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Effect of Nano-Fertilizers on Growth, Yield and Economics of Summer Hybrid Maize (*Zea mays* L.)

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ABSTRACT

The present experiment was carried out during summer seasons (February to May) of 2020 and 2021 at the Instructional Farm of Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India to assess the impact of nano-fertilizer managements on the summer hybrid maize. The experiment was laid down in a randomized block design replicated thrice with ten treatments having nano-N, nano-Zn, nano-Cu at different days of spraying in combinations with recommended Dose of Fertilizers (RDF). Results revealed that application of 50% RDZn and 100% N-P-K along with two-foliar sprays of Nano-Zn @ 4 ml l^{-1} at 25 and 50 DAS (T_8) recorded better results of growth attributes. The yield attributes like number of cobs plant^{-1} (1.30), cob length (21.30 cm), cob girth (16.25 cm), number of rows cob^{-1} (13.97), number of grains cob^{-1} (317.6), seed index (25.40 g) and single cob weight (128.74 g) also found highest from the same treatment. Higher grain (8.16 t ha^{-1}) and stover yield (12.22 t ha^{-1}) were recorded in T_8 treatment and yield variation was 2.21 to 63.86% over control with highest benefit-cost ratio (2.35). Hence, application of 50% RDZn and 100% N-P-K along with two-foliar sprays of Nano-Zn @ 4 ml l^{-1} at 25 and 50 DAS may be most effective in augmenting yield, available nutrient status and economics of summer maize.

KEYWORDS: Economics, growth, nano-fertilizer, summer hybrid maize, yield

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1. INTRODUCTION

Maize (*Zea mays* L.), 'Queen of Cereals', is one of the most adaptable crops, it can be grown in both tropical and temperate climates across the globe. After rice and wheat, it is India's third-largest food grain crop and among the cereals it has the highest production potential (Mahapatra et al., 2018, Anonymous, 2018, Suganya et al., 2020). It is grown on almost 205 mha with a global productivity of 5878 kg ha^{-1} and a production of 1210 million tonnes, having wider diversity of soil, climate, biodiversity, and management practises (Anonymous, 2022). India produced 33.62 mt of maize in 2021–2022 on an area of 10.04 mha, whereas 23.10 mt in *kharif* 2022–2023 (1^{st} Advance Estimates, 2022–2023) on an area of 9.68 million hectares (agricoop.nic). Maize being a C_4 crop extracts large amount of mineral nutrients from the soil due to large grain and stover yield (Adhikari et al., 2021). Thus, proper nutrient management should aim to supply fertilizers adequate for the demand of the crop and apply it in such ways that minimize loss and maximize the efficiency of use (Timsina et al., 2013). Maize has high demand for nitrogen (N) and phosphorous (P). It expressed nutritional dependence, especially of nitrogen (Cancellier, 2011). Nitrogen is an essential nutrient which is a constituent of protoplasm, chlorophyll and enzymes (Yeshiwas, 2017 and Kaur et al., 2020). Nitrogen fertilization in maize improves grain quality, increasing protein and mineral nutrients content, intervening positively in the number of cobs $plant^{-1}$, weight of cobs, as the mass of hundred seeds increased according to the nitrogen doses (Ferreira et al., 2001). Sandya et al. (2016) noted that yield attributing characters of maize recorded higher value with the higher level of nitrogen. Compared to other cereal crops, maize has a twice as great potential for grain yield (Potarzycki and Grzebisz, 2009). Since nitrogen is the most crucial and fundamental nutrient for the crop's growth and development, nitrogen management in the maize production system is one of the essential challenges (Blumenthal et al., 2008). In our country, zinc is the most significant critical micronutrient after major nutrients specifically as most Indian soils are low in zinc content. It has a comparable nutritional content to non-leguminous vegetables as cauliflower, cucumber, cabbage, and tomato (Palai et al., 2017). Numerous enzymatic processes require zinc either directly or indirectly, and plants' nitrogen metabolism heavily depends on it (Singh et al., 2021). Zn involved in root growth, synthesis of proteins and carbohydrates, increase flower setting (Moeinian et al., 2011). Copper, one of the micronutrients needed in very small quantities, functions in regulating growth and development, and also involved in several enzyme systems that regulate the rate of many biochemical reactions in maize, (Viera et al., 2019). Nanotechnology has received significant scientific and commercial attention in modern agriculture as one of the main enablers that has the ability to revolutionise agronomic practises by enhancing fertiliser usage and nutrient uptake in plants (Dhlamini et al., 2020). It appears to be a viable application technique for sustainable agricultural production since the use of nanoparticles had an impact on plant growth, yield, and crop product quality (Van Nguyen et al., 2021). We hypothesized that application of nano fertilizer (mainly nano N, Zn, Cu) could positively effect on growth, yield owing to improved soil fertility particularly under *pre kharif* condition. Hence, the objective of our study was to assess the application of nano-N, nano-Zn and nano-Cu on growth, yield attributes and yield of maize (hybrid variety Kaveri 50) in Gangetic alluvial soils of West Bengal.

2. MATERIALS AND METHODS

2.1. Environmental conditions

The experiment was conducted during the summer seasons of 2020 and 2021 (February to May) at Instructional Farm (22°93' N latitude, 88°53' E longitude and 9.75 m above mean sea level) of the Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal in medium land situation under tropical climate. The soil at the experimental site (0–15 cm depth) was loamy, containing 51.50% sand, 26.75% silt and 21.75% clay with 7.04 pH and 0.61% organic carbon (OC). Available N, P_2O_5 and K_2O contents were 191.1, 38.2 and 211.5 kg ha^{-1} respectively. Meteorological data pertaining to the cropping seasons revealed that maximum and minimum temperature fluctuated between 37.05 and 7.98 and 37.83 and 8.03°C in summer seasons of 2020 and 2021 respectively. Average relative humidity prevailed between 99.67 and 27.0% in both the years. The rainfall during the experimental period (February to May) was 290.6 mm and 289.8 mm (6 rainy days) in summer seasons of 2020 and 2021 respectively.

2.2. Experiment and treatments

The experiment was laid down in a randomized block design (RBD) with 3 replications, comprising 10 nutrient management practices i.e T_1: no fertilizer, T_2: only two spray of tap-water, T_3: Recommended Dose of Fertilizers (RDF), T_4: two-foliar spray of nano-N @ 4 ml l^{-1} at 25 and 50 DAS, T_5: two-foliar spray of nano-Zn @ 4 ml l^{-1} at 25 and 50 DAS, T_6: two-foliar spray of nano-Cu @ 4 ml l^{-1} at 25 and 50 DAS, T_7: 50% RDN+100% PKZn+two-foliar spray of nano-N @ 4 ml l^{-1} at 25 and 50 DAS, T_8: 50% RDZn+100% NPK+two-foliar spray of nano-Zn @ 4 ml l^{-1} at 25 and 50 DAS, T_9: RDF+two foliar spray of nano-Cu @ 4 ml l^{-1} at 25 and 50 DAS, T_{10}: 50% RDN and Zn+100% P and K+one-foliar spray of nano-N at 25 DAS+one-foliar spray of Nano-Zn (3 days after first spray, i.e., at 29 DAS)+one Foliar spray of nano-Cu (3 days after second spray, i.e., at 33 DAS).

2.3. Cultural operations

The seeds of maize hybrid variety 'Kaveri 50' were sown 60 cm apart from one row to another row while maintaining 20 cm plant-to-plant distance in the plots of 4.0× 3.0 m^2 area. Dropping of seeds was done manually at a depth of 3–5 cm below the soil surface with the help of hand tynes and covered properly with soils. Earthing up was done twice 30 DAS and 60 DAS. Weeding was done simultaneously along with earthing up operation. One pre-sowing irrigation was given five days prior to seed sowing to ensure better germination. Later-on two subsequent irrigations were given at 40 DAS and 55 DAS. according to the treatment details. Fertilizer was provided according to the treatment details. The crop was harvested at physiological maturity with 20% grain moisture content.

2.4. Observation recorded

Growth parameters, viz. plant height, leaf-area index (LAI), dry-matter accumulation (DMA) and crop-growth rate (CGR) were recorded periodically at 30, 60, 90 DAS and at harvesting. Yield attributes, viz. number of cobs plant^{-1}, cob length, cob grith, number of rows cobs^{-1}, number of grains cob^{-1}, seed index (100 seed weight), single cob weight, shelling percentage, grain yield and straw yield and harvest index were recorded at harvest. Common cost of hybrid maize cultivation in addition to variable nano fertilizer foliar spray (treatment cost) was estimated based on input used as per treatment details. The gross returns from the crop were calculated based on minimum procurement price of maize grain by the Government of West Bengal.

2.5. Analytical procedures

Initial soil samples were collected from different points of the field and were air-dried, thoroughly mixed and ground to pass through a 2 mm sieve. The soil textural class was determined by textural triangular method (Bouyoucos, 1962). Soil mechanical composition (sand, silt and clay%) was determined by hydrometer method (Bouyoucos, 1962). Soil pH and EC (in 1:2.5 soil: water) was measured by μ-processor based pH-EC-Ion meter (Jackson, 1967). The available nitrogen was estimated through the hot alkaline permanganate method (Subbiah and Asija, 1956). The available phosphorus (P) was extracted with 0.5 M $NaHCO_3$ (pH 8.5) and estimated through a UV-VIS spectrophotometer (Olsen et al., 1954). Available fraction of potassium (K) was extracted with neutral normal ammonium acetate (pH 7.0; 1:10 w/v) solution and estimated through a Flame photometer (Brown and Warncke, 1988).

2.6. Statistical analysis

The data were analyzed following the method described by Gomez and Gomez (1984). Significant difference of sources of variation was tested at the probability level of 0.05. The standard error of the mean (SEm±) and the CD value were indicated in the tables to compare the difference between the mean values. Correlation analysis was done using OPSTAT online software to assess the relationship among the different variables. In addition, the matrix plot analysis, as well as principal component analysis were carried out using PAST 4.02 software package (Hammer et al., 2001). Based on the performance of all these treatments, Square Euclidian distance between the components were calculated from the standardized data matrix by UPGMA method.

3. RESULTS AND DISCUSSION

3.1. Growth parameters

Plant height and dry-matter accumulation (DMA) increased as the age of the crop progressed towards maturity, irrespective of nano fertilizer management practices (Table 1). Both these attributes recorded at different interval was significantly influenced by the nano fertilizer management practices resulted in a significant increase in plant height and DMA. At maturity (110 DAS), the highest plant height and DMA were recorded in treatment T_8 treatment i.e., 50% RDZn+100% N - P - K+two-foliar sprays of Nano-Zn @ 4 ml l^{-1} at 25 and 50 DAS which was statistically at par with T_7 treatment and the least value was noticed under the control plot where no fertilizer as well as nano fertilizer was applied. The profound increase in growth parameter like plant height was probably due to the involvement of zinc in synthesis of tryptophan needed for production of growth hormone auxin which promotes hormonal activity and growth performance at critical crop growth stages. These findings corroborated the results of Karmakar et al. (2021). Highest dry aerial biomass due to foliar application of nano-zinc might be due to the involvement of Zn in synthesis of auxin which promotes enzyme activation and cell membrane integrity and also improve plant growth by stimulating diverse alterations at morphological, physiological, biochemical, and ultrastructural levels under adverse condition as reported by Khan et al., 2023. Leaf area index is an important parameter of plant growth which directly influences solar radiation interception by the crop canopy, photosynthesis and ultimately the yield of a crop. Leaf-area index (LAI) increased with the increase of aerial growth of hybrid maize crop over the time up to 90 DAS, and then declined at maturity, irrespective of nano fertilizer application (Table 1). The maximum LAI was obtained at 90 DAS obtained with the application of 50% RDZn and 100% N-P-K along with two-foliar sprays of Nano-Zn @ 4 ml l^{-1} at 25 and 50 DAS (T_8). In general, nano fertilizer application significantly altered the LAI, because macro and micro nutrients supply have a systematic and significant effect on leaf growth. The beneficial effect

Table 1: Effect of nano fertilizers on growth-attributing characters of hybrid maize grown during summer seasons

Treatment	Growth parameters							
	Plant height (cm)				Leaf area index			
	30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	45.80	144.80	161.50	165.30	0.69	1.49	2.57	2.22
T_2	46.60	147.60	165.20	169.60	0.64	1.45	2.63	2.24
T_3	61.70	171.60	213.30	222.20	1.18	3.15	4.14	3.07
T_4	52.30	158.40	172.30	180.10	0.80	2.10	2.97	2.66
T_5	49.70	153.20	170.10	175.90	0.75	1.98	2.88	2.59
T_6	48.60	150.90	168.50	173.60	0.72	1.93	2.79	2.55
T_7	60.20	179.60	235.80	241.60	1.15	3.29	4.32	3.23
T_8	64.20	182.80	241.70	249.50	1.23	3.45	4.55	3.32
T_9	62.90	168.70	222.70	227.70	1.20	3.18	4.21	3.11
T_{10}	58.30	175.40	230.90	235.30	1.13	3.22	4.24	3.16
SEm±	0.77	2.25	2.93	3.01	0.01	0.04	0.05	0.04
CD (p=0.05)	2.22	6.51	8.48	8.71	0.03	0.11	0.15	0.12

Table 1: Continue...

Treatment	Growth parameters						
	Dry aerial biomass (g m^{-2})				Crop growth rate (g m^{-2} day^{-1})		
	30 DAS	60 DAS	90 DAS	Harvest	30-60 DAS	60-90 DAS	90- harvest
T_1	30.6	158.80	622.20	870.30	4.27	15.45	12.41
T_2	30.9	160.20	629.00	877.10	4.31	15.63	12.41
T_3	45.1	237.80	954.30	1403.60	6.42	23.88	22.47
T_4	39.2	203.90	801.20	1153.30	5.49	19.91	17.61
T_5	37.7	200.80	780.70	1090.70	5.44	19.33	15.50
T_6	35.9	190.60	755.40	1033.60	5.16	18.83	13.91
T_7	44.8	248.90	1009.90	1539.80	6.80	25.37	26.50
T_8	50.9	255.50	1030.70	1543.70	6.82	25.84	25.66
T_9	47.5	240.70	975.80	1453.50	6.44	24.50	23.89
T_{10}	41.9	245.70	990.80	1488.70	6.79	24.84	24.90
SEm±	0.56	3.00	12.01	17.68	0.08	0.30	0.29
CD (p=0.05)	1.62	8.67	34.73	51.13	0.23	0.87	0.84

T_1: Control-1 (No fertilizer); T_2: Control - 2 (Only two-spray of tap-water); T_3: Recommended Dose of Fertilizers (RDF) [i.e., 100% N-P-K-Zn]; T_4: Two-foliar spray of nano-N @ 4 ml l^{-1} at 25 and 50 DAS; T_5: Two-foliar spray of nano-Zn @ 4 ml l^{-1} at 25 and 50 DAS; T_6: One-foliar spray of nano-Cu @ 4 ml l^{-1} at 25 and 50 DAS; T_7: 50% RDN+100% P - K - Zn+two-foliar spray of nano-N @ 4 ml l^{-1} at 25 and 50 DAS; T_8: 50% RDZn+100% N-P-K+two-foliar spray of nano-Zn @ 4 ml l^{-1} at 25 and 50 DAS; T_9: Recommended Dose of Fertilizers (RDF) [i.e., 100% N-P-K-Zn]+two-foliar spray of nano-Cu @ 4 ml l^{-1} at 25 and 50 DAS; T_{10}: 50% RDN and Zn+100% P and K+one-foliar spray of nano-N at 25 DAS+one-foliar spray of nano-Zn (3 days after first spray, i.e., at 29 DAS)+one-foliar spray of nano-Cu (3 days after second spray, i.e., at 33 DAS)]

of proper combination of nutrients on LAI might be due to the synthesis of certain phytohormones and vitamins which resulted in higher leaf area index in maize. Manasa and Devaranavadagi (2015) reported that soil application of recommended dose of N, P_2O_5, K_2O along with foliar application of $ZnSO_4$ @ 1% recorded significantly higher leaf area, thus, leaf area index (LAI) was maximum. In the present study, the rate of growth for hybrid maize (cv.

Table 2: Effect of nano fertilizers on yield attributes and yield of hybrid maize grown during summer seasons

Treatment	Yield attributes and yield										
	No. of cobs plant^{-1}	Cob length (cm)	Cob girth (cm)	No. of rows cob^{-1}	No. of grains cob^{-1}	100 grains weight (g)	Single cob weight (g)	Shelling %	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest index (%)
T_1	1.14	18.75	14.80	13.24	275.40	23.90	114.40	57.52	4.98	9.32	34.83
T_2	1.13	18.90	14.92	13.21	277.90	23.96	115.30	57.75	5.09	9.40	35.13
T_3	1.20	19.85	15.45	13.44	300.90	25.29	122.90	61.91	7.52	11.70	39.13
T_4	1.16	19.51	15.26	13.40	285.60	24.42	115.80	60.21	5.72	10.70	34.84
T_5	1.17	19.42	15.32	13.35	283.40	24.30	114.90	59.93	5.55	10.43	34.73
T_6	1.15	19.36	15.08	13.32	280.70	24.10	113.00	59.86	5.43	10.21	34.72
T_7	1.26	21.08	15.88	13.62	312.20	25.35	126.90	62.37	7.98	12.03	39.88
T_8	1.30	21.30	16.25	13.97	317.60	25.40	128.70	62.66	8.16	12.22	40.04
T_9	1.22	20.85	15.55	13.54	307.30	25.12	124.90	61.81	7.65	11.86	39.21
T_{10}	1.24	21.00	15.80	13.60	310.10	25.30	126.70	61.91	7.73	11.94	39.31
SEm±	0.02	0.27	0.21	0.18	4.04	0.34	1.65	0.79	0.09	0.15	0.51
CD (p=0.05)	0.06	0.79	0.62	0.53	11.69	0.97	4.77	2.29	0.27	0.45	1.48

Kaveri), as measured by computing CGR, reached at peak level during 60–90 DAS, beyond that it showed a declining trend towards maturity.

3.2. Yield attributes

Yield attributing parameters of maize like; number of cobs plant^{-1}, number of rows cob^{-1}, number of grains cob^{-1}, 100-seed weight (seed index), single cob weight, shelling % and yield associated parameters like, cob length and cob girth were recorded at the time of harvesting (Table 2). The number of cobs plant^{-1} was found to be statistically significant among the treatments and it was observed that number of cobs plant^{-1} was to the tune of 1.13 to 1.30 with a variation of 0.88 to 15.04% among the treatments. The highest number of cobs plant^{-1} was recorded by the treatment T_8 which was statistically at par with T_7 and T_{10} treatments and the lowest number of cobs plant^{-1} was observed in the T_2 (control-2) treatment, received only two spray of tap water. Among the different nutrient management treatments highest number of cobs plant^{-1} was obtained with the application of 50% RDZn and 100% N-P-K along with two-foliar sprays of Nano-Zn @ 4 ml l^{-1} at 25 and 50 DAS (T_8) and it might be due to the effect of Zn. The yield associated parameter of maize in terms of cob length was significantly influenced by different nutrient management treatments. It was observed that the cob length of maize varied from 18.75 to 21.30 cm with a variation of 0.8 to 13.6% and the maximum cob length was achieved from T_8 treatment, closely followed by T_7, T_{10} and T_9 treatments which were statistically at par with T_8. In case of crop girth, application of 50% RDZn and 100% N-P-K along with two-foliar sprays of Nano-Zn @ 4 ml l^{-1} at 25 and 50 DAS (T_8) recorded the highest value of cob girth. It might be due to the soil application of full dose of N-P-K along with soil and foliar application of Zn which significantly increased the yield associated parameters like cob length and cob girth as reported by Manasa and Devaranavadagi (2015). From the recorded data it was found that the number of rows of grains cob^{-1} varied significantly among the treatments and was to the tune of 13.21 to 13.97 with variation of 0.23 to 5.75%. The maximum number of rows cob^{-1} was obtained from the treatment T_8 followed by T_7, T_{10}, T_9 and T_3 all these treatments were statistically at par. The results support those Farina and Feyzi (2015) reported that highest number of rows of grains cob^{-1} was achieved with the foliar application of Zn fertilizer. The number of grains cob^{-1} has a direct impact on the grain yield of maize and it was significantly influenced by the different treatments. Number of grains cob^{-1} varied from 275.4 to 317.6 with the variation proportion of 0.91 to 15.32% and the maximum number of grains cob^{-1} was achieved by the treatment T_8 which was statistically at par with treatment T_7, T_{10} and T_9 lowest number of grains cob^{-1} was recorded in the control-1 treatment. It might be due to proper application of nutrients as per requirement of the crop. Moreover, Zn promotes tryptophane formation and is required for auxin synthesis (Maqbool and Beshir, 2019), increase translocation of metabolites as well as cell elongation and thus, increase the leaf area index, which increases yield components. who also opined that application of Zn significantly increased the yield attributes (like number of grains cob^{-1}, 1000-grain weight) and the grain yield of maize. Yield attributing character like 100-grain weight (seed index) represents the development and plumpness of grain and it is an important index of grain yield. From the experiment it can be revealed that seed index or 100-grain weight of maize varied significantly within the treatment. Seed index of maize varied from 23.90 to 25.40 g and the variation was recorded to the tune of 0.25 to 6.28% over the lowest value. Highest value of seed index (25.40 g) was obtained under the treatment T_8. Highest value of seed index which might be due to the application of plant nutrients in required quantity at proper time. Asadpour et al. (2020) reported that foliar application of Nano-Zn fertilizer significantly increased 100-grain weight of maize because they described that Zn treatment increased plant growth and development by higher translocation and accumulation of different nutrients and increasing metabolism and biological activity of plants. Single cob weight of maize was recorded before deshelling and it was significantly influenced by different nutrient management treatments and varied to the tune of 114.43 to 128.74 g with the variation proportion of 0.76 to 12.51%. Treatment T_8 recorded highest cob weight with a value of 128.74 g which was statistically at par with T_7, T_{10} and T_9. Application of Zn caused higher chlorophyll contents which had apparently a positive effect on photosynthetic activity, synthesis of metabolites and growth-regulating substances, oxidation and metabolic activities, thus ultimately better growth and development of crop, which led to increase in cob weight of maize. The results were in the same line of Ashoka et al. (2008). Shelling % of maize varied to the tune of 57.52 to 62.66%. Maximum shelling % was showed by treatment T_8 followed by T_7, T_{10}, T_3 and T_9 all these treatments were statistically at par with T_8.

3.3. Yield

In agronomy grain yield (economic yield) of a crop is the most vital criterion for comparing the efficiency of different treatments of an experiment. Economic yield of a crop depends on the ways in which the dry matter produced during the vegetative phase, and its distribution among the different sinks i.e., vegetative and reproductive parts of the plant. Data pertaining to grain yield as influenced by the different treatments were tabulated in Table 2. The grain yield of maize varied to the range of 4.98 to 8.16 t ha^{-1} and yield variation was to the tune of 2.21 to 63.86% over the control by the differential fertility gradient created by the application of different proportion of fertilizers. Treatment T_8 recorded highest grain yield (8.16 t ha^{-1}) which was statistically at par with T_7 (7.98 t ha^{-1}) while the lowest grain yield (4.98 t ha^{-1}) was recorded in the control-1 (T_1) treatment. The superiority of this treatment might be owing to better availability of macro and micro nutrient, improved vegetative growth Manasa and Devaranavadagi (2015). Stover yield remain highest in T_8 treatment (12.22 t ha^{-1}) followed by T_7 (12.03 t ha^{-1}), T_{10} (11.94 t ha^{-1}) and T_9 (11.86 t ha^{-1}) treatments which were statistically at par with T_8. Superiority of this treatment might be due to application of proper combination of macro and micro nutrient supply on time to the crop (Jana et al., 2020). In addition, HI show significant variation due to different nutrient management practices. The harvest index of maize varied to the tune of 34.83 to 40.04%. Highest harvest index with a value of 40.04% was obtained under the treatment T_8 followed by treatment T_7 (39.88%), T_{10} (39.31%), T_9 (39.21%) and T_3 (39.13%) which were statistically at par with T_8 and the lowest harvest index was recorded (34.83%) in the control-1 treatment (T_1) received no fertilizer input and the variation of data was 0.86 to 14.96% over the control.

3.4. Correlation study

The statistical association or correlation analysis is studied in this present experiment because it can indicate a predictive relationship between several variables and this explanation is congruous with earlier observations reported by several scientists. To evaluate the strength of relationship between growth parameters, yield and yield attributes under different nutrient management practices, this bivariate exploration is necessary. Correlation between yield and yield attributes were computed and presented in (Table 3). Among the quantitative traits evaluated, significant and positive correlations were observed between plant height and grain yield (r=0.995, $p≤0.01$), dry aerial biomass (r=0.975, $p≤0.01$), number of cobs $plant^{-1}$ (r=0.958, $p≤0.01$), number of rows cob^{-1} (r=0.888, $p≤0.01$), number of grains cob^{-1} (r=0.996, $p≤0.01$), single cob weight (r=0.989, $p≤0.01$), seed index (100-grain weight) (r=0.980, $p≤0.01$) and stover yield (r=0.958, $p≤0.01$). Dry aerial biomass showed highly significant and positive phenotypic correlation with grain yield (r=0.985, p≤0.01), number of cobs $plant^{-1}$ (r=0.932, $p≤0.01$), number of rows cob^{-1} (r=0.864, $p≤0.01$), number of grains cob^{-1} (r=0.980, $p≤0.01$), single cob weight (r=0.944, $p≤0.01$), seed index (r=0.987, $p≤0.01$) and stover yield (r=0.996, $p≤0.01$). Number of cobs $plant^{-1}$ recorded positive and highly significant ($p≤0.01$) correlation with grain yield (r=0.937), number of rows cob^{-1} (r=0.968), number grains cob^{-1} (r=0.969), single cob weight (r=0.947), seed index (r=0.915) and stover yield (r=0.916). Number of rows cob^{-1} played positive and significant correlation with grain yield (r=0.861, $p≤0.01$), number of grains cob^{-1} (r=0.910, $p≤0.01$), single cob weight (r=0.874, $p≤0.01$), seed index (r=0.837, $p≤0.01$) and stover yield (r=0.860, $p≤0.01$). No. of grains cob^{-1} exhibited highly significant ($p≤0.01$) and positive phenotypic correlation with grain yield (r=0.990), single cob weight (r=0.985), seed index (r=0.974) and stover yield (r=0.967). Significant and positive correlations were observed between single cob weight and grain yield (r=0.977, $p≤0.01$), seed index (r=0.958, $p≤0.01$) and stover

Table 3: Correlation coefficient analysis of different parameters recorded at harvest in maize (hybrid variety Kaveri 50)

Correlation	Plant height	Dry aerial biomass	No. of cobs plant^{-1}	No. of rows cob^{-1}	No. of grains cob^{-1}	Single cob weight	Seed index	Grain yield	Stover yield
Plant height	1.000	0.975**	0.958**	0.888**	0.996**	0.989**	0.980**	0.995**	0.958**
Dry aerial biomass		1.000	0.932**	0.864**	0.980**	0.944**	0.987**	0.985**	0.996**
No. of cobs plant^{-1}			1.000	0.968**	0.969**	0.947**	0.915**	0.937**	0.916**
No. of rows cob^{-1}				1.000	0.910**	0.874**	0.837**	0.861**	0.860**
No. of grains cob^{-1}					1.000	0.985**	0.974**	0.990**	0.967**
Single cob weight						1.000	0.958**	0.977**	0.921**
Seed index							1.000	0.991**	0.981**
Grain yield								1.000	0.974**
Stover yield									1.000

Units of different parameters; Plant height at harvest in cm, dry aerial biomass at harvest in g m^{-2}, single cob weight in g, seed index in g, grain and stover yield in t ha^{-1}; **: indicates correlation is significant at 1.0% level of significance (p=0.01)

yield (r=0.921, $p\leq0.01$). Seed index (100-grain weight) registered significant and positive phenotypic correlation with grain yield (r=0.991, $p\leq0.01$) and stover yield (r=0.981, $p\leq0.01$). Finally, highly significant ($p\leq0.01$) and positive correlation was observed between grain yield and stover yield (r=0.974). Generally, the positive associations of grain yield with traits like plant height, dry aerial biomass, number of cobs plant^{-1}, number of rows cob^{-1}, number of grains cob^{-1}, single cob weight and seed index (100-grain weight) suggested the prospect of improving this important growth and yield attributing traits concurrent with better management through application of nano-fertilizers or other sources of plant nutrient.

3.5. Principal component analysis

It is a technique that reduces the dimensionality of large data sets by transforming them into smaller ones without loss of information (Figure 1). In the present study, PCA of the different parameters comprised of two principal components explained 99.86% of the total variation in the experiment. Component 1 explained 99.33% and Component 2 explained 0.53% of the total variation. A strong correlation was observed between components, viz. grain yield, stover yield, number of grains cob^{-1}, single cob weight.

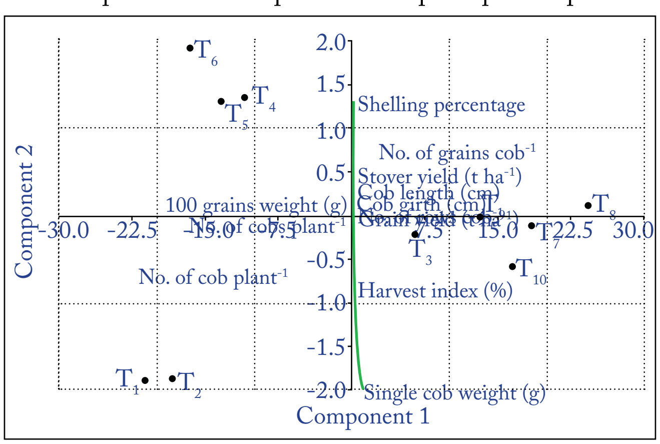

Figure 1: PCA graphs of 10 treatments for yield, yield attributes and agronomic traits of the experiment

3.6. Matrix plot analysis

Matrix plot is a data visualization process (Subrahmanyeswari et al., 2022), which gives overall visual clues about how the application of nano foliar nutrition influences various growth parameters such as number of cobs plant^{-1}, cob length, cob girth, number of rows cob^{-1}, number of grains cob^{-1}, 100 seed weight, single cob weight, shelling %, grain yield, stover yield, harvest index (Figure 2). In this case, the X-axis of the matrix plot was represented by various growth parameters whereas the Y-axis was represented by different treatments. The default colour gradient indicates the lowest value in the matrix plot to dark blue, highest value to the bright red, and mid ranges value to light green with their corresponding transition gradients. In this study, number

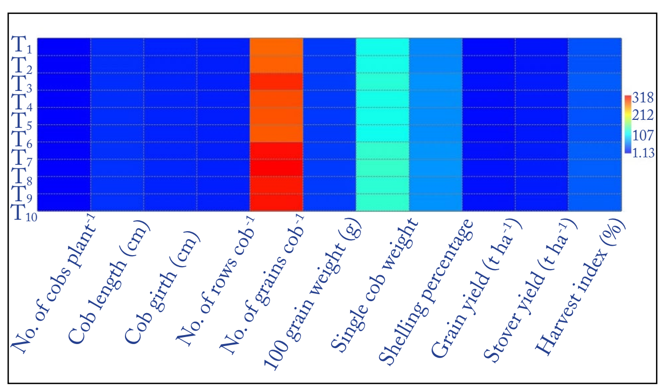

Figure 2: Matrix plot explaining the influence of nano fertilizer on growth, yield attributes and yield of maize

of grains cob^{-1} showed highest variation and treatments, T_7 and T_8 exhibited highest effect on number of grains cob^{-1} which ultimately help in yield increase. Treatment T_6 showed maximum effect on single cob weight. In this matrix plot, one can have an overview of individual treatments and their combinations, so as to easily identify which specific nano fertilizer application is optimum for different growth, yield attributes and yield of maize.

3.7. Inter-and intra-cluster distances

Based on the Dendrogram developed from Squared Euclidian distance matrix it is evident that there are 5 clusters were formed by ten resource components (Figure 3). Cluster I contains T_7, T_{10}, T_9, Cluster II contains T_8, Cluster III contains T_3, Cluster IV contains T_4, T_5, T_6 and Cluster V contains T_2, T_1. T_8, the single resource component of cluster II proved to be the best one out of the ten treatments in the present study and exhibited maximum inter cluster distance. T_3, the single resource component of cluster III also proved equally effective with T_8. Within the cluster I maximum intra cluster distance was exhibited by T_9 and within the cluster IV, T_6 shown maximum intra cluster distance. On the other hand, cluster V comprising of T_2 and T_1 proved to be the poorest. During a comparison between the tables and the dendrogram, it is established that there is the strong correlation between the tables and dendrogram presentation wherein one can conclude the best performing treatment and isolate the non-desirable or poorly performing ones. The said dendrogram proved to be a classical presentation of cumulative performance of all the treatments under study.

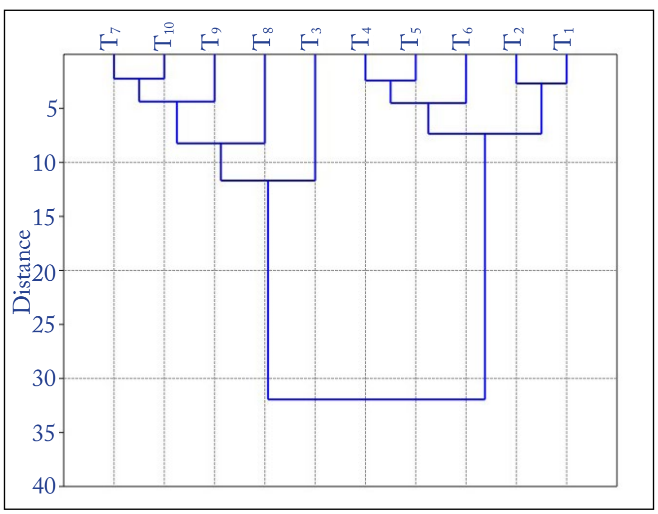

Figure3: Dendogram explaining the influence of nano fertilizer on growth, yield attributes and yield of maize

3.8. Nutrient status of post-harvest soil

The treatment 50% RDZn and 100% NPK along with two-foliar sprays of nano-Zn @ 4 ml l^{-1} at 25 and 50 DAS brought about greater positive changes of available N content in post-harvest soil over control situation (Table 4). However, it was statistically at par with RDF [i.e., 100% N-P-K-Zn]+two-foliar spray of nano-Cu @ 4 ml l^{-1} at 25 and 50 DAS. Significantly higher available P content was estimated in plots with 50% RDN and Zn and 100% P and K along with one foliar spray of nano-N at 25 DAS, nano-Zn at 29 DAS and nano Cu at 33 DAS i.e., treatment T_{10} and the lowest available phosphorus recorded in the control-1 plot (Table 4). However, a decreasing trend in available soil phosphorus than initial level was found in all the treatments. There is an antagonistic relationship between zinc and phosphorus, phosphorus is fixed as zinc phosphide which is an inorganic compound and insoluble in water. Therefore, phosphorus is rendered immobile and unavailable to plants. In the present study, application of nano fertilizer significant influence on residual soil K. The highest amount of available potassium was obtained from plot where 50% RDZn+100% N - P - K+two-foliar spray of nano-Zn @ 4 ml l^{-1} at 25 and 50 DAS was applied (Table 4). According to soil dynamics, this may be due to the rapid rate of conversion of exchangeable K from non-exchangeable K.

Table 4: Available soil nutrient status as influence by nano fertilizer application on hybrid maize (pooled over two years)

Treatment	Soil available N (kg ha^{-1})	Soil available P_2O_5 (kg ha^{-1})	Soil available K_2O (kg ha^{-1})
T_1	176.00	28.87	200.00
T_2	179.00	29.22	203.00
T_3	215.00	33.00	219.00
T_4	185.00	29.78	206.00
T_5	183.00	28.98	208.00
T_6	181.00	30.01	209.00
T_7	197.00	33.32	224.00
T_8	225.00	35.57	227.00
T_9	218.00	33.68	222.00
T_{10}	200.00	36.96	221.00
SEm±	2.69	0.44	2.91
CD (p=0.05)	8.01	1.31	8.66

3.9. Economics

Gross return (134.2×10^3 ha^{-1}), net return (77.1×10^3 ha^{-1}) and benefit: cost (B:C) ratio (2.35) were higher when the plot fertilized with 50% RDZn and 100% N-P-K along with two-foliar sprays of Nano-Zn @ 4 ml l^{-1} at 25 and 50 DAS i.e., treatment T_8 (Table 5). This was owing to higher grain and stover yields realized under this treatment. The superiority of T_8 treatment over others was due to highest grain and stover yield coupled with appreciable cost of cultivation which registered the better return under T_8 treatment. Similar results were reported by Ashoka et al. (2008). The next best economic benefit was obtained when the plot fertilized with 50% RDN+100% P-K-Zn+two-foliar spray of nano-N @ 4 ml l^{-1} at 25 and 50 DAS.

Table 5: Production economics of summer maize as influence by nano fertilizer (pooled over two years)

Treatment	Production cost (×10³ ₹ ha⁻¹)	Gross returns (× 10³ ₹ ha⁻¹)	Net returns (× 10³ ₹ ha⁻¹)	Benefit: cost
T_1	45.60	82.50	36.90	1.81
T_2	46.30	84.30	38.00	1.82
T_3	55.90	123.80	67.90	2.22
T_4	47.90	94.70	46.80	1.97
T_5	47.90	91.90	43.90	1.92
T_6	47.90	89.90	42.00	1.87
T_7	57.20	131.30	74.10	2.29
T_8	57.10	134.20	77.10	2.35
T_9	58.20	126.00	67.70	2.16
T_{10}	57.10	127.30	70.20	2.23

4. CONCLUSION

Application of 50% RDZn and 100% N-P-K along with two-foliar sprays of Nano-Zn @ 4 ml l^{-1} at 25 and 50 DAS can be considered as an effective treatment for obtaining better grain yields and higher profits from hybrid maize variety. Therefore, foliar application of nano fertilizer along with recommended dose of N, P_2O_5 and K_2O during summer season could be more effective in augmenting better yield of hybrid maize in the Gangetic plains of India.

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