Effect of agronomic biofortification on growth, yield, uptake and quality characters of maize (Zea mays L.) through integrated management practices under North-eastern region of Tamil Nadu, India

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How to Cite
R. Augustine and Kalyanasundaram, D. (2021). Effect of agronomic biofortification on growth, yield, uptake and quality characters of maize (Zea mays L.) through integrated management practices under North-eastern region of Tamil Nadu, India. Journal of Applied and Natural Science, 13(1): 278 - 286. https://doi.org/10.31018/jans.v13i1.2539

Abstract
Agronomic biofortification increases the concentration of target mineral in edible portions of crops by the use of mineral fertilizers to increase dietary intake of target minerals. Among these iron and zinc deficiencies in human nutrition are noticed in countries where maize is the staple food. The objective of this study was to evaluate agronomic biofortification performance in association with Integrated Nutrient Management in maize (Zea mays L.). The study was conducted under field conditions in Chinna-kandiankuppam village, Vriddhachalam Taluk, in the North-eastern region of Tamil Nadu state, India of Kharif 2020 season. Two hybrids in main plots (M1 – Non biofortified and M2 – Biofortified) were combined with six treatments in sub-plots (100 % RDF through NPK (S1), 100 % RDF through FYM (S2), 50% RDF through NPK + 50% through FYM (S3) as soil application, S1 + Zinc + Iron (S4), S2 + Zinc + Iron (S5) and S3 + Zinc + Iron (S6) as foliar application with evaluations were carried out in wet season period of the year. Application of 50 per cent RDF through NPK + 50 per cent RDF through FYM with Fe, Zn, foliar applications (S6) was the most efficient agronomic biofortification practice for growth attributes, yield and yield attributes, nutrient uptake and quality parameters for the maize cropping system under irrigated condition of north eastern zone of Tamilnadu State, India.

Keywords: Biofortification, Foliar, Iron, Nutrition, Zinc

INTRODUCTION
Unlike various other high value crops, the direct involvement of small and marginal farmers is very intense in the cultivation of maize. There is immense potential in the Indian Agribusiness ecosystem because of its value of output and degree of involvement of maize growers. Due to recent research advancements, the quality protein maize, single cross and 3-way cross hybrids have given a fillip to the nutritional quality of this cereal (NCoMM Special report, 2017). Indian maize production depends heavily on the Southwest monsoon as more than three-fourth of the maize is produced in the Kharif season. Maize is the third largest food grain crop next to wheat and rice, occupying 9.21 million hectares in India with a total production of 25.13 million tonnes and productivity of 6555 kg ha⁻¹ for both kharif and rabi seasons. In Tamilnadu (2018-19), maize occupies an area of 0.38 million ha with a production of 2.51 million tonnes and productivity of 6.55 T ha⁻¹ (Agricultural statistics at a glance, 2019).
In general, human population suffers from micronutrient deficiencies, which occurs due to inadequate intake of essential micronutrients in daily diet. To combat these deficiencies, the biofortification process through agronomic practices offers a sustainable solution, a short-term approach and the easiest way of availability in the diet through the edible parts (Roman et al., 2019). Although simple and inexpensive, the application of fertilizers containing essential mineral micronutrients
is complicated by several factors, such as the application method, soil compaction, mineral mobility in the plant and its accumulation site (Zhu et al., 2007). The bioavailability of micronutrients from soil to crop is influenced by many factors (i.e. pH, organic matter content, soil aeration and moisture and interactions with other elements) and by the crop variety that defines the structure and functioning of rooting systems (Alloway, 2009). Some plants can modify the rhizosphere by the excretion of H+ ions or organic acids that enhance micronutrient availability and uptake (Zhang et al., 2010; Marschner and Zed, 2012).

Due to its improved nutrient uptake and micronutrient availability in the edible plant parts, foliar fertilization was found superior to soil application (Lawson et al., 2015). The combination of soil and foliar application is often the most effective method (Phattarakul et al., 2012 and Cakmak et al., 2010). To avoid immobilization in the soil, foliar pathways were generally found more effective in ensuring nutrient uptake besides its costliness (Garcia-Bauelos et al., 2014).

Singh et al., (1995) reported that, Zn and Fe are part of the photosynthesis, assimilation and translocation of photosynthates from source (leaves) to sink (cob). Due to foliar application of Fe and Zn, significant increase in growth (plant height, leaf area, dry matter production) and yield attributes were recorded (Nikhil and Salakinkop, 2018). Similar results were obtained by Hythum and Nasser (2012) in maize (Zea mays. L.) crop. The effectiveness of agronomic biofortification lies with the interaction effects of both micronutrients with macronutrients. Both Fe and Zn interact positively with N and inversely with P. A positive N X Zn interaction in cereals was reported by a number of researchers (Lakshmanan et al., 2005; Pooniya and Shivay, 2013). There is a positive correlation between increased micronutrient (Fe and Zn) uptake and concentration in the edible parts of the crops (grains) due to high N application (Kutman et al., 2011a,b; Shi et al., 2010; Cakmak et al., 2010 and White and Broadley, 2011; Lakshmanan et al., 2005; Pooniya and Shivay, 2013).

Interestingly, increased Zn concentration in maize kernels is positively correlated with grain yield, 1000-grain weight, cob diameter and cob length (Shivay and Prasad, 2012; Mohsin et al., 2014 and Yashbir and Rajendra, 2014). Yuan et al. (2012) found improvement in grain yield, protein content and total amino acid content as the result of Fe and Zn spraying.

The timing of foliar application is an important factor determining its effectiveness in increasing Fe and Zn concentration. Foliar application of FeSO₄ has been a little more effective than soil application at increasing grain Fe concentration in cereals and can increase the yield of crops growing on soils with low Fe availability (Shahzad et al., 2014). The Zn foliar application done at late growth or reproductive stage have improved Zn content in grains (Ozturk et al., 2006; Yilmaz et al., 2007; Cakmak, 2008 and Zhang et al., 2010). Both kernel Fe and Zn concentration have a positive correlation with grain yield (Chakraborti et al., 2009; Cakmak et al., 2010; Saleem et al., 2016 and Roman Nissar et al., 2019). Thus, the present study was formulated to study the effect of agronomic biofortification on maize (Zea mays. L.) growth, yield and quality characters through integrated nutrient management practices in North-eastern agro-climatic zone of Tamilnadu under the semi-arid tropic region of India.

**MATERIALS AND METHODS**

**Experimental site description**

The investigation was carried out in July-2020 during kharif season at the Chinnakandiankuppam village, Vridhdhachalam Taluk, Tamilnadu state to study the Effect of Agronomic biofortification on growth, yield, uptake and quality characters of maize through integrated management practices under North-eastern region of Tamil Nadu. The experiment site was geographically located in North Eastern agro-climatic zone of Tamilnadu and is delineated under semi-arid tropic of India. It lies between 11.3°N, 79.26°E longitude at an altitude of 42.67 meters above mean sea level. The mean annual rainfall of Vridhdhachalam was 403.22 mm during the southwest monsoon and 580.50 mm during northeast monsoon and the mean maximum and minimum temperatures were 27 - 42°C and 19-24°C respectively. The Relative Humidity ranges between 65% -85%.

The pre-sowing soil samples collected from each treatment plots of the experimental field in three replicates were analysed for the initial physico-chemical properties. The soil of the experimental field was clay loam in texture belonging to Gadillum series, classified taxonomically as Typic Ustropepts. Maize hybrid, VH133545 (QPM biofortified) and NK 6668 (Non-biofortified) were used for trials during kharif 2020 seasons, respectively.

**Field experiment details**

The field experiment was laid out in split-plot design, and sampling was done in three replicates with 36 plots in total, each covering 20 m² (5 m x 4 m). The experiment was conducted during 2020 kharif season (July-October) with two hybrids (M₁- Non biofortified hybrid and M₂ – QPM biofortified hybrid) as main plots and six nutrient level treatments as sub-plots viz., **Soil Application - S₁ - 100 % RDF through NPK, S₂ - 100 % RDF through FYM, S₃ -50% RDF through NPK + 50% through FYM and Foliar Application - S₄ - S₅+ Zinc + Iron, S₆ - S₅+ Zinc + Iron, S₇ - S₅+ Zinc + Iron. For the**
present study, the soil samples were collected from thirty six plots. Each plot in the experimental field was ploughed once with tractor-mounted mouldboard plough and the field was harrowed and levelled to fine tilth without disturbing the layout for next season. After ploughing, bunds and irrigation channels of each plot were rectified. All the cultural practices and plant protection measures for maize were followed as per the recommendations of the crop production guide of Agricultural crops in Tamilnadu.

Soil application (Manure and fertilizer)
Well decomposed FYM were used as organic sources for nitrogen. The required quantities of organic manures were incorporated in the soil 10 days before puddling. The recommended dose of NPK 250:75:75 kg/ha in the form of urea (46% N), single super phosphate (16% P2O5) and muriate of potash (60% K2O) were applied as per the treatment. Of this, 50 per cent N and full dose of P2O5 and K2O were applied as basal. The remaining 50 per cent N was applied in two splits at 25 days after sowing (DAS) and 45 DAS.

Foliar application (Iron and Zinc)
Foliar application of 0.5 per cent FeSO4 and ZnSO4 as per treatments was done twice at 30 and 60 DAS, respectively.

Seeds and sowing
Seeds of Biofortified (QPM) and non biofortified (commercial) maize hybrid VH133545 and NK 6668 were used for the study. Seeds were pre-treated with Azospirillum and pseudomonas and were sown on the side of the ridges. Seeds were dibbled at the rate of one seed hill−1 with a spacing of 60 x 25 cm. Recommended agronomic practices and plant protection measures were followed. Gap filling was done 7 DAS and thinning 15 DAS to maintain one healthy plant hill−1. Two hand weedings were done to manage the weeds. The first hand weeding was given on 20 DAS and the other at 40 DAS.

Sampling procedures and measurements
The collected soil samples were analyzed for pH, EC and available macro nutrients. Standard procedures were adopted for analysis of the nutrients in the laboratory. Ten plants from each net plot area were tagged and used for recording all biometric observations for growth attributes (plant height, leaf area index, dry matter production, days taken to 50% flowering) and yield and yield attributes (cob length, cob girth, cob weight, no. of grains per row of cob, no. of grain rows per cob, thousand grain weight, grain yield and stover yield), nutrient uptake (N, P and K) and quality parameter (crude protein, starch, iron and zinc) were recorded at harvest.

Statistical analysis
The data obtained from various observations was statistically analyzed as the split plot design procedure using the standard techniques of Analysis of Variance (ANOVA) as suggested by Gomez and Gomez (1984). The critical difference at 5% level of probability was calculated for testing the significance of the difference between any two means wherever ‘F’ test was found significant. Wherever the calculated ‘F-value’ exceeded the tabulated value, the difference between the treatments was significant.

RESULTS AND DISCUSSION

Growth and attributes
The effect of agronomic biofortification in maize through integrated management practices on plant height, leaf area index, dry matter production and days to 50% flowering is presented in Table 1. It is obvious that with an integrated nutrient dose of fertilizers and micronutrient foliar application, any crop would perform at its best, because of adequate and balanced nutrient supply to the crop at the right time of crop requirement. Accordingly, the maize crop under adequate and comfortable nutrition produced the growth parameters of the highest stature.

Plant height (cm)
The plant height differed significantly (P≤ 0.05) due to integrated nutrient with foliar applications. The highest plant height at 90 DAS (208.25 cm) was recorded in S4 -50 per cent RDF through NPK and 50 per cent RDF through FYM with Fe, Zn foliar application, followed by S3 (204.00 cm) – 100 per cent RDF through NPK with Iron + Zinc foliar applications under different nutrient levels. This was followed by S2 (202 cm) – 100 per cent RDF through NPK and S1 (201.00 cm) – 50% RDF through NPK + 50% RDF through FYM nutrient level treatments. Increase in plant height was due to the slow and steady release of nutrients which perhaps enables the crop growth towards the reproductive stage. Increased plant height is due to increased uptake of N which being the constituent of protein and protoplasm, vigorously induced the vegetative development of the plants. Plant height was positively correlated and significantly associated with grain yield per plant. Similar results were reported by Rahman et al. (2013). The combined source of fertilizers, initially to get decomposed and mineralize before making available to plants, thus causing nutrients to be slowly released to crop (Okoroafor et al., 2013). Priya et al. (2014) recorded that plant height and number of leaves was maximum due to application of 100% NPK fertilizers with 10 t ha−1 FYM. The above findings were similar with Ravi et al., (2012) and Zerihun et al. (2013). Sindhi et al., (2018) reported that combined application of or-
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Table 1. Effect of agronomic biofortification through integrated nutrient management practices on growth attributes of *Zea mays*.

| Treatments (Main plots – M ; Sub plots – S) | 90 Days after sowing (DAS) | Days taken for 50% flowering |
|-------------------------------|----------------------------|-----------------------------|
|                              | PH (cm) | LAI | DMP (Kg ha\(^{-1}\)) | Days taken for 50% tasseling | Days taken for 50% Silking |
| Hybrid                        | PH (cm) | LAI | DMP (Kg ha\(^{-1}\)) | Days taken for 50% tasseling | Days taken for 50% Silking |
| M\(_1\) – Non biofortified     | 198.25  | 3.92 | 12839.17          | 55.22                      | 60.98                      |
| M\(_2\) – Biofortified         | 194.17  | 3.75 | 12640.33          | 54.35                      | 60.48                      |
| SEd                           | 0.29    | 0.12 | 3.00             | 0.30                       | 0.23                       |
| CD (p=0.05)                   | 1.24    | NS  | 12.91            | 1.29                       | NS                         |
| **Nutrient levels**           |         |     |                 |                           |                           |
| S\(_1\) - 100% RDF through NPK | 202.00  | 4.13 | 12825.00          | 55.25                      | 61.47                      |
| S\(_2\) - 100% RDF through FYM | 178.00  | 3.25 | 12315.00          | 53.15                      | 58.42                      |
| S\(_3\) - 50% through NPK + 50% through FYM | 201.00 | 3.90 | 12811.00 | 54.55 | 60.57 |
| S\(_4\) - S\(_1\) + Zinc and Iron as foliar application | 204.00 | 4.16 | 12920.00 | 55.85 | 61.92 |
| S\(_5\) - S\(_2\) + Zinc and Iron as foliar application | 184.00 | 3.31 | 12537.50 | 53.50 | 59.40 |
| S\(_6\) - S\(_3\) + Zinc and Iron as foliar application | 208.25 | 4.29 | 13030.00 | 56.40 | 62.62 |
| SEd                           | 0.17    | 0.05 | 1.73             | 0.17                       | 0.05                       |
| CD (p=0.05)                   | 0.35    | 0.10 | 3.61             | 0.36                       | 0.11                       |
| **Interaction**               |         |     |                 |                           |                           |
| M\(_1\) X S\(_1\)            | 203.00  | 4.25 | 12930.00          | 55.80                      | 61.90                      |
| M\(_1\) X S\(_2\)            | 182.00  | 3.25 | 12305.00          | 53.60                      | 58.50                      |
| M\(_1\) X S\(_3\)            | 202.00  | 4.27 | 12915.00          | 55.60                      | 60.70                      |
| M\(_1\) X S\(_4\)            | 206.00  | 4.10 | 13010.00          | 55.90                      | 62.20                      |
| M\(_1\) X S\(_5\)            | 185.00  | 3.32 | 12725.00          | 54.00                      | 59.47                      |
| M\(_1\) X S\(_6\)            | 211.50  | 4.35 | 13150.00          | 56.40                      | 63.10                      |
| M\(_2\) X S\(_1\)            | 201.00  | 4.01 | 12720.00          | 54.70                      | 61.03                      |
| M\(_2\) X S\(_2\)            | 174.00  | 3.25 | 12325.00          | 52.70                      | 58.33                      |
| M\(_2\) X S\(_3\)            | 200.00  | 3.70 | 12707.00          | 53.50                      | 60.43                      |
| M\(_2\) X S\(_4\)            | 202.00  | 4.05 | 12830.00          | 55.80                      | 61.63                      |
| M\(_2\) X S\(_5\)            | 183.00  | 3.29 | 12350.00          | 53.00                      | 59.33                      |
| M\(_2\) X S\(_6\)            | 205.00  | 4.22 | 12910.00          | 56.40                      | 62.13                      |
| **M X S**                     |         |     |                 |                           |                           |
| SEd                           | 0.11    | 0.03 | 1.17             | 0.12                       | 0.04                       |
| CD (p=0.05)                   | 0.28    | 0.09 | 2.88             | 0.29                       | 0.14                       |
| **S X M**                     |         |     |                 |                           |                           |
| SEd                           | 0.12    | 0.03 | 1.22             | 0.12                       | 0.04                       |
| CD (p=0.05)                   | 0.25    | 0.07 | 2.55             | 0.26                       | 0.08                       |

Where PH = plant height, LAI= leaf area index, DMP= dry matter production

Organic and inorganic fertilizer have achieved a significant plant growth, yield, quality and nutrient uptake. Similar findings were reported by Binoy and Sinha, (2017) that the combined treatments with 75% RDF + PSB + *Azotobacter* + vermicompost @ 5.0 t/ha were significant, compared to other treatments on maize at Cooch Behar, West Bengal.

**Leaf area index**

Leaf area Index (LAI) is an indicator of photosynthesis and its translocation. Significant increase in LAI at 90 DAS (4.29) was recorded in S\(_6\) followed by S\(_4\) (4.16) under different nutrient levels, which was on par with S\(_2\) (4.13) and S\(_3\) (3.90) nutrient level treatments. In the present study, better utilization of N resulted in higher leaf surface area and thereby higher LAI. This is in accordance with earlier findings of Agyenium *et al*., (2006).

**Dry matter production**

The higher DMP was significantly (P≤ 0.05) higher in the nutrient level (sub-plot) treatment S\(_6\) (13030 kg ha\(^{-1}\)) compared to S\(_4\) (12920 kg ha\(^{-1}\)). This was followed by nutrient level (sub-plot) treatment receiving S\(_4\) (12825 kg ha\(^{-1}\)).
kg ha$^{-1}$) and S$_3$ (12811 kg ha$^{-1}$). Amanullah (1997) reported that INM with micronutrient foliar spray enabled the leaf area duration to extend and provided an opportunity for the plants to increase the photosynthetic rate leading to the higher accumulation of dry matter. Leaf area index and dry matter were significantly correlated demonstrating that, higher amount of radiation associated with higher LAI contribute to enhanced dry matter production (Kolawole and Samson, 2009).

**Days to 50% flowering**

Increase in days to 50% tasselling and 50% silking was higher under S$_6$ (56.40 and 62.62) followed by S$_4$ (55.85 and 61.92) under nutrient (sub-plot) treatments, respectively. This treatment was on par with S$_1$ (55.25 and 61.47) and S$_2$ (54.55 and 60.57). Amanat (1998), Farooqui (1999) and Tasneem Khalique et al. (2004) observed that the availability of nitrogen and phosphorus at adequate quantity delays the tasselling period. Ayoola and Makinde (2009) reported that combined organic and inorganic source with micronutrient applications prolonged the vegetative phase of the plants leading to longer duration and ensuring higher yield.

**Yield and yield attributes**

The effect of agronomic biofortification in maize through integrated management practices on cob length, cob girth, cob weight, no. of grains per row of cob, no. of grain rows per cob, thousand-grain weight are presented in Fig. 1 and grain and stover yield recorded at harvest are presented in Fig. 2 respectively. The yield attributes were highly significant (Ps 0.05) for a different combination of nutrient levels in sub-plots. Among the treatments, the highest cob length (18.18 cm), cob girth (15.25 cm), No. of grains row$^{-1}$ (35.05) and No. of rows cob$^{-1}$ (15.02) was recorded in S$_6$ -50 per cent RDF through NPK and 50 per cent RDF through FYM with Fe, Zn foliar application. The cob length, cob girth, no. of grains row$^{-1}$ and no. of rows cob$^{-1}$ receiving inorganic fertilizer integrated with organic sources and the foliar application was on par with each other but was significantly higher than S$_2$ – 100 per cent RDF through FYM only treatment. Significant higher growth (plant height and leaf area) and yield and its parameters (number of grains per cob, cobs weight per plant, Test weight and Stover yield) were recorded with INM than 100% RDF alone (Auwal and Amit, 2017). It was also observed by Tetarwal et al. (2011) and Verma et al. (2012). Karan et al. (2018) reported that integrated organics and inorganics application to maize significantly improved the growth, yield attributes, grain and stover yield of maize at par with 100% inorganics. Rajesh Ranjan et al. (2018) reported that FYM combined 25% reduced inorganic have significantly increased the yield and yield attributes of maize. Nikhil and Salakinkop (2018) reported that growth (plant height, leaf area, dry matter production) and yield attributes were increased significantly by Zn and Fe foliar application and similar findings by Hythum and Nasser (2012) who reported that the foliar spraying of Zn + Mn + Fe gave the highest values of ears/plant, grains/ear, 100-grain weight and grain yield in both 2007 and 2008 seasons in maize grown under clayey soil in Egypt and also by Kalyanasundaram and Augustine (2020a) that Integrated nutrient management (RDF+ soil application of Beema green granules) with foliar application had shown a higher values in yield and yield attributing characters viz., grain weight/cob, number of grain/cob and test weight in hybrid maize (Z. mays L.).

The data on grain yield and stover yield showed that significantly higher grain yield (8349.36 kg ha$^{-1}$) and stover yield (10418.67 kg ha$^{-1}$) was recorded in the S$_6$ - 50 per cent RDF through NPK and 50 per cent RDF through FYM with Fe, Zn foliar application followed by S$_4$ - 100 per cent RDF through NPK with Iron + Zinc foliar applications (grain yield - 8273.29 kg ha$^{-1}$ and stover yield - 10414.17 kg ha$^{-1}$) compared to S$_2$ – 100 per cent RDF through FYM (grain yield – 8002.26 kg ha$^{-1}$ and stover yield – 10310.00 kg ha$^{-1}$). Higher yields in the integrated nutrient treatment receiving foliar applications might be due to increased availability of nutrients and the presence of Fe and Zn, etc. This increase might be due to the balanced availability of nutrients to assimilate sufficient photosynthates for dry matter production by conversion of the source to sink, reflecting in the form of higher cob length, grain yield, stover yield.

Shinde et al., (2014) recorded the highest cobs/plant, 1000 grain weight, grain yield and straw yield of maize were recorded with 100% RDF + 10 t FYM/ha. Similar findings were concluded by Pandey and Avasthi (2014). A similar observation was recorded by Auwai and Amit (2017) for 50% RDF along with either 5 t/ha FYM or pressmud and Karan et al., (2018) for 25% N through fortified vermicompost + 75% N through inorganic fertilizer. In one of the earlier study, foliar application of Fe$_2$SO$_4$ and ZnSO$_4$ has shown increased concentration in cereals (grain), which also enhances yield of crops (Augustine and Kalyanasundaram, 2020a). Increasing the concentration of Iron and Zinc in cereal crops of plant parts was achieved by agronomic biofortification by spraying at the later crop stage or early milking stage. It is predominantly efficient when Zn foliar applications were tried, shows a yield increase and Zn content in maize grain during harvest (Augustine and Kalyanasundaram, 2020b).

**Nutrient uptake**

The effect of agronomic biofortification in maize through integrated management practices on Nitrogen (N), Phosphorus (P) and Potassium (K) uptake recorded at
90 DAS during kharif season of 2020 are presented in Fig 3. The N and K were significantly (P ≤ 0.05) influenced by S6 - 50 per cent RDF through NPK and 50 per cent RDF through FYM with Fe, Zn foliar application (235.03, 41.15 and 171.93 kg ha⁻¹) and P was significantly influenced by S4 - 100 per cent RDF through NPK with Iron + Zinc foliar applications (41.37 kg ha⁻¹) at 90 DAS followed by N and K uptake by S5 (234.75 and 170.35 kg ha⁻¹) and P uptake by S6 (41.15 kg ha⁻¹). More nutrient uptake and presence of efficient minerals in edible portion happens better with foliar fertilization rather than soil fertilization. (Lawson et al., 2015). Both Fe and Zn interact positively with N and inversely with P. Similar findings were also reported by Pooniya and Shivay (2013) with 0.2% ZnSO₄ foliar application recorded highest N, K and Fe in basmati rice. Integrated nutrient management (RDF+ soil application of Beema green granules) with foliar application have shown improved nutrient uptake in hybrid maize (Zea mays L.) by Kalyanasundaram et al. (2020).

Quality parameters
The effect of agronomic biofortification in maize through integrated management practices on crude protein, starch, iron (Fe) and zinc (Zn) are presented in Fig. 4. Data revealed that under sub-plots (nutrient levels), S6, 50 per cent RDF through NPK and 50 per cent RDF through FYM with Fe, Zn foliar application was found to be efficient in providing crude protein (14.65%), starch (63.85 mg g⁻¹), Fe (37.80 mg kg⁻¹) and Zn (31.88 mg kg⁻¹) content in grains after harvest followed by S4 - 100 per cent RDF through NPK with Iron + Zinc foliar applications and S5 - 100% RDF through FYM with Iron + Zinc foliar applications. All these parameters were observed lowest in the application of S2 - 100% RDF through FYM. Yuan et al. (2012) reported that grain yield, protein content and total amino acid was im-
proved due to Fe-amino acid and 0.5% ZnSO₄ spraying in rice grain. Shinde et al. (2014) recorded that highest values of protein per cent and protein yield of maize were recorded with application of 100% RDF + 10 t FYM/ha. Similar findings were reported by Verma et al. (2012). Application of cattle manure + NPK significantly increased Zn concentration in corn grain over NPK (Manzeke et al. 2012). Soil amendment with small amounts of micronutrients has been suggested as a sustainable strategy to increase yields and nutritional quality of staple crops such as maize, rice, cassava, sorghum, millet, banana and sweet potato (Vanlauwe et al., 2015; Voortman and Bindraban, 2015; Manzeke et al., 2012). The Bioavailability of Zn in maize grains and stover was significantly increased by addition of organic manures and Zn fertilization. The results showed that a significant amount of Fe and Zn content persisted in maize grains when it was applied during the reproductive stage. The present results are in line with Tejada et al. (2006); Zhang et al. (2013); Patil et al. (2017) and Sadiq et al. (2018) who found that bioavailability of Zn in maize grains and stover was significantly increased by the addition of organic manures and Zn fertilization. Iron and Zinc foliar sprays were effective in Zn accumulation in grains (Augustine and Kalyanasundaram, 2020c).

**Conclusion**

The results of the present study showed that maize grown under irrigated condition in North eastern zone was highly responsive to agronomic biofortification. Since the nutrient levels by soil application offered no significant growth, yield, nutrient or quality advantages over the foliar applications, we concluded and recommended the nutrient levels of Fe and Zn foliar applications and 50 per cent RDF through NPK and 50 per cent RDF through FYM in the soil to hasten maize growth, productivity, yield attributes, nutrient uptake and quality. Such a combined long term approach may become a potential nutritional source for human and cattle populations. However, Zn and Fe foliar application at the reproductive stage have yielded a significantly higher content of Zn and Fe in maize grains besides improving other quality parameters. Thus integration of organic and inorganic fertilizers along with Fe and Zn foliar applications proved their efficiency to the reduction in inorganic fertilizer and with enhanced quality improvement. Experimental results concluded that the agronomic biofortification (integrated nutrient management with Fe and Zn foliar applications) practices can boost yields, nutrient uptake and maize quality by promoting in the North-eastern climatic zones of Tamil Nadu State.

**ACKNOWLEDGEMENTS**

The authors are thankful to the Professor and Head, Department of Agronomy, Faculty of Agriculture, Annamalai University for their advice and guidance during the research studies.

**Conflict of interest**

The authors declare that they have no conflict of interest.

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