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Enhance the sustainability of tomato farming and secure food supply, integrating organic and inorganic fertilizers can improve soil properties, particularly when facing heat stress conditions

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Abstract:

Background: With the growing concern over the effects of global warming on agriculture in regions where temperatures are high and the quality of the soil is low, there is an ever-greater need for us to find ways to increase the efficiency of producing food. Tomatoes, for example, are greatly affected by both temperature and soil quality. **Aim of study:** Therefore, the overall purpose of this research project is to examine whether the application of both organic and inorganic fertilizers can improve the quality of the soil and therefore increase the productivity of tomato plants as they undergo heat stress. **Methodology:** Tomato plants were treated with different mixtures of organic and inorganic fertilizers. Organic fertilizer alone was used, as well as in combination with other types of fertilizers to provide a sufficient quantity of fertilizer for the individual treatments depending on their particular characteristics. The effects of the treatments on the tomato plants and the soil were evaluated using experimental designs that were suitable for the current environmental conditions. The assessment considered the soil's physical and chemical properties, including organic matter content, saturated hydraulic conductivity at field capacity, and electrical conductivity. Additionally, it examined several plant characteristics, such as plant height, the fruit count per plant, and the total fruit weight. **Results:** The application of both organic and inorganic fertilizers has significantly improved soil structure and water-

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holding capacity as compared with the application of either organic or inorganic fertilizers alone. Also, organic and inorganic fertilizers have reduced the negative impacts of heat stress on tomato plants and increased both vegetative and reproductive growth in tomato plants. Lastly, organic and inorganic fertilizers have increased the use of nutrients in tomato plants while reducing the loss of nutrients from the soil. Therefore, organic and inorganic fertilizers can provide a means to increase sustainability in agriculture. **Conclusions:** The results suggest that it is possible to produce consistently high-quality tomatoes over time by combining organic and inorganic fertilizers (as a different approach) as a method for producing consistently high-quality tomatoes over time, while maintaining a sustainable approach. This research supports the growing trend of combining organic and inorganic fertilizers as a realistic way to achieve sustained increases in soil fertility and thus possibly provide positive outcomes for food security.

Keywords: organic fertilizers, soil characteristics, tomato plants, heat stress, sustainable agriculture, food security.

Introduction

The achievement of food security is currently one of the largest problems that we are experiencing. The increased population and diminished productivity of our agricultural resources, particularly those located in the dry and semi-dry areas where the soil quality continues to decline, the soil fertility decreases, and the temperature increases, have all contributed significantly to the difficulty in attaining food security [1]. All of these issues are serious threats to the long-term sustainability of agriculture, as well as providing direct threats to the productivity of horticultural crops [2].

Tomatoes are among the world's most significant vegetables based upon their great nutritional benefits and they represent a significant source of vitamins and antioxidants; additionally, tomatoes have a very large financial impact in many different nations [3]. Heat stress affects tomato production significantly, since high temperatures cause physiological changes within the plant which affect both the ability of the plant to produce fruit and the ability of the plant to be pollinated effectively. This in turn reduces the overall quality of the end-product [4].

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In contrast to the use of chemical fertilizer, which can result in quick gains in crop yields, there are serious environmental consequences to the practice including loss of organic matter, increased levels of salt in the soil, and a decrease in the number of microbes living in the soil [5]. As a result of these concerns, researchers have begun looking for alternative options for managing soils, such as applying both organic and inorganic fertilizers or developing other forms of sustainable soil management strategies [6].

The implementation of an integrated system of using both organic and inorganic fertilizers in developing integrated nutrient management has been a huge advancement towards having environmentally friendly agricultural practices. Studies have indicated that when using both types of fertilizers, plants are able to use the available nutrients more effectively while also enhancing the physical and chemical aspects of the soil [7]. Organic matter being added to the soil can help create better soil structure and allow the soil to retain more water. These two components of the soil need to be maintained during times of severe heat stress [8].

Organic and Inorganic Fertilizer Combination: Organic and Inorganic Fertilizer Combination: Organic and inorganic fertilizer combinations are effective at improving plant root environments and soil microbial populations in hot climate conditions where plants suffer from excessive temperature. By doing so, organic and inorganic fertilizer combinations minimize the negative impacts of high temperatures on plant growth [9]. Additionally, organic and inorganic fertilizer combinations produce positive effects on plant performance and ultimate yields because they provide a better balance of the essential nutrients necessary for successful plant development [10].

In addition to using the best method of applying fertilizer, as opposed to other factors including the type of fertilizer and when it was applied, applying both organic and chemical fertilizers in an appropriate combination was found to be the most influential factor contributing to increased vegetable yields under adverse weather conditions in Iraq [11].

The main objective of this study is to determine how the use of organic and/or inorganic fertilizers will affect the health of the soil and the quality and quantity of tomato

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production (when tomatoes are grown under extreme heat stress) as part of an overall effort to promote sustainable agricultural practices and provide food security.

Research Problem

1. Tomato plant production is greatly affected by the negative effects of heat stress in areas with high temperatures and low rainfall.
2. Plant physiology is altered when temperatures rise resulting in reduced fruit production and lower quality.
3. Increased reliance upon man-made fertilizer, has resulted in a degradation of the soil's natural physical characteristics (i.e. loss of organic material; decrease in microbial activity).
4. Organic fertilization on its own does not usually provide the nutrient-dense environment that is necessary for commercial tomato production.
5. The effects of combining organic and inorganic fertilizers to improve degraded soils and reduce temperature-related problems have not been well-studied.
6. We need to determine what the most effective fertilizer combination/formula would be so we have both good soil health and the ability to continue growing crops sustainably.
7. The purpose of this study is to examine whether the use of both organic and inorganic fertilizers can improve tomato yields when they are subjected to high temperatures.

The Importance of Research

The first objective of this study (what we are going to accomplish) through the last objective of this study, are based on addressing each hypothesis. The first objective is addressing the first hypothesis which is examining how the interaction of organic fertilizer and inorganic fertilizer improves soil health during tomato growth under heat-stress conditions.

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Research Objective:

1. This study will address the second hypothesis by comparing how organic and inorganic fertilizers can be used together to increase tomato yield compared to when each fertilizer is used alone.
2. The second step determines whether the third hypothesis is supported by data or not, through the evaluation of whether there is an effect on growth and/or production as a result of using various types of fertilizers and at what levels they are applied.
3. This study will evaluate the effects of different types of fertilizers on tomato plant production, which relates directly to the fourth hypothesis.

Research Hypothesis

1. Organic fertilizer combined with inorganic fertilizer will enhance the quality of soil during hot temperatures.
2. Combining organic and inorganic fertilizers has been found to produce greater yields of tomatoes than when either type is used alone.
3. Tomato plants vary in response to different types and amounts of fertilizer.

Materials and Methods

Experiment Location:

An experiment was performed in a greenhouse within an orchard of the Dhi-Qar governorate. The greenhouse was located near the city of Nasiriyah, in the central portion of the Nasiriyah district, and the experiment was conducted during the summer of 2025 (June 15 - October 15). This location was chosen as a representation of the high temperatures experienced in the region (average daytime temperature between 38 and 42°C).

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Soil:

The soil type was Sandy Loam (42% clay, 35% sand, and 23% silt). It was collected from locations near Nasiriyah and tested prior to planting to obtain data on how well it would perform.

pH: 7.8

Electrical conductivity: 2.1 dS/m

Organic matter: 0.8%

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

Plant material:

The 'Al-Nasiriya F1' tomato hybrid seed, which is heat tolerant, has been sown at a planting rate of 2.5 plants per square meter (with 40 cm between rows and 60 cm between plants). The six treatments used for the fertilizer treatments are listed below: (completely randomized block design, 3 replications).

Cultivation: No fertilization

The mature compost (20 tonnes/hectare) used to fertilize the soil has been made 100 percent organically from the cow manure of a local farm.

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

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

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

30% organic + 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)

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Thermal stress conditions:

Greenhouse temperatures were maintained at a specific level using 50% shade cloth and water-evaporative irrigation. Greenhouse temperatures were recorded daily.

Setting: 32°C (night/day)

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

Irrigation:

Drip Irrigation System: Four Liters Per Plant Per Day Of Water From The Euphrates River With An EC Of 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:

Three successive harvest periods beginning on August 15th, with a record of each harvest's total production volume.

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Statistical analysis:

An analysis of variance (ANOVA) was completed utilizing SPSS software, version 25. Subsequently, the results of the ANOVA were analyzed for statistical significance through the use of Duncan's Multiple Range Test, which utilized an alpha level of $P < 0.05$.

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. Effect of organic and mineral fertilizer ratios on soil properties and vegetative and fruit growth of tomato under heat stress

Treatment	Soil moisture (%)	pH	EC (dS m^{-1})	Organic matter (%)	Plant height (cm)	Fruits per plant	Fruit weight (g)
Control (unfertilized)	12.5	7.9	2.4	0.7	78	12	85
100% mineral	13.8	8.1	3.2	0.9	85	14	98
30% organic + 70% mineral	15.2	7.8	2.5	1.3	89	15	105
50% organic + 50% mineral	17.4	7.7	2.1	1.8	98	19	125
70% organic + 30% mineral	19.6	7.5	1.9	2.3	105	21	138
100% organic	18.2	7.6	1.8	2.1	92	16	112

Note: 70% organic, exceeding all standards

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Table 2. Effect of organic and mineral fertilizer ratios on yield and fruit quality of tomato under heat stress

Treatment	Yield (t ha^{-1})	Yield increase over control (%)	TSS (°Brix)	Vitamin C (mg 100 g^{-1})
Control (unfertilized)	18.2	0.0	4.2	14.5
100% mineral	22.4	23.1	4.8	16.8
30% organic + 70% mineral	26.3	44.5	4.9	17.3
50% organic + 50% mineral	32.1	76.4	5.4	20.1
70% organic + 30% mineral	36.8	102.2	5.9	22.4
100% organic	25.6	40.7	5.1	18.2
F-value	18.4			
P-value	**< 0.001**			

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

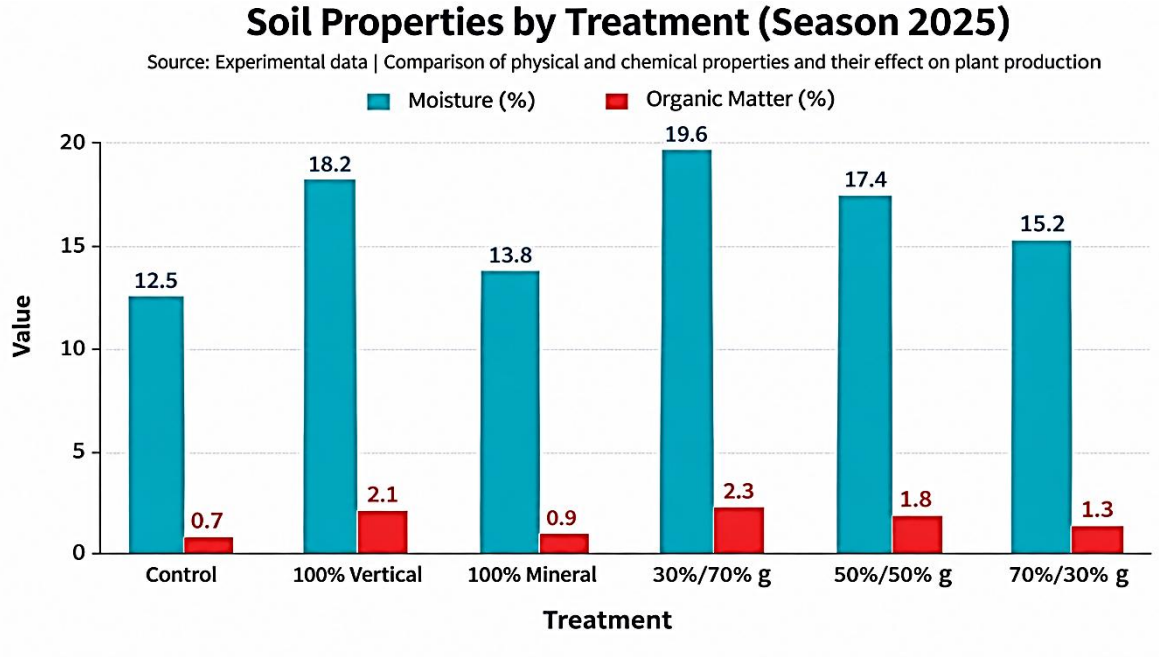


Figure 1 : Illustrates soil characteristics

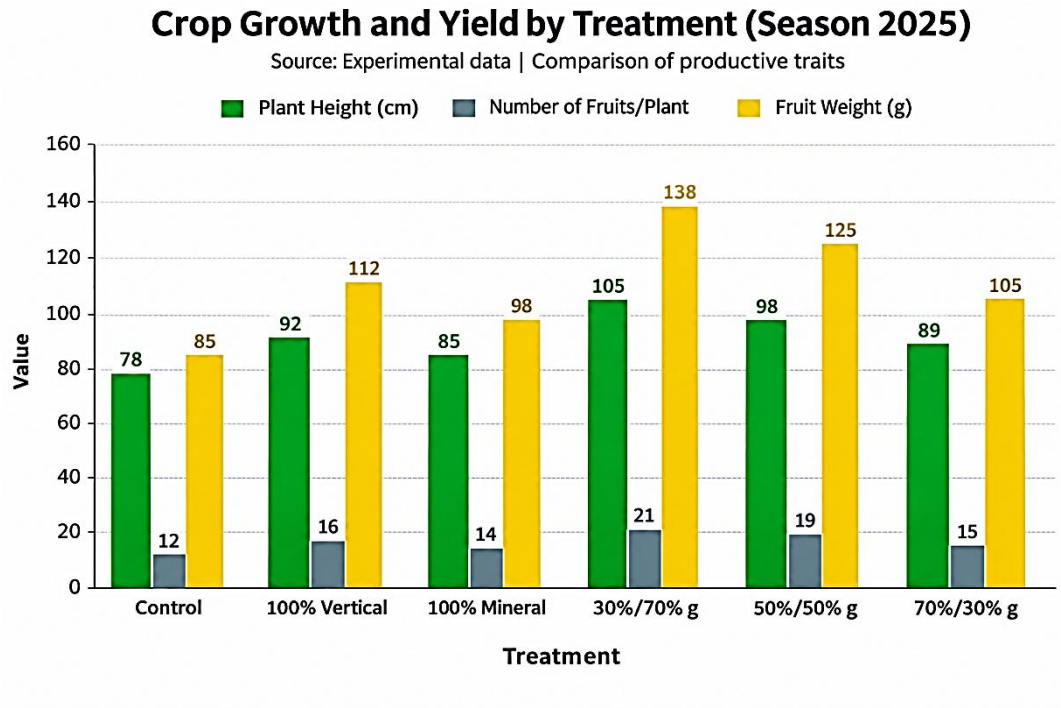


Figure 2 : Illustrates the growth and yield of tomatoes

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Discussion:

The results show that the combination of both organic and inorganic fertilizers can improve soil quality and productivity of tomatoes during periods of high temperature. The treatment of 70% organic and 30% mineral fertilizer produced better performance than the other treatments across most variables studied related to soil quality and tomato production. This is consistent with a global meta-analysis which showed that organic-inorganic mixtures increased tomato yields by 12.4% compared to inorganic fertilizers only a field study in Bangladesh which showed that a mixture of two thirds organic and one third inorganic fertilizer produced the greatest yield [12], who reported that the use of organic manure in conjunction with full-dose NPK was more effective than using either separately. However, there are some studies that have reported conflicting results. For example, during high temperatures, a trial reported its highest yield when using NPK alone; and a field experiment in Egypt reported that mineral fertilization provided higher vegetative growth and yields than organic manures. Additionally, the optimum mixture ratio may vary among studies. Nandhini et al. (2024) identified 75% organic and 25% inorganic as the most effective combination. Therefore, the 70:30 mixture ratio used in this study should be considered as optimal for the current environmental conditions, but not necessarily applicable globally [13].

In relation to soil characteristics, soils treated with a greater proportion of organic fertilizers exhibited higher levels of moisture, reduced electrical conductivity and elevated organic matter. These enhancements align with the function of organic matter as a means of improving soil structural stability and water retention capacity. For example, in a long-term semi-arid Mediterranean trial, demonstrated that organic amendments elevated organic matter concentration and decreased bulk density; while mineral fertilizer failed to increase organic matter accumulation [14]. Organic amendments have also been documented to enhance water retention in sandy soils; and to improve the water balance of sandy soils located within arid and semi-arid environments, where combination amendments outperformed individual ones [15]. It must be noted, though, that caution is required when evaluating the decrease in electrical conductivity: a recent review indicated that the impact of co-applied amendments on electrical conductivity was variable among

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trials [16]; thus, it is probable that this outcome varies based upon soil type, salinity and the specific amendment utilized. Organic inputs can potentially stimulate soil microbial activity and biomass production, thereby enhancing nutrient availability.

The mineral fertilizer treatment had some improvement in comparison to the control; however, it did not equal the performance of the mixed treatment. Mineral fertilizer will provide rapid growth of plants; however, it provides little benefits for improving the soil's structure. Therefore, mineral fertilizer alone will not provide a suitable environment for roots during periods of hot weather and rapid loss of water. In support of this statement, Çelik et al. (2010) found that the highest bulk density occurred when mineral fertilizer was used [14]. Also, long term research indicates that mineral fertilizer alone increases the rate at which organic carbon decomposes within the soil and that humus decreased by approximately 30-40% when only mineral fertilizers were applied to the soil. There are other studies indicating that mineral fertilizer also increases the amount of organic matter present in the soil; however, not as much as if organic fertilizer was used. Additionally, several authors state that the effects of using fertilizers on organic carbon levels within the soil are inconsistent. Therefore, mineral fertilizer alone does not create a stable environment for plants to grow, although it is not completely ineffective.

Organic/mineral mixtures resulted in better vegetative growth of plants (such as increased plant height, number of leaves, leaf surface area, and total plant dry weight). The results support the meta-analytic findings of organic-inorganic combination treatments resulting in taller plants and higher total plant dry weights when compared to inorganic fertilization alone as well as the work of Ahmed et al. (2022) which demonstrated that integrated bio-organic and chemical fertilization led to taller plants with higher levels of chlorophyll [17]. It may be hypothesized that the more balanced supply of nutrients and/or the improved root environment provided by the organic/mineral mixture could explain why it produced significantly better vegetative growth than did inorganic fertilization alone. On the other hand, inorganic fertilization was superior to organic manure treatments for every vegetative parameter tested in the Egyptian trial referenced earlier. Furthermore, it should be noted that while plants exhibiting vigorous vegetative growth can often tolerate extreme heat, there was no statistically significant relationship found by Xu et al. (2017) between

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the vegetative and reproductive components of plants exposed to heat stress conditions. Consequently, the relationship between improved vegetative growth and enhanced thermal resilience is being presented as a hypothesis rather than a proven mechanism [18].

In terms of fruit variable, the mix produced more fruits; a greater average fruit mass; and a significantly higher overall yield. In terms of percentage of increase in fruit weight (7.28%) and fruit per plant (5.58%), the global meta-analysis showed similar increases. Also, Ahmed et al. (2022) reported an increase in the number of fruits, fruit weight, fruit diameter, and total yield using integrated fertilization [17]. When subjected to thermal stress, the mainly primary determinant for fruit setting is pollen vitality, which decreases drastically at high temperatures and is believed to be the major limiting factor for fruit setting [17][18]. Therefore, improved nutritional status can likely support fruit setting through continued development of flowers and pollen, although these factors were not evaluated during this study. Quality index parameters, such as soluble solids and vitamin C, also exhibited the greatest performance under the mixture. Other researchers have also reported similar outcomes: the highest vitamin C concentrations were achieved when applying 50% NPK plus 50% compost, and a meta-analysis showed that organic fertilizers increased levels of both soluble solids and vitamin C compared to the control group [20].

However, there is some disagreement regarding the results obtained from studies evaluating the effects of organic fertilizers on quality. For example, in the meta-analysis cited earlier, organic fertilizer application resulted in a decrease in yield by 5.5% and a decrease in fruit firmness. Furthermore, studies conducted in Egypt indicated that organic manures improved quality; however, they resulted in lower yields than those obtained when applying mineral fertilizer. Finally, many authors describe the literature available concerning organic vs. mineral fertilizer effects on fruit quality as being contradictory [21].

The findings of this study reinforce the growing body of literature which supports the use of integrated nutrient management (INM) over the use of only one form of fertilizer. A recent article published in Frontiers in Microbiology stated that the combination of both organic and inorganic fertilizers can improve the physical properties of soils including their ability to retain water and nutrients. Additionally, research conducted by Sulaiman and

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Sadiq (2020) demonstrated that the implementation of integrated nutrition programs in Iraq was able to reduce the negative effects of heat on tomato plants [21]. It is likely that the synergy created by the addition of mineral nutrients to provide immediate demand for nutrients and organic matter to create a better environment for the plant to grow in contributes to the healthier plants and increased yields that have been observed, especially during times of extreme weather events such as high temperatures.

The 70% organic / 30% mineral mixture outperforms the other combinations because it balances the need for improving the soil with the high demand for nutrients during the early stages of development when the plant is most susceptible to injury. Organic materials improve water holding capacity in soils and help to reduce the negative impact of extreme temperature fluctuations; whereas minerals provide immediate access to essential nutrients during the key periods of growth. These findings are supported by the idea that mixed treatments supply nutrients from organic and inorganic sources at various times (Agriculture, 2017) and by previous research that shows adding more minerals to a treatment reduces the positive effects of improving the soil [14]. Although there are several studies that show that a 70% organic/30% mineral mixture is not the only optimal combination; there were several other optimal combinations identified including 75:25 [13], and 50:50 (African Journal of Biotechnology). Therefore, the "optimal" ratio is likely to vary depending on the specific characteristics of the soil, cultivar being grown, and the climatic conditions.

Integrated fertilization is therefore not only a viable alternative to the conventional method of fertilization, but it also has potential to be more efficient than traditional fertilization methods in the Dhi-Qar governorate, where there are significant temperature stresses, and therefore, other ways to preserve the soil structure and quality are required. Heat stress research carried out in Iraq indicates that integrated fertilization practices will help alleviate the negative effects of heat stress [22]. However, it should be noted that the application of integrated fertilization techniques may be less effective at stabilizing organic carbon within sandy, low-nutrient soils due to the lack of sufficient mineral protection. As a result, ongoing applications of organic material may be necessary to sustain the positive benefits associated with the use of integrated fertilization techniques. Nonetheless, there

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appears to be a clear rationale for implementing integrated fertilization practices as part of tomato production programs within areas that experience both high temperatures and poor soil fertility levels.

The combination of organic and inorganic fertilizers improved the quality of the soil, promoted the growth of the tomatoes, increased the yield of the crop, and produced better quality fruit during periods of heat stress. While the 70% organic/30% mineral fertilizer application was found to be a suitable compromise between environmental sustainability and productivity, this treatment is an effective method of increasing productivity for farmers in arid or semi-arid regions. It should be noted however, that the ideal ratio of organic to mineral fertilizer will depend upon local environmental factors.

Conclusions

1. During times of high temperature stress, there was a positive response to applying either organic or inorganic fertilizers to improve soil conditions.
2. Both treatment types (organic and mixed) were effective at increasing the moisture level in the soil compared to the control group; also, they reduced the relative amount of soil degradation.
3. Application of organic fertilizers contributed to increasing the amount of organic matter in the soil, as well as enhancing the activity of those living organisms that reside in the soil.
4. The maximum enhancement of all growth and yield characteristics was achieved when the treatment utilized an organic/inorganic fertilizer ratio of 70/30 percent.
5. This treatment promoted vegetative growth in tomatoes; it also produced a larger number of fruits on each plant and a higher average weight of each fruit.
6. Enhanced soil nutrient content and better soil quality, which will provide for greater overall plant productivity, and higher quality produce.
7. The results show that relying on mineral based fertilizer is less efficient than using an integrated nutrient management plan.



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8. Therefore, an 80/20% organic/mineral fertilizer ratio can serve as a logical framework from which to recommend effective methods of cultivating tomatoes in regions that experience severe weather conditions, like most of Dhi Qar Governorate.
9. Furthermore, using these types of methods will help maintain agricultural sustainability over time. This maintenance of agricultural sustainability will help improve global access to food.

Recommendations

1. The first action required will be to create a single system that integrates the use of organic and non-organic fertilizers for growing tomatoes, particularly in a hot dry climate.
2. The next step would be to prioritize those fertilizer types with a good mix of organic vs. inorganic elements, with about 70 percent organic content and 30 percent inorganic content, so they will provide the necessary nutrients for both the soil's fertility and the plant's health.
3. Next, increase your usage of properly aged compost to improve the structural characteristics of your soil and its capacity to retain moisture.
4. Lastly, try to use organic fertilizer as well as chemical fertilizer so you can avoid possible damage to the soil over time.
5. Fourthly, check your soil from time to time to find out how many nutrients exist in the soil prior to adding more fertilizer.
6. Use the above listed methods for applying fertilizers in either an outdoor (open field) system or an indoor (greenhouse) system during times of high temperature.
7. Finally, investigate other tomato varieties as well as other vegetable and flower types.
8. Sixthly, examine how the use of fertilizers affects other characteristics such as resistance to diseases and utilization of water.

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9. Lastly, perform long-term studies to assess how the application of this technique affects both the long-term viability of the soil and production.

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