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Article

Comparative Study of the Effects of Macro- and Micronutrient Nanofertilizers and Nano Amino Acids on Growth and Yield Traits of Okra cv. Clemson

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Abstract: This study aimed to evaluate the effects of macronutrient nano-fertilizers, micronutrient nano-fertilizers, and nano-amino acids, applied individually and in combination, on the growth and yield traits of okra (Abelmoschus esculentus L.) cv. Clemson. The experiment was conducted in the vegetable field of the Department of Horticulture and Landscape Gardening, College of Agriculture and Forestry, University of Mosul. Eight fertilizer treatments (T1–T8) were used, including the control, nano-amino acid foliar spray, macronutrient nano-fertilizers, micronutrient nano-fertilizers, and their binary and ternary combinations. The experiment was arranged in a randomized complete block design (RCBD) with three replicates. The results showed significant differences among the treatments in several of the studied traits. The triple combination treatment (T8) achieved the highest leaf area, while treatment (T3) recorded the highest significant difference in fruit number. The highest significant values of number of leaves, chlorophyll content, plant yield and total yield were recorded in treatment (T6) with 85.5 leaves, 15.48 SPAD, 553.55 g and 17.573 t ha-1 respectively. These results indicate that the combination of nanofertilizers and nano-amino acids has an effective role in the improvement of vegetative growth and the enhancement of the productive efficiency of okra plants.

Keywords: Okra, Nano-Fertilizers, Nano-Amino Acids, Growth, Yield

Introduction

Okra (*Abelmoschus esculentus L. Moench*) is regarded as one of the economically and nutritionally important summer vegetable crops in Iraq. It belongs to the family Malvaceae [1]. The crop is grown mainly for immature fruits (pods) which are eaten fresh and also processed as canned, frozen and dried products. Okra fruit is a good source of nutrition, as it contains a lot of dietary fibre, proteins, carbohydrates, minerals and vitamins. Okra fruits are not only important for nutrition but also have many medicinal and therapeutic benefits like regulation of blood glucose level, reduction of blood cholesterol concentration and reduction of toxic compounds in the kidneys. The high fibre content of okra also helps to enhance digestive functions by helping to move the intestines. Additionally, okra has industrial importance because fibers obtained from its stems are used in the manufacture of paper and textile materials [2]. Okra is widely consumed and of high market value, but its productivity is below the desired level indicating the need for the adoption of more efficient and sustainable plant nutrition strategies.

Hence, nanofertilizers have emerged as a modern tool in plant nutrition due to their potential to increase nutrient use efficiency, decrease nutrient losses, minimise adverse environmental impacts and reduce agricultural input costs. Foliar application is also considered as a good approach to provide plants with nutrients through the foliage, thus reducing the losses from leaching and volatilisation, enhancing the absorption of macro and micronutrients and resulting in improved plant growth, productivity and quality . Several studies have indicated that nanofertilizers can enhance photosynthetic efficiency and increase the accumulation of carbohydrates and dry matter, consequently resulting in improved crop yield [3] - [4].

Numerous studies conducted on okra have demonstrated that foliar application is more effective than other fertilization methods in improving vegetative and reproductive traits. [5] reported that foliar spraying with humic acid at a concentration of 2 ml L^{-1} resulted in superior vegetative growth characteristics and yield compared with lower concentrations and the control treatment. Moreover, foliar application showed greater efficiency than irrigation-based application in improving most evaluated traits. Similarly, [6] found that foliar spraying with amino acids and humic compounds produced significant positive responses in several fruit-related characteristics, particularly fruit number and plant yield. Furthermore, [7] demonstrated that foliar application of amino acids at a concentration of 2.5 g L^{-1} significantly increased the number of pods, pod weight, and total yield of okra plants.

With the advancement of nanofertilization technologies, recent studies have demonstrated that nanofertilizers can substantially enhance plant growth and crop yield. [8] reported that foliar application of nano-NPK fertilizer, particularly at a concentration of 1.5 mL L^{-1} applied twice, significantly improved the vegetative growth characteristics of okra, which was positively reflected in fruit yield and quality. Likewise, [9] also reported that the foliar application of a chitosan-based nanofertilizer at the rate of 120 ppm improved the growth and yield attributes of okra such as plant height, number of nodes, dry matter accumulation, number of fruits and yield per hectare, along with better economic returns.

In the same context, [4] demonstrated that foliar application of nano-DAP at 4 mL L^{-1}, combined with 75% of the recommended nitrogen and phosphorus rates and 100% of the recommended potassium rate, resulted in significant improvements in vegetative growth and yield attributes. These improvements included increases in plant height, number of branches, number of leaves, leaf area, dry matter accumulation, number of fruits, fruit length, individual fruit weight, and total yield. [10] further reported that foliar application of nano-urea, in combination with 100% of the recommended nitrogen rate and two sprays applied at 30 and 60 days after sowing, significantly improved growth, yield, and seed-quality characteristics in okra.

Moreover, [11] showed that foliar application of amino acid-coated nano-Fe_3O_4 particles promoted plant growth and improved the efficiency of iron biofortification in okra fruits. Among the tested treatments, glycine-coated nano-Fe_3O_4 (nFe_3O_4-Gly) at 75 mg L^{-1} was the most effective in enhancing vegetative growth, whereas arginine-coated nano-Fe_3O_4 (nFe_3O_4-Arg) at 75 mg L^{-1} was the most effective in increasing fruit iron content, while also producing a marked improvement in yield. Likewise, [12] found that the treatment consisting of 50% basal nitrogen, 25% top-dressed nitrogen, and a single foliar application of nano-urea at 40 days after sowing produced the highest values for plant height, stem girth, number of branches, number of leaves, dry matter accumulation, number of fruits, fruit dimensions, individual fruit weight, and total yield.

In the same year, [13] reported that the application of 75% of the recommended phosphorus dose combined with two foliar sprays of Gromor Nano DAP resulted in significant improvements in plant height, leaf area, and photosynthetic rate, which were subsequently reflected in enhanced fruit yield and quality.

Based on the foregoing evidence, nanofertilizers represent a promising approach for improving the growth and yield of okra by increasing nutrient-use and absorption efficiency, stimulating vegetative development, promoting fruit formation, and enhancing crop quality and productivity. Therefore, the present study aims to investigate the effects of nano-formulated macronutrients, micronutrients, and amino acids on the agronomic performance of okra within the framework of more efficient and sustainable crop-production systems.

Materials and Method

The experiment was conducted at the Vegetable Research Field of the Department of Horticulture and Landscape Design, College of Agriculture and Forestry, University of Mosul, Mosul, Iraq, to investigate the effects of nanofertilizers on the growth and yield of okra plants.

The seed-growing medium was prepared using a mixture of river soil and well-decomposed animal manure at a ratio of 1:3. The experimental site was prepared by plowing and leveling the soil, after which the field was divided into ridges. A drip-irrigation system was installed, with irrigation laterals placed along the center of each ridge. Planting holes were spaced 35 cm apart within each ridge, while the distance between adjacent ridges was 90 cm. Once the okra seedlings had developed two to three true leaves, they were transplanted into the previously prepared planting holes in the experimental field.

The experiment included the following fertilization treatments:

T1: Control treatment, with no fertilizer application.
T2: Foliar application of liquid nano-amino acids at a concentration of 2 mL L^{-1}.
T3: Foliar application of nano-macronutrient fertilizer at a concentration of 2 g L^{-1}.
T4: Foliar application of nano-micronutrient fertilizer at a concentration of 2 g L^{-1}.
T5: Foliar application of a combination of nano-amino acids at 2 mL L^{-1} and nano-macronutrient fertilizer at 2 g L^{-1}.
T6: Foliar application of a combination of nano-amino acids at 2 mL L^{-1} and nano-micronutrient fertilizer at 2 g L^{-1}.
T7: Foliar application of a combination of nano-macronutrient and nano-micronutrient fertilizers, each at a concentration of 2 g L^{-1}.
T8: Foliar application of a ternary combination consisting of nano-amino acids at 2 mL L^{-1}, nano-macronutrient fertilizer at 2 g L^{-1}, and nano-micronutrient fertilizer at 2 g L^{-1}.

Table 1. Specifications of the Nano fertilizers used in the experiment [14]

Nano fertilizer containing macronutrients	Nano fertilizer containing micronutrients	The Nano Amino Acids
It contains high-potassium NPK 12-12-36, produced by the Iranian company KHAZRA Green.	It contains Iron 8%, Zinc 1.5%, Manganese 1.5%, Copper 0.5%, Boron 0.5%, and Molybdenum 0.5%, and it is produced by the Iranian company KHAZRA Green.	Optimus Plus Nano Amino Acid Fertilizer (an agricultural fertilizer manufactured according to nanotechnology containing 30% amino acids, 5% nitrogen and 3% organic nitrogen)

Nanofertilizer treatments were applied as foliar sprays in three separate applications. The first application was performed 35 days after transplanting, the second one month after the first application, and the third one month after the second application. A wetting agent was added to the fertilizer solutions to reduce the surface tension of water and improve spray coverage. The plants were sprayed until complete wetting.

The experiment was laid out in a randomised complete block design (RCBD) with three replications. The experimental area was consequently divided into three equal blocks each containing eight experimental units. Each experimental unit was made up of a single ridge 3.0 m long and 0.6 m wide. There were 8 plants per ridge at 35 cm spacing.

Standard crop-management practices were carried out from transplanting until the last harvest, which was the 28th picking on 28 September, 2019, following the recommended practices for okra production described by [1].

Data for the measured traits were statistically analysed following the adopted experimental design, using SAS software [15]. The treatment means analysed by Duncan multiple range test at 0.05 probability level as described by [16].

To assess the performance of okra plants following foliar application of the studied prepared nanofertilizers, the following growth, physiological, yield, and fruit quality attributes were measured: plant height (cm), number of leaves per plant, leaf area (cm^2), leaf dry matter percentage (%), total chlorophyll content (%), number of branches per plant, stem diameter (cm), fruit length and diameter (mm), fruit dry matter percentage (%), mean number of fruits per plant, mean yield per plant, and total yield (t ha^{-1}).

Results and Discussion

The fertilization treatments exerted a marked effect on the vegetative growth characteristics of the Clemson okra plants (Table 1). The effects were more pronounced for the number of leaves, leaf area, chlorophyll content and number of branches, but there were no significant differences in the plant height or stem diameter.

Plant height was not significantly different among treatments, with the mean values ranging from 140.53 to 148.90 cm. The maximum value was recorded in T7 followed by T2 and minimum value was recorded in T5. Instead, the treatments had a significant influence on the number of leaves. The highest number of leaves (85.50 leaves $plant^{-1}$) was recorded in T6 followed by T3 (83.83 leaves $plant^{-1}$), whereas the lowest value was recorded in T7.

Moreover, T6 and T3 had the highest chlorophyll contents which indicate the betterment of the plant nutritional status and photosynthetic efficiency. Such enhancement may directly contribute to the greater dry matter accumulation and better physiological activity within the plant. Leaf area was also significantly different among treatments, with T8 having the highest value, followed by T3 and T6. Such increase points to the development of a larger effective photosynthetic surface and hence to an improved ability of the plants to intercept and utilise solar radiation efficiently.

Maximum number of branches was observed in T2 followed by T5 and T6 and minimum in T8. These results suggest that certain fertilizer treatments were more effective than others in stimulating lateral vegetative growth. However, the treatments did not significantly affect stem diameter, even if there was a numerical variation in the treatment means.

In general, T3, T6 and T8 were the best treatments to improve the main growth vegetative traits. These treatments increased number of leaves, leaf area, chlorophyll content and other indicators of vegetative growth. Therefore, the results showed that nanofertilizer application led to vigorous vegetative growth, enhanced photosynthetic performance and formed a more active and productive canopy which can support further plant growth and yield development.

Table 1. Effect of fertilization treatments on the vegetative growth characteristics of Clemson okra plants

Treat.	Plant height (cm)	Number of leaves (leaves $plant^{-1}$)	Leaf dry matter (%)	Leaf area (cm^2)	Chlorophyll content (SPAD)	Number of branches	Stem diameter (mm)
T1	147.5	59 de	26.36	1142.33 de	13.95 b	7.77 ab	40.46
T2	144.75	68.75 cd	26.13	1544.03 a-d	13.43 b	8.43 a	43.75
T3	142.1	83.83 ab	26.78	1842.27 ab	15.40 a	6.70 b	42.07
T4	148.53	73.61 bc	26.46	1365.64 cde	13.70 b	6.77 b	40.56
T5	140.53	72.67 c	26.68	1467.80 b-e	13.85 b	8.13 ab	39.62
T6	143.1	85.5a	26.03	1748.14 abc	15.48 a	7.87 ab	41.73
T7	148.9	57.00 e	26.31	1078.87 e	14.50 ab	7.30 ab	41.6
T8	147.11	77.00 abc	26.03	1921.71 a	13.65 b	6.93 b	35.44
LSD's	N.S.	9.97	N.S.	379.6	1.197	1.331	N.S

Means followed by the same letter within each column are not significantly different at the 5%.

Table (2) displays that the fertilization treatments had variable effects on the yield-related traits of okra cv. However, most significant responses were observed for fruit number, plant yield and total yield. Treatment (T3) recorded the highest significant fruit number (103.94 fruits $plant^{-1}$) followed by treatment (T6) with 96.067 fruits $plant^{-1}$. Treatment (T6) produced also the highest significant values for plant yield and total yield which reached 553.55 g $plant^{-1}$ and 17.573 t ha^{-1}, respectively. However, no significant differences were observed among treatments in fruit diameter, fruit length and fruit dry matter percentage although there was numerical variation.

The superiority of treatment (T3) in fruit number and treatment (T6) in plant yield and total yield probably reflects improvement of plant nutritional status, that improved the efficient utilisation of photosynthetic assimilates and their allocation towards fruit set and filling . The results obtained are in line with [8] who reported that foliar application of nano-NPK fertiliser improved the productive performance of okra. They also supported the work of [4] who showed that the nano treatments based on Nano DAP led to an increase in grow and yield traits due to enhanced nutrient uptake efficiency and improved physiological activity. Similarly, [17] found that the foliar application of nano-iron on red cabbage significantly increased the number of leaves, chlorophyll content, and total yield. Moreover the general trend found in the present study is further supported by the report of [10] that foliar application of nano-urea significantly increased okra yield.

Fruit diameter ranged from 12.57 to 13.46 and maximum value was noted in treatment 5 followed by treatment 6 while minimum values were recorded in treatments 1 and 3. Similar trend was also observed for fruit length varied from 41.01 to 43.42 and maximum value was recorded in treatment 8 but this was statistically not significant. This is in agreement with [12] who observed that the most pronounced effects of nano-treatments in okra are often expressed in vegetative growth and final yield rather than in individual fruit dimensions.

Fruit dry matter percentage values were in a narrow range of 10-11%, and no significant differences were found among treatments. The treatments did not affect significantly dry matter accumulation in fruits. This could be due to the fertilization regime has enhanced mostly the number and weight of fruits and did not alter the composition of fruits.

Table 2. Effect of fertilization treatments on yield and yield components of Clemson okra plants.

Treat.	Fruit diameter (mm)	Fruit length (mm)	Fruit dry matter (%)	Fruits No. per plant	Yield per plant (g)	Total yield (t ha^{-1})
T1	12.57	41.1	10.25	73.067 d	444.81 b	14.121 b
T2	12.75	41.38	10.5	85.44 c	451.39 b	14.33 b
T3	12.57	41.85	10	103.94 a	479.02 b	15.207 b
T4	13.2	42.62	11	68.317 d	462.14 b	14.671 b
T5	13.46	41.01	10	81.317 c	462.2 b	14.673 b
T6	13.42	41.38	10	96.067 b	553.55 a	17.573 a
T7	12.95	42.83	11	81.25 c	471.87 b	14.98 b
T8	13.25	43.42	10	82.00 c	481.57 b	15.288 b
LSD's	N.S.	N.S.	N.S	7.6611	61.73	1.9599

Means followed by the same letter within each column are not significantly different at the 5%.

Overall, the beneficial effects of foliar application of the investigated nanofertilizers on most of the measured traits may be attributed to their distinctive mechanisms of action, whether formulated with macronutrients, micronutrients, or amino acids. The small size of nanoparticles facilitates their rapid and efficient passage across cellular membranes, while also enhancing enzymatic activity, reducing harmful oxidative processes within plant cells, and regulating key physiological and biochemical processes in plants [3].

Conclusion

It is concluded from this study that treatment with nanofertilizers supplemented with macronutrients or micronutrients, as well as amino acids, had an effective impact on improving the growth and yield traits of okra, and that foliar spraying with the nano-amino acid combination at a concentration of 2 mL L^{-1} together with micronutrient nanofertilizers at a concentration of 2 g L^{-1} produced the highest significant values for leaf number, chlorophyll content, plant yield, and total yield.

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