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Effect of Nano-ZnO on Growth and Yield of Summer Maize under Drip Irrigation in Laterite Soil

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ABSTRACT

A field experiment was conducted at Agricultural Farm, Palli Siksha Bhavana, Visva-Bharati, West Bengal, India during summer season (February–June), 2022 and 2023, respectively to investigate the effects of drip irrigation and nano zinc oxide biofortification on maize. In the main plot, four drip irrigations scheduling treatments viz., once-in-2 days, once-in-3 days, once-in-4 days and Irrigation by surface flooding method were accommodated. The sub-plot treatments consisted of five methods of zinc applications viz., control, soil application of ZnSO4 at 20 kg ha^{-1}, foliar application of ZnO NP at 40 ppm, seed priming of ZnO NP (NP:Nano Particles) at 40 ppm, and seed coating of ZnO NP at 40 ppm. Growth parameter like plant height and number of leaves were highest with application water through drip irrigation once-in-3 days and seed coating of ZnO NP at 40 ppm at 30 DAS for both the years but at 90 DAS, drip irrigation once-in-2 days and seed coating of ZnO NP recorded highest growth parameters. Aerial dry matter accumulation in unit area recorded maximum in drip irrigation once-in-3 days and seed coating of ZnO NP at 40 ppm at 30 DAS but at 90 DAS drip irrigation once-in-2 days and seed coating of ZnO NP recorded highest. Cob girth, number of grains cob^{-1}, seed index, grain yield and biological yield was observed highest with drip irrigation once-in-2 days and seed coating of ZnO NP in zinc treatment for both the years.

KEYWORDS: Coating, drip irrigation, maize, priming, yield, ZnO nano

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1. INTRODUCTION

Maize is a significant cereal crop due to its exceptional production capacity and ability to thrive in diverse environments, earning it the title of 'Queen of Cereals' contributing 9% of national food security of India (Biswas et al., 2022). In India, maize is put in 3rd position among the grains in terms of its significance, behind rice and wheat (Anonymous, 2018, Mahapatra et al., 2018, Pandey et al., 2016 and Suganya et al., 2020). India produced 33.62 mt of maize (4th advance estimates) in an area of 10.04 m ha in 2021–22 (Anonymous, 2022). Maize crop covered 0.37 m ha, with an output of 2.64 mt and yield (71.58 q ha^{-1}) was in West Bengal during 2021–22 (Anonymous, 2022). Maize not only supplies the basic nutrition for the inhabitants, but also an important crop in industrial and animal production (Anonymous, 2012).

Water is an essential natural resource and its rising scarcity has led to concerns for its effective use, management and sustainability. Water scarcity restrict the development and production of crops in many places of the world (Falqueto et al., 2017). Continuous water deficit situations might harm on plant development, cell multiplication, and produce sterility and abortion (Ozga et al., 2017). The excessive use of traditional irrigation methods has led to over exploitation of ground water and abuse of surface water (Mohammadzadeh et al., 2014). Under such water shortage situations, drip irrigation appears as the top alternative for effective usage of water to sustain output notably in broad row spaced crops like maize. Drip irrigation system allows water and nutrients to be effectively and recurrently supplied to the rhizosphere of the crops through drippers (Bajpai et al., 2020; Ding et al., 2019; Moursy et al., 2023). Most evidently, compared to other irrigation methods, drip irrigation enhanced water use efficiency as it minimized moisture loss through surface run off, deep percolation and evaporation (Flores et al., 2021 and Fukai et al., 2022). The execution of drip irrigation not only increase crop productivity directly but indirectly increase in water resources (Pourgholam-Amiji et al., 2020).

Nanotechnology has emerged as a multipotent, effective, and extensively acceptable scientific method in life sciences such as agriculture (Orooji et al., 2020; Karimi-Maleh et al., 2021; Salam et al., 2022). Nanoparticles (NPs) have unique key features such as nano size, large surface area to volume ratio, shape modifications, and ability of efficiently supplying specific chemicals to cells (Shahid et al., 2021 and Sharma et al., 2022). In this context, using nano fertilizer to regulate the release of nutrients may be an effective approach towards achieving sustainable agriculture and atmosphere. Therefore, exogenous application of nano-ZnO is effectively gaining the enormous attention to the agricultural scientists due to their high performance in productivity, slow release, cost effective, eco-friendly nature (Cicek and Nadaroglu, 2015; Shang et al., 2019; Zulfiqar et al., 2019) over conventional zinc fertilizers to farmers.

Zinc is one of the important micronutrient elements that controls cellular metabolism and a co-factor of several key enzymes including ligases, hydrolases, isomerases, and transferases (Garcia-Lopez et al., 2019). It plays a significant part in several physiological processes in plant like transformation of carbohydrates, chlorophyll and protein synthesis (Singh, 2009). Zn is well-known for its regulating role in plant water relations, nutrient uptake, and chemiosmotic balance, thus helping to mitigate abiotic stress like drought and salinity (Elamawi et al., 2016 and Sturikova et al., 2018). Keeping in views, the present study was taken up to investigate the performance of various methods of nano-zinc oxides on growth and productivity of maize under drip irrigation.

2. MATERIALS AND METHODS

The field experiment was conducted during summer season (February–June), 2022 and 2023 at the Agriculture Farm, Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan, Birbhum, West Bengal, India.

2.1. Experimental site description

The research was conducted in the geographical location of 23° and 40.190'of north latitude and 87° and 39.485' of east longitude with height of 60 m from the sea level. During the cropping period the average fortnightly meteorological parameters of the experiment site for the two consecutive years were like maximum temperature was observed on 2nd fortnight of April (38.5°C) and 1st fortnight of June (40.3°C), minimum temperature on 1st fortnight of February (12.3°C and 12.9°C), total rainfall 176.2 mm and 273.9 mm, maximum relative humidity on 1st fortnight of February (84.4%) and 2nd fortnight of February (76.5%), minimum relative humidity on 2nd fortnight of March (50.4%) and 1st fortnight of April (34.9%), Average sunshine hours 6.7 and 7.3 hours, total evaporation 462.7 mm and 505.2 mm. Before conducting the experiment, at the beginning of each growing season, a combined sample (depth 0–30 and 30–60) was randomly prepared from the farm soil so as to examine the physical and chemical characteristics of the soil. The soil of the experimental field was sandy loam (Ultisol) in texture with slightly acidic pH (6.15), organic carbon 0.38%, available nitrogen of 283.4 kg ha^{-1} (Alkaline permanganate method by Subbiah and Asija, 1956), available phosphorus (P_2O_5) of 18.5 kg ha^{-1} (Olsen's calorimeter method by Olsen et al., 1954) and available potassium of 156.1 kg ha^{-1} (0.1 N Ammonium acetate extractable K method; Jackson, 1973).

2.2. Experimental design and crop management

The experiment was conducted in the form of a split plot design with three repetitions. The main plot included the treatment of drip irrigation at different interval of days and the control treatment (Irrigation by surface flooding method). The sub-plot included different form of zinc application with untreated control. The land preparation operation included mouldboard tillage with the depth of 30 cm, rotavator and, then, drainage was done twice. After preparing the seed bed, adding fertilizers was performed based on the results of soil test. The basic fertilizers used in the farm include nitrogen fertilizer from the source of urea to the amount of 150 kg ha^{-1} divided in three stages (at sowing 25%, at 25 DAS 50% and at 45 DAS 25%), phosphorus and potash fertilizer from the source single superphosphate and muriate of potash to the amount of 75 kg each ha^{-1} were used during land preparation. The first irrigation was done immediately after sowing and the irrigations treatments were started after fully emergence of seedlings.

2.3. Treatment details

The 20 treatment combinations were comprising four irrigation scheduling through drip irrigation i.e., DI_1- once-in-2 days, DI_2-once-in-3 days, DI_3-once-in-4 days and DI_4-Irrigation by surface flooding method in main plot along with five methods of biofortification of nano zinc oxide i.e., Zn_0-control (no-zinc application), Zn_1-soil application of $ZnSO_4$ at 20 kg ha^{-1}, Zn_2-foliar application of ZnO NP at 40 ppm, Zn_3-seed priming of ZnO NP at 40 ppm and Zn_4-seed coating of ZnO NP at 40 ppm in subplot.

In order to determine the volume of irrigation water required in each treatment was calculated using the bellow equation

$$WR_C = CPE \times K_P \times K_C \times W_P$$

Where,

WR_C=Computed water requirement (mm), CPE=Cumulative pan evaporation for the periods (mm), K_P=Pan factor (0.75), K_C=Crop factor, W_P=Wetted percentage (80)

Full dose of zinc sulphate ($ZnSO_4$, $7H_2O$) @ 20 kg ha^{-1} as basal was applied according to treatment. The stock suspensions for zinc oxide nanoparticles were prepared by suspending 40 mg of dried powder nano ZnO in 100 mL of deionized water. The suspension of nano ZnO was applied as foliar spray evenly on standing crop with a hand-held sprayer at 45 DAS. For the purpose of seed treatment through seed priming method, 40 ppm nano ZnO solution was prepared. To coat the seeds days prior to sowing, for each kilogram of seeds, 40 g of gum acacia powder was mixed with 200 ml of 40 ppm nano ZnO solution and the suspension was then spread on the seeds and mixed uniformly to get coated seeds of maize.

2.4. Observations and procedure of data recorded

The biometric observations for different growth parameters, yield attributes and yield of summer maize were recorded at regular interval. The crop was harvested after the completion of pre-harvest observations. Average plant height and number of leaves were measured and recorded by taking ten plants in each plot. Randomly selected plants were harvested from each plot and plants were dried in an oven at 60^0C to a constant weight for recording aerial dry matter accumulation which was then expressed as grams m^2. NAR was calculated by the following formula:

$$NAR=(W_2-W_1/t_2-t_1)\times(\ln(LA_2)-\ln(LA_1)/LA_2-LA_1)$$

Where, W_2 and W_1 are plant dry weights at time t_1 and t_2 and ln (LA_2) and ln (LA_1) are the natural log of dry weight at time t_1 and t_2.

Whereas, at maturity period the yield parameters like cob girth, seed index and biological yield were recorded to estimate the yield of maize.

2.5. Methods of statistical analysis

The statistical analysis was done on the pooled data 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.

3. RESULTS AND DISCUSSION

3.1. Growth parameters

3.1.1. Plant height

The observations on plant height of maize recorded at 30 and 90 DAS were affected by irrigation scheduling and methods of zinc application were presented in Table 1. At 30 DAS among all the irrigation treatments maximum plant height was observed in application of water through drip irrigation once-in-3 days which was at par with application of water through drip irrigation once-in-2 days but at 90 DAS the highest plant height was recorded with application of water through drip irrigation once-in-2 days over other drip irrigation treatments and minimum plant height was observed in application of irrigation water through irrigation by surface flooding method. The higher plant height with application of water through drip irrigation once-in-2 days might be due to the frequent irrigation and optimum soil moisture under drip irrigation might have led to effective absorption and utilization of available nutrients and better proliferation of roots resulting in quick canopy growth (Ayotamuno et al., 2007), which would have accelerated the production of growth regulators such as auxins (IAA)

Table 1: Effect of nano-ZnO and drip irrigation on plant height, number of leaves, aerial dry matter accumulation and net assimilation ratio at different growth stages of summer maize

Treatments	Plant height (cm)		No. of leaves		Aerial dry matter accumulation (g m^{-2})		NAR (g m^{-2} day^{-1})	
	30 DAS	90 DAS	30 DAS	90 DAS	30 DAS	90 DAS	30-60 DAS	60-90 DAS
Drip irrigation								
DI_1	73.82	207.1	6.62	13.36	78.53	790.8	7.12	2.23
DI_2	74.67	197.9	6.79	13.18	82.12	782.6	6.89	2.26
DI_3	71.39	190.0	6.43	12.64	75.20	758.7	7.30	2.18
DI_4	67.62	178.1	6.27	12.20	71.17	683.2	7.56	2.06
SEm±	0.70	2.57	0.07	0.14	0.93	11.42	0.14	0.10
LSD (p=0.05)	2.15	7.93	0.22	0.44	2.85	35.20	0.43	NS
Zinc application								
Zn_0	66.16	175.5	6.23	12.09	71.39	654.2	6.81	2.15
Zn_1	72.41	188.6	6.41	12.62	78.00	751.2	6.95	2.38
Zn_2	66.61	193.6	6.33	12.71	71.27	756.0	7.37	2.34
Zn_3	76.14	201.2	6.71	13.30	80.50	801.8	7.45	2.03
Zn_4	78.07	207.5	6.97	13.49	82.62	806.1	7.50	2.00
SEm±	0.64	2.57	0.07	0.14	0.95	10.62	0.12	0.10
LSD (p=0.05)	1.98	7.92	0.23	0.44	2.92	32.72	0.37	0.30

and cytokinins which in turn stimulated the action of cell elongation and cell division and resulted in increased plant height (Anitta et al., 2011). Higher growth parameters were mainly due to greater accessibility of soil moisture along with improved nutrient uptake which might have favoured cell elongation and division leading to higher growth of maize (Mondal et al., 2020 and Sujatha et al., 2023). The highest plant height was recorded with seed coating of ZnO NP at 40 ppm which was at par with seed priming of ZnO NP at 40 ppm and minimum plant height was noted in both no-zinc application and foliar application of ZnO NP at 40 ppm and at 30 DAS whereas, application of ZnO NP at 40 ppm through seed coating and seed priming recorded significantly maximum plant height over other method of zinc application at 90 DAS. This enhancement in plant height may be attributed to the role of zinc in cell elongation, membrane function, and protein synthesis (Bala et al., 2019). Increased plant with nano zinc oxide has been corroborated by Barman et al. (2013) and Prasad et al. (2012). Singh et al. (2021) also reported that the significant response to zinc in terms of improvement in plant height. ZnO nanoparticles can also moderate phytohormone biosynthesis of cytokinins and gibberellins which can lead to an increase in the number of internodes plant^{-1} (Sturikova et al., 2018).

3.1.2. Number of leaves

The maximum number of leaves per plant have been recorded at 30 and 90 DAS under the drip application (Table 1). Result pointed out that application of water through drip irrigation once-in-3 days which was at par with once-in-2 days followed by once-in-4 days and irrigation by surface flooding method at 30 DAS in respect of number of leaves plant^{-1}. Whereas at 90 DAS, application of water through drip irrigation once-in-2 days and drip irrigation once-in-3 days recorded maximum number of leaves plant^{-1} over other irrigation scheduling. The higher number of leaves plant^{-1} is could be attributed to maintenance of higher soil water potential constant availability of nutrients which resulted in better translocation of photosynthates and more carbohydrate synthesis contributing to favorable plant water balance through application of water by drip irrigation (Constable and Hodgson, 1990). These results are in conformity with Kumar et al. (2009).

Among all the zinc application methods maximum number of leaves was observed in seed coating of ZnO NP at 40 ppm followed by seed priming of ZnO NP at 40 ppm. Minimum number of leaves count at 30 DAS recorded both control and foliar application of ZnO NP at 40 ppm. However, at 90 DAS maximum number of leaves was obtained from treatment having seed coating of ZnO NP at 40 ppm which was at per with seed priming of ZnO NP at 40 ppm. Seed coating recorded maximum physiological parameters might be due to directly deliver precise quantity of zinc close to the germinating seed and enhance nutrient status within the vicinity of seed which helps early stages of growth and root development and therefore aids early crop establishment resulting in higher number of leaves plant^{-1} (Adhikari et al., 2016 and Amanullah et al., 2014).

3.1.3. Aerial dry matter accumulation

The higher aerial dry matter accumulation has been recorded significantly at 30 and 90 DAS under the drip application treatments (Table 1). Maximum aerial dry matter accumulation m^{-2} noted with drip irrigation once-in-3 days over other irrigation scheduling at 30 DAS. Whereas at 90 DAS, application of water through drip irrigation once-in-2 days recorded maximum aerial dry matter accumulation m^{-2} which was on par with once-in-3 days and once-in-4 days. Irrigation by surface flooding method recorded lowest aerial dry matter accumulation m^{-2} for both the observations. The results confirm the findings of, Brar and Vashist (2020) and Brar et al. (2016) who reported marked decrease in shoot dry weight with water stress in maize plants in comparison to well-watered plants which further strengthen the explanation that active production and translocation of photosynthates must have existed for longer period to fill the sink to its capacity under good availability of moisture in root zone.

Among all the zinc application methods maximum aerial dry matter accumulation m^{-2} was observed in seed coating of ZnO NP at 40 ppm followed by seed priming of ZnO NP at 40 ppm. Minimum number of aerial dry matter accumulation m^{-2} at 30 DAS recorded both control and foliar application of ZnO NP at 40 ppm as foliar application done at 45 days after sowing so the effect did not show at 30 DAS. However, at 90 DAS maximum aerial dry matter accumulation m^{-2} was recorded from treatment having seed coating of ZnO NP at 40 ppm which was on par with seed priming of ZnO NP at 40 ppm. Seed coating recorded maximum physiological parameters that could be attributed to the proper supply of Zn up to harvesting stages in soil and which might have led to increased photosynthetic activity for longer period and their beneficial effect on metabolism of plants thereby finally increased dry-matter accumulation (Singh et al., 2021).

3.1.4. Net assimilation ratio

Net assimilation ratio is influenced by many factors. Therefore, the results for NAR differ among researchers. Water stress had significant effect on the parameter of net assimilation rate for the crops. Irrigation treatments had profound influence on net assimilation rate of plant and registered higher values at 30–60 DAS and comparatively less during 60–90 DAS (Tables 1). Shah et al. (2018) also made similar discussion that proper irrigation could have enhanced the durability of the leaves, potentially leading to a better net assimilation rate (NAR) when compared to the outcomes of limited irrigation. A meta-analysis reviewed various studies by Cui et al., in 2024 and found that while drip irrigation and fertilization increased yields, the effect on NAR was not always significant, indicating that other factors may play a more dominant role in yield improvement.

3.2. Yield attributes yield

3.2.1. Cob girth (cm)

Application of water through drip irrigation once-in-2 days noticed maximum cob girth over all the irrigation treatments. The increase in mean cob girth may be due to positive effect of water availability and nutrient on better root development which resulted in increase in nitrogen, phosphorus, potassium and other nutrient availability besides producing vitamins and plant growth promoting substances for better plant growth. This result is in accordance with Kiran et al. (2022). Higher growth attributes like number of leaves per plant might have resulted in higher photosynthesis, carbon assimilation and carbohydrate reserves in the plant which enhanced in development of higher number of reproductive parts and larger size sink i.e., size of the cob (Sujatha et al., 2023). There was a significant effect on cob girth due to zinc application. Highest cob girth was recorded with seed coating of ZnO NP at 40 ppm which were on par with seed priming of ZnO NP at 40 ppm and significantly superior to treatment without zinc application. The increase of cob girth is might be due to the increased availability of macronutrients like nitrogen, phosphorus and potassium contents in rhizosphere due to pre sowing zinc treatments. Priming and coating with different concentration of ZnO NP significantly influenced the nutrient concentration in soil (Tondey et al., 2021).

3.2.2. Number of grains cob^{-1}

The two years pooled data revealed that drip irrigation and zinc treatment have significant effect on number of grains cob^{-1} of maize. Result revealed that application of drip irrigation through once-in-2 days recorded maximum number of grains cob^{-1}. Minimum number of grains cob^{-1} was recorded in Irrigation by surface flooding method. Sujatha et al., in 2023, also supported that significantly higher yield parameters in lowest interval of irrigation was mainly achieved due to application of frequent water and availability of higher soil moisture in the root zone throughout the crop growth period. Higher soil moisture in the root zone helped in maintaining higher leaf water potentials in the source. Hence, this resulted in higher photosynthesis, carbon assimilation and carbohydrate reserves in the plant by harmonizing higher soil moisture and nutrient uptake. Higher carbohydrate reserves in the plant helped in development of reproductive parts (tassel and cob) and larger sized sink. Besides, favourable water status in the plant during the reproductive phase might have enhanced the viability of pollens and receptivity of silk leading to proper pollination and fertilization. Bigger sized cobs with higher cob length and girth were coupled with proper fertilization and accommodated higher number of grains per cob. Among the zinc treatments highest value of number of grains cob^{-1} was obtained with seed coating of ZnO NP at 40 ppm which was on par with seed priming of ZnO NP at 40 ppm. Ehsanullah et al. (2015) noted that the increase in number of grains cob^{-1} was significantly enhanced by the application of Zn. Singh et al. in 2021, also supported that the increased availability of photosynthates might have enhanced number of flowers and their fertilization resulting in higher number of yield attributes (Table 2).

3.2.3. Seed index

Analysis of pooled data revealed that drip irrigation and zinc treatment have significant effect on seed index of maize. Result revealed that application of drip irrigation through once-in-2 days recorded maximum seed index which was on par with drip irrigation through once-in-3 days. Minimum seed index was recorded in irrigation by surface flooding method treatment. Kadasiddappa and Rao in 2018, also supported that water deficits caused increased leaf senescence, reduced photosynthate supply to grains resulting in reduced grain size and weight. Liu et al. (2023) also stated that drip irrigation under film changed the water supply site and irrigation frequency, thus affecting the infiltration mode and distribution characteristics of irrigation water, increasing the effective water content in maize root zone, which was beneficial to maize growth and thus increased maize seed weight. On other hand, many physiological processes in plants are impaired by drought stress including photosynthesis enzyme activity membrane stability pollen viability and ultimately growth and yield parameters (Abdelgalil et al., 2022). Among the zinc treatments highest value of seed index was obtained with seed coating of ZnO NP at 40 ppm which was on par with seed priming of ZnO NP at 40 ppm. Increase in seed index might be due to zinc which plays a pivotal role as an activator of enzymes in plants and it involved in the biosynthesis of auxin which produces more cells and dry matter that in turn is stored in grains as sink. Thus, the increase in the kernels is more expected might be due to the balance and adequate supply of Zn increased the uptake of nitrogen during the grain formation stage and ultimately improved the seed index of maize (Kumar and Dhaliwal, 2021).

Table 2: Effect of nano-ZnO and drip irrigation on cob girth, number of grains cob^{-1}, seed index, grain yield and biological yield on summer maize

Treatments	Cob girth (cm)	No. of grains cob^{-1}	Seed index (g)	Grain yield (t ha^{-1})	Biological yield (t ha^{-1})
Drip irrigation					
DI_1	15.55	495.10	290.76	7.79	18.69
DI_2	15.06	462.71	286.88	7.20	17.65
DI_3	14.82	428.01	280.97	6.90	16.23
DI_4	14.72	396.76	270.31	5.97	14.69
SEm±	0.10	5.32	2.33	0.12	0.17
LSD (p=0.05)	0.32	16.38	7.19	0.37	0.53
Zinc application					
Zn_0	14.49	411.02	274.95	6.16	15.17
Zn_1	14.84	435.17	279.33	6.70	15.88
Zn_2	15.12	439.26	281.23	6.85	16.60
Zn_3	15.24	467.98	284.93	7.47	17.88
Zn_4	15.50	474.79	290.73	7.64	18.56
SEm±	0.11	5.28	2.45	0.13	0.19
LSD (p=0.05)	0.33	16.27	7.54	0.40	0.60

3.2.3. Yield

Grain yield and biological yield increased significantly with each increase in drip irrigation regime. Significantly highest grain yield and biological yield was recorded in the drip irrigation treatment for both the years with once-in-2 days (7.79 t ha^{-1} and 18.67 t ha^{-1}) followed by once-in-3 days (7.20 t ha^{-1} and 17.61 t ha^{-1}) and once-in-4 days (6.90 t ha^{-1} and 16.17 t ha^{-1}). Lowest grain yield and biological yield was recorded in irrigation by surface flooding method as 6.12 t ha^{-1} and 13.97 t ha^{-1}, respectively. Higher grain yield and biological yield through drip irrigation once-in-2 days and once-in-3 days could be attributed to the fact that higher uptake of N, P, K and Zn by crop plant and ultimately accelerate photosynthetic activities resulting in better growth and yield attributes which laid down the foundation for accumulating higher plant dry matter as well as continuous and steady supply of nutrient from soil solution through roots to meet the required nutrients for physiological processes, which in turn improved the grain yield and biological yield. The increase in yield was due to the improved performance of all crop growth and yield attributing characters due to better availability of soil moisture and plant nutrients throughout the crop growth period under drip irrigation. Drip irrigation maintains the soil moisture around the field capacity between two irrigation intervals. Similar result also reported by Brar and Vashist (2020).

Among the different zinc application treatments seed coating of ZnO NP at 40 ppm recorded highest grain yield and biological yield (7.67 t ha^{-1} and 18.52 t ha^{-1}) over all the zinc treatments. The grain yield and biological yield was higher under the treatments of seed coating of ZnO NP at 40 ppm (23.9% and 26.7%), seed priming of ZnO NP at 40 ppm (21.6% and 21.7%) foliar application of ZnO NP at 40 ppm (11.1% and 12.1%) and soil application of $ZnSO_4$ at 20 kg ha^{-1} (8.7% and 10.8%) respectively over the control treatment. Singh et al. (2021) also reported similar result of mays grain and biological yield influenced by zinc application. Arya and Singh (2000), who found the grain yield and biological yield increased owing to zinc application which takes part in metabolism of plant as an activator of several enzymes and in turn may directly or indirectly affect the synthesis of carbohydrate and protein. Positive results may be attributed due to the rapid transport and assimilation of Zn nanoparticles, which leads to the expression of growth promoting plant hormones like auxins and gibberellins (Szollosi et al., 2020).

4. CONCLUSION

Drip irrigation once-in-2 days or once-in-3 days and application of nano-ZnO as seed coating or priming to maize resulted in more growth and productivity than bulk $ZnSO_4$. Drip irrigation improves yield, on the other hand less requirement of nano-ZnO can reduce fertilizer application doses, fertilizer waste, environmental risks and boost nutrient usage efficiency.

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