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Maize Yield and Iron Uptake as Impacted by Iron Citrate Treatment

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Authors' contributions

This work was carried out in collaboration between both authors. Author PM designed the study, conducted the experiment, performed statistical scrutiny of the data and wrote the first manuscript. Author KMS helped in the analyses of data and provided technical assistance. Both authors read and approved the final manuscript.

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ABSTRACT

Chelated iron formulations prepared using synthetic chelating agents are widely used and they are harmful to the environment. The present study was aimed at developing and evaluating new chelated iron citrate formulation. New chelated iron citrate formulation with 10.9% Fe was developed and evaluated in comparison with Ferrous sulphate and commercial Ferric citrate during 2018-19 in Tamil Nadu Agricultural University, Coimbatore. A field experiment was conducted with TNAU maize hybrid CO6. Nine treatments replicated thrice in Randomized Block Design. The results revealed that foliar spray of 1% Tamil Nadu Agricultural University Fe citrate thrice on 30,40 and 50 days after sowing registered significantly highest grain yield (7065 kg ha^{-1}) and stover yield (12583 kg ha^{-1}). This was on par with foliar spray of 1% commercial Ferric citrate (T_9). At late vegetative stage, significantly highest Fe content (268 mg kg^{-1}) and Fe uptake (2.13 kg ha^{-1}) were observed in foliar spray of 1% TNAU Fe citrate (T_8). Significantly highest grain and stover Fe content (192 and 219 mg kg^{-1} respectively), grain and stover Fe uptake (1.28 and 2.58 kg ha^{-1} respectively) were observed with foliar spray of 1 % TNAU Fe citrate (T_8).

Keywords: Iron formulations; maize; iron content and uptake; yield.

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1. INTRODUCTION

Due to intensive cropping, growing high yielding varieties and hybrids and reduced use of organic manures, iron (Fe) deficiency in soil is increasing at an alarming rate. Fe deficiency is commonly observed in coarse textured, calcareous, alkaline or sodic soils having sandy texture, high pH and low organic matter soils. Fe plays an inevitable role in the physiology of plants and involved in enzymatic transformations and energy transfer reactions in plants. Fe is a constituent of chlorophyll. Due to deficiency of Fe in soil, yield and concentration of Fe in the edible parts will be reduced. There is a dire need to enhance the Fe content in the edible parts for efficiently tackling the nutritional problems associated with Fe malnutrition in human beings.

Chelated forms of iron fertilizers showed higher use efficiency than inorganic Fe fertilizers. Advantages of using Fe-chelates over inorganic Fe compounds for foliar application were established by [1] and [2]. Foliar applied chelated forms of micronutrients can easily penetrate in to leaf tissue, reduces the risk of phytotoxicity and compatible for tank mixing when compared to the nutrients in the form of inorganic salts. At present, Fe chelates prepared using synthetic chelating agents such as EDTA and EDDHA are available in the market and used by farmers. Since synthetic chelating agents are foreign molecules inside the plant system and environmentally not safe, an attempt was made to prepare Fe chelates using citric acid as a chelating agent and their influence on yield and Fe uptake by maize crop was studied.

2. METHODOLOGY

"To evaluate the effect of newly developed chelated Fe formulation on the yield and Fe uptake by maize crop (TNAU Maize hybrid CO6), a field experiment was conducted at Eastern Block farm of Tamil Nadu Agricultural University, Coimbatore during 2019. Newly developed TNAU Fe citrate (10.9% Fe) formulation was evaluated in comparison with Ferrous sulphate and commercial Ferric citrate. Nine treatments replicated thrice in Randomized Block Design (RBD). The treatments included T_1 - control (NPK alone), T_2 - soil application (basal) of $FeSO_4$ @ 9.5 kg Fe ha^{-1}, T_3 - 0.95 kg Fe ha^{-1} as TNAU Fe citrate, T_4 - 1.9 kg Fe ha^{-1} as TNAU Fe citrate, T_5- 0.95 kg Fe ha^{-1} as commercial Ferric citrate, T_6 - 1.9 kg Fe ha^{-1} as commercial Ferric citrate, T_7 - Foliar spray of 1.0 % $FeSO_4$, T_8 - Foliar spray of 1.0% TNAU Fe citrate, T_9 - Foliar spray of 1.0% commercial Ferric citrate. Foliar spray given thrice on 30, 40 and 50 days after sowing (DAS)" [3].

Soil Test Crop Response (STCR) based NPK fertilizer dose for Maize hybrid for a yield target of 9 t ha^{-1} was 259, 96 and 38 kg ha^{-1} N, P_2O_5 and K_2O, respectively. NPK fertilizers and $ZnSO_4$ @ 25 kg ha^{-1} were applied to all treatments to correct the available Zn deficiency in the experimental soil. Necessary crop protection measures were taken up. "Plant samples were collected at late vegetative stage and harvest stage for assessing the Fe content and uptake. Fe content in plant samples was estimated using Atomic Absorption Spectrophotometer" [4] and "Fe uptake was calculated. Grain and Stover yield were recorded. The data obtained were subjected to statistical analysis" as suggested by [5].

3. RESULTS AND DISCUSSION

The physicochemical characteristics of experimental soil are given in Table 1. The experimental soil belongs to Periyanaickenpalayam series coming under the taxonomic classification fine, montmorillonitic, isohyperthermic, calcareous Typic Haplustert. The experimental soil was clay loam, calcareous, alkaline in reaction (pH 8.07) and non saline (EC 0.24 dS m^{-1}). Organic carbon content of the soil was low (4.79 g kg^{-1}). The available N, P and K content of the soil were low (134 kg ha^{-1}), medium (16.7 kg ha^{-1}) and high (657 kg ha^{-1}) respectively. Regarding micronutrients, the soil was deficient in DTPA-Zn (0.60 mg kg^{-1}), DTPA-Fe (2.27 mg kg^{-1}), DTPA-Cu (0.89 mg kg^{-1}) and sufficient in DTPA-Mn (5.08 mg kg^{-1}). Since the study focusses on evaluating iron formulations, Fe deficient soil was chosen for conducting the field experiment.

3.1 Grain and Stover Yield

The treatment foliar spray of 1.0% TNAU Fe citrate (T_8) registered significantly highest grain yield of 7065 kg ha^{-1} followed by foliar spray of 1.0% commercial Ferric citrate (T_9) (6904 kg ha^{-1}) which were on par (Table 2). Grain yield registered in the treatments soil application of 1.9 kg Fe ha^{-1} as TNAU Fe citrate (T_4) and as commercial Ferric citrate (T_6), soil application of 9.5 kg Fe ha^{-1} as $FeSO_4$ (T_2) and foliar application of 1% $FeSO_4$ (T_7) were statistically comparable. Lowest grain yield of 5857 kg ha^{-1}

was observed in control (NPK alone - T_1) which was on par with soil application of 0.95 kg Fe ha^{-1} as TNAU Fe citrate (T_3) and as commercial Ferric citrate (T_5) [3].

With respect to stover yield, significantly highest value of 12583 kg ha^{-1} was observed with foliar spray of 1.0 % TNAU Fe citrate (T_8) followed by foliar spray of 1.0% commercial Ferric citrate (T_9) which were on par (Table 2). Statistically comparable stover yields were recorded in the treatments soil application of 1.9 kg Fe ha^{-1} as TNAU Fe citrate (T_4) and as commercial Ferric citrate (T_6), soil application of 9.5 kg Fe ha^{-1} as $FeSO_4$ (T_2) and foliar application 1% $FeSO_4$ (T_7). Control (NPK alone - T_1) recorded the lowest stover yield of 10279 kg ha^{-1} (NPK alone - T_1).

Improved plant growth or yield by Fe fertilizer application was already reported [6]. Similar to the results of this study, highest significant values of fodder yield with Fe citrate when compared to other types of chelates and $FeSO_4$ was observed [7].

3.2 Fe Content and Uptake at Late Vegetative Stage

"At late vegetative stage, significantly highest Fe content of 268 mg kg^{-1} was observed in foliar spray of 1.0 % TNAU Fe citrate (T_8) which was on par with foliar spray of 1.0 % commercial Ferric citrate (T_9) (261 mg kg^{-1}) (Table 2). The treatments foliar application 1% $FeSO_4$ (T_7), soil application of 1.9 kg Fe ha^{-1} as TNAU Fe citrate (T_4) and as commercial Ferric citrate (T_6) and soil application of 9.5 kg Fe ha^{-1} as $FeSO_4$ (T_2) registered comparable Fe contents. Lowest Fe content of 229 mg kg^{-1} was recorded in control (NPK alone - T_1)" [3].

"Regarding Fe uptake at late vegetative stage, the treatment foliar spray of 1.0% TNAU Fe citrate (T_8) recorded significantly highest Fe uptake of 2.13 kg ha^{-1} followed by foliar spray of 1.0% commercial Ferric citrate (T_9) (1.97 kg ha^{-1}) (Table 2). Fe uptake in the treatments soil application of 1.9 kg Fe ha^{-1} as TNAU Fe citrate (T_4) and as commercial Ferric citrate (T_6), soil

Table 1. Analysis of soil properties

Properties		Value
pH	:	8.07
EC	:	0.24 dSm^{-1}
Organic Carbon	:	4.79 g kg^{-1}
Available N	:	134 kg ha^{-1}
Available P	:	16.7 kg ha^{-1}
Available K	:	657 kg ha^{-1}
DTPA-Fe	:	2.27 mg kg^{-1}
DTPA-Zn	:	0.60 mg kg^{-1}
DTPA-Mn	:	5.08 mg kg^{-1}
DTPA-Cu	:	0.89 mg kg^{-1}

Table 2. Effect of different Fe formulations on Fe content and uptake at late vegetative stage and yield of maize

Treatments	Late Vegetative Stage		Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})
	Fe content (mg kg^{-1})	Fe uptake (kg ha^{-1})		
T_1 - Control (NPK alone)	229	1.44	5857	10279
T_2 - 9.5 kg Fe ha^{-1} as $FeSO_4$	245	1.68	6403	11212
T_3 - 0.95 kg Fe ha^{-1} as TNAU Fe citrate	235	1.52	6225	11007
T_4 - 1.9 kg Fe ha^{-1} as TNAU Fe citrate	252	1.80	6638	11703
T_5- 0.95 kg Fe ha^{-1} as commercial Ferric citrate	232	1.49	6188	10934
T_6 - 1.9 kg Fe ha^{-1} as commercial Ferric citrate	249	1.74	6592	11674
T_7 - Foliar spray of 1.0 % $FeSO_4$ *	254	1.71	6307	11025
T_8 - Foliar spray of 1.0 % TNAU Fe citrate*	268	2.13	7065	12583
T_9 - Foliar spray of 1.0 % commercial Ferric citrate *	261	1.97	6904	12324
SEd	7	0.12	192	330
CD (*P* = .05)	15	0.26	400	688

**thrice on 30, 40 and 50 DAS*

application of 9.5 kg Fe ha^{-1} as $FeSO_4$ (T_2) and foliar application 1% $FeSO_4$ (T_7) were statistically on par. Among the treatments viz., soil application of 0.95 kg Fe ha^{-1} as TNAU Fe citrate (T_3), commercial Ferric citrate (T_5) and control (NPK alone - T_1) notable variation was not observed with respect to Fe uptake at late vegetative stage. Lowest Fe uptake was recorded in control (NPK alone - T_1)" [3].

3.3 Fe Content and Uptake at Harvest Stage

With respect to grain Fe content, the values varied from 162 to 192 mg kg^{-1}. Foliar spray of 1.0 % TNAU Fe citrate (T_8) registered significantly highest grain Fe content of 192 mg kg^{-1} followed by foliar spray of 1.0% commercial Ferric citrate (T_9) which were statistically comparable (Table 3). Lowest grain Fe content was noticed in control (NPK alone - T_1). Significantly highest grain Fe uptake of 1.28 kg ha^{-1} was observed in the treatment foliar spray of 1.0 % TNAU Fe citrate (T_8) which was on par with foliar spray of 1.0% commercial Ferric citrate (T_9) (Table 3). Foliar application 1% $FeSO_4$ (T_7), soil application of 1.9 kg Fe ha^{-1} as TNAU Fe citrate (T_4) and as commercial Ferric citrate (T_6) and soil application of 9.5 kg Fe ha^{-1} as $FeSO_4$ (T_2) registered comparable grain Fe uptake values. Lowest grain Fe uptake of 0.87 kg ha^{-1} was observed in control (NPK alone - T_1).

Stover Fe content values varied from 186 to 219 mg kg^{-1}, the highest being observed in the treatment foliar spray of 1.0 % TNAU Fe citrate (T_8) and the lowest in control (NPK alone - T_1) (Table 3). Stover Fe uptake was significantly highest (2.58 kg ha^{-1}) in the treatment foliar spray of 1.0 % TNAU Fe citrate (T_8) which was on par with foliar spray of 1.0 % commercial Ferric citrate (T_9) (2.48 kg ha^{-1}) (Table 3). Significantly lowest stover Fe uptake of 1.76 kg ha^{-1} was recorded in control (NPK alone - T_1) and it remained statistically comparable with soil application of 0.95 kg Fe ha^{-1} as TNAU Fe citrate (T_3) and commercial Ferric citrate (T_5).

When compared to control, Fe application registered significantly higher Fe content and uptake. In line with the findings of this study, increased Fe uptake with Fe application was observed [8]. Foliar spray of TNAU Fe citrate recorded significantly higher Fe content and uptake over foliar spray of $FeSO_4$. This might be due to the better absorption and translocation of Fe applied as chelated form when compared to the Fe applied as inorganic salts. Better plant translocation of Fe chelates when compared to Fe-salts was already reported [9,10]. Application of non-charged or negatively-charged Fe-chelates for foliar sprays seems to be the most reasonable alternative as suggested by [11]. Further, the use of Fe chelates will minimize interactions with spray components and allows treatment at optimal pH values for penetration purposes [12]. Higher Fe uptake registered in the treatment foliar spray of 1.0% TNAU Fe citrate might have contributed for the higher grain and stover yield observed in this treatment.

Table 3. Effect of different Fe formulations on Fe content and uptake at harvest stage of maize

Treatments	Grain		Stover	
	Fe Content (mg kg^{-1})	Fe Uptake (kg ha^{-1})	Fe Content (mg kg^{-1})	Fe Uptake (kg ha^{-1})
T_1 - Control (NPK alone)	162	0.87	186	1.76
T_2 - 9.5 kg Fe ha^{-1} as $FeSO_4$	175	1.05	198	2.07
T_3 - 0.95 kg Fe ha^{-1} as TNAU Fe citrate	167	0.94	191	1.92
T_4 - 1.9 kg Fe ha^{-1} as TNAU Fe citrate	180	1.11	203	2.22
T_5- 0.95 kg Fe ha^{-1} as commercial Ferric citrate	165	0.93	189	1.89
T_6 - 1.9 kg Fe ha^{-1} as commercial Ferric citrate	178	1.09	201	2.15
T_7 - Foliar spray of 1.0 % $FeSO_4$ *	180	1.04	205	2.09
T_8 - Foliar spray of 1.0 % TNAU Fe citrate*	192	1.28	219	2.58
T_9 - Foliar spray of 1.0 % commercial Ferric citrate *	189	1.21	215	2.48
SEd	5	0.07	6	0.14
CD (*P* = 0.05)	11	0.14	12	0.29

**thrice on 30, 40 and 50 DAS*

4. CONCLUSION

Since the experimental soil is calcareous in nature, foliar application of Fe fertilizers outperformed soil application. Foliar application of TNAU Fe citrate performed better than foliar application of $FeSO_4$. The treatment foliar spray of 1% TNAU Fe citrate recorded highest grain and stover yield as well as Zn content and Zn uptake at late vegetative and harvest stages over all other treatments.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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