Nano iron fertilization effects on growth, yield, and quality of fresh market tomato under drip-irrigated plasticulture

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RESEARCH HIGHLIGHTS

- Iron (Fe) fertilization consistently increased the tomato growth, yield and nutrient density.
- Both nano- and chelate Fe fertilizations were effective when compared to the control; however, nano Fe had more consistent effects on tomato than that of the chelate Fe.
- Total fruit yields per plant was 43 to 87% higher in nano Fe when compared to the chelate Fe and control treatments.
- Total marketable fruit produced under nano Fe fertilization was 11.6 tons/acre higher than the control and 5 tons/acre higher when compared to the chelate Fe fertilization.
- Nano Fe increased nutrient density by1.5 to 2-folds when compared to the control.
- The effect of 10 to 20 ppm nano Fe was more effective for fresh market tomato production.

INTRODUCTION

Iron (Fe) is one of the important micronutrients essential for plant growth. Due to its oxidation-reduction properties, Fe plays a critical role in various physiological and biochemical pathways in plants such as DNA synthesis, respiration, and photosynthesis processes. Moreover, Fe serves as a critical component of several vital enzymes that carry out electron and oxygen transport functions, facilitate chemical transitions, regulate protein stability, and is thus required for a wide range of biological functions.

An imbalance among the Fe input, availability, and its demand by the plant are the primary causes of widespread Fe deficiency in most of the vegetable crops. While abundant in most soils, the ionic activity of Fe (solubility) is low as it often forms insoluble Fe compounds in soil. While the chelate Fe is better than conventional mixed Fe fertilizers; but at pH above 6, almost 50% of the chelate Fe becomes unavailable to plants.

Nanotechnology is increasingly adapted in agriculture, aiming to reduce the use of reactive chemicals, minimize nutrient losses, and increase economic yields by precision nutrient management practices. Our preliminary greenhouse studies have shown that Fe nanotechnology is far more effective in supplying Fe to plants, compared to the commonly used Fe fertilizers/chemicals. Substituting nano Fe fertilizer for conventional and chelate Fe fertilizations is expected to increase Fe availability to plants in a controlled way to increase the growth, yield, and quality of vegetable crops. Despite all these potential advantages, the use of nano-Fe in the agricultural sector is still relatively limited.

OBJECTIVES:

The objective of the research was to determine the effects of different rates of nano-Fe fertilization on the growth, yield and quality of fresh market tomatoes compared to chelate Fe fertilization and disseminate the science-based knowledge and production economics to the farmers and educators.

MATERIALS and METHODS:

Description of the study area

The replicated field study was conducted at The Ohio State University (OSU) South Centers at Piketon, Ohio (lat. 39.07° N, long. 83.01° W with mean sea level elevation of 578 feet). While average maximum monthly air temp. (90 ^{0}F) was recorded highest in August, it was lowest of less than 60 ^{0}F in September during the crop growing season (**Fig. 1**). Average min. monthly temp. was more less same (~ 60 ^{0}F) thru-out the season. Highest volume of monthly rainfall (~ 6 in) was recorded in July and the rainfall decreased over time (**Fig. 2**).

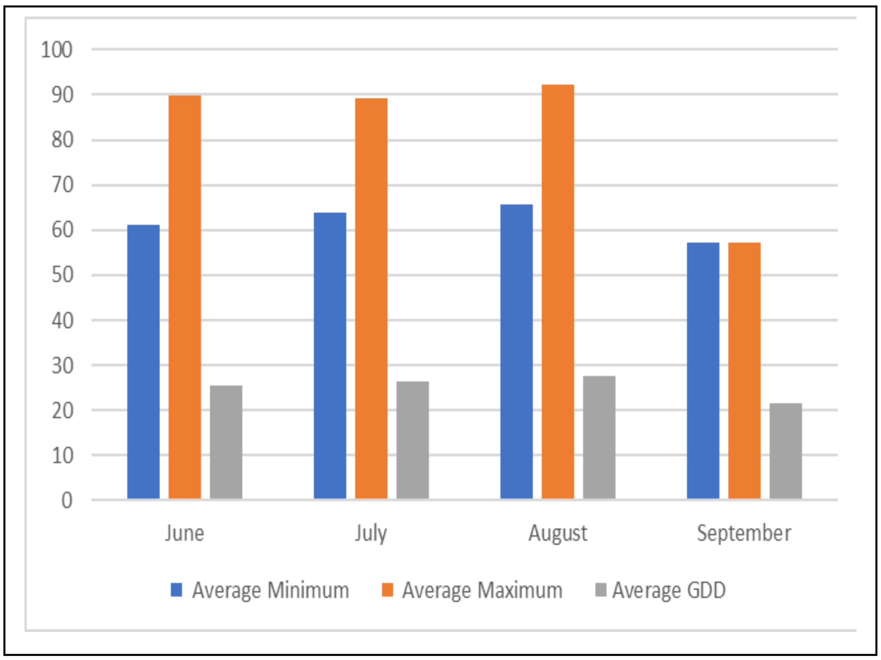

Fig. 1. Average minimum and maximum temp. and growing degree days in 2021.

The soil is a Doles silt loam, with 0 to 3% slopes. It is a deep, nearly level and somewhat poorly drained soil. Typically, the soil surface is a brown, friable silt loam about 8 inch deep and beneath this the subsoil is about 7.3 inch deep.

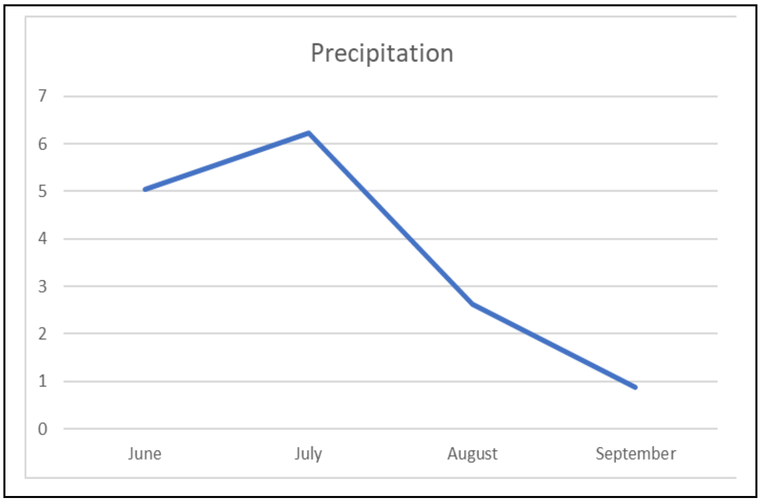

Fig. 2. Monthly rainfall distribution (inch) during the tomato growing season in 2021.

Experiment and cultural practices

A field trial in completely randomized design (CRD) was established to evaluate the effects of different rates of nano- and chelate Fe, respectively compared to the routinely used Fe compounds ($FeCl_3$ as a control) in mixed fertilizers. Both nano-Fe and chelate Fe fertilizers were applied at the rate of 10, 20, and 40 ppm, respectively via drip irrigation over the active growing period of tomato. The treatments were replicated four times.

Tomato (cv. Sunbrite) was seeded into 72 cell plug trays containing Metro Mix 360 soilless media and placed in the plant growth chamber. About 5 to 6 inches tall seedlings were planted in the field under plasticulture system. Prior to laying plastic, the field was plowed and prepared followed by surface application of 19-19-19 (NPK) fertilizers at the rate of 100 lbs./acre). Plastic rows were 5’ apart with tomato seedlings being spaced 2’ apart within rows. Tomato transplants was planted onto raised beds using a waterwheel transplanter on June 3rd. Nano- and chelated Fe along with $FeCl_3$ (control) treatments were applied on 6/17/21 and 7/6/21, respectively. All the Fe treatments and watering of the tomato plants were applied via the drip irrigation.

All irrigation valves were shut off except for the Fe treatment that was being applied. Lines was pressurized then the iron treatments was injected into the irrigation water, each treatment took fifteen min to inject then was allowed to irrigate for 10 more min to purge the lines then the valve was shut off at each treatment. The header line was then uncapped to empty header line between each treatment. Cultural practices and fungicides were applied following recommendations from the Midwest Vegetable Production Guide for Commercial Growers (ID-56).

Growth and yield parameters of tomatoes

During the various growth stages of tomato plants, plant height and leaf SPAD readings were recorded. At each harvest, the tomatoes were graded and sized as small, medium and large, and their weight were taken. The collected data were processed to calculate for various growth and yield parameters of tomato including harvest index.

Nutrient content of tomatoes

After harvesting, tomatoes were processed, and a 1.0 g oven-dried replicated samples of tomato was digested using 10 mL of conc nitric acid and 5 mL of 30% hydrogen peroxide. After cooling, the digested aliquot was diluted with distilled deionized water and filtered to obtain clear aliquots. Nutrients and heavy metals were analyzed using Inductively Coupled Plasma-Emission spectrometry (ICP-AES, model: ICPE-9000, Shimadzu, Japan). After every 10 samples, a QC/QA sample, made from certified standard solution, was analyzed to check the analytical quality with a relative standard deviation of QA/QC samples were 5 to 8%. Analytical quality control was maintained by analyzing certified reference material NIST 1567b (Wheat Flour). Replicated analysis of this reference material showed a recovery of 94±12%. Analytical precision as determined by QA/QC procedures, reagent blanks, and internal standards, was better than ±10%.

Statistical analysis

Tomato growth, yield and nutrient content parameters were processed for multivariate statistical analysis to interpret the results. Data were subjected to one-way analysis of variance and significant tests (Least Significant Test, LSD) following completely randomized design at $p<0.05$ unless otherwise mentioned.

RESULTS and DISCUSSION

Growth and Yield of Tomatoes

Results on growth and yield parameters of tomatoes were presented in Tables 1 to 5 and Fig. 3 to 4, respectively. Tomato leaf SPAD reading as a measure of vegetative growth and nitrogen uptake associated with chlorophyll content influenced by both nano- and chelate Fe fertilization and the highest SPAD values were observed at maximum vegetative growth then declined over time (Fig. 3). Both nano and chelate Fe showed significant effects on SPAD at lower rates (10 and 20 ppm) when compared with the control.

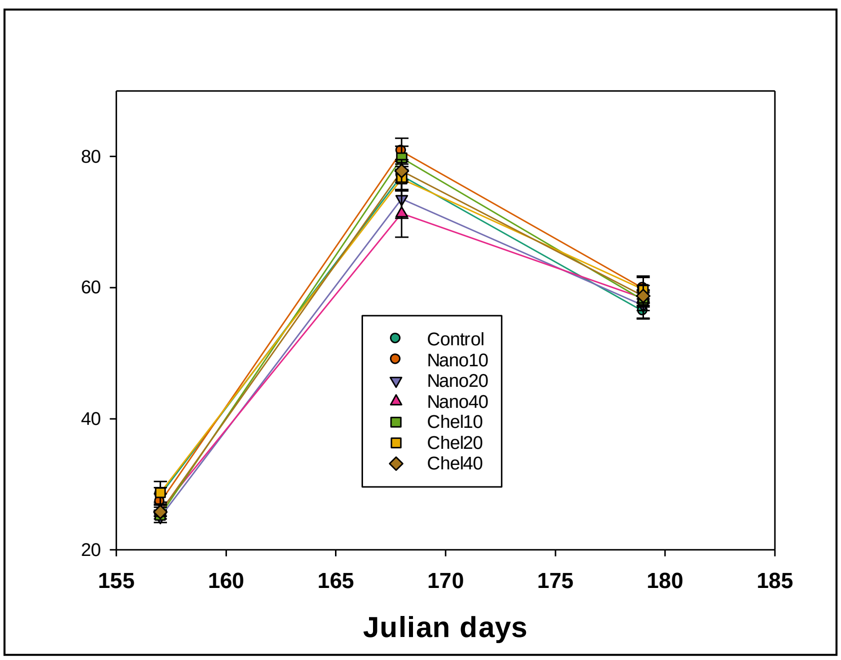

Fig. 3. Effects of chelate and nano iron fertilization on leaf SPAD (chlorophyll content) of tomatoes.

Results showed that both nano and chelate Fe treatments have significantly influenced the number, size and weight of tomato fruit yield compared with the control (Table 1 to 3). Among the treatments, nano Fe when applied at 10 and 20 ppm significantly increased the number of tomatoes than that of the chelate Fe and control treatments (Table 1). Total number of tomato fruits increased by 78% when nano Fe fertilizer was used compared with the control. Likewise, nano Fe increased the total number of tomatoes by 34% than that of the chelate Fe. The effect of nano Fe was more pronounced at 10 and 20 ppm, respectively. The chelate Fe also increased the total number of tomatoes by 33% compared to the control. However, increasing nano Fe concentration decreased total number of tomatoes.

Table 1: Effects of chelate and nano iron fertilization on the growth (number and size) of fresh market tomatoes.

Iron trt. (ppm)	No. small fruit/plant	%	No. med. fruit/plant	%	No. large fruit/plant	%	Total no. fruit/plant
Control	10c	69a	4c	25c	1a	6b	14c
Nano10	15b	58b	8a	32a	2a	10a	25a
Nano20	18a	66a	8a	29b	1a	5b	27a
Nano40	14b	61b	7ab	29b	2a	11a	23a
Chelate10	11c	57c	6b	31a	2a	13a	19b
Chelate20	11c	57c	6b	30ab	2a	13a	19b
Chelate40	11c	59bc	5bc	30ab	2a	11a	18b

Means under each column separated by same lower-case letter were not significant different by iron sources and rates at $p \leq 0.05$.

The size and weight of tomatoes significantly affected by sources and rates of Fe fertilization (Table 2). Nano Fe fertilized tomato plants had higher yields (lbs./plant) in small, medium and large size classes when compared with the control. When combined, the total tomato fruit yields per plant was 63 to 87% higher in nano Fe treatments than that of the control. Likewise, the nano Fe fertilized tomato plants had significantly higher fruit yields compared to chelate Fe treatments. The chelate Fe treated plants had also higher tomato fruits by more than 45%, than that of the control; however, there was a lack of significant difference in tomato fruit yields per plant among the chelate Fe treatments.

Table 2: Effects of chelate and nano iron fertilization on the growth (size and weight) of fresh market tomatoes.

Iron trt. (ppm)	Small fruit wt. (lbs./plant)	Medium fruit wt. (lbs./plant)	Large fruit wt. (lbs./plant)	Total fruit wt. (lbs./plant).
Control	4.0b	2.4c	0.7b	7.1c

Nano10	5.8ab	5.3a	2.2a	13.3a
Nano20	6.8a	5.0a	1.2a	13.0a
Nano40	5.8ab	4.1ab	1.7a	11.6b
Chelate10	4.7b	3.7b	1.9a	10.3b
Chelate20	4.8b	3.8b	1.9a	10.4b
Chelate40	4.6b	3.6b	1.8a	10.0b

Means under each column separated by same lower-case letter were not significant different by iron sources and rates at $p \leq 0.05$.

The average fruit yield of tomatoes did not vary significantly except large-sized by the influence of nano and chelate Fe fertilization when compared with respect to the control (Table 3). The large-sized tomato weight was significantly higher by 7 and 18% at 10 and 20 ppm nano Fe treatments when compared to the control. Likewise, the weight of large-sized tomato produced at 20 ppm nano Fe was significantly higher than chelate Fe treatments. The chelate Fe and control treatments did not vary among themselves to affect the large-sized tomato weights (Table 3). When combined the weight of small, medium and large-sized tomatoes, the average weight of tomato fruit did not vary significantly by Fe sources and their rates.

Table 3: Effects of chelate and nano iron fertilization on growth and yield (size and average weight) of fresh market tomatoes.

Iron trt.		Average fruit weight (lbs.)		
(ppm)	Small	Med	Large	Average
Control	0.41a	0.66a	0.83b	0.63a
Nano10	0.40a	0.67a	0.89ab	0.65a
Nano20	0.38a	0.63a	0.98a	0.66a
Nano40	0.41a	0.62a	0.70c	0.58a
Chelate10	0.44a	0.64a	0.83b	0.64a
Chelate20	0.44a	0.66a	0.79bc	0.63a
Chelate40	0.43a	0.66a	0.84b	0.64a

Means under each column separated by same lower-case letter were not significant different by iron sources and rates at $p \leq 0.05$.

Marketable small fruit yield of tomato was highest in nano Fe fertilized treatments especially at 10 and 20 ppm when compared to the chelate Fe and control treatments (Table 4 to 5). Nano Fe when applied at the rate of 20 ppm significantly increased the fruit yields (72%) followed by 47% at the rate of 10 and 40 ppm nano Fe, respectively. In other words, 10 ppm nano Fe fertilization increased small tomato fruit yield of 29633 lbs./acre (14.8 tons/ac) compared to only 17246 lbs./acre (8.6 tons/ac) in the control. Similar effects of nano Fe fertilization were observed on marketable medium and large-sized tomatoes.

Table 4: Effects of chelate and nano iron fertilization on the marketable fruit yield (lbs./acre) of fresh market tomatoes.

Iron trt. (ppm)	Small fruit yield (lbs./ac)	Medium fruit yield (lbs./ac)	Large fruit. yield (lbs./ac)	Total fruit yield (lbs./ac)
Control	17245.7d	10499.4c	2996.9c	30742.0c
Nano10	25311.8b	22905.0a	9558.7a	57775.5a
Nano20	29633.2a	21772.6a	5219.3b	56625.1a
Nano40	25085.7b	17720.8b	7548.4a	50354.9a
Chelate10	20515.2c	16135.6b	8338.2a	44989.0b
Chelate20	20736.5c	16355.6b	8265.3a	45357.4b
Chelate40	19984.8c	15681.6b	7686.2a	43352.5b

Means under each column separated by same lower-case letter were not significant different by iron sources and rates at $p \leq 0.05$.

When combined, marketable total fruit yield was 79% higher (30742 lbs./acre vs. 50354 to 57775 lbs./acre or 15.4 tons/acre vs.25.2 to 28.9 tons/acre), when compared with the control treatment (Table 5). Likewise, nano Fe increased marketable fruit yield of tomato by 3.5 to 6.5 tons/acre when compared to the chelate Fe and the effect was more pronounced at 10 ppm nano Fe fertilization. In contrast, chelate Fe increased marketable total fruit yield of tomato by 45% only than that of the control.

Table 5: Effects of chelate and nano iron fertilization on the marketable fruit yield (tons/acre) of fresh market tomatoes.

Iron trt. (ppm)	Small fruit yield (ton/ac) %	Medium fruit yield (ton/ac) %	Large fruit yield (ton/ac) %	Total fruit yield (tons/ac)

Control	8.6d	56a	5.2c	34c	1.5c	10b	15.4c
Nano10	12.7b	44b	11.5a	74a	4.8a	17a	28.9a
Nano20	14.8a	52a	10.9a	71a	2.6b	9b	28.3a
Nano40	12.5b	50a	8.9b	58b	3.8a	15a	25.2a
Chelate10	10.3c	46b	8.1b	52b	4.2a	19a	22.5b
Chelate20	10.4c	46b	8.2b	53b	4.1a	18a	22.7b
Chelate40	10.0c	46b	7.8b	51b	3.8a	18a	21.7b

Means under each column separated by same lower-case letter were not significant different by iron sources and rates at $p \leq 0.05$.

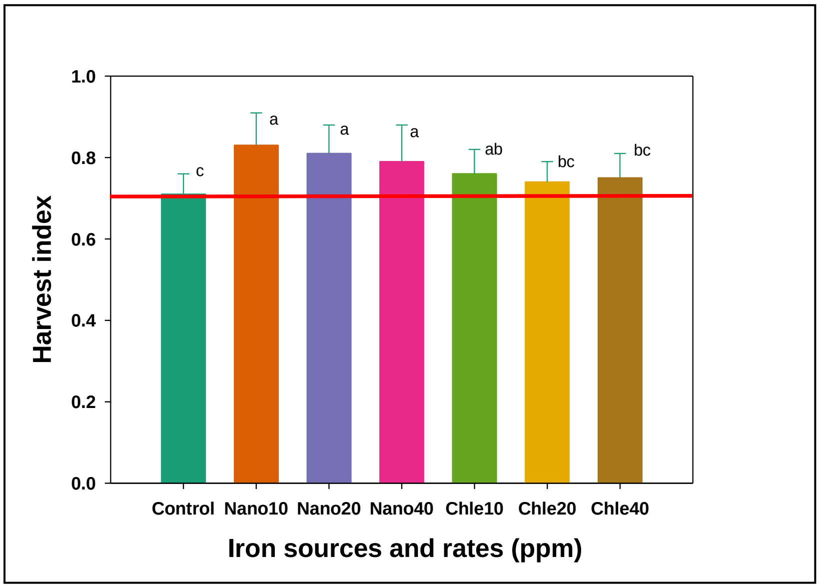

Fig. 4. Effects of chelate and nano iron fertilization on harvest index of tomatoes.

The harvest index (fruit yield over total production) of tomatoes was affected by iron sources and rates (Fig. 4). Both nano- and chelate Fe fertilization increased harvest index of tomatoes. The harvest index of tomatoes increased consistently by12, 10 and 9% in response to 10, 20 and 40 ppm nano Fe, respectively when compared with the control. The harvest index significantly when nano 10 ppm Fe applied than that of the chelate Fe treatments. In contrast, the chelate Fe increased harvest index of fruit yield not significantly, when compared with the control.

Macro- and micronutrients concentration in tomato

Macronutrient density of tomato fruits such as phosphorus (P), sulfur (S), potassium (K), calcium (Ca), and Magnesium (Mg) improved significantly and consistently by nano Fe fertilization (Table 6). The macronutrients density was consistently higher under nano Fe fertilization when compared to the control. While increasing nano Fe fertilization non-significantly increased P, S, K, and Mg, it decreased Ca density in fruits. In contrast, the chelate Fe did not increase the macronutrient density significantly except K, when compared to the control. Increasing rates of chelate Fe fertilization increased the K concentration in tomato fruits when compared with the control.

Table 6: Effects of chelate and nano iron fertilization on macronutrient concentration (%) of fresh market tomatoes.

Iron trt. (ppm)	Macro-nutrient concentration (%)				
	Phosphorus	Sulfur	Potassium	Calcium	Magnesium
Control	0.15b	0.029b	2.56c	0.046b	0.099b
Nano10	0.21a	0.046a	3.45a	0.123a	0.152a
Nano20	0.25a	0.051a	3.59a	0.110a	0.164a
Nano40	0.26a	0.052a	3.79a	0.105a	0.181a
Chelate10	0.21a	0.046a	2.68c	0.097a	0.160a
Chelate20	0.24a	0.046a	3.06b	0.109a	0.179a
Chelate40	0.26a	0.050a	3.37ab	0.113a	0.184a

Means under each column separated by same lower-case letter were not significant different by iron sources and rates at $p \leq 0.05$.

Likewise, the micronutrients density (concentration) such as iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), boron (B), and molybdenum (Mo) concentrations in tomato fruits variably and significantly affected by nano- and chelate Fe, when compared to the control (Fig. 7). Both nano- and chelate Fe fertilization increased the Fe, Mn, Co, Zn, B, Mo density by 1.5 to 2-fold over the control treatment; however, the effects nano Fe was more pronounced than the effects of chelate Fe fertilization.

Table 7: Effects of chelate and nano iron fertilization on micronutrient concentration (ppm) of fresh market tomatoes.

Iron trt. (ppm)	Micronutrient concentration (ppm)						
	Iron	Manganese	Copper	Zinc	Boron	Molybdenum	Sodium
Control	30.1d	10.3b	3.2d	12.0c	6.1c	1.1b	43.4d
Nano10	62.6b	19.3a	4.6c	19.7b	11.5a	1.9a	72.4b
Nano20	55.4b	19.7a	6.7a	23.1a	12.2a	1.9a	74.1b
Nano40	81.9a	22.2a	7.6a	24.1a	12.5a	2.1a	83.3a

Chelate10	48.6c	17.3a	4.3cd	17.8c	9.4b	1.2b	63.9c
Chelate20	55.2b	19.5a	5.7b	21.8a	10.9b	1.7a	64.5c
Chelate40	56.2b	22.2a	6.3ab	23.6a	10.7b	1.8a	72.6bc

Means under each column separated by same lower-case letter were not significant different by iron sources and rates at $p \leq 0.05$.