Evaluation of Maize for Different Methods and Levels of Zinc Application

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Abstract

The different methods of zinc (Zn) application with various doses were studied in maize (*Zea mays* L.).The methods adopted namely, seed priming (1, 2 and 3%), seed treatment (2, 4 and 6 g kg^{-1} seed), soil application (4, 6 and 8 kg ha^{-1}) and foliar application (0.25, 0.50 and 0.75%) with three levels of each. Foliar application of Zn at 0.75% has exhibited phytotoxicity initially but later the phytotoxicity disappeared after 8-10 days. Irrespective of the Zn application method and level growth, yield, Zn content and quality of maize was significantly enhanced over absolute control. Seed treatment was found to be the cheapest Zn application method. Seed treatment of Zn at 4 g kg^{-1}produced highest maize grain yield, net returns and the maize grains were enriched with Zn and were suitable for human consumption as a biofortified Zn source. Maximum residual elemental Zn in soil was found due to foliar application of Zn at 0.75%. However, seed treatment of Zn at 4 g kg^{-1}resulted suitable for an eco-friendly and sustainable method of Zn application for agronomic package and practices.

Introduction

Throughout the world, 2 billion peoples are currently coming across micronutrients deficiency (Velu et al, 2014). Zn deficiency is a cause of concern for crops, humans and animals in micronutrient deficient soils (Behera et al, 2015). Deficiency of Zn may cause acrodermatitis, infertility and mental lethargy, while through excess Zn, peoples may succumb to cause altered lymphocyte function, epigastric pain and nausea (Zaman et al, 2017). Zn controls auxin synthesis in plants; hence, Zn deficiency leads to leaf distortion and internodes shortening, which ultimately results in inadequate plant protein synthesis (Begum et al, 2016). Throughout the world maize crop responds to Zn application (Potarzycki and Grzebisz, 2009). Unfortunately, the total requirement of Zn is higher, and its availability is meager for the population who are depending on staple food like maize (Nuss and Tanumihardjo, 2010). Hence, Zn deficiency is very high in the countries where maize is consumed as a staple food of the population. (Imran and Rehim, 2017; Imran et al, 2015).

The process of deliberate enrichment of cereal grains during crop growth period with important elements like Zn is known as Agronomic biofortification (Cakmak, 2008). Agronomically, Zn can be applied via soil, seed treatment, foliar spray and seed priming or by dipping seedlings into a fertilizer solution.

Soaking of seeds in water/nutrient solution for given time and air dried them before sowing is called as "on-farm seed priming" method (Harris and Jones, 1997), which is a simple and low-cost technique (Harris et al, 2000). Seed priming of maize supports plant growth and increases maize seed yield and Zn content in seed under limited Zn supply condition (Harris et al, 2007b). Micronutrient seed treatment helps to have good crop stand, improves crop growth and yield and enrich the grains with micronutrient. Seed treatment is advantageous because it is economically convenient as micronutrient requirement for biofortification is less (Singh et al, 2003). Seed treatment is a good option in comparison to soil application, as the requirement of nutrients is reduced. Zn can be soil applied through broadcasting or banding below seed (Martens and Westermann, 1991). Zn foliar application is promising to enrich Zn in the seed, but its effectiveness depends on various factors, time is one of the factor for it (Cakmak, 2008).

Hence, seed enrichment of Zn through different application methods can improve crop production and consumer health, especially for those consumers who often consume cereal grains. These Zn supplemented crop grains can be added in the food chain after harvesting by food processing and direct consumption, which provides a nutritive, balanced and mineral enriched diet to a particular population. However, in maize, this experiment was executed from grain Zn enrichment, crop yield and economic point of view to test all four Zn application methods with three levels of each to find out the most suitable method to boost up Zn in maize.

Materials and Methods

Location and soil of experimental field plot

The experiment was carried out during February-May 2016 at Navsari Agricultural University, India. Pre-planting composite soil samples were collected from 0-30 cm before experiment for initial soil analysis. The samples were mixed thoroughly and analyzed by standard procedures (Jackson, 1973) . The soil texture of the experimental site was clayey; slightly alkaline with pH 7.8 and 0.36 dSm^{-1} electrical conductivity. The soil was low in elemental nitrogen (N) (185.74 kg ha^{-1}), medium in elemental phosphorus (P_2O_5) (26.33 kg ha^{-1}), high in elemental potassium (K_2O) (334.57 kg ha^{-1}) and elemental Zn content was 0.64 mg kg^{-1}.

Climatic conditions

The climate of experimental sites was typically tropical, characterized by humid, diurnal and warm monsoon with heavy rainfall, quite cold winter and relatively hot summer. Agro-climatically, the area falls under the heavy rainfall zone of South Gujarat of India (25°- 57' N Latitude and 72°-54' E Longitude at an altitude of 10 meters above the mean sea level).

Zn application methods and levels

The experimental treatments were consisted of four methods of $ZnSO_4$ application *viz.* seed priming, seed treatment, soil application and foliar spray application comprised of three levels of each *i.e.* seed priming @1, 2 and 3%, seed treatment @ 2, 4 and 6 g kg^{-1} seed, soil application @ 4, 6 and 8 kg ha^{-1} and foliar application @ 0.25, 0.50 and 0.75%. Seed priming was done by dissolving $ZnSO_4$ in water for two hours and air-dried in shadow there after. Seed treatment was given by mixing $ZnSO_4$ in viscous jaggery solution and dried the seeds in shadow. Soil application of Zn was done through fertigation at 15 DAS at three-leaf stage. Foliar application of Zn were done twice, first at 60 days after sowing (DAS) and second at tasseling stage. Absolute control and control (seed priming with pure water) were considered for better comparison of the experimental data.

Agronomic practices

Maize variety GM-6 was sown by dibbling method. Spacing was maintained at row-to-row 60 cm and plant-to-plant 20 cm, in plots size of 4.8 m x 4.2 m. The recommended dose of fertilizer for the crop was 120: 60 : 00 of NPK kg ha^{-1}. Crop was fertilized with full dose of phosphorus (single super phosphate) and half dose of nitrogen (urea) at the time of sowing and remaining dose of nitrogen was applied at 60 DAS and tasseling stage with equal split. Fertilizers were applied through band method of placement before sowing the seeds in previously opened furrows at a depth of about 8 cm. The experimental area was hand-weeded to control the weeds as and when required.

Protein content and yield

Nitrogen content of seed was determined by micro Kjheldahl's method (Jackson, 1973). The protein content of seed was determined by multiplying nitrogen percentage with 6.25 and expressed in percentage. Protein yield (kg ha^{-1}) was calculated by multiplying protein content in seed with maize grain yield.

Nutrient soil composition

The soil samples were collected at harvest to check the nutrient availability, as suggested by Page et al, 1982. For estimation of available N, P, K and Zn, soil samples were taken from each plot at 30 cm depth and analyzed for determination of the content of respective nutrients as per the accepted methods (Jackson, 1973). The content and uptake of N, P, K and Zn from grain and straw (leaf, stem and central core) were worked out by drying plant samples in diffused sunlight, then in an oven at 60 °C and finely powdered to form a composite sample. The samples were further digested (diacid extract) with 1:1 mixture of the concentrated H_2SO_4 and 30% H_2O_2 in Kjeldahl digestion unit at required temperature (Parkinson and Allen, 1975). Total individual nutrient content was calculated by adding nutrient content in grains and straw (average of nutrient content in leaf, stem and central core). The uptake was calculated by multiplying seed and straw yield to N, P and K concentration (Jackson, 1973). For Zn, the soil samples after harvest of maize were also collected to analyse DTPA-Zn content (Lindsay and Norvell, 1978). Digested plant samples in the acid extract were used to analyze Zn content in plant by following the standard analytical procedures through Atomic Absorption Spectrophotometer and the uptake was also calculated.

Table 1- Effects of Zn application methods on maize growth

Treatment	Plant height (cm)	No. of leaves plant^{-1}	Leaf area (cm^2)	Dry matter plant^{-1} (g)
Control (absolute)	159.10	12.15	2951	69.43
Control (water priming)	161.58	12.43	3111	72.90
Seed priming 1 %	169.78	12.91	3338	75.33
Seed priming 2 %	183.65	13.70	3566	81.88
Seed priming 3 %	173.36	12.97	3491	77.14
Seed treatment 2g kg^{-1} seed	190.68	14.40	3645	84.85
Seed treatment 4g kg^{-1} seed	206.07	15.60	3886	89.76
Seed treatment 6g kg^{-1} seed	202.24	15.02	3767	88.77
Soil application 4 kg ha^{-1}	176.63	13.19	3544	78.09
Soil application 6 kg ha^{-1}	199.61	14.63	3716	86.78
Soil application 8 kg ha^{-1}	186.88	13.80	3592	83.15
Foliar application 0.25% (twice)	164.94	12.74	3288	73.30
Foliar application 0.50% (twice)	182.36	13.27	3549	80.15
Foliar application 0.75% (twice)	198.38	14.48	3705	85.84
S.Em. ±	10.36	0.66	176	4.36
C.D. at 5%	30.13	1.93	512	12.67

Maize economic evaluation

The gross and net realization of maize were calculated based on the grain and straw yield and the prevailing market prices of maize during the crop seasons. Benefit:cost ratio (B : C) was calculated by dividing the net realization from total cost of cultivation.

Statistical analysis

The experiment was conducted in randomized block design, where in different methods of Zn application were tested with three replications. A statistical analysis of results obtained in the various plots and treatments (14 treatments) was performed with the standard method of analysis and treatments were compared using the standard error of means and critical difference values. The best treatment effect was worked out on the basis of the least significant difference (lsd) at 5% probability level (Gomez and Gomez, 1983).

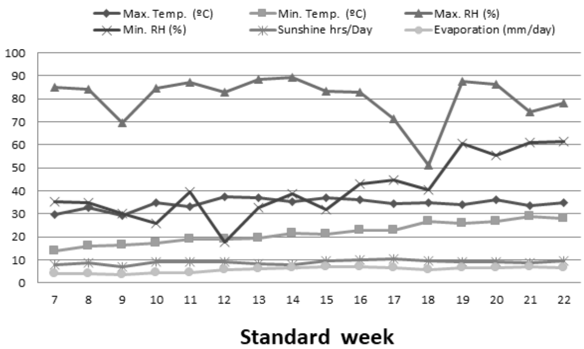

Fig. 1 - Weather parameters during the period of experimentation (2016).

Results and discussion

The average annual rainfall of the tract is about 1606 mm (30 years), with 54 rainy days. Monthly averages of meteorological variables including rainfall, temperature, relative humidity, sunshine hours and evaporation were measured with an automatic weather station near the experimental site (ICT International) (Figure 1). The minimum and maximum temperature, relative humidity, sunshine and evaporation hours during the crop growing period varied from 13.8 to 37.3 °C, 17.8 to 89.1% and 7.1 to 10.0 hours day^{-1}, 3 . 3 to 6.9 mm day^{-1}, respectively and rainfall during the crop season was nil. The Meteorological conditions were suitable to cultivate maize crop.

Phytotoxicity symptoms

Foliar spray of Zn at 0.75% on maize at 60 DAS did not show phytotoxiocity, however phytotoxicity symptoms were noticed at tasseling stage with this treatment like yellowing of leaf, premature leaf fall and dropping of few maize plants. However, within 8-10 days all the plants were recovered fast after the follow up irrigation. No other method showed phytotoxicity symptoms.

Growth and yield contributing characters

The experimental data indicated that, the growth contributing characters (Table 1) namely plant height (206.07 cm), number of leaves per plant (15.60), leaf area per plant (3886 cm^2), dry matter per plant (89.76 g) and the yield contributing characters namely (Table 2) cob plant^{-1} (1.34), number of rows cob^{-1} (14.19), number

Table 2 - Effects of Zn application methods on maize yield contributing characters

Treatment	Number of cob plant^{-1}	Number of row cob^{-1}	Number of seed cob^{-1}	Cob weight (g)	Cob length (cm)	Cob girth (cm)	Cob diameter (mm)
Control (absolute)	0.95	11.32	285	70.56	10.82	10.85	28.57
Control (water priming)	0.97	11.54	290	71.69	11.12	10.93	29.18
Seed priming 1 %	1.08	11.93	321	77.59	11.55	11.70	31.61
Seed priming 2 %	1.23	12.72	359	85.14	12.82	12.38	36.09
Seed priming 3 %	1.10	12.16	328	78.06	11.92	12.08	32.55
Seed treatment 2g kg^{-1} seed	1.27	13.45	374	88.74	13.48	12.98	36.98
Seed treatment 4g kg^{-1} seed	1.34	14.19	405	97.88	14.82	13.90	41.41
Seed treatment 6g kg^{-1} seed	1.31	13.90	399	89.41	14.28	13.69	39.11
Soil application 4 kg ha^{-1}	1.17	12.26	333	83.34	12.37	12.16	33.11
Soil application 6 kg ha^{-1}	1.29	13.83	391	89.17	13.98	13.57	38.20
Soil application 8 kg ha^{-1}	1.25	12.97	367	88.32	13.02	12.68	36.52
Foliar application 0.25% (twice)	1.04	11.68	308	73.23	11.32	11.66	30.18
Foliar application 0.50% (twice)	1.21	12.40	351	83.85	12.62	12.21	35.57
Foliar application 0.75% (twice)	1.28	13.56	384	89.29	13.62	13.34	37.35
S.Em. ±	0.07	0.63	24.12	5.08	0.74	0.66	2.30
C.D. at 5%	0.22	1.85	70.12	14.79	2.16	1.92	6.71

of seeds cob^{-1} (405), cob weight (97.88 g), cob length (14.82 cm), cob girth (13.90 cm) and cob diameter (41.41 mm) were significantly higher by seed treatment of Zn at 4 g kg^{-1}, however both in control and absolute control, comparatively reduced growth was observed. Zn is an element of vital importance and it has numerous essential functions in plants. Zn is important for plant growth as it induces photosynthesis and the enzymatic activity of carbonic anhydrase (Rengel, 1995). The different biochemical processes like auxin metabolism, chlorophyll formation, nucleotides production and enzyme activation are governed by Zn (Chang et al, 2005). Zn is also very essential for the normal functioning of the enzyme ribulose 1-5-bisphosphate carboxylase/oxygenase (Rubisco). Reactive oxygen species is responsible for the decrement of CO_2 assimilation by decreasing Rubisco activity in Zn deficient plants. Zn deficiency in plants is responsible for declining in the fixation of CO_2 and stomatal conductance (Samreen et al, 2013).

Individually among the Zn application methods, seed priming @ 2 %, foliar application @ 0.75%, soil application @ 6 kg ha^{-1} and seed treatment @ 4g Zn kg^{-1} seed had significantly increased all growth and yield contributing parameters per plant among their three levels. Regular application of Zn is essential for plant growth and yield. Seed treatment of maize at 0.5 g kg^{-1} seed by using $ZnSO_4$ has resulted elongated roots in seedlings as compared to the treatment of ZnO (Santos et al, 2017). Soil application of Zn to different maize varieties at 3 mg kg^{-1} has produced highest dry matter production, but at a higher dose of Zn, i.e. 9 and 27 mg kg^{-1} soil, dry matter yield reduced drastically (Kanwal et al, 2009), hence optimum Zn dose through any method affects maize yield. Foliar application of Zn has enhanced the leaf area index (LAI) of maize (Mohsin et al, 2014). Foliar spray of Zn has justified the role of auxin in crop, which increases leaf size by enhanced length and width of the leaf and ultimately increased LAI. In this experiment also all growth and yield contributing characters increased with an increase in Zn up to second levels, but at the third level of Zn, growth and yield contributing characters were reduced, except foliar application.

Maize yield

Application of Zn through priming, seed treatment and soil application increased yield parameters up to their first two levels of Zn application; however, the third level has shown a decreasing trend except for foliar application (Table 3). Both control treatments showed lowest yield parameters, but seed soaking with water indicated a higher yield value in comparison to absolute control. Application of Zn through seed treatment at 4g kg^{-1} seed has exhibited significant

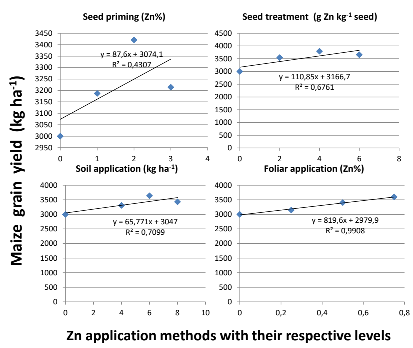

Fig. 2 - Relationship between Zn application and grain yield

Table 3 - Effects of Zn application methods on maize yield

Treatment	Grain yield plant^{-1} (g)	Straw yield plant^{-1} (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Seed index (g)	Harvest index (%)	Shelling (%)
Control (absolute)	34.51	106.29	3000	4426	15.13	40.23	60.45
Control (water priming)	35.65	108.77	3045	4502	16.09	40.28	61.29
Seed priming 1 %	38.14	117.06	3187	4674	16.77	40.55	63.34
Seed priming 2 %	39.91	123.54	3421	4906	17.90	41.11	69.14
Seed priming 3 %	38.55	118.25	3214	4711	17.14	40.57	66.13
Seed treatment 2g kg^{-1} seed	41.45	126.84	3546	5059	18.18	41.23	71.28
Seed treatment 4g kg^{-1} seed	44.64	133.97	3795	5254	20.32	42.02	74.37
Seed treatment 6g kg^{-1} seed	43.79	132.80	3656	5144	19.45	41.53	73.91
Soil application 4 kg ha^{-1}	39.05	119.96	3306	4819	17.79	40.70	67.39
Soil application 6 kg ha^{-1}	42.85	130.59	3638	5133	19.11	41.47	73.35
Soil application 8 kg ha^{-1}	40.90	125.90	3428	4924	18.10	41.13	70.61
Foliar application 0.25% (twice)	36.92	114.70	3148	4653	16.43	40.33	62.72
Foliar application 0.50% (twice)	39.46	122.28	3403	4899	17.82	41.00	67.61
Foliar application 0.75% (twice)	42.06	128.52	3598	5111	18.60	41.32	72.67
S.Em. ±	1.97	5.81	167.31	174.21	0.91	--	3.26
C.D. at 5%	5.73	16.90	486.36	506.43	2.67	--	9.49

increase in grain yield (44.64 g plant^{-1} and 3795 kg ha^{-1}), straw yield per plant (133.97 g plant^{-1} and 5254 kg ha^{-1}), seed index (20.32 g), harvest index (42.02%) and shelling percentage (74.37%), were at par with all other Zn application methods and levels except seed priming at 1 and 3%, foliar application at 0.25% and both the control methods. The increased level of hydrolytic enzymes like acid phosphatase and peroxidase under Zn deficient conditions suppress pollen tube growth (Roggen and Stanley, 1969), which ultimately leads to poor fertilization and seed set. Zn deficiency is responsible for deformed and under developed seed due to the retarded activity of the starch synthase enzyme (Shrotri et al, 1980). This decreases seed weight, per plant yield of maize and ultimately final yield. Top four treatments among all fourteen treatments which exhibited highest grain and straw yield of maize were, seed treatment @ 4g kg^{-1}seed (3795 and 5254 kg ha^{-1}) followed by soil application @ 6 kg $ZnSO_4$ ha^{-1} (3638 and 5133 kg ha^{-1}) followed by foliar application @ 0.75% (3598 and 5111 kg ha^{-1}) and seed priming at 2% (3421 and 4906 kg ha^{-1}). The earlier mentioned Zn treatments correspondingly increased the grain yield by 126.50, 121.86, 121.26 and 119.70% and straw yield by 118.70, 116.22, 115.97 and 115.47% of maize over absolute control.

Zn priming of wheat and chickpea increased grain yield significantly and enhanced wheat and chickpea grain yield by 114 and 119%, respectively (Harris et al, 2007a). Zn influence its carbohydrate metabolism through its role in photosynthesis, the sugar transformations and ultimately seed development (Kanwal et al, 2010). Hence, enhanced Zn uptake through its higher content in seed helps for bolder grains production and ultimately increasing grain yield (Alloway, 2008; Fageria et al, 2011). The leaves readily absorbed foliar application of Zn and further translocated to other plant parts hence maize yield increased. An increase in maize grain yield by 18% reported (Potarzycki and Grzebisz, 2009) when Zn was applied as a foliar spray at the rate of 1-1.5 kg ha^{-1}. Seed treatment of $ZnSO_4$ at 3.6 g kg^{-1} seed with NPK has increased corn yield in field conditions as compared to the only application of recommended NPK fertilizers (Shabaz et al, 2015). In this experiment application of Zn was sufficient to increase the grain and straw yield of maize in all methods up to second level of Zn and then it was little toxic in third level to reduce the grain and straw yield of maize, but the third level was always superior over the first level of Zn. On the contrary, grain and straw yield of maize increased linearly with increase in foliar application level from 0.25 to 0.75%. Seed treatment at 4g kg^{-1} seed can be recommended for the highest maize grain yield among all tested treatments, looking to its optimum dose.

Nutrient content and uptake influence by Zn application

Nitrogen content and uptake

In this experiment, nitrogen content was evaluated in maize grain, leaf, stem and central core. Zinc deficiency interrupts chlorophyll synthesis, reduction in nitrate absorption, photosynthesis, starch synthesis, glycolysis, protein synthesis, membranes destabilization, etc. (Brown et al, 1993; Hisamitsu et al. 2001). Zinc increases

Table 4 - Effects of Zn application methods on N content and uptake of maize

Treatment	N content (%)				Total N content (%)	Total N uptake (kg ha^{-1})
	Grain	Straw				
		Leaf	Stem	Central Core		
Control (absolute)	1.52	0.89	1.31	0.35	2.37	83.23
Control (water priming)	1.62	0.86	1.37	0.55	2.55	91.05
Seed priming 1 %	1.57	0.94	1.29	0.60	2.51	94.12
Seed priming 2 %	1.64	0.92	1.44	0.70	2.68	107.96
Seed priming 3 %	1.83	0.97	1.58	0.71	2.90	109.23
Seed treatment 2g kg^{-1} seed	1.58	0.63	1.44	0.78	2.53	104.10
Seed treatment 4g kg^{-1} seed	1.95	0.99	1.57	0.98	3.12	136.01
Seed treatment 6g kg^{-1} seed	1.61	0.95	1.25	0.70	2.58	108.60
Soil application 4 kg ha^{-1}	1.48	0.59	1.15	0.62	2.26	86.51
Soil application 6 kg ha^{-1}	1.50	0.88	1.34	0.76	2.49	105.57
Soil application 8 kg ha^{-1}	1.83	1.22	1.61	0.90	3.07	123.95
Foliar application 0.25% (twice)	1.36	0.77	1.26	0.69	2.27	85.01
Foliar application 0.50% (twice)	1.58	0.91	1.29	0.71	2.55	101.29
Foliar application 0.75% (twice)	1.69	1.09	1.40	0.80	2.97	116.86
S.Em. ±	0.045	0.027	0.042	0.020	0.084	4.90
C.D. at 5%	0.137	0.083	0.130	0.060	0.25	14.98

chlorophyll contents and acts as a structural and catalytic component of proteins, enzymes and behave as a co-factor for normal development of pigment biosynthesis (Balashouri, 1995). Hence Zn helps to absorb plant nitrogen and convert it into various metabolic forms. Nitrogen fractions of maize showed that, highest nitrogen accumulation was observed in the following order, grain (35.28%) > stem (29.91%) > leaf (19.54%) > central core (15.27%) (Table 4). Zinc deficiency reduced the partitioning of 15N into different proteinous and non-proteinous N fractions in roots and shoots of maize to as low as 50% that of control (Dhillon et al, 1987). In this experiment, Zn application methods has correspondingly increased all N fractions and seed uptake with increase in respective Zn levels except in seed treatment. Samreen et al, in 2017 applied with Zn solutions at 0,1 and 2 μM concentrations to four varieties of mungbean. Plant growth, chlorophyll contents and crude proteins were noted to be higher at higher Zn levels. Deficiency of Zn negatively affected NO^{3-} reduction and NH_4^+ assimilation and enhanced photorespiration and changed the free AAs profile in cabbage and lettuce. In this case lettuce found more suitable for Zn deficient soils over cabbage, as it was able to accumulate a higher Zn concentration in leaves equivalent biomass reduction. However, cabbage accumulated nitrogen derived protective compounds to manage with Zn deficiency stress (Leon *et al.*, 2016). Among all zinc application treatments, significantly highest N content was recorded in maize grain (1.95%) and central core (0.98%) by application of 4g Zn kg^{-1} seed and the same treatment has registered highest total N content (3.12%) and N uptake (136.01 kg ha^{-1}) and this was followed by soil application of 8 kg Zn ha^{-1}, which has given highest N content in leaf and stem of maize significantly. Soil application 8 kg Zn ha^{-1} gave equivalent N content in grain (1.83%), total N content (3.07%) and N uptake (123.95 kg ha^{-1}) to that of seed treatment of 4g $ZnSO_4$ kg^{-1} seed. By comparing all agronomic Zn application methods and levels, chronologically highest nitrogen fractions and uptake was observed through seed treatment of Zn at 4g kg^{-1} seed, soil application at 8 kg ha^{-1}, foliar application at 0.75% and seed priming at 3%.

Phosphorus content and uptake

Phosphorus content was analyzed from different parts of maize plant revealed the highest phosphorus content in grain (37.73%) followed by leaf (26.71%) followed by stem (21.93%) and central core (13.63%) (Table 5). Safaya, 1976 reported P and Zn physiological coupling in maize, at low soil zinc more P is transported in leaves; however, at high soil P absorption rate of Zn reduced (Cakmak and Marschner 1986). Yadav et al, in 1987 applied Zn to cowpea at 0, 2.5, 5.0 and 10 ppm as a soil application and highest phosphorus was partitioned in grain (35.53%) followed by in root (34.47%) and shoot (30.00%), also phosphorus concentration increased up to 2.5 ppm and decreased in the following two levels in all plant parts, viz., grain, root and shoot at maturity. Samreen et al, 2017 also observed the same results in mungbean; phosphorus content decreased linearly with increase Zn from 1 to 2 μM, which signifying Zn/P complex foundation, preventing phosphorus movement in plant, on the other hand, crude protein increased with increase in Zn concentration. In

Table 5 - Effects of Zn application methods on P content and uptake of maize

Treatment	P content (%)				Total P content (%)	Total P uptake (kg ha^{-1})
	Grain	Straw				
		Leaf	Stem	Central core		
Control (absolute)	0.41	0.25	0.25	0.18	0.64	22.24
Control (water priming)	0.42	0.28	0.29	0.14	0.66	23.65
Seed priming 1 %	0.43	0.33	0.22	0.16	0.67	24.71
Seed priming 2 %	0.48	0.34	0.24	0.18	0.73	28.86
Seed priming 3 %	0.53	0.37	0.31	0.13	0.79	29.74
Seed treatment 2g kg^{-1} seed	0.45	0.32	0.27	0.11	0.68	27.80
Seed treatment 4g kg^{-1} seed	0.51	0.40	0.42	0.21	0.85	37.34
Seed treatment 6g kg^{-1} seed	0.53	0.27	0.31	0.10	0.76	31.11
Soil application 4 kg ha^{-1}	0.40	0.32	0.22	0.21	0.65	25.34
Soil application 6 kg ha^{-1}	0.50	0.41	0.27	0.23	0.81	34.09
Soil application 8 kg ha^{-1}	0.61	0.40	0.20	0.17	0.87	33.59
Foliar application 0.25% (twice)	0.40	0.31	0.25	0.18	0.65	24.10
Foliar application 0.50% (twice)	0.54	0.38	0.29	0.20	0.82	32.33
Foliar application 0.75% (twice)	0.57	0.42	0.40	0.25	0.93	38.88
S.Em. ±	0.012	0.010	0.008	0.006	0.022	1.45
C.D. at 5%	0.036	0.031	0.024	0.018	0.066	4.44

this experiment also phosphorus content of leaf, stem and central core was decreased with an increase in Zn concentration by seed treatment and soil application methods. However, all the Zn application methods improved the uptake and accumulation of phosphorus linearly in different parts of maize plant while increased its dose. Phosphorus partitioning in the root (40.27%) and shoot (59.73%) of maize was reduced with an increase in Zn concentration from 0 to 160 μM (Brandt et al, 2012). When Zn concentration was increased gradually from 0 to 10 ppm the P partitioning in shoots and roots decreased and increased, respectively, at 48 days after sowing in maize (Safaya, 1976). Among all zinc application methods and levels studied significantly highest P content in maize grain (0.61%) was observed by soil application of Zn @ 8 kg ha^{-1}, whereas highest P content in stem (0.42%) was given by seed treatment of 4g Zn kg^{-1} seed and both of these treatments were statistically similar with foliar application of Zn at 0.75%. However, the highest phosphorus was found in maize leaf (0.42%) and central core (0.25%) by foliar application of Zn at 0.75%. This same treatment also revealed highest total P content (0.93%) and total P uptake (38.88 kg ha^{-1}) by maize. The order of highest phosphorus partitioning in maize and its uptake is seed priming at 3%, seed treatment of Zn at 4g kg^{-1} seed, soil application at 8 kg Zn ha^{-1}, foliar application at 0.75%.

Potassium content and uptake

Potassium partitioning in maize grain, stem, leaf and central core has shown contrasting results as compared to N and P partitioning. Following is the K partitioning pattern in maize plant parts shown in the ascending order; central core (9.67%) < grain (14.83%) < stem (37.35%) < leaf (38.16%). Potassium accumulated more in maize plant leaf as compared to maize grain and stem. Carbohydrate partitioning is governed by K nutrition through phloem export of photosynthesis (sucrose) or growth rate of source and/or sink organs; also, K participates in photosynthates translocation from source to sink (Cakmak et al, 1994). However, total potassium content and uptake of maize were linearly increased with increase in Zn levels of seed priming and foliar application, on the other hand, seed treatment and soil application of Zn have increased total potassium content and uptake up to second level, this also differs with total N and P content and uptake. When Zn was applied as a soil application from 0 to 57.6 g ha^{-1} the K uptake increased from 574 to 997 mg plant^{-1} in cotton (Zakaria et al, 2008). Keshavarz et al, 2011 applied Zn as a foliar application to walnut at 0, 1050 and 1750 mg L^{-1} and they also found that leaf potassium was increased with increase in Zn foliar concentration. On the contrary, Samreen et al (2017) applied Zn to mungbean at 0,1 and 2 μM as a soil application and they discovered that mungbean plants potassium content was linearly decreased with increase in Zn level. Hasani et al (2012) sprayed Zn on pomegranate at 0, 0.3 and 0.6% concentration and opined that foliar K increased K up to second level and decreased at third level, which also confirms these findings reported in our research. A significantly highest K content (Table 6) in maize grain (0.70%), leaf (1.72%) and stem (1.69%) and central core

Table 6 - Effects of Zn application methods on K content and uptake of maize

Treatment	K content (%)				Total K content (%)	Total K uptake (kg ha^{-1})
	Grain	Straw				
		Leaf	Stem	Central core		
Control (absolute)	0.60	1.47	1.47	0.42	1.72	67.58
Control (water priming)	0.62	1.55	1.48	0.40	1.77	70.35
Seed priming 1 %	0.60	1.53	1.55	0.39	1.76	73.18
Seed priming 2 %	0.62	1.61	1.57	0.45	1.83	80.57
Seed priming 3 %	0.64	1.72	1.69	0.34	1.90	79.46
Seed treatment 2g kg^{-1} seed	0.46	1.38	1.43	0.40	1.53	70.45
Seed treatment 4g kg^{-1} seed	0.68	1.63	1.68	0.47	1.93	92.02
Seed treatment 6g kg^{-1} seed	0.65	1.62	1.39	0.42	1.79	82.59
Soil application 4 kg ha^{-1}	0.58	1.45	1.59	0.39	1.72	74.27
Soil application 6 kg ha^{-1}	0.70	1.70	1.67	0.40	1.96	89.98
Soil application 8 kg ha^{-1}	0.60	1.52	1.42	0.28	1.68	73.42
Foliar application 0.25% (twice)	0.54	1.58	1.46	0.36	1.67	69.74
Foliar application 0.50% (twice)	0.63	1.63	1.54	0.40	1.82	79.74
Foliar application 0.75% (twice)	0.64	1.64	1.62	0.46	1.88	86.40
S.Em. ±	0.014	0.050	0.046	0.012	0.053	3.72
C.D. at 5%	0.045	0.153	0.142	0.035	0.164	11.37

(0.47%) was respectively found by soil application at 6 kg Zn ha^{-1}, seed priming at 3% and seed treatment of 4g Zn kg^{-1} seed, however, all these treatments were at par with seed treatment of 4g Zn kg^{-1} seed and this has gave highest total K content (1.96%) and uptake (92.02 kg ha^{-1}). Considering all four Zn application methods, the highest K content and uptake was registered with seed priming at 2%, foliar application at 0.75%, soil application at 6 kg ha^{-1} and seed treatment of 4g Zn kg^{-1} seed in the ascending order.

Zinc content and uptake

Among different parts of the maize plant, zinc partitioning decreased in the order of leaf (42.29%) > stem (23.67%) > grain (18.91%) > central core (15.13%), indicating that maize leaf and stem are much denser in Zn content than maize kernels (Table 7).The higher Zn content in leaf and stem compared to the maize kernel reflects low mobilization of Zn from different parts to the kernel, producing the lowest Zn content in the kernel. Ghasal et al (2018) also studied Zn biofortification and its partitioning in rice and they have found that rice straw and hull were more rich with Zn than rice kernel. All Zn application methods in maize has served the purpose of the experiment to enrich maize grain with Zn. Variety wise differences in nutrient content in crops depends on its genetic makeup and ability to absorb soil nutrient (Yadi et al, 2012). Within plants, zinc is more mobile than other nutrients and foliar application leads to translocation of Zn in leaves other than the treated leaf as well as to root tips. In this experiment variegated findings were observed for different plant parts of maize for Zn accumulation. Highest Zn accumulation in maize grain (57.81 mg kg^{-1}), leaf (135.24 mg kg^{-1}) and stem (72.79 mg kg^{-1}) + central core (44.00 mg kg^{-1}) was observed, respectively by seed treatment at 4g kg^{-1} seed, soil application at 6 kg ha^{-1}and foliar Zn spray at 0.75%, respectively. Zn priming of seeds increased grain yield and also significantly enhanced the Zn concentration of grain by 12 and 29%, respectively, in wheat and chickpea (Harris et al, 2007). In this experiment maximum total Zn accumulation (135.08 mg kg^{-1}) and total Zn uptake (625.40 g ha^{-1}) was registered by seed treatment at 4g kg^{-1} and it was statistically similar with soil application of Zn at 6 kg ha^{-1} (126.83 mg kg^{-1} and 576.27 g ha^{-1}) and foliar Zn spray at 0.75% (128.30 mg kg^{-1} and 576.53 g ha^{-1}).The highest increase in Zn uptake by maize plants was observed through seed treatment followed by soil application (Kanwal et al, 2009). Foliar application of Zn at 2% has increased the grain Zn content in maize hybrids as compared to seed priming of Zn at 2% during both the two years of the experiment (Mohsin et al, 2014). The chronological order of the highest Zn enrichment in maize crop was seed treatment > soil application > foliar application. This justifies why seed treatment at 4g kg^{-1} enriched Zn in seed most; however, maize crop received foliar application of Zn most late and hence highest Zn accumulated in stem and central core. Shivay et al. (2016) found that zinc recovery with foliar application was about eight times higher over soil application in rice; however, in this experiment, seed treatment has given highest zinc uptake and which is statistically similar with foliar application. Looking to the purpose of the experiment of Zn enrichment in

Table 7 - Effects of Zn application methods on Zn content and uptake of maize

Treatment	Zn content (mg kg^{-1})				Total Zn content (mg kg^{-1})	Total Zn uptake (g ha^{-1})
	Grain	Straw				
		Leaf	Stem	Central core		
Control (absolute)	33.81	99.07	46.57	35.20	94.07	368.17
Control (water priming)	41.60	102.02	58.78	34.02	107.53	419.00
Seed priming 1 %	40.60	99.41	66.40	35.60	107.73	443.16
Seed priming 2 %	48.00	109.40	68.56	40.60	120.85	521.63
Seed priming 3 %	49.37	105.13	49.00	38.13	113.47	460.62
Seed treatment 2g kg^{-1} seed	47.05	98.05	50.80	40.41	110.07	485.74
Seed treatment 4g kg^{-1} seed	57.81	121.67	66.60	43.67	135.08	625.40
Seed treatment 6g kg^{-1} seed	50.59	99.40	54.81	38.40	114.82	515.38
Soil application 4 kg ha^{-1}	49.23	119.22	51.00	37.03	118.27	495.49
Soil application 6 kg ha^{-1}	50.03	135.24	57.59	37.60	126.83	576.27
Soil application 8 kg ha^{-1}	52.80	92.80	58.00	42.40	117.20	498.13
Foliar application 0.25% (twice)	48.32	102.63	70.83	30.00	116.12	467.64
Foliar application 0.50% (twice)	51.79	110.59	71.02	41.61	126.19	540.75
Foliar application 0.75% (twice)	52.37	111.03	72.79	44.00	128.30	576.53
S.Em. ±	1.18	3.64	2.00	1.15	3.98	25.75
C.D. at 5%	3.62	11.14	6.13	3.53	12.15	78.68

maize seeds, seed priming at 3%, seed treatment at 4g Zn kg^{-1} seed, soil application at 8 kg Zn ha^{-1} and foliar application at 0.75% has fortified maize seeds through Zn respectively by 146.02, 170.98, 156.17 and 154.89 %. Hence seed treatment came out to be most efficient method to fix Zn in maize grain.

Protein content and yield influenced by different Zn application methods

Among all Zn application methods, significantly highest protein content (12.21%) and yield (463 kg ha^{-1}) was registered by seed treatment at 4g Zn kg^{-1} seed, however it was found at par with seed priming at 3% (11.46% and 368 kg ha^{-1}) and soil application of Zn at 8 kg ha^{-1} (11.42% and 391 kg ha^{-1}) (Table 8). Protein content and yield increased linearly with increase in Zn levels in all methods of Zn application except seed treatment. Lowest protein content and yield was observed in absolute control (9.52% and 285 kg ha^{-1}). Zn controls auxin synthesis in plants and its deficiency in plants causes distortion of leaf and internodes shortening, which results in poor synthesis of plant proteins (Begum et al, 2016). All Zn application methods has shown an increasing trend of protein content and protein yield with increase in Zn level, except seed treatment, where protein content and yield increased up second level (4g Zn kg^{-1} seed) and decreased further at third level also. And the same treatment has increased protein content and yield by 128.26% and 162.45%, respectively over absolute control (Table 8). Zn content of grain have a positive correlation with a protein content of maize grain. No change in protein content of two maize hybrids DK-919 and Pioneer 30-Y87 was found when Zn was applied through seed priming and foliar application alone or in combination of both over no application of Zn (Mohsin et al, 2014). Protein content and yield increased linearly with increase in the level of Zn in every application methods in general, hence this experiment has shown that different Zn application methods increases N content and, ultimately, protein content in maize crop.

Elemental N, P, and K in soil affected by different Zn application methods

Method wise two different trends of elemental soil nitrogen were observed in four Zn application methods. Two methods, namely seed priming from 1 to 2% (170.19 and 185.78 kg ha^{-1}) and seed treatment from 2 to 4g kg^{-1}seed (177.42 and 190.29 kg ha^{-1}) has registered highest elemental soil nitrogen with an increasing trend and it was further decreased in their respective third levels. Maize grain yield was also decreased at third level of seed priming and seed treatment. However, soil application from 4 to 8 kg ha^{-1} and foliar spray from 0.25 to 0.75% were observed an inverse trend of elemental soil nitrogen with an increase in the respective level of Zn.However, highest maize grain yield was seen at second level of soil and foliar application of Zn. Highest N (190.29 kg ha^{-1}) and P (35.19 kg ha^{-1}) in soil was observed by seed treatment of 4 g Zn kg^{-1}seed and the same treatment has given highest grain yield of maize (3795 kg ha^{-1}) and residual N in soil over initial N (185.74 kg ha^{-1}).

Method wise two different trends of elemental soil

Table 8 - Effects of Zn application methods on protein yield of maize and soil nutrient composition

Treatments	Protein content (%)	Protein yield (kg ha^{-1})	Soil N (kg ha^{-1})	Soil P_2O_5 (kg ha^{-1})	Soil K_2O (kg ha^{-1})	Soil Zn (mg kg^{-1})
Control (absolute)	9.52	285	168.58	20.61	268.21	0.66
Control (water priming)	10.10	307	175.81	31.17	312.83	0.67
Seed priming 1 %	9.83	313	170.19	19.61	263.55	0.68
Seed priming 2 %	10.27	351	185.78	32.18	291.63	0.67
Seed priming 3 %	11.46	368	162.15	26.14	304.80	0.69
Seed treatment 2g kg^{-1} seed	9.85	349	177.42	29.66	365.87	0.67
Seed treatment 4g kg^{-1} seed	12.21	463	190.29	35.19	318.81	0.70
Seed treatment 6g kg^{-1} seed	10.08	368	151.69	24.13	302.10	0.84
Soil application 4 kg ha^{-1}	9.23	305	183.05	22.12	375.32	0.84
Soil application 6 kg ha^{-1}	9.35	340	157.32	34.18	367.86	1.15
Soil application 8 kg ha^{-1}	11.42	391	154.11	32.18	309.53	1.72
Foliar application 0.25% (twice)	8.48	305	163.75	24.21	276.60	2.09
Foliar application 0.50% (twice)	9.85	310	163.27	23.13	275.41	3.78
Foliar application 0.75% (twice)	10.58	360	153.30	14.08	254.07	2.98
S.Em. ±	0.29	18.34	7.00	1.38	13.82	0.052
C.D. at 5%	0.88	56.03	21.40	4.23	42.20	0.158

phosphorus were observed. Three Zn application methods, namely seed priming, seed treatment and soil application has registered highest elemental soil phosphorus with increasing trend up to second level and it was further decreased in their respective third levels. However, the foliar application of Zn has shown a decreasing trend of elemental soil phosphorus with increasing foliar spray levels from 0.25 to 0.75% (24.21, 23.13 and 14.08 kg ha^{-1}). Among all treatments highest residual elemental soil P_2O_5 was observed by seed treatment of 4g Zn kg^{-1} seed (37.95 kg ha^{-1} highest maize grain yield), soil application at 6 kg Zn ha^{-1} and seed priming at 2% (35.19, 34.18 and 32.18 P_2O_5 kg ha^{-1}, respectively) (Table 8). The antagonistic effect between Zn and phosphorus is known. Whenever elemental soil Zn is high in soil, the availability of elemental soil phosphorus is always low in general. Safaya, 1976 also had same findings, soil P was decreased with increase in Zn from 0 to 10 ppm. Here, in this case, all Zn application methods has increased the elemental soil phosphorous up to their second level and decreased in third level, except foliar application method where soil phosphorus decreased with increase in foliar Zn level. However, Yadav et al, 1985 emphasized that the site of interaction between P and Zn was not soil but probably plant root surfaces and plants.

In the case of elemental soil K_2O, application of 4 kg Zn ha^{-1} has shown the highest elemental soil K_2O (375.32 kg ha^{-1}) (Table 8). Seed priming has increased K_2O in soil with increase in Zn level from 1 to 3% over initial K_2O (334.57 kg ha^{-1}). Except for the first level of seed treatment and first two levels of soil application of Zn, all treatments eroded initial K_2O in soil. On the contrary, the other three methods of Zn application namely seed treatment, soil application and foliar spray has shown a decreasing trend of elemental soil K_2O with increase in all three Zn levels. Maize roots are usually distributed in top soil and its half roots are with the layer of 0-15 cm layer (Peng et al, 2010). Hence, the uptake and translocation of Zn from roots to shoots can be more if Zn is fertilized in 0 – 15 cm soil layer (Zhang *et al*, 2013).There is a negative correlation between Zn availability in soil and higher concentration of phosphate and pH in soil, which is a cause of the Zn deficiency problem in rice (Sadeghzadeh, 2013).

Elemental Zn in soil affected by Zn application

Residual elemental soil Zn was increased with the increase in Zn dose through various application methods and levels (Table 8). Zn priming has shown no specific trend of elemental soil Zn. Application of Zn through seed treatment and soil application has shown an increasing trend of elemental soil Zn. Residual elemental soil Zn was increased with increase in Zn foliar dose from 0.25 (2.09 mg kg^{-1}) to 0.50% (3.78 mg kg-1) and decreased further with 0.75% foliar dose (2.98 mg kg^{-1}), which was very high over initial Zn in soil (0.64 mg kg^{-1}). Zn availability increased in soil from 1.33 to 7.5 ppm when zinc dose increased from 0 to 10 ppm (Safaya, 1976). In rice, there is no alternative for Zn application through soil, as it is more efficient over foliar sprays (Krishnaswamy et al, 1994). On the contrary, when Zn was applied as foliar sprays, it easily absorbed and transported in plants (Pathak et al, 2012). Soil applied Zn may have formed complexes with humic substances due to organic matter in soil and Zn

Table 9 - Effects of Zn application methods on economics of maize

Treatment	Cost of production (€ ha^{-1})	Gross realization (€ ha^{-1})	Net realization (€ ha^{-1})	Benefit: Cost Ratio
Control (absolute)	283	709	425	2.50
Control (water priming)	283	720	436	2.54
Seed priming 1 %	288	752	464	2.61
Seed priming 2 %	292	803	510	2.74
Seed priming 3 %	297	758	461	2.55
Seed treatment 2g kg^{-1} seed	284	831	547	2.92
Seed treatment 4g kg^{-1} seed	285	883	598	3.10
Seed treatment 6g kg^{-1} seed	286	854	568	2.98
Soil application 4 kg ha^{-1}	355	779	423	2.19
Soil application 6 kg ha^{-1}	391	850	459	2.17
Soil application 8 kg ha^{-1}	427	805	378	1.88
Foliar application 0.25% (twice)	297	744	447	2.51
Foliar application 0.50% (twice)	310	799	489	2.57
Foliar application 0.75% (twice)	324	842	519	2.60

mineralisation results due to the formation of a number of insoluble Zn complexes. Hence, this results in increase in Zn availability to maize plants. Progressively higher Zn antagonism is seen on the absorption rate of Mn by the roots of maize as the level of P increased (Safaya, 1976). As Zn supply in soil increased through all application methods, its elemental availability also increased in soil in general, but at the same time, residual P availability in soil decreased at third level in priming, seed treatment and soil application methods. However, there was a sharp and clear antagonistic effect between elemental P and Zn was seen in the foliar application of Zn; this was because Zn was applied at 60 DAS and at tasseling stage of maize crop. The crop utilized the required Zn and the remaining Zn was sent to soil by the crop at its reproduction stage, hence its residual Zn availability became high at reproduction stage of crop due to foliar Zn application over priming, seed treatment and soil application methods which were applied at crop sowing time, hence required Zn for metabolic activity was utilized and remaining Zn was fixed by various ways. In this experiment, one more clear finding regarding residual elemental K in soil is that the K availability decreases with increase in Zn dose in seed treatment, soil and foliar application method of Zn application.

Maize economic evaluation

Application of Zn to maize has influenced the yield and economic returns. Soil application (427 € ha^{-1}) of Zn at 8 kg ha^{-1} turned out to be the most expensive, followed by soil application (391 € ha^{-1}) at 6 kg ha^{-1}(Table 9). Among all treatments, seed treatment of Zn at 4 g kg^{-1} seed gained the highest gross realisation (883 € ha^{-1}), net realisation (598 € ha^{-1}), and benefit:cost ratio (3.10) which was followed by seed treatment of Zn at 6 g kg^{-1} seed. Method wise economic study shows that, application of Zn through seed priming at 2% (803 € ha^{-1}, 510 € ha^{-1}, 2.74, respectively), seed treatment of Zn at 4 g kg^{-1} seed (883 € ha^{-1}, 598 € ha^{-1}, 3.10, respectively), soil application of 6 kg ha^{-1} (850 € ha^{-1}, 459 € ha^{-1}, 2.17, respectively) and foliar spray at 0.5% (842 € ha^{-1}, 519€ ha^{-1}, 2.60, respectively) executed highest gross realisation, net realisation and benefit:cost ratio. Hence seed treatment of Zn at 4 g kg^{-1} seed can be recommended for giving highest maize yield and economics from the farmer's point of view.

Regression study of yield through Zn application methods

The regression model for each of different forms of Zn application like seed priming, seed treatment, soil application, and foliar application has been described in Figure 2. The coefficient of determination for various conditions of Zn application had been varied hugely. Firstly from seed priming, seed treatment and soil application, it can be seen that the r^2 value cannot be considered to closer or nearly to 1, which implies the regression models are not in good fit compared to the last condition of Zn application, i.e., foliar application, revealed the r^2 value is 0.99 is in good fit one. As it can be seen that, in case of seed priming and soil application slope in comparative is lower than the other two models (seed treatment and foliar application), which can imply that effect of application of Zn is slower as compared to the seed treatment and foliar application. Hence the total variation in yield cannot be described by the different levels of Zn concentrations for earlier three models i.e. seed priming, seed treatment, and soil application, whereas in the fourth case, the yield is much more dependable or effected or improved by the foliar application of Zn. In this case, the slope is also higher i.e. y = 819.6x + 2979, which means the application of Zn works faster in the foliar application method compared to other methods. In a nutshell it can be inferred that, though foliar application of Zn seems to be better but it creates soil pollution due to Zn accumulation in soil as it is applied at grand growth and tasseling period hence the Zn removal from the soil cannot take place in effective manner where as in case of soil application of Zn in three leaf stage gets more time for Zn removal from soil. On the other hand, the application of Zn through seed treatment has increased maize grain yield highest and at the same time, it has produced Zn enriched kernels with also highest net realization and benefit:cost ratio. Hence application of 4g $ZnSO_4$ kg^{-1} seed as seed treatment can be preferred over the other three Zn application methods to be incorporated in agronomic package of practice in maize cultivation.

Conclusions

Zn application through seed treatment at 4g kg^{-1} seed produced highest growth, yield, nutrient content, uptake and quality of maize over control and absolute control. Hence the seed treatment method turned out to be the cheapest method among all the other methods studied and served the purpose of experiment to determine the actual form of Zn application. Application of Zn @ 4g kg^{-1} seed gave rise the highest Zn accumulation in grain (57.81 mg kg^{-1}), leaf (121.67 mg kg^{-1}) , stem (66.60 mg kg^{-1}) and central core (43.67 mg kg^{-1}) with an uptake of 625.40 g ha^{-1} Zn which is highest among all the other Zn application methods tested. However, from the point of view of residual elemental Zn in soil, foliar application of Zn at 0.50% was sustainable to keep more Zn in soil. This study signified specifically seed treatment @ 4g kg^{-1} with Zn to enrich the maize crop over the other methods of application both in yield and quality.

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