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# Enrichment of Maize Grains with Zinc through Agronomic Biofortification

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A field experiment was conducted at instructional-cum-research farm of Assam Agricultural University, Jorhat, Assam to enrich zinc (Zn) in grains of a hybrid maize variety (PAC 740) through soil application of Zn with six levels of $ZnSO_4.7H_2O$ *viz*. 0, 20, 40, 60, 80 and 100 kg $ha^{-1}$ with and without foliar spray of 0.5% $ZnSO_4.7H_2O$ at tasseling stage. Highest grain yield (7.83 t $ha^{-1}$) was recorded with 60 kg $ZnSO_4.7H_2O$ (soil) + 0.5% foliar spray. Significant increase in grain yield over control was observed at 40 kg $ZnSO_4.7H_2O$ and above. Foliar application of Zn though improved yield, but statistically had no effect on yield, plant height and number of grains per cob between graded doses of Zn with and without foliar application. However, grain Zn concentration and uptake were more effectively increased by Zn fertilization, especially with soil and foliar applications. Significantly highest grain Zn concentration (46.9 mg $kg^{-1}$) and uptake of Zn (358.2 g $ha^{-1}$) was observed with 100 kg $ZnSO_4.7H_2O$ $ha^{-1}$ (soil)+0.5% foliar application over control. Nitrogen and potassium concentration and uptake by grains increased with the increasing level of Zn but phosphorus concentration and uptake decreased. Agronomic efficiency and apparent recovery efficiency was found highest in the treatment with 60 kg $ZnSO_4.7H_2O$ $ha^{-1}$ (soil)+0.5% foliar application. Soluble protein increased significantly over control with 40 kg $ZnSO_4.7H_2O$ $ha^{-1}$ (7.41%) and above. Although, crude protein and starch content increased with the increase in Zn concentration, the effect was not significant with increasing dose of $ZnSO_4.7H_2O$.

**Key words:** Zinc, concentration, uptake, foliar application, soil application, maize

Micronutrient malnutrition is becoming a serious concern worldwide. Measures to correct micronutrient deficiencies aim at ensuring consumption of a balanced diet that is adequate in every nutrient. Zinc (Zn) deficiency is a severe micronutrient deficiency problem in human health globally, which affects more than one-third of the world's population (Stein 2010). According to Sharma *et al.* (2013), availability of Zn to plant is hampered by its immobile nature and adverse soil conditions. Thus, Zn deficiency is observed even though high amount is available in soil. Root-shoot barrier, a major controller of Zn transport in plant is highly affected by changes in the anatomical structure of conducting tissue and adverse soil conditions like pH, clay content, calcium carbonate content, *etc*.

The grain and straw Zn content can be increased by biofortification through Zn fertilization. Concentration of Zn in cereal grain can be increased with an increase in Zn fertilizer additions at critical growth stages. Zinc use efficiency can also be improved through foliar application of Zn fertilizers because plants are capable of absorbing soluble compounds and gases through leaves. Application of foliar spray implies that nutrient applied will be absorbed from the point of application (leaves) to the point of utilization (growing tissue). Maximum absorption of Zn occurs at near physiological maturity stage which corresponds to tasseling (Borges *et al.* 2009), and the most effective method for increasing grain Zn is the soil+foliar application method which may results in an about 3-fold increase in grain Zn concentration (Cakmak 2010).

Maize is the third most important food crop after rice and wheat and contributes around 24% of total cereal production (Singh *et al.* 2011). It is grown in Assam in about 32264 ha with a production of 105003 tonnes and productivity of 3254 kg $ha^{-1}$ (Anonymous 2019). In India, at present about 35% of the maize produced in the country is used for human

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consumption, 25% each in poultry feed and cattle feed and 15% in food processing (corn flakes, popcorn *etc*.) and other industries (starch, dextrose, syrup, oil *etc*.). Hence, considering the importance of Zn and maize crop in human and animal nutrition, it is necessary to improve the Zn nutritional status of the crop and to mitigate Zn malnutrition.

**Materials and Methods**

A field experiment was conducted during *kharif* season of 2018 in the Instructional-cum-Research Farm, Assam Agricultural University, Jorhat to study enrichment of maize grains with Zn through agronomic biofortification. The experiment was carried out with twelve treatments in a randomised block design with three replications having plot size of 4.2 m × 3 m. The treatments were:

$T_1$: RDF (Recommended dose of fertilizers)
$T_2$: RDF+0.5% foliar spray of $ZnSO_4.7H_2O$ $ha^{-1}$
$T_3$: RDF+20 kg $ZnSO_4.7H_2O$ $ha^{-1}$
$T_4$: RDF+20 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray
$T_5$: RDF+40 kg $ZnSO_4.7H_2O$ $ha^{-1}$
$T_6$: RDF+40 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray
$T_7$: RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$
$T_8$: RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray
$T_9$: RDF+80 kg $ZnSO_4.7H_2O$ $ha^{-1}$
$T_{10}$: RDF+80 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray
$T_{11}$: RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$
$T_{12}$: RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray

The hybrid maize (variety PAC 740) was sown on 12th March 2018 and harvested on 8th June 2018. Recommended dose of fertilizers (RDF) of N, $P_2O_5$ and $K_2O$ @ 60, 40 and 40 kg $ha^{-1}$, respectively and different levels of $ZnSO_4.7H_2O$ (20, 40, 60, 80 and 100 kg $ha^{-1}$) were made as soil application before sowing of crop. While, 0.5% $ZnSO_4.7H_2O$ was applied as foliar spray at tasseling stage.

Before commencement of the field experiment, surface soil samples (0-15 cm) were collected randomly from the experimental site using stainless steel auger and a composite sample was prepared. The soil sample was processed after drying under shade, passed through 2-mm sieve and stored in polythene bags and physicochemical properties of the soils were determined. Soil samples were analyzed for mechanical composition by International Pipette Method (Piper 1966), organic carbon (Walkley and Black 1934), pH and electrical conductivity (Jackson 1973) using soil:water ratio of 1:2.5, cation exchange capacity (CEC) by neutral normal $NH_4OAc$ leaching method (Jackson 1973), available nitrogen (N) by alkaline potassium permanganate method (Subbiah and Asija 1956), available phosphorus (P) by Bray's I method (Bray and Kurtz 1945), available potassium (K) by extracting the soil with neutral normal ammonium acetate (Jackson 1973), available sulphur (S) by extraction with 0.15% $CaCl_2$ (Chesnin and Yien 1951), exchangeable calcium (Ca), magnesium (Mg) by ethylene diamine tetra-acetic acid (EDTA) titration method (Jackson 1973), available iron (Fe), copper (Cu), zinc (Zn) and manganese (Mn) by diethylene triamine penta-acetic acid (DTPA) extraction method (Lindsay and Norvell 1978) and boron (B) by Azomethine-H method (Bingham 1982).

Plant attributes such as plant height, number of grains per cob, cob yield, grain and stover yields were recorded plot-wise at maturity. Grain and straw samples were ground, digested with diacid mixture ($HNO_3$:$HClO_4$ at 3:1) as per the procedure of Jackson (1973) and analyzed for Zn content by atomic absorption spectrophotometer. Nitrogen content in grain and stover was determined by modified Kjeldahl method (Jackson 1973). The Zn uptake by maize grain and straw was calculated by multiplying the grain and straw yield with respective Zn content. Soluble protein content in maize grain was estimated by the method as described by Lowry *et al.* (1951). Crude protein of maize grain was estimated by multiplying per cent N content in grain by 6.25. Starch content in maize grain was determined by anthrone reagent method (Hedge and Hofreiter 1962). The Zn use efficiency (kg grain $kg^{-1}$ Zn applied) and apparent Zn recovery (%) of maize grain were calculated following the procedure of Baligar *et al.* (2001).

**Results and Discussion**

*Physicochemical properties of soil*

The soil of the experimental site was sandy clay loam in texture, strongly acidic in reaction (pH of 4.67), medium in organic carbon content (6.0 g $kg^{-1}$) and low in CEC [5.30 cmol($p^+$)$kg^{-1}$] (Table 1). The available nutrients (N, P, K, Ca and Mg) in soil were found to be low but available S was sufficient. The DTPA-extractable Zn was found to be very high with a value of 1.87 mg $kg^{-1}$.

*Yield attributing characters, cob yield, grain yield and stover yield*

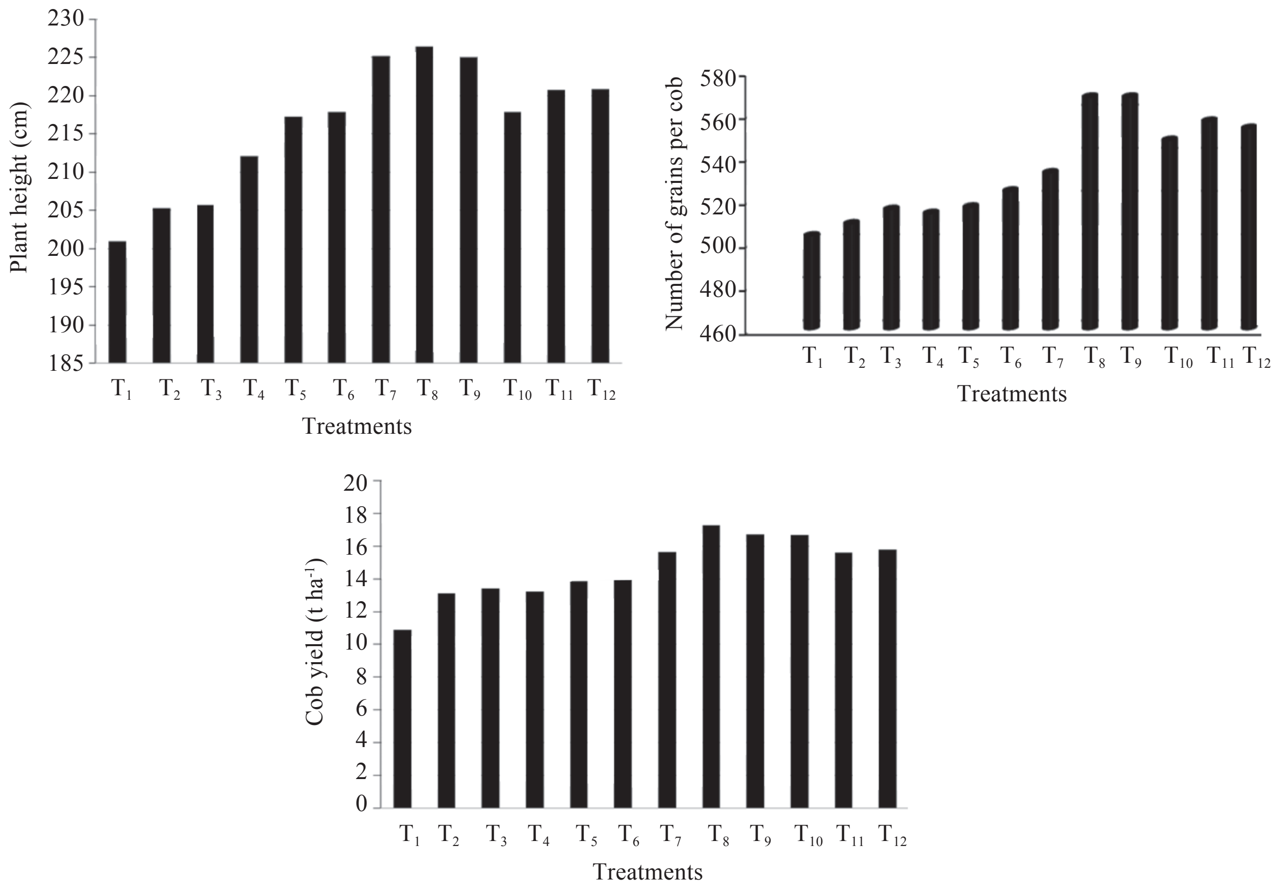
Application of $ZnSO_4.7H_2O$ alone as soil application or with 0.5% foliar spray improved plant height, number of grains per cob and cob yield over control (Fig. 1) but there was no significant difference between the graded doses of Zn with or without foliar

**Table 1.** Physicochemical properties of the initial soil

| Properties | Values |
|---|---|
| Sand (%) | 53.3 |
| Silt (%) | 12.4 |
| Clay (%) | 34.3 |
| Textural class | Sandy clay loam |
| pH (soil:water :: 1: 2.5) | 4.67 |
| Electrical conductivity (dS $m^{-1}$) | 0.12 |
| Organic carbon (g $kg^{-1}$) | 6.0 |
| Cation exchange capacity [cmol($p^+$) $kg^{-1}$] | 5.30 |
| Available N (kg $ha^{-1}$) | 196.0 |
| Available P (kg $P_2O_5$ $ha^{-1}$) | 17.32 |
| Available K (kg $K_2O$ $ha^{-1}$) | 189.5 |
| Available Ca [cmol($p^+$) $kg^{-1}$] | 0.90 |
| Available Mg [cmol($p^+$) $kg^{-1}$] | 0.60 |
| Available S (mg $kg^{-1}$) | 25.9 |
| Available Zn (mg $kg^{-1}$) | 1.87 |
| Available Fe (mg $kg^{-1}$) | 78.1 |
| Available Cu (mg $kg^{-1}$) | 2.12 |
| Available Mn (mg $kg^{-1}$) | 24.2 |
| Available B (mg $kg^{-1}$) | 0.42 |

spray. This was probably due to the high DTPA extractable Zn (1.87 mg $kg^{-1}$) in the initial soil, which was well above the critical level of soil Zn deficiency (0.6 mg $kg^{-1}$). Similar results of slight increase in growth and yield attributing characters were also reported by Panneerselvam *et al.* (2014) while applying varied levels of Zn in a high initial Zn status soil.

Grain yield responded positively to Zn application up to $T_8$ (60 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray), and beyond this treatment it showed decline in yield (Table 2). Highest grain yield (7.83 t $ha^{-1}$) was obtained in $T_8$ (RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$ +0.5% foliar spray). A significant increase in grain yield after foliar application of Zn could be expected when plants are grown on a Zn deficient soil as reported by Cakmak (2010). Compared to soil application of Zn, supplementing it with foliar spray increased grain yield of maize, irrespective of Zn fertilizer doses. However, the difference in grain yield




*$T_1$: RDF (Recommended dose of fertilizers); $T_2$: RDF+0.5% foliar spray of $ZnSO_4.7H_2O$ $ha^{-1}$; $T_3$: RDF+20 kg $ZnSO_4.7H_2O$ $ha^{-1}$; $T_4$: RDF+20 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray; $T_5$: RDF+40 kg $ZnSO_4.7H_2O$ $ha^{-1}$; $T_6$: RDF+40 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray; $T_7$: RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$; $T_8$: RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray; $T_9$: RDF+80 kg $ZnSO_4.7H_2O$ $ha^{-1}$; $T_{10}$: RDF+80 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray; $T_{11}$: RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$; $T_{12}$: RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray*

**Fig. 1.** Effect of zinc levels on plant height (Fig. 1a), number of grains (Fig. 1b) and cob yield (Fig. 1c) of maize

**Table 2.** Effect of zinc levels on grain yield and stover yield of maize

| Treatments | Maize yield (t $ha^{-1}$) | |
|---|---|---|
| | Grain yield | Stover yield |
| $T_1$: RDF (Recommended dose of fertilizers) | 4.60 | 13.0 |
| $T_2$: RDF+0.5% foliar spray of $ZnSO_4.7H_2O$ $ha^{-1}$ | 4.77 | 14.3 |
| $T_3$: RDF+20 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 5.03 | 15.0 |
| $T_4$: RDF+20 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 5.40 | 15.9 |
| $T_5$: RDF+40 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 6.00 | 13.9 |
| $T_6$: RDF+40 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 6.53 | 14.3 |
| $T_7$: RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 6.63 | 13.2 |
| $T_8$: RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 7.83 | 17.4 |
| $T_9$: RDF+80 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 7.57 | 15.6 |
| $T_{10}$: RDF+80 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 7.50 | 17.1 |
| $T_{11}$: RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 7.47 | 14.8 |
| $T_{12}$: RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 7.63 | 15.9 |
| SEm ± | 0.57 | 1.88 |
| *CD (P=0.05)* | 1.19 | 3.91 |
| CV | 8.73 | 12.7 |

between soil application with or without foliar spray was not significant among the graded doses of Zn. Nevertheless, foliar spraying is normally applied to increase plant nutrient uptake when soil immobilization mechanisms reduce $ZnSO_4$ movement in the soil. Similar trend was also observed in stover yield with highest yield (17.1 t $ha^{-1}$) in $T_8$ (RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray).

*Zinc content in maize*

Zinc content in maize grain (Table 3) was highest (46.9 mg $kg^{-1}$) in $T_{12}$ (RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray). This may be due to the direct application of Zn at critical growth stage (tasseling), which helped in increasing its absorption in the grain during ripening (Gogoi *et al.* 2016). Application of Zn with or without foliar spray increased per cent grain Zn content over control (Table 3); the increase was up to 113.6 per cent at 100 kg $ZnSO_4.7H_2O$ $ha^{-1}$ without foliar spray and up to 114.9 per cent at 100 kg $ZnSO_4.7H_2O$ $ha^{-1}$ with 0.5% foliar spray. The results are also in agreement with those of (Manzeke *et al.* 2011) who reported that application of Zn in maize increased grain Zn content by as much as 100 per cent over control.

Stover Zn content was also increased significantly with application of different levels of $ZnSO_4.7H_2O$ with or without foliar spray except in

**Table 3.** Effect of zinc levels on zinc content in maize grain and straw

| Treatments | Grain Zn | | Stover Zn | |
|---|---|---|---|---|
| | Zn content (mg $kg^{-1}$) | % increase over control | Zn content (mg $kg^{-1}$) | % increase over control |
| $T_1$: RDF (Recommended dose of fertilizers) | 21.8 | | 25.9 | |
| $T_2$: RDF+0.5% foliar spray of $ZnSO_4.7H_2O$ $ha^{-1}$ | 22.5 | 2.9 | 25.9 | 0.1 |
| $T_3$: RDF+20 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 25.1 | 14.7 | 31.4 | 21.2 |
| $T_4$: RDF+20 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 30.0 | 37.1 | 34.6 | 33.8 |
| $T_5$: RDF+40 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 32.4 | 48.1 | 41.1 | 58.8 |
| $T_6$: RDF+40 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 35.6 | 62.8 | 41.2 | 59.3 |
| $T_7$: RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 37.8 | 73.0 | 45.8 | 76.8 |
| $T_8$: RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 41.1 | 88.4 | 49.4 | 90.7 |
| $T_9$: RDF+80 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 43.9 | 100.8 | 50.3 | 94.2 |
| $T_{10}$: RDF+80 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 46.7 | 113.6 | 52.2 | 101.8 |
| $T_{11}$: RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 46.7 | 113.6 | 55.3 | 113.6 |
| $T_{12}$: RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 46.9 | 114.9 | 56.3 | 117.5 |
| SEm ± | 1.22 | | 1.86 | |
| *CD (P=0.05)* | 2.54 | | 3.26 | |
| CV | 3.37 | | 7.68 | |

**Table 4.** Effect of zinc levels on zinc uptake by maize grain and straw

| Treatments | Maize Zn uptake (g $ha^{-1}$) | |
|---|---|---|
| | Grain | Stover |
| $T_1$: RDF (Recommended dose of fertilizers) | 100.5 | 336.4 |
| $T_2$: RDF+0.5% foliar spray of $ZnSO_4.7H_2O$ $ha^{-1}$ | 107.2 | 371.0 |
| $T_3$: RDF+20 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 126.1 | 401.5 |
| $T_4$: RDF+20 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 161.7 | 552.2 |
| $T_5$: RDF+40 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 194.1 | 560.1 |
| $T_6$: RDF+40 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 232.1 | 591.1 |
| $T_7$: RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 250.5 | 605.3 |
| $T_8$: RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 322.1 | 859.7 |
| $T_9$: RDF+80 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 332.0 | 782.2 |
| $T_{10}$: RDF+80 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 350.0 | 891.6 |
| $T_{11}$: RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 348.6 | 819.1 |
| $T_{12}$: RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 358.2 | 892.0 |
| SEm ± | 22.6 | 76.9 |
| *CD (P=0.05)* | 46.9 | 159.4 |
| CV | 8.99 | 11.9 |

$T_{10}$ (Table 3). The highest stover Zn content (56.3 mg $kg^{-1}$) was recorded in $T_{12}$ (RDF +100 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray). Treatments associated with foliar spray recorded higher increase in stover Zn content compared to same treatment without foliar spray. These findings are in corroboration with Naz *et al.* (2015). Application of Zn with or without foliar spray increased per cent stover Zn content over control; the increase was up to 113.6 per cent at 100 kg $ZnSO_4.7H_2O$ $ha^{-1}$ without foliar spray and up to 117.5 per cent at 100 kg $ZnSO_4.7H_2O$ $ha^{-1}$ with 0.5% foliar spray.

*Zinc uptake by maize*

Zinc uptake in maize grain (Table 4) was the highest (358.2 g $ha^{-1}$) in $T_{12}$ (RDF +100 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray). There was significant increase in Zn uptake by maize grain between graded doses *e.g.* 20 kg $ha^{-1}$ over 0 kg $ha^{-1}$ (25.5%), 40 kg $ha^{-1}$ over 20 kg $ha^{-1}$ (53.9%), 60 kg $ha^{-1}$ over 40 kg $ha^{-1}$ (29.0%) and 80 kg $ha^{-1}$ over 60 kg $ha^{-1}$ (32.5%) without effect on grain yield which may be due to the significant increase in grain Zn content with increase in graded doses of Zn. Likewise, the positive change in grain Zn uptake with foliar spray supplementation between graded doses *e.g.* 20 kg $ha^{-1}$ over 0 kg $ha^{-1}$ (50.8%), 40 kg $ha^{-1}$ over 20 kg $ha^{-1}$ (43.5%), 60 kg $ha^{-1}$ over 40 kg $ha^{-1}$ (38.8%) may also be due to the significant increases in grain Zn content between these graded doses. Moreover, Zn plays an important role in biosynthesis of enzymes and resulted in favourable effect of Zn on metabolic reaction within the plants which provided more uptake of nutrients for plants which was reported by Dwivedi *et al*. (2002). Similar findings were also reported by Meena *et al.* (2016) in maize.

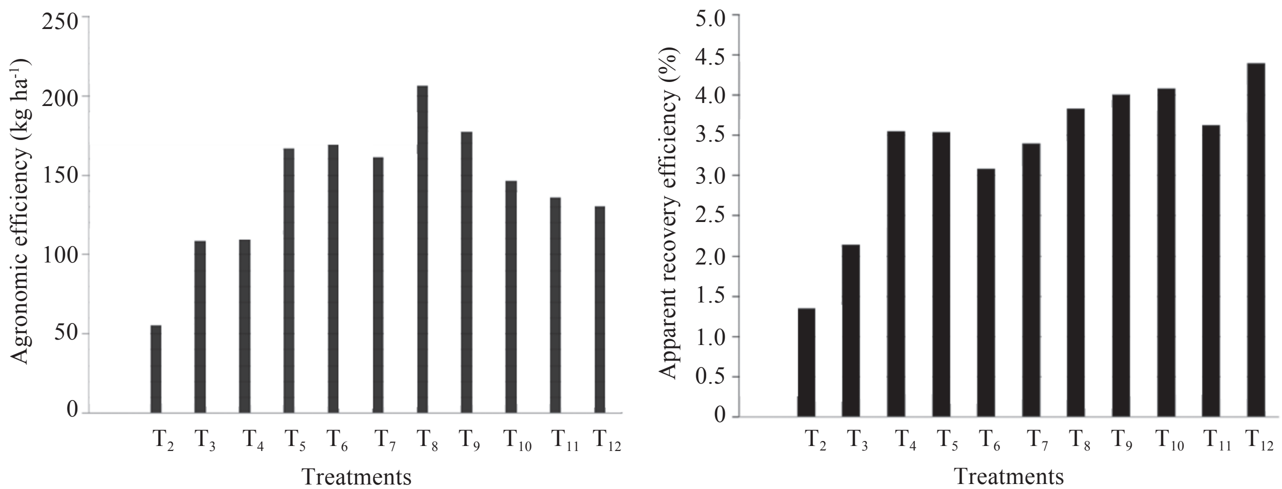
Stover Zn uptake was also increased with increase in graded doses of Zn (Table 4). The highest Zn uptake (892.0 g $ha^{-1}$) was recorded with $T_{12}$ (RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray) as compared to soil or foliar application alone. The results suggest that maize hybrids absorb and accumulate more Zn in stover as compared to grain. These findings are supported by those of Tariq *et al.* (2014).

*Soluble protein, crude protein and starch content in grain*

Soluble protein content in maize grain was increased significantly from $T_4$ (RDF+20 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray) to $T_9$ (RDF +80 kg $ZnSO_4.7H_2O$ $ha^{-1}$) over control (Table 5). This may be attributed to the direct involvement of Zn in the metabolism of the plant. These findings are in close proximity with those of Patil *et al. (*2017). Although crude protein increased gradually with increasing doze of Zn, the increase was not significant among the treatments (Table 5). The highest crude protein (12.4%) was recorded in $T_{11}$ (100 kg $ZnSO_4.7H_2O$ $ha^{-1}$). The increase in crude protein content with increasing doze of Zn may be because Zn acts as an activator of many enzymes in plants and is directly involved in the biosynthesis of metabolites. Similar findings were also reported by Zeidan *et al.* (2010). In general, application of $ZnSO_4.7H_2O$ along with foliar spray slightly increased crude protein content as compared to the treatments without foliar spray except in $T_{12}$.

**Table 5.** Effect of zinc levels on quality parameters of maize

| Treatments | Soluble protein (%) | Crude protein (%) | Starch (%) |
|---|---|---|---|
| $T_1$: RDF (Recommended dose of fertilizers) | 4.24 | 8.63 | 66.4 |
| $T_2$: RDF+0.5% foliar spray of $ZnSO_4.7H_2O$ $ha^{-1}$ | 4.50 | 9.25 | 66.8 |
| $T_3$: RDF+20 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 6.95 | 9.50 | 67.9 |
| $T_4$: RDF+20 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 7.26 | 9.82 | 68.0 |
| $T_5$: RDF+40 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 7.41 | 10.1 | 68.6 |
| $T_6$: RDF+40 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 7.48 | 10.6 | 68.9 |
| $T_7$: RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 7.40 | 10.8 | 68.9 |
| $T_8$: RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 7.42 | 11.2 | 69.1 |
| $T_9$: RDF+80 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 8.05 | 11.9 | 71.3 |
| $T_{10}$: RDF+80 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 7.25 | 12.1 | 71.9 |
| $T_{11}$: RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$ | 6.95 | 12.4 | 71.7 |
| $T_{12}$: RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray | 7.23 | 12.3 | 71.4 |
| SEm ± | 1.45 | 2.36 | 1.61 |
| *CD (P=0.05)* | 3.02 | NS | 13.7 |
| CV | 12.3 | 10.2 | 9.59 |




*$T_1$: RDF (Recommended dose of fertilizers); $T_2$: RDF+0.5% foliar spray of $ZnSO_4.7H_2O$ $ha^{-1}$; $T_3$: RDF+20 kg $ZnSO_4.7H_2O$ $ha^{-1}$; $T_4$: RDF+20 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray; $T_5$: RDF+40 kg $ZnSO_4.7H_2O$ $ha^{-1}$; $T_6$: RDF+40 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray; $T_7$: RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$; $T_8$: RDF+60 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray; $T_9$: RDF+80 kg $ZnSO_4.7H_2O$ $ha^{-1}$; $T_{10}$: RDF+80 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray; $T_{11}$: RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$; $T_{12}$: RDF+100 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray*

**Fig. 2.** Agronomic efficiency and apparent recovery as influenced by levels of zinc fertilizer

Starch content in maize grain increased with the application of graded doses of $ZnSO_4.7H_2O$. The starch content ranged from 66.4-71.4% (Table 5). There was no significant increase in starch content with graded doses of Zn with or without foliar spray. The highest starch content was recorded in $T_{10}$ (80 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray. These findings are in corroboration with those of Debnath *et al.* (2016). Zinc helps in activating many enzymes that have major role in carbohydrate metabolism and also increases K content in plants. It also activates enzymes to metabolize carbohydrates for the manufacture of amino acids and proteins, facilitates cell division and growth by helping to move starches and sugars between plant parts.

*Zinc use efficiencies*

The agronomic efficiency of Zn increased with increase in graded doses of Zn up to 60 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray ($T_8$) beyond which it decreased (Fig. 2). This might be due to proportional increase in yield with increase in Zn level. The apparent recovery efficiency of Zn increased with increase in Zn level (Fig. 3). The highest apparent recovery efficiency was recorded in treatment of 100 kg $ZnSO_4.7H_2O$ $ha^{-1}$+0.5% foliar spray ($T_{12}$) which might be due to highest uptake of Zn in this treatment. The Zn use efficiency was higher in treatments receiving Zn as soil plus foliar spray as compared to soil or foliar sprays alone which is also confirmed by Saha *et al.* (2015).

## Conclusions

It can be concluded that the Zn fertilizer strategy is an effective way to improve Zn content in maize grain and it is also advantageous because it contributes to better yield depending on the extent of soil Zn deficiency. However, soil+foliar application of Zn in this study did not significantly affect grain yield and different plant parameters compared to only soil application, probably due to already high availability of Zn in the studied field. But combined soil+foliar application of Zn significantly increased grain Zn content up to 80 kg $ZnSO_4.7H_2O$ ha$^{-1}$+0.5% foliar spray compared to only soil application of $ZnSO_4.7H_2O$.

## Reference

Anonymous (2019) *Statistical Hand Book Assam.* Directorate of Economics and Statistics, Government of Assam, Guwahati, Assam, 331p.

Baligar, V.C., Fageria, N.K. and He, Z.L. (2001) Nutrient use efficiency in plants. *Communications in Soil Science and Plant Analysis* **7-8**, 921-950.

Bingham, F.T. (1982) Boron. In *Methods of Soil Analysis*, Part II, Second edition (A.L. Page, R.H. Miller and D.R. Keeney, Eds.) Agronomy Monogram. No. 9. ASA and SSSA, Madison, WI, pp. 437-447.

Borges, I.D., Von Pinho, R.G. and Pereira, J.L.A. (2009) Micronutrient accumulation at different maize accumulation stages. *Ciência Agrotechnologia Lavras* **33**, 1018-1025.

Bray, R.H. and Kurtz, L.T. (1945) Determination of total, organic and available form of phosphorus in soils. *Soil Science* **59**, 39-45.

Cakmak, I. (2010) Biofortification of cereals with zinc and iron through fertilization strategy. *19th World Congress of Soil Science, Soil Solutions for a Changing World.* 1-6 August 2010, Brisbane, Australia. Published on DVD.

Chesnin, L. and Yien, C.H. (1951) Turbidimetric determination of available sulfates. *Soil Science Society of America Proceedings* **15**, 149-151.

Debnath, P., Hemalatha, S. and Bhowmik, S. (2016) Effect on yield, quality parameters and nutrient uptake studies of biofortified corn with soil and foliar applied zinc. *Ecology, Environment and Conservation* **22**, 97-103.

Dwivedi, S.K., Singh, R.S. and Dwivedi, K.N. (2002) Effect of sulphur and zinc nutrition on yield and quality of maize in Typic Ustochrept soil of Kanpur. *Journal of the Indian Society of Soil Science* **50**, 70-74.

Gogoi, N., Basumatary, A., Goswami, G., Hazarika, S., Bhattacharyya, D. and Medhi, B.K. (2016) Enrichment of rice grains with zinc through agronomic bio-fortification. *Journal of the Indian Society of Soil Science* **64**, 414-418.

Hedge, J.E. and Hofreiter, B.T. (1962) Carbohydrates. In *Methods in Carbohydrate Chemistry* (R.L. Whistler, and J.N. Be Miller, Eds.), Academic Press, New York, pp. 17-22.

Jackson, M.L. (1973) *Soil Chemical Analysis*. Prentice Hall of India (Pvt.) Ltd., New Delhi.

Lindsay, W.L. and Norvell, W.A. (1978) Development of DTPA test for zinc, iron, manganese and copper. *Soil Science Society of American Journal* **42**, 421-428.

Lowry, O.H., Rosebrough, N.J., Farr, A.L. and Randall, R.J. (1951) Protein measurement with the folin phenol reagent. *Jorurnal pf of Biological Chemistry* **193**, 265-275.

Manzeke, G., Mapfumo, P., Mtambanengwe, F., Chikowo, R., Tendayi, T. and Cakmak, I. (2012) Soil fertility management effects on maize productivity and grain zinc content in small holder farming systems of Zimbabwe. *Plant and Soil* **361**, 57-69.

Meena, S.K., Mundra, S.L. and Singh, P. (2016) Response of maize (*Zea mays*) to nitrogen and zinc fertilization. *Agricultural Research Journal* **53**, 196.

Naz, S., Yousaf, B., Tahir, M.A., Qadir, A. and Yousaf, A. (2015) Iron and zinc bio-fortification strategies in wheat crop by exogenous application of micronutrients. *Food Science and Quality Management* **35**, 49-55.

Panneerselvam, S.P. and Palaniyandi, S. (2014) Response of maize to soil applied zinc fertilizer under varying available zinc status of soil. *Indian Journal of Science and Technology* **7**, 939-944.

Patil, S., Girijesh, G.K., Nandini, K.M., Kumar,K., Pradeep, L.S. and Ranjith Kumar, T.M. (2017) Effect of zinc application through soil and foliar means on bio-fortification of zinc and rainfed maize (*Zea mays* L.). *International Journal of Pure and Applied Bioscience* **5**, 246-253.

Piper, C.S. (1966) *Soil and Plant Analysis.* University of Adelaide, Australia.

Saha, B., Saha, S., Hazra, G.C., Saha, S., Basak, N., Das, A. and Mandal, B. (2015) Impact of zinc application methods on zinc concentration and zinc-use efficiency of popularly grown rice (*Oryza sativa*) cultivars. *Indian Journal of Agronomy* **60**, 391-402.

Sharma, A., Patni, B., Shankhdhar, D. and Shankhdhar, S.C. (2013) Zinc - An indispensable micronutrient. *Physiology and Molecular Biology of Plants* **19**, 11 20.

Singh, R., Sharma, A.R., Dhyani, S.K. and Dube, R.K. (2011) Tillage and mulching effects on performance of maize (*Zea mays*) – wheat (*Triticum aestivum*) cropping system under varying landslopes. *Indian Journal of Agricultural Sciences* **81**, 330-335.

Stein, A.J. (2010) Global impacts of human mineral malnutrition. *Plant and Soil* **335**, 133-154.

Subbiah, B.V. and Asija, G.L. (1956) A rapid procedure for the estimation of available nitrogen in soils. *Current Science* **25**, 259-260.

Tariq, A., Anjum, S.A., Randhawa, M.A., Ullah, E., Naeem, M., Qamar, R. and Nadeem, M. (2014) Influence of zinc nutrition on growth and yield behaviour of maize (*Zea mays* L.) hybrids. *American Journal of Plant Sciences* **5**, 2646-2656.

Walkley, A. and Black, I.A. (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science* **37**, 29-38.

Zeidan, M.S., Mohamed, M.F. and Hamouda, H.A. (2010) Effect of foliar fertilization of Fe, Mn and Zn on wheat yield and quality in low sandy soils fertility. *World Journal of Agriculture Sciences* **6**, 696-699.

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