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Research Communication

Agronomic bio-fortification and productivity of maize (*Zea mays* L.) through zinc application

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ABSTRACT

A field experiment was conducted during the winter (*rabi*) season of 2018 and 2019 at instructional farm of Uttar Banga Krishi Viswavidyalaya, West Bengal, India, to find out a cost-effective method of zinc application for improving productivity and profitability of maize cv. 'Kaveri 2018' cultivation in randomized block design with 8 treatments and 3 replications. Soil application of 10 kg Zn/ha resulted in significantly tallest plant, maximum leaf-area index (LAI) and dry-matter accumulation. Yield attributes, viz. cob length, cob width, grains/row and grains/cob, were found highest with the application of 10 kg Zn/ha and showed 23.98 and 19.80% yield advantage over the control, which was followed by soil application of 5 kg Zn/ha, seed priming with 2% Zn solution and seed priming with 1% Zn solution + foliar application of 0.5% Zn at tasseling stage. Zinc concentration in grain was the highest (25 and 26.07 mg/kg) with soil application of 10 kg Zn/ha followed by seed priming with 2% Zn solution (21.33 and 23.60 mg/kg) and soil application of 5 kg Zn/ha (19.50 and 23.83 mg/kg) during both the years. Economic analysis revealed that, seed priming with 2% Zn solution fetched higher benefit: cost (B: C) ratio of 1.88 and 2.33 during 2018 and 2019, respectively, followed by soil application of 5 kg Zn/ha and soil application of 10 kg Zn/ha. Thus, to maintain the productive performance of hybrid maize cv. 'Kaveri 218' seed priming with 2% Zn solution may be used.

Key words: Bio-fortification, Maize, Priming, Productivity and Zinc

Maize is one of the most vital cereal crops of the world and adds in mitigating food security in most of the developing countries. In India, maize is third most important foodgrains next to rice and wheat. Several million people, particularly in developing countries, derive their protein and calorie requirements from maize (Prasanna *et al*., 2001). An estimate showed that the world human population will reach 9 billion by the year 2050 (Girgis *et al*., 2010). In future, an increase in the grain productivity may cause decreased mineral content in grains. Meenakshi *et al*. (2010) reported that, the deficiency of micronutrient is directly related with food security.

Among different micronutrients zinc deficiency is most wide-spread nutritional disorder next to iron, vitamin A, and iodine while its deficiency is a major public health threat worldwide. According to the WHO, Zn deficiency stands fifth risk factor for causing diseases among children's in developing countries. Zinc deficiency in crops directly correlates to zinc deficiency in humans, a critical issue with significant impacts on food security and health. Adding zinc to soils and crops can make a key contribution towards the global food production and nutritional value problem with significant social, health and economic benefits. Zinc plays a crucial role in chlorophyll formation, carbohydrate metabolism, auxin metabolism and maximizing the biosynthesis of carotenoids, chlorophyll and eventually helpful for the photosynthetic mechanism of the plant (Aravind and Prasad, 2003).

Maize is the most susceptible crop to zinc deficiency (Mattiello *et al*., 2015). In the last decades, Zn deficiency in soil-crop system has been widely reported. Improvement of grain yield owing to zinc application was established worldwide. With the intention to overcome Zn deficiency, several strategies like fortification, supplementation, diversification and bio-fortification are being employed. Among these strategies Zn bio-fortification of food crops is considered to be sustainable, because it is simple, relatively inexpensive and enhancement can be achieved very rapidly. Keeping the above cited facts into consideration, a field

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study was planned to assess the performance of maize under zinc application during the winter season (*rabi*) 2018 and 2019.

MATERIALS AND METHODS

Present research was conducted at Instructional Farm of Uttar Banga Krishi Viswavidyalaya, Pundibari (26°19’86" N, 89°23’53" E, 43 m above mean sea-level) Cooch Behar, West Bengal, India. The soil at the experimental site was sandy loam (62.51% sand, 19.74% silt and 17.39% clay) and acidic having *p*H of 5.57. The initial organic carbon 0.67%, available nitrogen 182.76 kg/ha, available phosphorus 21.56 kg/ha, available potash 172.45 kg/ha and available zinc 0.26 ppm were recorded before initiation of experiment in 2018. The amount of rainfall received during experimental period was 555.71 mm and 443.3 mm in the year 2018 and 2019 respectively. During the period of experimentation (January to May), average maximum and minimum temperature was 30.92 and 9.25°C and 30.92 and 9.0°C, respectively, during 2018 and 2019.

The experiment was laid out in randomized block design with 3 replications, having 8 treatments, viz. T_1, control (no zinc); T_2, soil application of 10 kg Zn/ha; T_3, soil application of 5 kg Zn/ha; T_4, seed priming with 2% Zn solution; T_5, seed priming with 1% Zn solution + foliar application of 0.5% Zn at tasseling stage; T_6, seed priming with 1% Zn solution + foliar application of 0.5% Zn at silking stage; T_7, foliar application of 1% Zn at silking stage and T_8, foliar application of 0.5% Zn at tasseling stage + 0.5% Zn at silking stage. Maize hybrid ‘Kaveri 218’ was sown during *rabi* season (January to May) with a spacing of 60 cm × 30 cm. All the plots received recommended fertilizer rate of 140 kg N + 70 kg P_2O_5 + 70 kg K_2O/ha. Full amount of phosphorus, 75% of potassium and 40% of nitrogen was applied at the time of final land preparation. Remaining 60% nitrogen was applied in 3 equal splits–at 4-leaf, 8 leaf and tasseling stage, while rest of potassium was applied at tasseling stage. The $ZnSO_4$ (24% Zn) was used for seed priming as well as for soil application, while Zn-EDTA (14%) was used for foliar application. Other crop-management practices were similar during both the years. Maize was sown on 24 January and 15 January in 2018 and 2019 respectively. Two hand-weedings were given at 20 and 40 days after sowing (DAS) and simultaneously earthing-up was done**.** Irrigation (twice) was given after weeding and earthing-up at 20 and at 40 DAS. Harvesting (19 and 14 May in 2018 and 2019 respectively) was done when the shells of cobs were dried and the kernel colour turned yellow.

Five randomly selected plants from the net plot area were used to record the plant height and dry-matter production at 30, 50, 70, 90 DAS and harvesting. The height was measured from base of the plant to fully opened top leaf before tasseling, whereas after tasseling the plant height was measured from the base of the plant to collar of the flag leaf and mean values were worked out. For estimation of dry matter, sampled plants were separated into leaves (including sheath), stem, tassel and cob with husk. These samples were first air-dried then air-dried sampled plants were dried in an oven at 65°C till they attained a constant dry weight. Total dry-matter accumulation was expressed in g/plant. Leaf-area index (LAI) was calculated as per Watson (1947). At maturity all the plants from net plot area (28/m^2) were harvested at physiological maturity and data on grain and stover yield for maize crop were measured and expressed in t/ha. Ten plants from each plot were selected randomly and harvested to measure cob length, cob width, grain rows/cob, grains/cob and 100-grain weight for maize. Composite soil sample from each plot were collected at 30, 50, 70, 90 DAS and at harvesting. The samples were thoroughly dried in shade, pulverized, sieved through 0.2-mm mesh and analyzed for the available zinc using DTPA extract. Plant and grain samples from each plot were collected for the purpose of the determination of zinc content using atomic absorption spectrophotometer.

Data were subjected to analysis of variance (ANOVA) appropriate for a randomized block design using SPSS software version 20. Treatments differences were considered significant based on results of F test, critical differences (CD) were calculated at 5% level of probability.

RESULTS AND DISCUSSION

Growth attributes of hybrid maize

Plant height of maize was recorded 20-day intervals, starting from 30 days after sowing (DAS) to harvesting and presented in Table 1. Plant height increased continuously up to 90 DAS thereafter declined sharply towards harvesting. At 30 DAS, significantly tallest plant (22.78 cm) was found in soil application of 5 kg Zn/ha over the control, foliar application of 1% Zn at silking stage and foliar application of 0.5% Zn at tasseling stage + 0.5% Zn at silking stage, and rest of the treatments are statistically at par. Thereafter in all the dates of taking observation soil application of 10 kg Zn/ha, recorded tallest plant (112.01, 219.07, 225.07 and 224.17 cm at 50, 70, 90 and at harvest respectively). Higher plant height might be due to the synthesis of more auxin, which awakens cell elongation (Mehdi *et al*., 2012). Vasconcelos *et al.* (2011) also observed that higher doses of zinc applied both to soil and foliage results in increased height of maize plants, but soil applied zinc gave more effective values.

There was an increasing trend of leaf-area index (LAI) values up to 70 DAS and thereafter declined towards maturity due to senescence of lower leaves (Fig. 1). The LAI differed significantly among different methods of zinc application over the control at all the stages of observations during both the years. At 30 DAS, the maximum LAI (1.19 and 1.26 in 2018 and 2019 respectively) was recorded with soil application of 10 kg Zn/ha which was statistically at par with soil application of 5 kg Zn/ha, seed priming with 2% Zn solution seed priming with 1% Zn solution + foliar application of 0.5% Zn at tasseling stage and seed priming with 1% Zn solution + foliar application of 0.5% Zn at silking stage. The trend was similar at later stages of observations too. At 75 DAS, the LAI was the highest with soil application of 10kg Zn/ha and the lowest LAI with the control plot (no zinc) in both the years. The application of zinc helped in stimulating the photosynthetic pigments and enzyme activity thereby persuaded the vegetative augmentation of the plants and also enhanced the LAI (Mohamed *et al.*, 2010; Chaab *et al.*, 2011). Mehdi *et al.* (2012) reported a significant increase of LAI with the application of 10 kg Zn/ha in fodder maize.

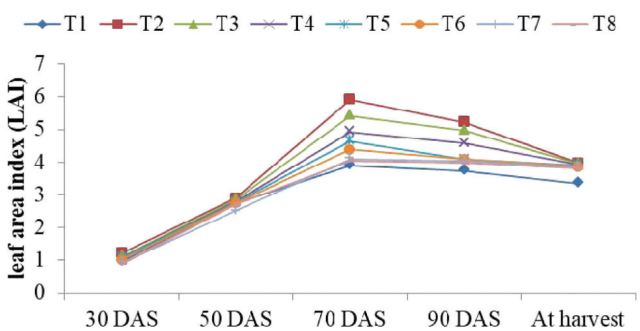

Fig. 1. Leaf-area index (LAI) at different growth stages of maize under different method of zinc application (Details of treatments are given under Materials and Methods; DAS, days after sowing)

As expected, with the advancement of growth stages maize produced more dry-matter (Table 1). Data clearly exhibited that among different methods of zinc application, soil application had more pronounced effect on dry matter followed by seed priming and foliar application. Pooled data revealed that soil application of 10 kg Zn/ha produced significantly highest dry-matter at 30, 50, 70, 90 DAS and at harvesting over the control (Table 1). Higher dry-matter accumulation (DMA) in the zinc-treated plot was owing to

Table 1. Plant height, dry matter accumulation, zinc concentration and uptake at different growth stages of maize in response to zinc application (pooled data over 2 years)

Treatment	30 DAS	50 DAS	70 DAS	90 DAS	At harvesting	30 DAS	50 DAS	70 DAS	90 DAS	At harvesting
	Plant height (cm)					Dry matter accumulation (g/plant)				
T_1	20.0	105.2	209.4	213.8	212.5	0.7	4.6	92.5	147.8	166.9
T_2	22.3	112.0	219.1	225.1	224.2	1.0	5.8	128.0	187.1	217.3
T_3	22.8	110.0	218.7	223.1	222.5	0.9	5.6	110.4	180.4	196.0
T_4	22.7	108.0	217.8	222.3	221.4	0.9	5.2	105.4	175.2	186.4
T_5	22.4	106.1	217.0	220.8	220.1	0.8	4.8	104.9	170.6	184.4
T_6	21.9	105.8	216.7	220.4	219.7	0.7	4.8	103.5	158.7	179.2
T_7	21.2	102.8	214.3	219.7	219.0	0.7	4.0	101.1	157.8	177.7
T_8	21.0	103.6	215.5	218.1	217.3	0.7	4.5	98.9	153.3	174.5
SEm±	0.5	3.1	2.4	2.1	2.0	0.1	0.4	3.8	6.4	6.4
CD (P = 0.05)	1.5	9.0	6.9	NS	5.9	0.2	1.0	11.1	18.5	18.5
	Zinc concentration (mg/kg)					Zinc uptake (g/ha)				
T_1	14.2	21.2	24.9	15.0	14.5	0.5	5.9	131.6	128.7	105.9
T_2	38.1	80.9	130.3	46.2	28.8	2.1	25.0	617.1	508.2	296.4
T_3	30.8	71.3	119.3	40.6	20.6	1.5	21.3	515.4	435.4	259.7
T_4	25.8	33.6	38.2	16.4	13.6	1.1	9.5	268.0	220.9	170.8
T_5	23.3	31.6	40.8	16.5	16.0	1.1	8.7	251.9	174.4	153.9
T_6	20.9	29.3	66.3	19.8	13.8	1.0	9.4	257.0	239.8	168.0
T_7	18.5	26.1	42.4	25.5	17.2	1.1	8.1	248.8	198.2	164.2
T_8	17.3	23.7	46.6	32.6	19.1	0.7	6.9	365.5	308.1	222.1
SEm±	2.6	2.8	7.1	4.2	2.0	0.2	1.2	19.9	34.0	15.3
CD (P = 0.05)	7.5	8.3	20.5	12.0	5.9	0.5	3.5	57.2	98.6	44.4

T_1, Control (no zinc); T_2, soil application of 10 kg Zn/ha; T_3, soil application of 5 kg Zn/ha; T_4, seed priming with 2% Zn solution; T_5, seed priming with 1% Zn solution + foliar application of 0.5% Zn at tasseling stage; T_6, seed priming with 1% Zn solution + foliar application of 0.5% Zn at silking stage; T_7, Foliar application of 1% Zn at silking stage; T_8, Foliar application of 0.5% Zn at tasseling stage + 0.5% Zn at silking stage

DAS, Days after sowing; NS, non-significant higher photosynthesis and simultaneous translocation of more photosynthates from source to sink. Zinc also helped in increased synthesis of tryptophan and indole acetic acid which are 2 main factors in fresh and dry weight expansion (Tetarwal *et al*., 2011). Hong *et al.* (2003) also proved that application of zinc @ 3.0 mg/kg in soil considerably enhanced dry matter weight of roots, stems, leaves and thereby whole plant under sufficient availability of soil moisture. Lower dry matter in no-zinc plot might be due to lower number of leaves which in turns reduced the photosynthetic capacity of plant.

Yield components and yield of hybrid maize:

Grain yield of maize is the cumulative effect of cob length, cob diameter, kernel rows/cob, grains/row and seed index. The addition of zinc in maize exhibited noticeable effect on yield components, grain and stover yield unrelatedly of its modes of use compared to no zinc. Among the methods of zinc application soil application, of 10 kg Zn/ha had pronounced effect on yield components of maize and showed the highest values of cob length, cob diameter, rows/cob, grains/row, grains/cob and seed index), which ultimately lead to higher grain (10.64 t/ha) yield of maize followed by soil application of 5 kg Zn/ha, seed priming with 2% Zn solution, seed priming with 1 % Zn solution + foliar application of 0.5% Zn at tasseling stage and seed priming with 1% Zn solution + foliar application of 0.5% Zn at silking stage (Table 2). Increased supply of zinc through soil resulted in grain yield enhancement by an increase in length and girth of maize cob, as it involves as a catalyst in various growth processes and in hormone production including protein synthesis (Ehsanulah *et al*., 2015).

Pooled data reveals that, foliar application of 0.5% Zn at tasselling stage + 0.5% Zn at silking stage and 1% Zn at silking stage resulted in 15.45 and 13.62% higher grain yield over the control (Table 2). Splitting of zinc at tasselling and silking ensued 1.61% yield advantage over single application at silking. Treatment, where zinc was not applied either through soil or foliage, recorded the lowest grain yield of 8.09 and 9.39 t/ha during 2018 and 2019 respectively.

Harvest index (HI) refers to the aptitude of a crop to convert the photosynthate into economic yield. The highest value of HI was found in soil application of zinc 10 kg/ha, while control plot registered lowest value of HI (Table 2). Pooled data reveals that, soil application of 10 kg zinc/ha recorded significantly highest shelling percentage, which was followed by soil application of 5 kg Zn/ha and seed priming with 2% Zn solution. Higher shelling percentage is due to more test weight and kernels/cob. Our results confirm the findings of Karki *et al*. (2005) and Tetarwal *et al*. (2011).

Status of zinc in post-harvest soil, maize plant and grain

Irrespective of dose and method, zinc application showed an affirmative response in enriching the zinc concentration in post-harvest soil, plant and grain than the control plot. Among different treatments, soil application of Zn proved superiority in upholding the status of zinc in post-harvest soil, plant and grain followed by seed priming, seed priming + foliar and foliar application. Zinc concentration in maize plants can be augmented through the application of zinc either in soil or by seed priming (Harris *et al*., 2007). It is quite obvious that available zinc will be more

Table 2. Yield attributes and yields of maize as influenced by different methods of zinc application (pooled data 2 over years)

Treatment	Cob length (cm)	Cob diameter (cm)	Grain rows/ cob	Grains/ row	Grains/ cob	Seed index (g)	Grain yield (t/ha)	Stover yield (t/ha)	Harvest index (%)	Shelling (%)
T_1	15.8	15.6	14.4	33.3	476.7	34.6	8.74	10.77	44.74	71.81
T_2	19.1	17.5	15.1	37.7	580.7	36.8	10.64	9.27	53.52	74.51
T_3	18.8	17.4	15.1	37.4	553.9	36.0	10.49	9.69	51.97	73.87
T_4	18.7	17.3	15.0	37.2	550.7	36.3	10.28	9.87	51.02	73.59
T_5	18.4	17.0	14.7	36.7	546.8	34.8	10.11	9.95	50.35	73.56
T_6	18.6	16.6	14.8	37.0	548.3	34.0	10.24	10.35	49.34	72.90
T_7	17.8	17.2	14.6	36.1	531.8	34.7	9.93	10.24	50.01	72.82
T_8	18.1	16.6	14.5	36.6	540.6	34.0	10.09	10.61	48.34	72.63
SEm±	0.6	0.3	0.3	1.1	20.7	0.6	0.1	0.3	0.9	0.6
CD (P=0.05%)	1.8	0.9	NS	3.1	60.0	1.6	0.3	NS	2.6	1.6

T_1, Control (no zinc); T_2, soil application of 10 kg Zn/ha; T_3, soil application of 5 kg Zn/ha; T_4, seed priming with 2% Zn solution; T_5, seed priming with 1% Zn solution + foliar application of 0.5% Zn at tasseling stage; T_6, seed priming with 1% Zn solution + foliar application of 0.5% Zn at silking stage; T_7, Foliar application of 1% Zn at silking stage; T_8, Foliar application of 0.5% Zn at tasseling stage + 0.5% Zn at silking stage;

DAS, Days after sowing; NS, non-significant in the treatments where zinc was applied in the soil than seed priming and foliar application. In case of foliar application, most of the zinc is absorbed by the leaves and stems of plant, so very meager amount will reach to the soil. Available zinc in soil was increasing up to 50 DAS, thereafter declined towards advancement of crop-growth stages irrespective of treatments and year of experimentation, which might be due to vigorous uptake of zinc by maize after tasseling stage. It was clearly from Fig. 2 that, an application of 10 kg Zn/ha in soil resulted in significantly highest amount of available zinc (1.98, 2.05, 1.30, 1.01, 0.87 mg/kg at 30, 50, 70, 90 DAS and harvesting) over the control (no zinc) which was followed by soil application of 5 kg Zn/ha, seed priming with 2% Zn solution and seed priming with 1% Zn solution +foliar application of 0.5% zinc at tasseling stage, although they were statistically non-significant.

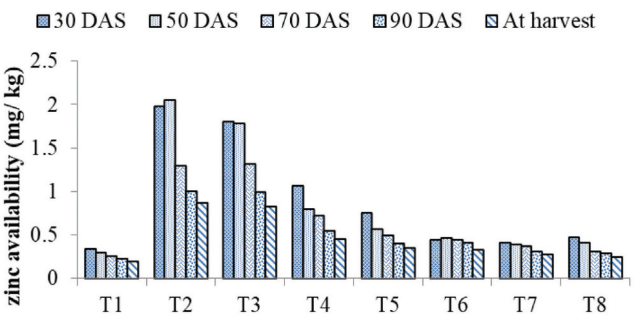

Fig. 2. Available soil zinc at different growth stages of maize under different methods of zinc application (Details of treatments are given under Materials and Methods; DAS, days after sowing)

Plant zinc concentration and uptake were increased continuously up to 70 DAS, thereafter declined rapidly towards maturity irrespective of treatments and year of experimentation (Table 1). At harvesting, zinc concentration in plant was almost similar to 30 DAS. Soil application of zinc was found superior to seed priming and foliar application. Application of 10 and 5 kg Zn/ha showed significantly highest values of zinc concentration (38.13 and 30.77, 80.87 and 71.33, 130.30 and 119.30, 46.20 and 40.63 and 28.77 and 20.63 mg/kg at 30, 50, 70, 90 DAS and harvesting respectively) and uptake (2.09 and 1.53, 25.03 and 21.29, 617.10 and 515.39, 508.18 and 435.44 and 296.35 and 259.68 g/ha at 30, 50, 70, 90 and harvesting respectively) over the other treatments. Zinc helped in accelerating root growth which in turn increased the zinc uptake and simultaneously owing to greater availability of zinc and maximum dry matter production (Arabhanvi and Hulihalli, 2018). Foliar application of 1% Zn at silking stage and foliar application of 0.5% Zn at tasseling stage + 0.5% Zn at silking stage did not show achieve level of significance in terms of plant zinc concentration and uptake over no zinc application.

Enrichment of grain zinc content is the need of the hour in order to minimize zinc deficiency in cereals. Zinc content in grain varied from 15.10 to 25.0 mg/kg during 2018 and 18.20 to 26.07 mg/kg during 2019 (Fig. 3). Pooled data revealed that, significantly highest zinc content (25.33 mg/kg) was achieved through soil application of zinc @ 10 kg/ha followed by seed priming with 2% zinc solution and soil application of zinc @ 5 kg/ha, which might be owing to more Zn availability in soil for root absorption (Arabhanvi and Hulihalli, 2018).

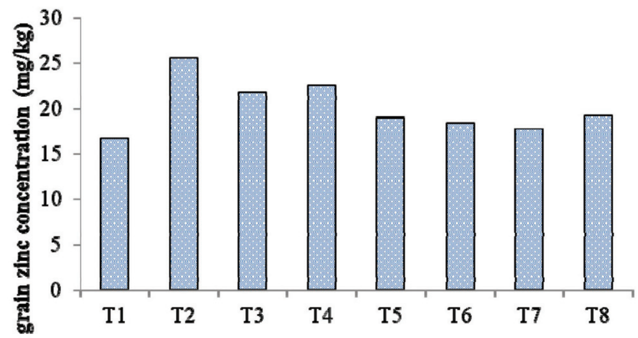

Fig. 3. Grain zinc concetration under different methods of zinc application (Details of treatments are given under Materials and Methods; DAS, days after sowing)

Economics of hybrid maize cultivation

Acceptance or rejections of any technology or methods at farmers' level ultimately depends on their economic feasibility. Present experimental finding clearly indicated (Fig. 4) that application of 10 kg Zn/ha fetched higher gross returns (₹150,450 and ₹177,300 during 2018 and 2019), followed by soil application of 5 kg Zn/ha (₹147150 and ₹176196) and seed priming with 2% Zn solution (143250 and ₹173,675.20) and also highest net return (₹94,546.87 during 2018), followed by soil application of 5kg Zn/ha (₹94,388.37) and seed priming with 2% Zn solution (₹93,504.21) simply owing to higher grain yield. Badiyala and Chopra (2011) also obtained significantly better economic return of maize with the application of 25 kg $ZnSO_4$/ha. In the present study, control plot in regards to zinc ap-

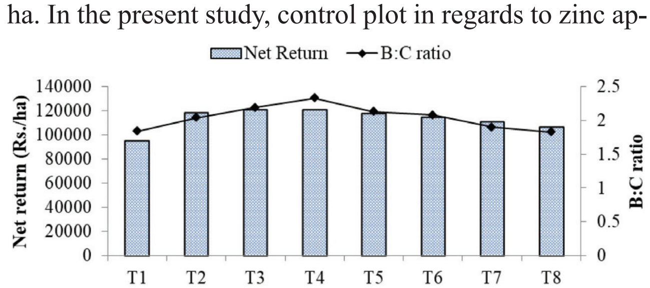

Fig. 4. Economics of maize cultivation as influenced by methods of zinc application (Details of treatments are given under Materials and Methods; DAS, days after sowing)

plication recorded the lowest gross and net returns to the tune of ₹121,350 and ₹147,986.40 in 2018 and ₹71,729.87 and ₹95,884.65 in 2019 simply due to lower grain yield. Subedi and Ma (2009) opined that, inadequate supply of zinc drastically decreased the yield and thereby net returns of maize cultivation. Seed priming with 2% Zn solution was realized maximum benefit: cost (B: C) ratio of 1.88 and 2.33 during 2018 and 2019, respectively, followed by soil application of 5 kg Zn/ha with a value of 1.79 and 2.19, which was owing to lower treatment cost as compared with other treatments and almost equivalent grain yield with the treatment receiving 10 kg Zn/ha.

Conclusively soil based application of 10 kg Zn/ha was found the best along with RDF (140 kg N + 70 kg P_2O_5 + 70 kg K_2O/ha) in order to maximize grain yield of hybrid 'Kaveri 218' maize. Grain Zn concentration can be augmented with the application of 10 kg Zn/ha, thereby minimizing the zinc deficiency in maize grain which will be supportive in extenuating zinc under-nourishment. To maintain the productive performance and profitably of maize cultivation seed priming with 2% Zn solution may be recommended, as it fetched higher B : C ratio.

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