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Effect of Drip Irrigation and Nano Zinc Oxide Biofortification on Yield Formation of Maize (*Zea mays* L.) in Sandy Loam Soil

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Abstract

The combination of sufficient irrigation and balanced nutrition methods leads to higher crop yields of the grains. An experiment was performed to assess the impact of several drip irrigation schedules, *viz.*, DI_1: once-in-2 days, DI_2: once-in-3 days, DI_3: once-in-4 days and DI_4: surface flooding method (farmers' practice), alongside agronomic biofortification of zinc, *viz.*, Zn_0: no zinc treatment, Zn_1: soil application of zinc sulphate at 20 kg ha^{-1}, Zn_2: foliar application of nano zinc oxide at 40 ppm, Zn_3: seed priming with zinc oxide at 40 ppm and Zn_4: seed coating with nano zinc oxide at 40 ppm on yield-contributing parameters and grain production of maize during the summer seasons of 2022 and 2023 at the Agricultural Farm, Palli Siksha Bhavana, Visva-Bharati, West Bengal. The heightened frequency of drip irrigation programs markedly enhanced yield components and elevated maize grain yield. Biofortification of nano zinc oxide as seed coating enhanced yield parameters and grain yield. Correlation studies pointed out that grain numbers row^{-1}, length of cob, girth of cob, weight of cob and seed weight cob^{-1} were highly significant and positively correlated with grain yield except number of grains-rows cob^{-1}. Results also revealed that a highly positive and significant correlation was obtained between grain yield with seed weight cob^{-1} (0.744*** and 0.867***) during 2022 as well as 2023. It is rational to conclude that number of grains row^{-1}, cob length, cob weight and seed weight cob^{-1} are the major contributors towards grain yield since these characters had high positive correlation.

Keywords: Drip irrigation, ZnO Biofortification, Correlation, Maize, Yield components

Introduction

The worldwide human population is assumed to surpass 9 billion by 2050. Hence, the worldwide demand for food is anticipated to rise consistently, possibly leading to future food shortages (Cui *et al.*, 2018; Bailey-Serres *et al.*, 2019). Enhancing land productivity per unit area or water efficiency per unit area can effectively address the food demands of the growing human population within the constraints of limited lands and water resources globally (Shen *et al.*, 2024). The world's food security is directly correlated with strong and steady maize yields, since it is the main food crop globally. With a potential output of over 1162 million tons from 197 million ha, maize (*Zea mays* L.) cultivation plays a key role in global agriculture. Maize occupies the second most extensively cultivated crop globally preceded by wheat with an average yield of 5.8 t ha^{-1} (FAO, 2022).

However, maize cultivation suffers substantive yield losses due to lack of soil moisture, inadequate nutrient and other agricultural management practices. For effective irrigation system management and agricultural planning, an impartial assessment of plant water needs is necessary. Numerous studies were carried out in varying soil and climate circumstances showing that irrigation may significantly affect maize productivity (Zamora-Re *et al.*, 2020; Simic *et al.*, 2023) and that enough water is available for getting enhanced production of maize. Excessive irrigation or water scarcity will lower grain output, especially in irrigated agricultural regions (Payero *et al.*, 2008; Trout and DeJonge, 2017;

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Shen *et al.*, 2024). Research has shown that there are ways to lower the ET_c of maize, such as mulching straw and film (Shen *et al.*, 2019; Hou *et al.*, 2022) or using drip irrigation instead of flood irrigation to raise crop yield and lower crop ET_c, both of which improve WUE (Soranj *et al.*, 2022). As drip irrigation supplies water precisely to the rhizosphere of plant, it reduces evaporation (Patel and Rajput, 2009) and allows for deep percolation of water beyond the plant root zone (Irmak *et al.*, 2016) *via* pressure pipes. It has a significant water-saving and productivity-boosting impact when compared to conventional flood irrigation (Cetin and Bilgel, 2002; Yang *et al.*, 2019). Drip irrigation, which is mostly used by farmers as a practical irrigation technique rather than as a technology that increases production by conserving water, has many drawbacks because of problems with water shortage, including illogical irrigation schedule designs. Among micronutrients, zinc is a vital micronutrient that is important to plant homeostasis and regulatory processes (Bana *et al.*, 2021).

Plant cells need zinc to maintain membrane integrity and develop chloroplasts and produce photosynthesis pigments that also enable hormone synthesis including auxin, gibberellins, cytokinin and abscisic acid (Zulfiqar and Ashraf, 2021). Widespread zinc deficiency represents an important obstacle for achieving maximum grain yield production particularly in cereal crops (Hossain *et al.*, 2019; Bhatt *et al.*, 2020) thus making these crops more vulnerable to damage (Cakmak and Kutman, 2018; Nadeem and Farooq, 2019). The zinc deficiency is increased many folds under caustic conditions where Zn^{2+} is strongly taken up by crop plants (García-Gómez *et al.*, 2020; Recena *et al.*, 2021). To overcome this problem, we often use zinc sulphate but its poor availability due to soil fixation is leading to limited absorption by crops (Elemike *et al.*, 2019). Because of its tiny size and vast surface area, gradual release, cheap cost, increased efficiency and environmentally benign nature, exogenous zinc delivery in the form of Zn nano particle has an advantage over traditional zinc fertilisers (Shang *et al.*, 2019; Zulfiqar *et al.*, 2019; Seleiman *et al.*, 2023). Nano zinc oxide is a potential tool for reducing various plant stresses in agriculture; nevertheless, further research is required to optimise the dosage, comprehend its effectiveness and understand crop-specific reactions.

Considering the above points, a field experiment was performed on maize over a two-year period to examine the impact of four irrigation schedules and agronomic biofortification with nano zinc on the various yield parameters and grain yield. Both genetic and abiotic factors govern the grain yield traits (Dixit and Dubey, 1984). According to the studies by Maske *et al.* (2018), a stronger positive correlation between cob yield and weight of cob with husk was noticed. Correlation studies offer insight into the relationship between grain production and its constituent components. Therefore, our hypothesis was to employ the drip irrigation schedules and agronomic biofortification with nano ZnO as coating, priming, foliar application to enhance yield components and grain yield during summer season.

Materials and Methods

Experimental Site Description

The research was performed during the summer season (February-June) for two consecutive years (2022 and 2023) in the Agricultural Farm of Palli Siksha Bhavana, Visva-Bharati, West Bengal. The altitude of the research area was 60 m from the mean sea level and the latitude and longitude was 23°40.190' N and 87°39.485' E, respectively. Soil in the research site had a sandy-loam (Ultisol) texture with a slightly acidic pH of 6.15. It contained 0.38% organic carbon, 283.4 kg ha^{-1} of available nitrogen (Subbiah and Asija, 1956), 18.5 kg ha^{-1} of available phosphorus (Olsen *et al.*, 1954) and 156.1 kg ha^{-1} of available potassium (extracted using the 0.1 N Ammonium acetate methods as described by Jackson, 1973).

Meteorological Data

In 2022, the overall rainfall sustained during the crop-growing period was 358.1 mm and average monthly air temperature recorded (27.3 °C), which were favourable for the growing of summer maize (Figure 1). In, 2023, the average air temperature was raised by 0.7 °C in comparison to 2022, whereas the total rainfall shown a reduction of 177.7 mm, shown in figure 2.

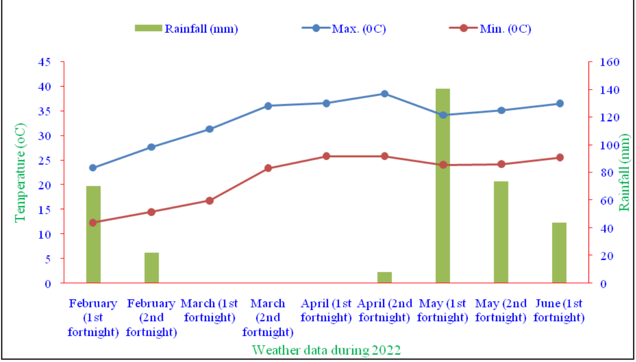

Figure 1: Weather parameters during crop period (2022)

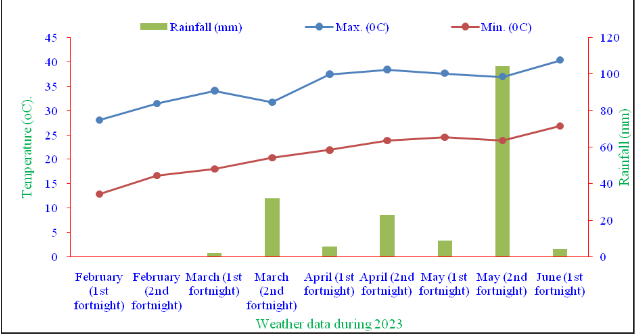

Figure 2: Weather parameters during crop period (2023)

Experimental Design and Crop Management

Three replications of a split plot design were used to carry out the experiment. The drip irrigation scheduling treatment and the control treatment (surface flooding method) were included in the main plot. Agronomic biofortification of zinc through nano ZnO and bulk zinc sulphate were used in the subplot, along with an untreated control. A mould-board tillage to a depth of 30 cm and two rotavator were performed twice as part of the land preparation process.

Based on the findings of the soil test, fertilisers were added after the seed bed was prepared. The primary fertilisers utilised were nitrogen (150 kg ha^{-1}) from the source of urea and split into three stages (25% at sowing, 50% at 25 DAS and 25% at 45 DAS). During land preparation, phosphorus and potassium (75 kg ha^{-1} each) from the source of SSP and MOP were also used. Following seeding, the initial watering was completed right away and irrigation treatments began once the seedlings had completely emerged.

Treatment Details

The study comprised of 20 treatment combinations, encompassing four distinct irrigations scheduling through drip methods, *viz.*, DI_1: once-in-2 days, DI_2: once-in-3 days, DI_3: once-in-4 days and DI_4: surface flooding approach were all implemented. In addition, the subplot involved five different agronomic biofortification of zinc using nano zinc oxide, *viz.*, Zn_0: control (without zinc application), Zn_1: 20 kg ha^{-1} of $ZnSO_4$ is applied to the soil, Zn_2: 40 ppm of nano ZnO is applied foliarly, Zn_3: 40 ppm of nano ZnO is used for seed priming and Zn_4: 40 ppm of nano ZnO is applied to the seed coating.

The following formula was used to predict the minimum amount of irrigation water required for each treatment:

Computed water requirement (lit plant^{-1}) = CPE × K_P × K_C × W_P

Where, CPE = Cumulative pan evaporation for the periods (mm), K_P = Pan factor (0.75), K_C = Crop factor, W_P = Wetted percentage (80).

For the treatment of soil application of zinc, zinc sulphate ($ZnSO_4 \cdot 7H_2O$) was applied as a basal treatment at 20 kg ha^{-1}. The stock solutions for nano zinc oxide production contained 40 mg of nano ZnO powder dispersed in 1000 mL of deionized water using a magnetic stirrer during continuous stirring for 30 minutes. The standing crop received equal amounts of nano ZnO suspension using a hand operated knapsack sprayer at 45 days after sowing (DAS). 40 ppm of nano ZnO solution was prepared following the same way for the seed priming treatment. A mixture containing 40 g of starch powder along with 200 ml of solution containing 40 ppm of nano ZnO was prepared for treating each kilogram of seeds through seed coating procedures. There were twenty treatment combinations, *viz.*, T_1: scheduled drip irrigation once-in-2 days with control or no zinc application; T_2: scheduled drip irrigation once-in-2 days with zinc sulphate applied in soil; T_3: scheduled drip irrigation once-in-2 days with 40 ppm nano ZnO as foliar spray; T_4: scheduled drip irrigation once-in-2 days with 40 ppm nano ZnO as seed priming; T_5: scheduled drip irrigation once-in-2 days with 40 ppm nano ZnO as seed coating; T_6: scheduled drip irrigation once-in-3 days with control or no zinc application; T_7: scheduled drip irrigation once-in-3 days with zinc sulphate applied in soil; T_8: scheduled drip irrigation once-in-3 days with 40 ppm nano ZnO as foliar spray; T_9: scheduled drip irrigation once-in-3 days with 40 ppm nano ZnO as seed priming; T_{10}: scheduled drip irrigation once-in-3 days with 40 ppm nano ZnO as seed coating; T_{11}: scheduled drip irrigation once-in-4 days with control or no zinc application; T_{12}: scheduled drip irrigation once-in-4 days with zinc sulphate applied in soil; T_{13}: scheduled drip irrigation once-in-4 days with 40 ppm nano ZnO as foliar spray; T_{14}: scheduled drip irrigation once-in-4 days with 40 ppm nano ZnO as seed priming; T_{15}: scheduled drip irrigation once-in-4 days with 40 ppm nano ZnO as seed coating; T_{16}: surface flooding with control or no zinc application; T_{17}: surface flooding with zinc sulphate applied in soil; T_{18}: surface flooding with 40 ppm nano ZnO as foliar; T_{19}: surface flooding with 40 ppm nano ZnO as seed priming; T_{20}: surface flooding with 40 ppm nano ZnO as seed coating.

Observations and Procedure of Data Recorded

Maize was harvested manually. The observations for different yield attributing characteristics, including number of grains-rows cob^{-1}, number of grains row^{-1}, cob length, cob girth, cob weight and seed weight cob^{-1} of summer maize were recorded from net plot at maturity. The crop was harvested after the completion of pre-harvest observations. After harvesting and sun-drying the cobs from the net plot, all of the grains were taken with a hand seller and the weight was recorded at 14% moisture.

Methods of Statistical Data Analysis

The Shapiro-Wilk test was performed to access whether the data was usual/regular. For the evaluation of association between irrigation scheduling and nano ZnO biofortification, Principal Component Analysis (PCA) was used as a dimensionality reduction approach. SPSS was employed to carry out the statistical analysis. An additive main effect and multiplicative interaction (AMMI) analysis was performed to validate the experimental data. Results are graphically presented through biplots. The AMMI1 biplot displays the ratio of the first principal component (PC1) to the mean value of the observed attributes, whereas the AMMI2 biplot illustrates the ratio of the first and second principal components (PC1 and PC2). The analysis was conducted using the free version (4.3.2) of R software. The correlation between the two variables was assessed using the Pearson correlation coefficient for each year individually.

Results and Discussion

Descriptive Statistics and Variations in Parameters

Table 1 presents the detailed statistical overview and variances for yield contributors and grain production in maize hybrids. Figure 3 illustrates the frequency distributions of the hybridised investment parameters. Length of the cob ranged from 15.63 cm to 20.50 cm, with a mean of 18.15 cm during 2022; whereas cob length ranged from 15.68 cm to 21.88 cm, with a mean of 18.69 cm during 2023 under scheduled drip irrigation and nano zinc oxide biofortification. Cob girth also recorded from 13.20 cm to 15.90 cm, with a mean of 14.89 cm in 2022; while it recorded from 13.79 cm to 16.90 cm, with a mean of 15.19 cm in 2023 with scheduled drip irrigation and nano zinc oxide biofortification. In case of cob weight, it was observed that 124.7 g to 174.0 g, with a mean of 149.0 g during 2022; whereas it was extended from 135.1 g to 179.4 g, with a mean of 160.7 g during 2023. Number of grain-rows cob^{-1} also noted 11.80 to 14.45, with a mean

Table 1: Descriptive statistics of yield components and grain yield of summer maize under different scheduled drip irrigation and zinc biofortification

Parameters	Year	Mean	Minimum	Maximum	SD	CV, %	Shapiro-Wilk	
							W	P
Cob length (cm)	First	18.15	15.63	20.50	0.98	5.43	0.997	1.000
	Second	18.69	15.68	21.88	1.49	7.98	0.974	0.225
Cob girth (cm)	First	14.89	13.20	15.90	0.51	3.41	0.956	0.030
	Second	15.19	13.79	16.90	0.81	5.33	0.968	0.117
Cob weight (g)	First	149.0	124.7	174.0	11.85	7.96	0.973	0.203
	Second	160.7	135.1	179.4	10.22	6.36	0.974	0.226
No of grain-rows cob^{-1}	First	13.11	11.80	14.45	0.65	4.97	0.978	0.363
	Second	13.55	12.40	14.90	0.53	3.93	0.985	0.659
No of grains row^{-1}	First	32.76	27.25	38.13	2.79	8.50	0.976	0.273
	Second	34.00	27.22	40.61	3.18	9.36	0.983	0.576
Seed wt. cob^{-1} (g)	First	128.3	102.8	151.7	12.26	9.56	0.974	0.217
	Second	132.4	101.4	164.8	14.87	11.24	0.982	0.524
Grain yield (t ha^{-1})	First	6.57	4.96	8.75	0.83	12.65	0.988	0.820
	Second	7.36	4.91	11.22	1.30	17.69	0.967	0.100

[SD: standard deviation; CV: coefficient of variation]

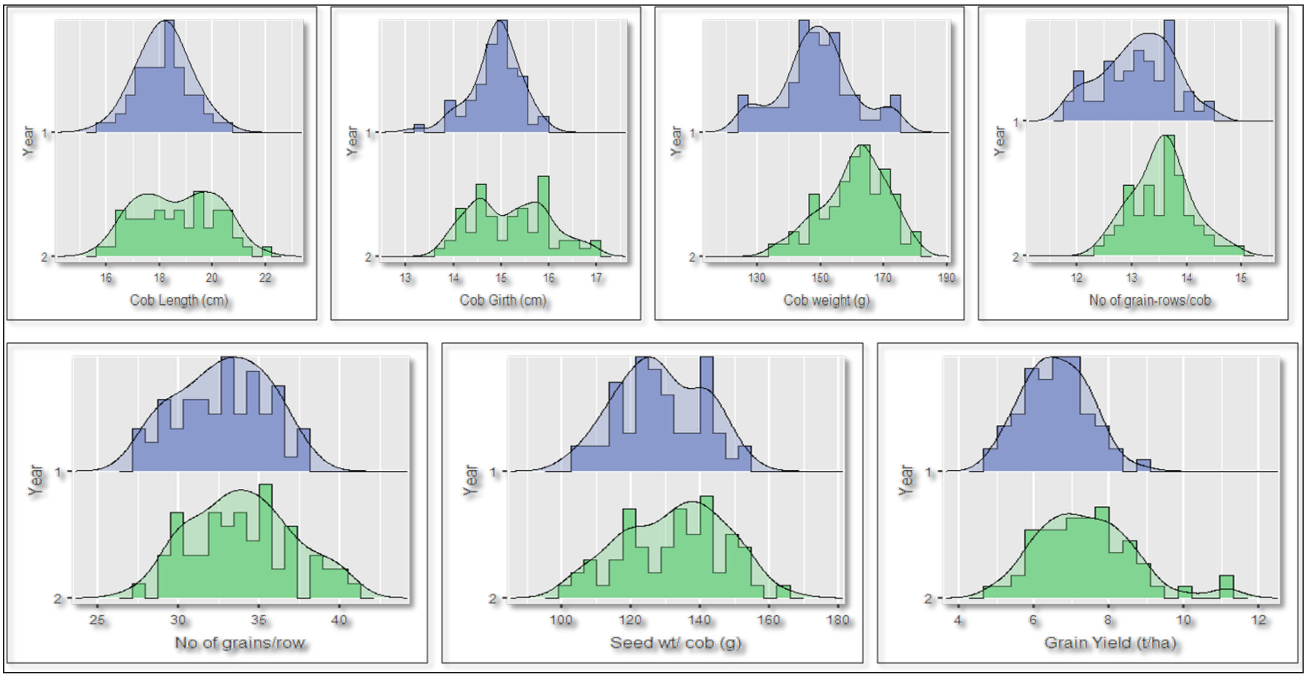

Figure 3: Frequency distribution curve for: (a) cob length, (b) cob girth, (c) cob weight, (d) number of grain-rows cob^{-1}, (e) number of grains row^{-1}, (f) seed weight cob^{-1} and (g) grain yield

of 13.11 and from 12.40 to 14.90, with a mean of 13.55, in the year 2022 and 2023, respectively. Again number of grains row^{-1} was recorded from 27.25 to 38.13, with a mean of 32.76 in 2022 and from 27.22 to 40.61, with a mean of 34.00 in 2023 (scheduled drip irrigation and biofortification of nano zinc oxide); seed weight cob^{-1} derived a range of 102.8 g to 151.7 g, with a mean of 128.3 g in 2022 with scheduled drip irrigation, biofortification of nano zinc oxide; while in 2023 it ranged from 101.4 g to 164.8 g, with an average of 132.4 g. Grain production varied from 4.96 t ha^{-1} to 8.75 t ha^{-1}, with a mean of 6.57 t ha^{-1} and from 4.91 t ha^{-1} to 11.22 t ha^{-1}, with a mean of 7.36 t ha^{-1} for both the 2022 and 2023, with a scheduled drip irrigation and nano zinc oxide biofortification.

Correlation Studies

Correlation studies were conducted to demonstrate the relationship between grain yield and several yield-contributing features (Figures 4 and 5). The study revealed

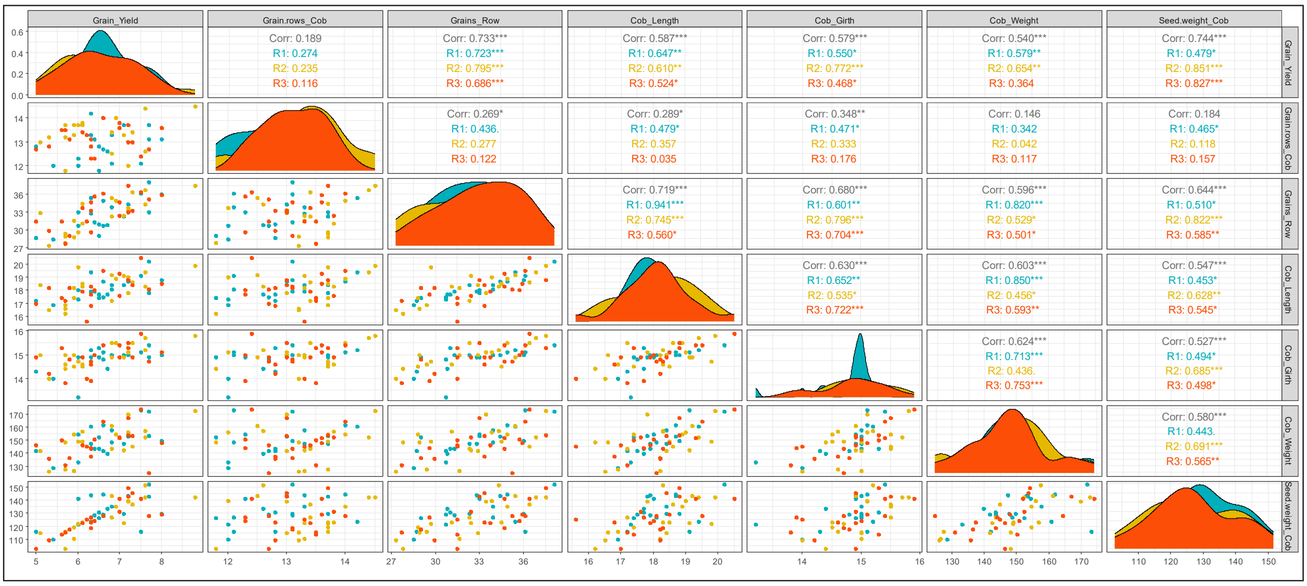

Figure 4: Correlation among yield and yield attributing parameter during 2022 of experiment

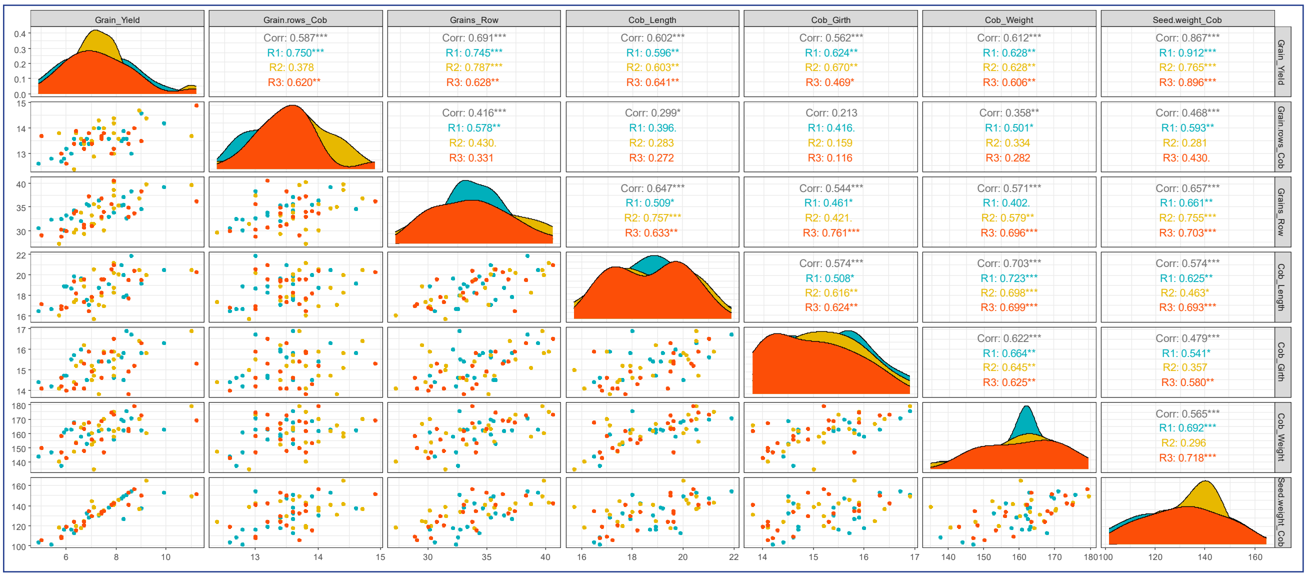

Figure 5: Correlation among yield and yield attributing parameter during 2023 of experiment

that grain yield (t ha^{-1}) has a major positive correlation with the number of grains row^{-1}, cob length (cm), cob girth (cm), single cob weight (g) and seed weight cob^{-1} (g) during both years of the study.

Grain Yield (t ha^{-1})

In the years of experiment, the grain yield exhibited a positive and strong association with seed weight cob^{-1} (0.744***) and (0.867***). A positive correlation also recorded between grain yield (kg ha^{-1}) and the number of grains row^{-1} (0.733*** and 0.691***), cob length (0.587*** and 0.602***), cob girth (0.579*** and 0.562***) and cob weight (0.540*** and 0.612***) in both the years of 2022 and 2023. However, only in the second year of experiment, grain production exhibited a positive correlation with the number of grain-rows cob^{-1} (0.587***). These results are in the same pipeline with Roy *et al.* (2023).

Number of Grain-Rows Cob^{-1}

Positive and considerable correlation of number of grain-rows cob^{-1} noticed with cob girth (0.348***) in the first year of experiment but cob length (0.289*) and (0.299*), number of grains row^{-1} (0.269*) and (0.416***) recorded in both the year of experiment. Number of grain-rows cob^{-1} was registered significant positive correlation only in second year of experiment with grain yield (0.587***), seed weight cob^{-1} (0.468***) and cob weight (0.358**).

Number of Grains Row^{-1}

The higher positive correlation was noted among grains row^{-1} and grain yield (0.733***) and (0.691***), grain-rows cob^{-1} (0.269*) and (0.416***), cob length (0.719***) and (0.647***), cob girth (0.680***) and (0.544***), seed weight cob^{-1} (0.644***) and (0.657***) and cob weight (0.596***) and (0.571***), respectively in the year of 2022 and 2023.

Cob Length (cm)

The cob length revealed a positive significant correlation with grain yield (0.587***) and (0.602***), grain-rows cob^{-1} (0.289*) and (0.299*), grains row^{-1} (0.719***) and (0.647***), cob girth (0.630^{***}) and (0.574^{***}), cob weight (0.603^{***}) and (0.703^{***}), seed weight cob^{-1} (0.547^{***}) and (0.574^{***}) in both the years of investigation.

Cob Girth (cm)

Significant and positive correlation was observed of cob girth with grain yield (0.579^{***}) and (0.562^{***}), cob weight (0.624^{***}) and (0.622^{***}), number of grains row^{-1} (0.680^{***}) and (0.544^{***}), cob length (0.630^{***}) and (0.574^{***}), seed weight cob^{-1} (0.527^{***}) and (0.479^{***}) in both the year of experiment but number of grain-rows cob^{-1} (0.348^{***}) only in the first year of experiment.

Cob Weight (g)

Cob weight showed progressive and significant correlation with grain production (0.540^{***}) and (0.612^{***}), number of grains row^{-1} (0.596^{***}) and (0.571^{***}), cob length (0.603^{***}) and (0.703^{***}), cob girth (0.624^{***}) and (0.622^{***}), seed weight cob^{-1} (580^{***}) and (565^{***}) in both the year of experiment, whereas cob weight recorded positively significant correlation with number of grain-rows cob^{-1} (0.358^{**}) only in the second year of experiment.

Seed Weight Cob^{-1} (g)

Seed weight cob^{-1} exhibited a positively significant correlation with grain yield (0.644^{***} and 0.657^{***}), number of grains row^{-1} (0.644^{***} and 0.657^{***}), cob length (0.547^{***} and 0.574^{***}), cob girth (0.527^{***} and 0.479^{***}) and cob weight (580^{***} and 565^{***}), with the exception of number of grain-rows cob^{-1} (0.468^{***}), which demonstrated a significant correlation solely in 2023. Consequently, the correlation coefficients between yield and its components serve as a crucial tool for breeders to enhance selection methodologies aimed at improving the expression of desired traits (Silva *et al.*, 2016).

Matrix Plot Analysis

A matrix plot is a method of data visualisation (Subrahmanyeswari *et al.*, 2022), that provides comprehensive perceptible ideas about scheduled drip irrigation and agronomic biofortification of zinc using nano zinc oxide that influences various yield parameters *viz.*, cob length (CobL), cob girth (CobG), single cob weight (CobW), grains cob^{-1} (NGraperCob), grains row^{-1} (NGraperR), grain weight cob^{-1} (GrWperC) and grain yield (GY) in figure 6. The X-axis of the matrix plot portrayed a diverse yield metrics, while the Y-axis indicated alternative treatment combinations. The default colour gradient specifies the lowest value in the matrix plot as dark blue, the greatest value as bright red and mid-range values as yellow, accompanied by their conforming transition gradients. In this experiment, single cob weight (CobW) showed highest variation and treatment combinations; T_5 and T_4 exhibited maximum effect on single cob weight which finally helps in yield increase.

Principal Component Analysis

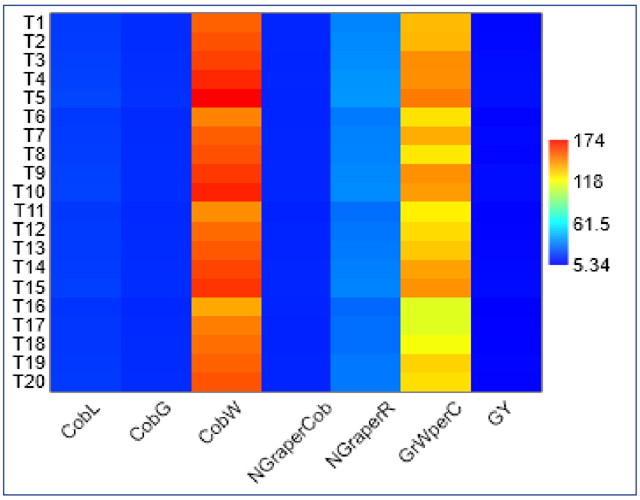

Figure 6: Matrix plot explaining yield parameters of maize as influenced by scheduled drip irrigation and zinc sulphate applied in soil and nano zinc oxide applied through foliar, seed priming and seed coating [Where, CobL: cob length; CobG: cob girth; CobW: single cob weight; NGraperCob: number of grains cob^{-1}; NGraperR: number of grains row^{-1}, GrWperC: grain weight cob^{-1} and GY: grain yield. T_1 to T_{20} was explained in treatment details]

PCA is a method for diminishing the dimensionality of extensive data sets by converting them into more compact forms while preserving information integrity. Interdependence between scheduled drip irrigation, nano ZnO biofortification and evaluated factors was analyzed by PCA. The PCA approach of the current experiment of various yield parameters revealed two main components, with the first axis representing 86.8% of the total variability and the second for 7.1% of the total variability (Figure 7). This study revealed that the number of grains row^{-1}, cob length, cob girth, cob weight, seed weight cob^{-1} and grain yield exhibited significant positive correlations with the first axis; conversely, the number of grains cob^{-1} showed a strong positive correlation with the second axis. The longest vector lines in the PCA graphic suggested that the quantity of grains per cob had a crucial role in elucidating the variables. Comparable findings were documented by Roy *et al.* (2023).

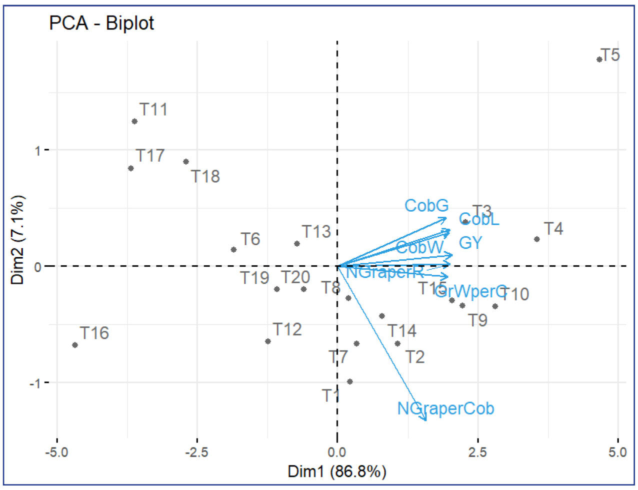

Figure 7: PCA analysis showing yield parameters of maize as influenced by scheduled drip irrigation and zinc sulphate applied in soil and nano zinc oxide applied through foliar, seed priming and seed coating

Conclusion

From this study, PCA, matrix plot and correlation coefficient indicate that the number of grains row^{-1}, cob length, cob girth, cob weight, seed weight cob^{-1} and grain yield correlated significantly and positively. From PCA study, the treatment combination *i.e*., scheduled drip irrigation once-in-2 days, with nano ZnO applied as seed coating (T_5) and scheduled drip irrigation once-in-2 days, with nano ZnO applied as seed priming (T_4) may be promoted for higher production of summer maize in sandy loam soil.

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