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Effect of zinc and iron biofortification on quality, post-harvest soil nutrient status, and economic performance of hybrid maize

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Abstract
A research work titled "Fortification of hybrid maize through soil and foliar application of nutrients" was carried out at Agricultural College and Research Institute, Killikulam during summer 2021. The trial framed in Randomized Block Design consisting of 10 treatments, replicated thrice. The treatment incorporated with the micronutrient application of zinc and ferrous sulphate as foliar, soil application and also combined application and also the application of TNAU Micronutrient mixture and Maize maxim. The observations that were recorded are quality parameters and economics. The results revealed that the crude protein (14.06%), zinc (41.3 mg kg^{-1}) and iron content (90.8 mg kg^{-1}) was also increased in T_7. In terms of economics the gross return (Rs.133910 ha^{-1}) and net return (Rs.85039 ha^{-1}) was higher in T_7 and the B:C ratio (2.79) was higher in T_5 (STCR based NPK + 30 kg TNAU Micronutrient mixture as enriched FYM) in hybrid maize. The lowest values for yield and quality parameters were recorded in the absolute control (T_{10}).

Keywords: Hybrid maize, STCR, maize maxim, zinc and iron uptake

Introduction
Maize (*Zea mays*), one of the staple foods next to rice and wheat in the world. The higher productive nature of maize procured the name, the miracle crop and Queen of Cereals. It is a versatile crop that can adopt and performs better in wider Agro climatic conditions. The production of maize crop was expanding according to the multiplication of poultry industry which can be serve as feed for poultry birds. The humans obtained various byproducts from maize crop such as corn meal, corn syrup, sweeteners, pharmaceuticals etc.

India occupies seventh position in production of maize in the world. India accounts the production and productivity of about 34.6 million tonnes. Maize grains was lack in vitamin A, amino acids (lysine and tryptophan) and micronutrients such as Zn, Fe, Se and Mn). This will create malnutrition to humans and children and reduces the population growth in the country. One of the reasons behind this effect was in India the soils are 39 percent, 37 percent, 36 percent and 47 percent deficient in micronutrients namely Zinc, Iron, Sulphur and Boron respectively.

Zn act as an enzyme that plays a crucial role in folding and structural integrity of proteins (Zaheer *et al.*, 2020) [24]. Zinc is found in many enzymes namely lyases, hydrolases, ligases, oxidoreductase and isomerases. In plants it helps in synthesis of proteins, gene activation and regulation and metabolism of carbohydrates (Hafeez *et al.*, 2013) [6]. Iron act as electron carrier in electron transport chain and thereby it is required by plants to perform metabolic activities such as synthesis of DNA, respiration, photosynthesis, nitrate and sulphate reduction, and is also responsible for maintaining the structure and function of chloroplasts (Rout *et al.*, 2015) [19].

Zinc plays a significant importance in human life as increasing the immune system building protein, DNA creation, curing of damaged cells. Iron is required for haemoglobin synthesis which act as oxygen carrier from lungs to all parts of the body. For this requirement the zinc and iron content have to be enriched in the food grains. This can be done by agronomical and genetical methods. To ameliorate the micronutrient deficiencies and to improve the micronutrient status of the soil, the same has to be enriched by the application of micronutrients in soil and also through foliage. With this background, the present study was conducted to know the impact of STCR based NPK application and soil and foliar application of micronutrients and crop booster on Maize yield and soil status.

Materials and Methods
Experimental Site
Research conducted at Agricultural College & Research Institute, Killikulam located at Southern region of Tamil Nadu with a latitude and longitude of about $8^0$46'N and $77^0$42'E respectively. The field was prepared by using cultivator and rotavator to get fine tilth and ridges and furrows were formed with a distance of 60 cm. The macronutrients were applied based Soil Test Crop Response (STCR) value. The initial soil sample was analyzed and it was sent to Tami Nadu agricultural University to feed the results on STCR formula to get the recommendation of macronutrients for that particular field. The initial soil analysis revealed that the Soil was low in available nitrogen (235.2 kg ha^{-1}), medium in available phosphorus (14.83 kg ha^{-1}) and potassium (260 kg ha^{-1}) and STCR recommendation was 155:90:56 kg N, P2O5, K2O ha^{-1}. Initially the Zinc and Iron content present in the soil was 0.37 mg kg^{-1} and 2.95 mg kg^{-1} respectively.

Experimental design and data collection
Hybrid Maize COH(M) 8 was sown with a spacing of 60 x 25 cm and the experiment was laid in Randomized Block Design with ten treatments and three replications. The treatment details are given below:

Treatments
T_1- STCR-IPNS (Soil Test Crop Response – Integrated Plant Nutrition System).
T_2- STCR + 37.5 kg $ZnSO_4$
T_3- STCR + 50 kg FeSO4
T_4- STCR + 37.5 kg ZnSO4 + 50 kg FeSO4
T_5- STCR + 30 kg TNAU Micronutrient mixture as enriched FYM
T_6- STCR + 0.5% ZnSO4 + 0.5% FeSO4
T_7- STCR + 1% ZnSO4 + 1% FeSO4
T_8- STCR + Maize maxim @ 1.5% two times application
T_9- STCR + Maize maxim @ 1.5% four times application
T_{10}- Absolute control

The data collected in this experiment are growth parameters, yield parameters and quality parameters such as crude protein, zinc and iron content. The protein content of the grain was calculated using the multiplication factor 6.25 with the Nitrogen content which was estimated by Microkjeldhal digestion method. The Zn and Fe content in the grains were estimated with the required quantity of sample by triple acid digestion method and fed in atomic absorption spectrophotometer from where values were read and indicated mg kg^{-1}.

Results and Discussion
Crude protein
Significant differences were observed between the treatments in terms of the crude protein content of the grains. Among the various treatments, the treatment T_7 (STCR based NPK + Foliar spray of 1% $ZnSO_4$ + Foliar spray of 1% $FeSO_4$) was found to be effective in terms of achieving the higher crude protein content (14.06%) in the grains of hybrid maize. The treatments T_5 and T_8 were found to be on par with T_7 with a protein content of 13.88% and 13.63%, respectively. Meanwhile, the lowest content of crude protein (8.94%) in maize grains was obtained in the absolute control plot (T_{10}). The micronutrients applied as foliar are responsible for the production of metabolites by activating the enzymes in plants, thereby increasing the crude protein content in grains (Kandali *et al.*, 2021) [8]. Similar study was reported by Kandoliya *et al.*, (2018) [9] and Mahdi *et al.*, (2012) [14].

Zn content and uptake
The zinc content in the grains of maize varied significantly with respect to the treatments. The treatment T_7 (STCR based NPK + Foliar spray of 1% $ZnSO_4$ + Foliar spray of 1% $FeSO_4$) achieved the highest zinc content of 41.3 mg kg^{-1}. The treatment T_7 was on par with the treatment T_5 (STCR based NPK + 30 kg TNAU Micronutrient mixture as enriched FYM) and T_8 (STCR based NPK + Foliar spray of Maize maxim @1.5% two times application) with the content of 40.5 mg kg^{-1} and 39.2 mg kg^{-1}. The minimum Zn content was recorded in the absolute control (T_{10}) with the values of 18.5 mg kg^{-1} in the grains of hybrid maize.
With respect to the zinc uptake treatment T_7 (STCR based NPK + Foliar spray of 1% $ZnSO_4$ + Foliar spray of 1% $FeSO_4$) was found to be higher with the uptake of 301.4 g ha^{-1}. The treatment T_5 was found to be equivalent with T_7 by registering the zinc uptake (289.5 g ha^{-1}) in maize grains. At the same time the lowest uptake of zinc (65.0 g ha^{-1}) in grains was found in the treatment T_{10} (Absolute control). When the zinc was applied directly as foliar during the various stages of the crop, including the critical stage of the crop, it aided in the enrichment of the content in the grains at the time of ripening (Gogoi *et al.*, 2016) [5]. The uptake of zinc in the plants was improved by the application of zinc which involved in the enzyme synthesis and the metabolic actions (Dwivedi *et al.*, 2002) [4]. The result was related with Mona (2015) [17] and Mohsin *et al.*, (2014) [15].

Fe content and uptake
The iron content and uptake produced significant differences among the treatments. The iron content (90.8 mg kg^{-1}) was higher in T_7 (STCR based NPK + Foliar spray of 1% $ZnSO_4$ + Foliar spray of 1% $FeSO_4$), which was found to be on par with the treatment T_5 (STCR based NPK + 30 kg TNAU Micronutrient mixture as enriched FYM) with the iron content of 89.5 mg kg^{-1}. The treatment T_8 (STCR based NPK + Foliar spray of Maize maxim @ 1.5% two times application) with an uptake of 88.7 mg kg^{-1} ranked next followed by T_9 (STCR based NPK + Foliar spray of Maize maxim @ 1.5% four times application) with an uptake of 86.8 mg kg^{-1}. The treatment T_{10} (Absolute control) registered the lowest content (38.6 mg kg^{-1}) of iron in the grains of hybrid maize.
The iron uptake was also enhanced in the treatment T_7 (STCR based NPK + Foliar spray of 1% $ZnSO_4$ + Foliar spray of 1% $FeSO_4$) by registered 662.6 g ha^{-1}. The treatment T_5 (STCR based NPK + 30 kg TNAU Micronutrient mixture as enriched FYM) recorded 639.9 g ha^{-1} and was on par with the best treatment. The minimum iron uptake (135.6 g ha^{-1}) was obtained in the treatment T_{10} (Absolute control). The foliar application of zinc has positive effect in increasing the zinc and iron content in the plants which was due to the pleotropic effect between the genes responsible for Zn and Fe uptake (Xia *et al.*, 2019) [23]. Similar research was noted by Kumar *et al.*, (2020) [11]. The micronutrient improvement was due to the production of organic compounds which were found to act as chelating agents that were secreted by high biomass producing crops (Dotaniya *et al.*, 2013) [3]. The iron content was improved by the better absorption in the leaves, and it

was stored as ferric phosphoproteins known as phytoproteins when it was translocated to the source (Prasad 2006) [18].

Post harvest soil status

The post-harvest soil available nitrogen and phosphorus was higher in the treatment T_1 (STCR based NPK) while the soil available potassium was higher in the treatment (T_{10}) absolute control after harvest. The higher amount of available nutrients in soil was due to the lower uptake of nutrients by the plants. Similar report was found by Jyothi *et al.*, (2015) [7] who documented that the plant uptake of nutrients at the required quantity for growth and development resulted in the left over quantity of nutrients in the soil after harvest. The result was similar to Saha *et al.*, (2006) [20].

The decline in the amount of phosphorus in the post-harvest soil was due to the massive uptake of P by plants and also by the soil fixation (Mollah *et al.*, 2015) [16]. When the soil pH is above 8.5, it led to the fixation of phosphorus in the soil and limited its availability to crops. The soil available potassium was higher which was due to the transformation of K from unavailable form to available form. The result was similar with Sathiya *et al.*, (2009) [22], Bouain *et al.*, (2014) [2].

Soil available zinc and iron

The treatments produced a statistical difference in relation to the soil's available zinc and iron. With respect to the soil available zinc, the maximum content was registered in the treatment T_4 (STCR based NPK + Soil application of 37.5 kg $ZnSO_4$ + Soil application of 50 kg $FeSO_4$) by recording the zinc content of 0.84 mg kg^{-1}. The treatment T_2 (STCR based NPK + Soil application of 37.5 kg $ZnSO_4$) was noted as the next best treatment with the content of 0.78 mg kg^{-1}. The minimum soil available zinc (0.24 mg kg^{-1}) was found in the treatment T_7 (STCR based NPK + Foliar spray of 1% $ZnSO_4$ + Foliar spray of 1% $FeSO_4$).

With regard to the soil available iron, maximum of 2.69 mg kg^{-1} was recorded in the treatment T_3 (STCR based NPK + Soil application of 50 kg $FeSO_4$). It was followed by the treatment T_4 (STCR based NPK + Soil application of 37.5 kg $ZnSO_4$ + Soil application of 50 kg $FeSO_4$) with the content of 2.52 mg kg^{-1}. The least amount of iron content was observed in the treatment T_6 (STCR based NPK + Foliar spray of 0.5% $ZnSO_4$ + Foliar spray of 0.5% $FeSO_4$) with a value of 1.98 mg kg^{-1} of soil available Fe. The zinc and ferrous sulphate application mobilizes the native nutrients and increases uptake in plants by nutrient utilization and results in minimum availabitiy in the final soil (Sathisha *et al.*, 2019) [21]. The result was in confirmation with Latha *et al.*, (2001) [12].

Economics

In this study, the maximum net return and the benefit cost ratio was obtained in the treatment T_5 (STCR based NPK + 30 kg TNAU Micronutrient mixture as enriched FYM), though maximum grain yield was obtanined in the treatment T_7 (STCR based NPK + Foliar spray of 1% $ZnSO_4$ + Foliar spray of 1% $FeSO_4$). This is because in the foliar applied treatments, the foliar nutrient was sprayed for two to four times, which incurred more costs for the required spray quantity and also the labour charges for spraying each time. But in the treatment applied with TNAU Micronutrient mixture as enriched FYM, the FYM cost was low and it was applied only as a basal application. The net return and the B: C ratio were related to the grain and stover yield obtained from the field (MAGANUR *et al.*) [13]. The report was similar with the study of Arabhanvi (2017) [1] and Kannan *et al.*, (2014) [10].

Table 1: Effect of Zinc and Iron Biofortification on Quality of Hybrid Maize

	Treatments	Crude protein (%)	Zn content (mg kg^{-1})	Zn uptake (g ha^{-1})	Fe content (mg kg^{-1})	Fe uptake (g ha^{-1})
T_1	STCR based NPK	11.81	24.7	142.9	55.7	322.3
T_2	STCR based NPK + Soil application of 37.5 kg $ZnSO_4$	12.56	30.2	190.8	65.1	411.2
T_3	STCR based NPK + Soil application of 50 kg $FeSO_4$	12.38	28.8	175.9	73.5	448.8
T_4	STCR based NPK + Soil application of 37.5 kg $ZnSO_4$ + Soil application of 50 kg $FeSO_4$	12.88	32.7	210.9	78.3	505.1
T_5	STCR based NPK + 30 kg TNAU Micronutrient mixture as enriched FYM	13.88	40.5	289.5	89.5	639.9
T_6	STCR based NPK + Foliar spray of 0.5% $ZnSO_4$ + Foliar spray of 0.5% $FeSO_4$	13.31	38.4	262.6	85.9	587.3
T_7	STCR based NPK + Foliar spray of 1% $ZnSO_4$ + Foliar spray of 1% $FeSO_4$	14.06	41.3	301.4	90.8	662.6
T_8	STCR based NPK + Foliar spray of Maize maxim @ 1.5% two times application	13.63	39.2	274.3	88.7	620.7
T_9	STCR based NPK + Foliar spray of Maize maxim @ 1.5% four times application	13.00	37.8	254.0	86.8	583.3
T_{10}	Absolute control	8.94	18.5	65.0	38.6	135.6
S.Ed		0.25	1.01	7.18	2.05	12.38
CD (p=0.05)		0.52	2.13	15.08	4.30	26.00

Table 2: Effect of Zinc and Iron Biofortification on Post-Harvest Soil Nutrient Status of Hybrid Maize

	Treatments	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Zn (mg kg^{-1})	Fe (mg kg^{-1})
T_1	STCR based NPK	220.61	17.14	157.10	0.28	2.07
T_2	STCR based NPK + Soil application of 37.5 kg $ZnSO_4$	225.74	15.92	137.61	0.78	2.1
T_3	STCR based NPK + Soil application of 50 kg $FeSO_4$	222.93	16.42	145.5	0.29	2.69
T_4	STCR based NPK + Soil application of 37.5 kg $ZnSO_4$ + Soil application of 50 kg $FeSO_4$	218.84	15.30	132.4	0.84	2.52
T_5	STCR based NPK + 30 kg TNAU Micronutrient mixture as enriched FYM	183.16	12.50	118.9	0.59	2.38
T_6	STCR based NPK + Foliar spray of 0.5% $ZnSO_4$ + Foliar spray of 0.5% $FeSO_4$	194.23	13.72	120.0	0.26	1.98
T_7	STCR based NPK + Foliar spray of 1% $ZnSO_4$ + Foliar spray of 1% $FeSO_4$	181.37	12.20	115.1	0.24	2.01
T_8	STCR based NPK + Foliar spray of Maize maxim @ 1.5% two times application	186.15	12.70	122.4	0.25	2.04
T_9	STCR based NPK + Foliar spray of Maize maxim @ 1.5% four times application	209.98	14.61	127.3	0.29	2.01
T_{10}	Absolute control	168.54	11.60	166.9	0.27	2.06
S.Ed		0.25	5.18	0.26	2.09	0.01
CD (p=0.05)		0.52	10.88	0.56	4.40	0.02

Table 3: Effect of Zinc and Iron Biofortification on Economic Performance of Hybrid Maize

	Treatments	Cost of cultivation (Rs. ha^{-1})	Gross return (Rs. ha^{-1})	Net return (Rs. ha^{-1})	B:C
T_1	STCR based NPK	46144.00	106461	60317.00	2.31
T_2	STCR based NPK + Soil application of 37.5 kg $ZnSO_4$	48581.50	116148	67566.50	2.39
T_3	STCR based NPK + Soil application of 50 kg $FeSO_4$	47394.00	112291	64897.00	2.37
T_4	STCR based NPK + Soil application of 37.5 kg $ZnSO_4$ + Soil application of 50 kg $FeSO_4$	49831.50	118543	68711.50	2.38
T_5	STCR based NPK + 30 kg TNAU Micronutrient mixture as enriched FYM	46991.50	131223	84231.50	2.79
T_6	STCR based NPK + Foliar spray of 0.5% $ZnSO_4$ + Foliar spray of 0.5% $FeSO_4$	48196.00	125607	77411.00	2.61
T_7	STCR based NPK + Foliar spray of 1% $ZnSO_4$ + Foliar spray of 1% $FeSO_4$	48871.00	133910	85039.00	2.74
T_8	STCR based NPK + Foliar spray of Maize maxim @ 1.5% two times application	51112.00	128490	77378.00	2.51
T_9	STCR based NPK + Foliar spray of Maize maxim @ 1.5% four times application	56080.00	123464	67384.00	2.20
T_{10}	Absolute control	33745.00	66016	32271.00	1.96

Conclusion

The treatment T_7 (STCR based NPK + Foliar spray of 1% $ZnSO_4$ + Foliar spray of 1% $FeSO_4$) was the best treatment in terms of growth, yield, quality and economics in hybrid maize. With respect to the study, the micronutrient enrichment was achieved in the treatment T_7 (STCR based NPK + Foliar spray of 1% $ZnSO_4$ + Foliar spray of 1% $FeSO_4$). The treatment T_5 (STCR based NPK+ 30 kg TNAU Micronutrient mixture as enriched FYM) and T_8 (STCR + Foliar spray of Maize maxim @ 1.5% two times) also produced similar effect in enhancing the micronutrient in grains. So, it was concluded that to obtain the higher micronutrient content in hybrid maize it is advisable to use foliar spray of 1% zinc and ferrous sulphate or 30 kg TNAU Micronutrient mixture as enriched FYM or Foliar spray of Maize maxim@ 1.5% two times application along with the N, P, K recommendations. In terms of economics the treatment T_5 (STCR based NPK + 30 kg TNAU Micronutrient mixture as enriched FYM) was found to be superior by attaining the benefit of Rs.2.79 for every Re.1 investment costs.

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