Original Research Article

IMPACT OF IRON CITRATE ON YIELD AND Fe UPTAKE BY MAIZE CROP

Comment [h1]: Suggested change: Maize yield and iron uptake is impacted by iron citrate treatment

ABSTRACT

Chelated iron formulations prepared using synthetic chelating agents are widely used and they are harmful to the environment. New chelated iron formulation using citric acid with Fe content of 10.9% Fe was developedandevaluated in comparison with Ferrous sulphate and commercial Ferric citrate.Nine treatments replicated thrice in Randomised Block Design (RBD). The results revealed that foliar spray of 1 % TNAU 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}) which 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 219mg 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).

Comment [h2]: Write a complete word to identify the abbreviation

Comment [h3]: This is a long sentence , I prefer to make it shorter or two sentences instead of one

Comment [h4]: Unclear abbreviation

Key words :*Maize, Ironformulations, Yield, Fe content and uptake*

Comment [h5]: Rearrange alphabetically

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 chlorphyll. Due to deficiency of Fe in soil,yieldandconcentration 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 problemsassociated with Fe malnutrition in human beings.

Comment [h6]: chlorophyll

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 Basiouny and Biggs [1] and Leonard [2].Foliar applied chelated forms of micronutrients can easily penetrate in to leaf tissue, reduces the risk of phyto-toxicity 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 agentand their influence on yield and Fe uptake by maize crop was studied.

2. MATERIALS AND METHODS

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 wasevaluated in comparisonwith Ferrous sulphate and commercial Ferric citrate. Nine treatments replicated thrice in Randomised Block Design (RBD). The treatments included control (NPK alone), soil application (basal) of $FeSO_4$ @ 9.5 kg Fe ha^{-1}, TNAU Fe citrate and commercial Ferric citrate @ 0.95 and 1.9 kg Fe ha^{-1}, foliar spray of 1.0 % $FeSO_4$, TNAU Fe citrate andcommercial Ferric citrate thrice on 30, 40 and 50 days after sowing (DAS).

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} to correct the available Zn deficiency in the experimental soil were applied to all treatments. 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 [3]. Grain and Stover yield were recorded. The data obtained were subjected to statistical analysis as suggested by Panse and Sukhatme[4].

3. RESULTS AND DISCUSSION

The physico chemical 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. Regardingmicronutrients, 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}).

Comment [h7]: recheck

Comment [h8]: add comma after

Table 1. Characteristics of Experimental Soil

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

Comment [h9]: Soil analyses of metal contents

Comment [h10]: the author can re-edit the table make it two columns and write the unit beside the value. A title for columns should be added

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).

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 recorded the lowest stover yield of 10279 kg ha^{-1} (NPK alone - T_1).

Mostaghimi&Matocha [5] reported improved plant growth or yield by iron fertilizer application. The results of this study are in agreement with the findings of Sangeetha et al. [6] who reported highest significant values of fodder yield with Fe citrate when compared to other types of chelates and $FeSO_4$.

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} wasrecorded in control (NPK alone - T_1).

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 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).

Table 2. Effect of 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=0.05)	15	0.26	400	688

Comment [h11]: different Fe formulations

Comment [h12]: I thought T0, T1, ...

*thrice on 30, 40 and 50 DAS

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).

Table 3. Effect of 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

When compared to control, Fe application registered significantly higher Fe content and uptake. This is in line with the findings of Durgude et al. [7] who reported increased Fe uptake with Fe application.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 by Hsu and Ashmead [8] ;Fernández et al. [9]. Application ofnon-charged or negatively-charged Fe-chelates for foliar sprays seems to be themost reasonable alternative as suggested by Fernández [10]. Further, the use of Fe chelates will minimize interactions with spraycomponents and allows treatment at optimal pH values for penetration purposesFernández et al. [11]. 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.

4. CONCLUSION

Since the experimental soil is calcareous in nature, foliar application of Fe fertilizers outperformed over 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 yieldas well as Zn content and Zn uptake at late vegetative and harvest stages over all other treatments.

REFERENCES

1. Basiouny FM, Biggs RH. Uptake and distribution of iron in citrus. Proceedings of Florida State Horticultural Society. 1971;84:17-22.
2. Leonard CD. Use of dimethyl sulfoxide as a carrier for iron in nutritional foliar sprays applied to citrus. Annals of New York Academy of Science. 1967;141:148-158.
3. Jackson M. Methods of chemical analysis: Prentice Hall of India (Pvt.) Ltd., New Delhi.1973.
4. Panse VG, Sukhatme PV. Statistical methods for agricultural workers. Statistical methods for agricultural workers.(Ed. 3). 1978.
5. Mostaghimi S, Matocha JE. Effects of normal and Fe treated organic matter on Fe chlorosis and yields of grain sorghum. Commun. Soil Sci. Plant Anal. 1988;19: 1415-1428.
6. Sangeetha SS, Jawahar D, Chitdeshwari T, Babu C, Lakshmanan L. The Influence of Iron Chelates on Chlorophyll Content and Yield of Bajra Napier. Current Journal of Applied Science and Technology. 2021; 40(6): 1-6.
7. Durgude AG, Kadamanda SR, Pharande L. Response of hybrid maize to soil and foliar application of iron and zinc on Entisols. An Asian Journal of Soil Science. 2014; 9(1) : 36-40.
8. Hsu HH, Ashmead HD. Effect of urea and ammonium nitrate on the uptake of iron through leaves. Journal of Plant Nutrition, 1984;7:291-299.
9. Fernández V, Ebert G, Winkelmann G. The use of microbial siderophores for foliar iron application studies. Plant and Soil. 2005;272:245–252.
10. Fernández V. Investigations on foliar iron application to plants – a new approach. Aachen, Germany: Shaker Verlag.2004.
11. Fernández V, Winkelmann G, Ebert G. Iron supply to tobacco plants through foliar application of iron citrate and ferric dimerum acid. Physiologia Plantarum. 2004;22:380-385.