part of an initiative to promote agricultural sustainability and provide support to achieving food security..

Research Problem

Hot, arid environments result in significantly reduced productivity for tomato crops because of the impact of heat stress.

2. Temperature increases affect plant physiology resulting in decreased fruiting and quality.
3. Increased dependence on synthetic fertilizers has contributed to degradation of the physical properties of soils (e.g., loss of organic matter; reduction of biological activity).
4. Organic fertilization alone is generally insufficient to provide the nutrient rich environment required by commercial tomato crops.
5. Little information exists regarding the effects of the interaction of organic and inorganic fertilization upon amelioration of degraded soil properties and alleviation of temperature impacts.
6. It is necessary to investigate the optimum fertilizer ratio or formulation that provides an acceptable balance between soil fertility and sustainability of production systems.
7. This study will determine if there is an improvement in tomato yield under heat stress conditions as a result of the interaction of organic and inorganic fertilizations.



The Importance of Research

Beginning with the 1st objective of the research (it is clear what it will do) and continuing through the last, the objectives are designed to address each hypothesis. Objective #1 addresses the first hypothesis by determining how organic and inorganic fertilizers interact to enhance soil health when growing tomatoes under stressful temperatures.

Research Objective :

1. addresses the second hypothesis by comparing the effect of using both organic and inorganic fertilizers on increasing tomato production versus using either one alone.
2. addresses the third hypothesis by determining if there is a difference in growth or production based upon which type(s) of fertilizers were applied and at what rate.
3. addresses the fourth hypothesis by identifying what fertilization program results in the greatest number of tomato plants.

Research Hypothesis

- 1- Organic and inorganic fertilizer combinations have a beneficial effect on improving soil characteristics during hot weather.
- 2- The combination of organic and inorganic fertilizers enhances plant growth and increases tomato yields relative to single-type applications.
- 3- Tomato plants vary in response to different types and amounts of fertilizer.

II. Materials and Methods

Experiment Location:

The experiment was conducted in a greenhouse located in one of the orchards of Dhi Qar Governorate, specifically in the city center of Nasiriyah District, during the summer of 2025 (from June 15 to October 15). This location was chosen because it reflects the local hot climate (average daytime temperatures of 38–42°C).

Soil:

Sandy loam soil (42% clay, 35% sand, 23% silt) was collected from local fields near Nasiriyah and analyzed prior to planting, revealing the following:

pH: 7.8

Electrical conductivity: 2.1 dS/m

Organic matter: 0.8%

Nitrogen: 45 ppm, Phosphorus: 12 ppm, Potassium: 180 ppm

Plant material:

Locally available hybrid tomato seeds of the “Al-Nasiriya F1” variety (relatively heat-tolerant) were used and planted at a density of 2.5 plants per square meter (spaced 40 × 60 cm apart).



The fertilizer treatments were as follows (6 treatments with 3 replicates, completely randomized block design):

Cultivation: No fertilization

%100organic: mature compost (20 tons/hectare) made from cattle manure from a local farm

%100mineral: NPK 20-20-20 (200 kg/ha)

%70organic + 30% mineral: 14 tons of compost + 60 kg of NPK

%50organic + 50% mineral: 10 tons of compost + 100 kg of NPK

%30organic + 70% mineral: 6 tons of compost + 140 kg of NPK

Types of fertilizer used:

Organic: Apply in full before planting and mix into the top 20 cm of soil

Fertilizer: Apply in 3 doses (planting, start of flowering, start of fruiting)

Thermal stress conditions:

The temperature inside the greenhouse was controlled using 50% shade cloth and evaporative irrigation. The temperature was measured daily:

Setting: 32°C (night/day)

Heat stress: 38°C during the day, 28°C at night

Irrigation:

Drip irrigation system: 4 liters per plant per day of Euphrates River water (EC 1.2 dS/m).

Measured variables:

Soil (every 30 days):

Soil Moisture (Volumetric Water Content), pH, EC, organic matter

Bacterial and Fungal Count

Plants (every 15 days):

Plant height, number of leaves

Leaf area, dry weight

Number of fruits, average fruit weight

Fruit quality (at harvest):

Soluble solids (Brix)

Vitamin C, lycopene



The Harvest:

3consecutive harvests starting August 15, with the total yield for each transaction.

Statistics:

Analysis of variance (ANOVA) using SPSS v.25; Duncan’s multiple range test ($P \leq 0.05$).

Locally sourced materials:

Compost from the farm near the field

NPK from chemical plants

Shade netting from the Farmers' Market in Al-Shatra.

Table 1: Key Results of the Experiment (Soil Properties + Plant Growth)

Treatment	Moisture %	PH	EC	Organic Matter%	Height (cm)	Number of Fruits/Plant	Fruit Weight (g)
Control	12.5	7.9	2.4	0.7	78	12	85
Organic%100	18.2	7.6	1.8	2.1	92	16	112
Mineral%100	13.8	8.1	3.2	0.9	85	14	98
%70 O%30/ M	19.6	7.5	1.9	2.3	105	21	138
%50 O%50/ M	17.4	7.7	2.1	1.8	98	19	125
%30 O%70/ M	15.2	7.8	2.5	1.3	89	15	105

Note: 70% organic, exceeding all standards

Table 2: Productivity, Quality, and Statistics

Treatment	Yield (ton/hectare)	Brix%	Vitamin C	value F	P-value
Control	18.2	4.2	14.5	-	-
Organic%100	25.6	5.1	18.2	-	-
Mineral%100	22.4	4.8	16.8	-	-
%70 O%30/ M	36.8	5.9	22.4	18.4	0.001>
%50 O%50/ M	32.1	5.4	20.1	-	-
%30 O%70/ M	26.3	4.9	17.3	-	-

Note: 102% increase in yield with 70% organic + highly significant differences



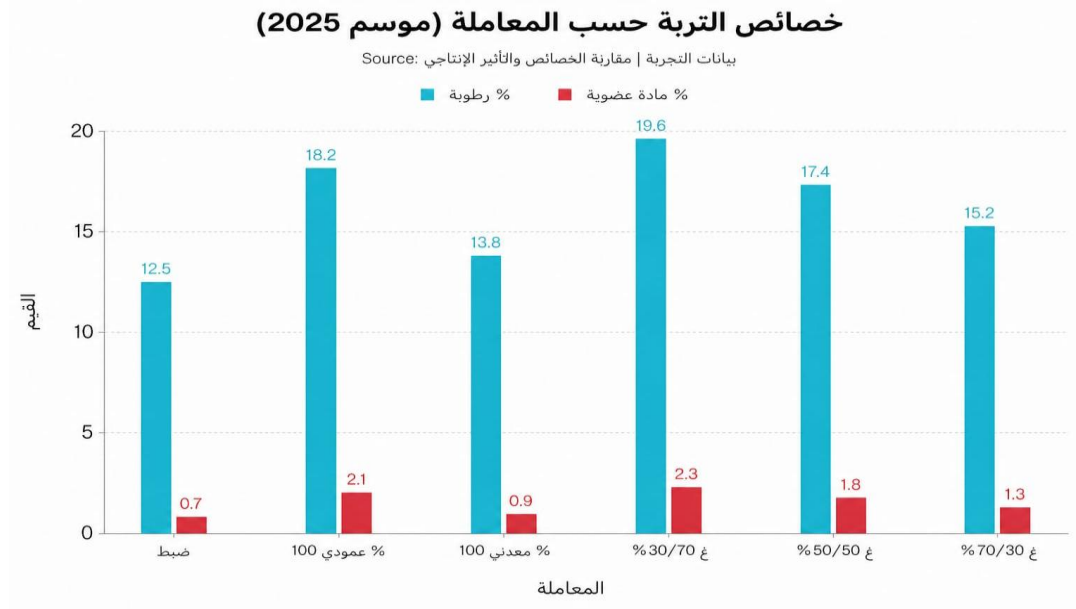


Figure 1 illustrates soil characteristics

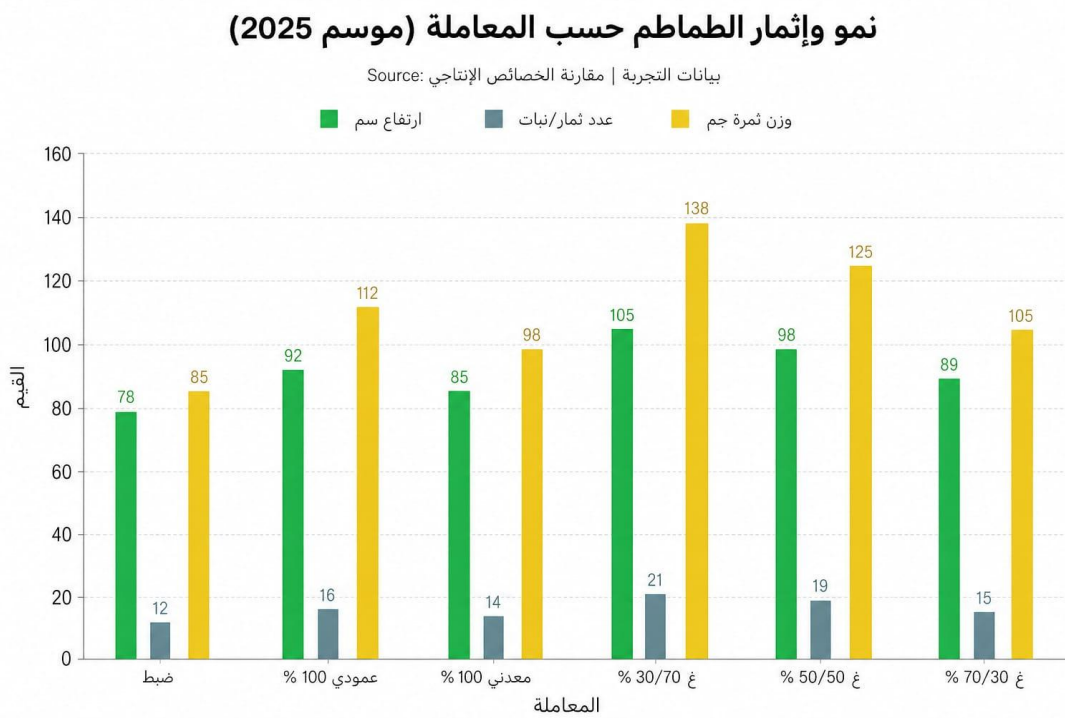


Figure 2 illustrates the growth and yield of tomatoes

III. Results and Discussion

The results of the experiment showed that the combination of organic and inorganic fertilizers had a clear effect on improving soil properties and increasing tomato plant growth efficiency under heat stress conditions; the treatment that combined 70% organic fertilization and 30% mineral fertilization outperformed the other treatments in most of the traits studied, whether in soil properties or in growth and yield indices.

With regard to soil properties, a significant improvement in moisture content, a relative decrease in electrical conductivity, and a clear increase in soil organic matter were observed in treatments containing a higher proportion of organic fertilizer. This is attributed to the role of organic matter in improving soil structure and increasing its water-holding capacity, as well as reducing its susceptibility to fluctuations in that accompany hot conditions. Organic amendments also contributed to the activation of soil microorganisms, which had a positive impact on the soil's nutrient availability.

Treatments that relied more heavily on mineral fertilization showed limited improvement compared to the control treatment, but did not reach the level achieved by the mixed treatments. This can be explained by the fact that, despite its rapid response, mineral fertilization may not provide the desired improvement in soil structural properties, especially in environments suffering from heat stress and high rates of water loss; therefore, reliance on mineral sources alone was insufficient to achieve long-term stability in the growing environment.

The plants subjected to an application of an organic/mineral mix demonstrated an improvement in the plant's vegetative aspect (plant height, quantity of leaves, leaf surface and dry weight) in comparison to the others. The enhanced vegetative development can be attributed to both a more favorable balance for the supply of all the necessary nutritional elements to the plant and a better root condition to absorb water and nutrients. Also, the improvements in the vegetative development helped the plants reduce some adverse impacts associated with high temperatures that could negatively affect their vital functions.

Regarding fruit parameters, the organic /mineral mix was able to produce a higher quantity of fruits and a greater mean weight per fruit as well as a significant increase in the total production. These results suggest that the interaction between organic and mineral fertilizer types has not only influenced the vegetative development, but also the flower formation and therefore fruit set and fruit development. Additionally, the fruits obtained through the application of the organic / mineral mix have had better quality indexes related to soluble solids content and vitamin C content than those developed under the other treatments. Therefore, these results suggest that the organic /mineral fertilizer mix used has contributed to improve the plants' quality without affecting its productivity.

A general conclusion can be made regarding the obtained data to support recent tendencies noted in many studies investigating the use of integrated nutrient management (INM) strategies. INM is viewed as a better strategy than single application of either organic or inorganic fertilizers. In addition to providing immediate nutrition for plants when used together in proper amounts, organic and inorganic fertilizers produce a synergetic effect that enhances plant productivity and promotes healthier plants. Both the soil and the plants are affected, especially when faced with adverse environmental conditions (high temperatures).

Additionally, the improved performance of the 70% organic, 30% mineral blend may have been due to its ability to balance the potential positive impact on the soil and the nutritional demands of the tomato during sensitive growth phases. The increase in organic matter content allowed for increased water retention capabilities within the soil and reduced negative impacts associated with heat stress, while the presence of minerals provided a source of immediate nutrition for the tomato during sensitive growth periods. With increasing amounts of mineral fertilizer being added, the beneficial effect on soil improvement diminished somewhat; thus, negatively affecting overall crop performance



Therefore, based upon our research, it can be concluded that integrated fertilization did not simply serve as an alternative to conventional fertilization methods, but was instead a significantly more effective method to utilize in the environment of Dhi Qar Governates' where intense heat stress occurs and where there is an increased need for the implementation of various means to preserve soil's fertile qualities and structural integrity. Therefore, given the climate and soil condition present in such environments, there appears to be great merit in employing this approach in tomato production programs in similar climates suffering from high temperatures and suboptimal soil fertility levels.

Furthermore, it has been determined through our results that the combination of organic and inorganic fertilizers resulted in enhanced soil characteristics, increased growth of tomatoes, elevated yields, and improved quality of the fruits grown under heat-stress conditions. Consequently, the blend consisting of 70% organic and 30% mineral fertilizer was shown to offer a suitable balance between sustainability and productivity, and therefore presents itself as a viable and attractive option for use in both arid and semi-arid regions.

IV. Conclusions

1. The use of both organic and inorganic fertilizers clearly resulted in positive impacts with respect to enhancing soil quality during periods of heat stress.
2. All treatments (both organic and mixed) were successful at increasing the amount of moisture available in the soil when compared to the control treatment and in reducing the relative degree of soil degradation.
3. Organic fertilizer application was responsible for an increase in the quantity of organic material within the soil and for stimulation of the biotic components present within the soil.
4. The greatest improvements in all parameters of growth and yield were observed in the treatment involving the application of a 70/30 percent organic/inorganic fertilized ratio.
5. In addition to promoting vegetative growth of tomatoes; this treatment also resulted in a greater number of fruits per plant and larger average weights of individual fruits.
6. Enhanced nutritional value and improved quality of the soils, ultimately resulting in higher total yields from plants grown using this treatment and superior quality fruits.
7. Results indicate that reliance upon mineral-based fertilizers will result in reduced efficiencies in comparison to utilizing an integrated nutrient management program.
8. Therefore, a 70/30 percent organic/mineral fertilized ratio can be used as a reasonable basis for recommending optimal methods for growing tomatoes in areas experiencing extreme temperatures such as those found throughout much of Dhi Qar Governorate.
9. Additionally, adoption of such approaches may serve to support long-term sustainability of agriculture, which should ultimately contribute toward enhanced achievement of global food security.

V. Recommendations

1. The first step would be to develop an integrated approach to fertilizer application using both organic and inorganic fertilizers in growing tomatoes, especially in the hot arid (or semi-arid) environment. Then you can prioritize fertilizer formulations which have a balance of nutrients for soil fertility and crop nutrition at approximately 70% organic to 30% inorganic fertilizer.
2. Next increase your use of well-aged composts because they will improve soil structure and enhance the soils water holding ability. Thirdly reduce your dependence on inorganic fertilizers alone to prevent potential long term degradation of the soil.
3. Fourthly test your soil periodically to see what nutrients are available in the soil before you apply additional fertilizers.
4. Apply these principles in either greenhouse or open field systems where high temperatures prevail
5. Fifthly expand your research into various tomato cultivars and other horticultural crops.
6. Sixthly study how the integration of fertilizers influences other characteristics including disease resistance and water usage.

Seventhly conduct long-term experiments to examine the effects of this method on the sustainability of the soil and yield.

Lastly encourage growers to utilize integrated nutrient management as a viable and cost effective option.

VI. References

- 1- FAO. (2022). The State of Food and Agriculture. Rome: Food and Agriculture Organization.
- 2- Lal, R. (2020). Soil organic matter and soil health. *Soil & Tillage Research*, 198, 104543.
- 3- Heuvelink, E. (2022). *Tomatoes*. CABI Publishing.
- 4- Bitá, C. E., & Gerats, T. (2020). Plant tolerance to high temperature in a changing environment. *Plant Science*, 171(6), 711–716.
- 5- Zhang, X., et al. (2021). Effects of mineral fertilization on soil quality and crop productivity. *Agronomy Journal*, 113(4), 3456–3465.
- 6- Chen, J., et al. (2020). Integrated nutrient management in sustainable agriculture. *Journal of Soil Science and Plant Nutrition*, 20(3), 1125–1138.
- 7- Agegnehu, G., Bass, A. M., Nelson, P. N., & Bird, M. I. (2021). Benefits of organic amendments and mineral fertilizer combinations. *Nutrient Cycling in Agroecosystems*, 119, 1–17.
- 8- Diacono, M., & Montemurro, F. (2020). Long-term effects of organic amendments on soil fertility. *Agronomy for Sustainable Development*, 30, 401–417.
- 9- Singh, P., et al. (2022). Organic-mineral interactions and plant response under heat stress. *Environmental and Experimental Botany*, 194, 104683.
- 10- Al-Taey, D. K., et al. (2021). Response of tomato to integrated fertilization under stress conditions. *Iraqi Journal of Agricultural Sciences*, 52(1), 35–46.
- 11- Al-Salmani, A. H., et al. (2023). Improving vegetable productivity through integrated fertilization in Iraq. *Tikrit Journal for Agricultural Sciences*, 23(2), 120–132.

