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The Periodic Variation in Iron Availability in Soils Affected by Saline Water Conditions

Pushpa S. Parmar [a++*] and K. C. Patel [b#]

[a] Department of Soil Science and Agricultural Chemistry, College of Agriculture, Anand Agricultural University, Vaso, India.
[b] Micronutrient Research Center (ICAR), Anand Agricultural University, Anand, India.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

An incubation study was carried out at Department of Soil Science and Agricultural Chemistry, College of Agriculture, AAU, Vaso for 60 days to find out the effect of Fe nanoparticles on periodical availability of iron in soil under saline water condition with different levels of Fe nanoparticle with two types of irrigation water in loamy sand soil. The treatments were repeated thrice adopting CRD factorial (2 factors) design. Irrigation water samples was drawn as per standard protocol and important chemical parameters were analyzed. The 100 g soils were treated in plastic beaker with seven levels of Fe nanoparticle (0, 0.2, 0.4, 0.6, 0.8, 1.0 and 5.0 mg Fe/kg soil) and three level of $FeSO_4$ (2.5, 5.0 and 10.0 mg/kg) under saline water condition i.e (i) High saline water (EC > 4dSm^{-1}) and Low saline water (EC < 1dSm^{-1}). The four sampling was done at an

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[++] *Assistant Professor;*
[#] *Research Scientist;*
**Corresponding author: Email: pushpa78767@aau.in;*

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interval of time i.e 10, 20, 40 and 60 days after treatment. Each set was completely withdrawn after 10, 20, 40 and 60 days and was analyzed for DTPA-Fe. The DTPA extractable Fe content after 10, 20, 40, 60 days of incubation in soil was significantly decreased due to high saline irrigation water (EC > 4dS m^{-1}) over low saline irrigation water (EC < 1dS m^{-1}). The significantly highest DTPA-Fe content (6.83, 7.58, 8.32 and 8.48 mg kg^{-1}) was recorded at 10, 20, 40 and 60, respectively days after incubation due to 10.0 mg kg^{-1} soil through $FeSO_4$ application, which was found at par with treatment 5.0 mg Fe kg^{-1} soil through $FeSO_4$ or Fe nanoparticles. The DTPA-Fe availability adversely affected over the time under high saline irrigation water condition.

Keywords: Fe nanoparticles; $FeSO_4$; saline irrigation water condition.

1. INTRODUCTION

The iron deficiency is widespread among many different crops. To alleviate Fe deficiency of plants, Fe application in conventional mixed fertilizers is still the most prevalent to improve crop yields; however, Fe applied with conventional fertilizers are often ineffective with a low nutrient-use efficiency (Laurie & Reymondie, 1991; Connorton et al., 2017). Iron nanoparticles are being investigated as a substitution for Conventional and Chelated iron fertilizers. Several recent studies have reported that Fe nano fertilizer is more effective in supplying Fe to plants, compared to the commonly used Fe fertilizers/chemicals in agriculture production systems (Cheng et al., 2016; Connorton et al., 2017; El-Desouky et al., 2021). Soil salinization may be caused by natural processes (primary salinization) or human activities (secondary salinization). However, in cultivated lands, the most common origin of salts is the circulating water (Aragüés et al., 2014; Wang et al., 2015). The mechanisms involved in Fe dynamics under saline conditions and the precise regulatory elements of these interactions are still poorly understood. Salinity decreases the solubility of trace elements, such as Fe (Lesch et al., 2012), and recent studies suggest that salinity correlates negatively with Fe availability to plants (Abbas et al., 2014; Purohit et al., 2017). Salinity has an additive effect on Fe deficiency in plants, and chlorosis, related to Fe deficiency, is enhanced (Nenova, 2008; Abbas et al., 2014). It has been proposed that Fe limitation may develop from a downregulation of Fe transporters in response to salinity (Cotsaftis et al., 2011). Iron availability in well-aerated soils is usually high. However, in these soils, Fe usually forms insoluble ferric compounds at neutral pH values, thus rendering it unavailable to plants. Several studies have reported that Fe nanoparticles are very effective to minimize leaching and volatilization and increase Fe availability to growing plants when compared to the commonly used traditional Fe fertilizers or chelated Fe fertilization (Barzana et al., 2022; El-Desouky et al., 2021). The iron deficiency is widespread among many different crops. To alleviate Fe deficiency of plants, Fe application in conventional mixed fertilizers is still the most prevalent to improve crop yields; however, Fe applied with conventional fertilizers are often ineffective with a low nutrient-use efficiency (Laurie & Reymondie, 1991; Connorton et al., 2017). Iron nanoparticles are being investigated as a substitution for Conventional and Chelated iron fertilizers. Several recent studies have reported that Fe nano fertilizer is more effective in supplying Fe to plants, compared to the commonly used Fe fertilizers/chemicals in agriculture production systems (Cheng et al., 2016; Connorton et al., 2017; El-Desouky et al., 2021).

2. MATERIALS AND METHODS

2.1 Laboratory Study

An incubation study was carried out at Department of Soil Science and Agricultural Chemistry, College of Agriculture, AAU, Vaso for 60 days to study the different levels of Fe nanoparticle and conventional $FeSO_4$ with two types of irrigation water i.e (i) High saline water (EC > 4 dSm^{-1}) and Low saline water (EC < 1 dSm^{-1}) in loamy sand soil of Vaso campus.

2.2 Methods of Analysis of Soil and Water Samples

Bulk soil samples were collected from the field at a depth of 0-15 cm before commencement of an incubation study and were analyzed for the various physical and chemical properties of the soil. The soil of experimental field was loamy sand in texture, having bulk density (1.53Mg m^{-3}), Maximum Water Holding Capacity (40.0%), pH (8.21), EC (0.65dS m^{-1}), low in organic carbon (0.42%) and DTPA - Fe (5.09mg kg^{-1}) by following International Pipette method (Piper, 1966), Cylindrical core method (Veihmeyer & Hendrickson, 1949), Brass Cup box (Chopra & Kanwar, 1976), Potentiometry method (Jackson, 1973), Conductometry method (Jackson, 1973), Wet oxidation method (Walkley & Black, 1934), 0.005 M DTPA, pH 7.3, Atomic Absorption Spectrometry (Lindsay & Norvell, 1978), respectively.

The high saline water was collected from College of Agriculture, Vaso campus bore well and low saline water from RO water from water purification system. Irrigation water samples was drawn as per standard protocol and important chemical properties like, pH, EC, Na^+, K^+, Ca^{++}, Mg^{++}, CO_3^{-2}, HCO_3^-, Cl^-, SO_4^{-2}, by following Potentiometric method (Richards, 1954) for pH, Conductivity method (Richards, 1954) for EC, Flame photometry (Richards, 1954) for Na^+ and K^+, Versenate method (Chang & Bray, 1951) for Ca^{++} and Mg^{++}, Volumetric titration (Richards, 1954) for CO_3^{-2} and HCO_3^- , $AgNO_3$ precipitation method (Richards, 1954) for Cl^-, Turbidity method (Chesnin & Yien, 1950) for SO_4^{-2}, respectively. The values of high saline and low saline irrigation water were analyzed and recorded 7.6, 7.2 of pH, 4.96, 0.24 dS m^{-1} of EC, 35.5, 5.2 m.eq./L of Na^+, 4.2, 0.1 m.eq./L of K^+, 2.1, 0.6 m.eq./L of Ca^{++}, 7.8, 1.8 m.eq./L of Mg^{++}, 0.8, 0.0 m.eq./L of CO_3^{-2} , 9.2, 0.0 m.eq./L of HCO_3^-, 27.6, 2.5 m.eq./L of Cl^- and 2.4, 0.0 m.eq./L of SO_4^{-2}, respectively. The following water and soil quality indices were calculated by standard categorization purpose.

1) Sodium Adsorption Ratio

$$\mathrm{SAR} = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

(Concentrations of all cations in me L-1)

2) Residual Sodium Carbonate

$$\mathrm{RSC} = (CO_3^- + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

(Concentrations of all cations in me L^{-1})

2.3 Rating Used for Water Quality Appraisal

2.3.1 Sodium adsorption ratio (Abbas et al., 2014)

The SAR is used to assess the suitability of water for agricultural irrigation and to evaluate the sodicity hazard of soils. It considers the concentrations of key cations (sodium, calcium, and magnesium) present in water. Here’s how it works:

1. S1 (Low Na water): SAR values ranging from 0 to 10 fall into this category. Water with low sodium content is suitable for irrigation. Plants can thrive without adverse effects.
2. S2 (Medium Na water): SAR values between 10 and 18 indicate moderate sodium levels. While still manageable, it’s essential to monitor soil health and consider amendments if needed.
3. S3 (High Na water): SAR values in the range of 18 to 26 signify high sodium content. Irrigation with such water may impact soil structure and permeability. Soil amendments become crucial to prevent long-term damage.
4. S4 (Very high Na water): When SAR exceeds 26, water becomes very saline. It can severely affect soil properties, leading to poor crop production. Mitigating measures are necessary.

2.3.2 Residual sodium carbonate (Barzana et al., 2022)

The RSC index helps assess the alkalinity hazard associated with irrigation water or soil water. It considers the balance between bicarbonate (HCO_3^-) and carbonate (CO_3^{--}) anions relative to calcium (Ca^{++}) and magnesium (Mg^{++}) ions. Here’s how the RSC value translates into practical classes:

1. **Safe:** When the RSC value is less than 1.25 me L-1, the water is considered safe. It poses minimal alkalinity risk for soil and is suitable for irrigation.
2. **Marginal:** An RSC value falling between 1.25 and 2.50 me L-1indicates moderate sodium levels. While manageable, monitoring soil health and considering amendments is essential.
3. **Unsafe:** If the RSC value exceeds 2.50 me L-1, the water becomes very saline. It can severely affect soil properties, leading to poor crop production. Mitigating measures are necessary.

The values of high saline and low saline irrigation water of SAR were 15 and 3.4 and it was categorized in S2 (Medium Na water) and S1 (Low Na water), respectively. The values of high saline and low saline irrigation water of RSC values were 0.1 and -2.4 and was categorized in Safe class. The class of high saline irrigation water and low saline irrigation water was C_4S_2 and C_1S_1 as per the USSSL has prepared the diagram for use of water having different values of EC as well as SAR.

The 100 g soils were treated in plastic beaker with seven levels of Fe nanoparticle (0, 0.2, 0.4, 0.6, 0.8, 1.0 and 5.0 mg Fe/kg soil) and three level of FeSO4 (2.5, 5.0 and 10.0 mg/kg). The treatments were repeated thrice adopting CRD factorial (2 factors) design. The four sampling was done at an interval of time i.e 10, 20, 40 and 60 days after treatment. The soil moisture was maintained at field capacity (FC) i.e., 50% MWHC (Maximum water holding capacity) throughout the incubation period. Each set was completely withdrawn after 10, 20, 40 and 60 days and was analyzed for DTPA-Fe.

2.4 Statistical Analysis

The statistical analysis was performed in the Department of Agricultural Statistics, BACA, AAU, Anand. The data were subjected to statistical analysis as per the methods suggested by Steel & Torrie, (1960). The value "F" was worked out and compared with value of "F" at 5% level of significance. The value of standard error (mean) (S.Em. ±). Critical difference (C.D) and Coefficient of variation (C.V. %) were also calculated and appropriately used for the interpretation of data, which are presented in respective tables.

3. RESULTS AND DISCUSSION

The results presented in Table 1 indicated the changes due to application of Fe sources on periodical availability of DTPA-Fe at 10, 20, 40 and 60 days after incubation in soil under saline water condition.

3.1 Effect of Saline Irrigation Water

The DTPA-Fe content in soil was non-significantly affected by the application of saline irrigation water condition IW_1: High saline water (EC > 4dS m^{-1}). The significantly highest DTPA-Fe content (6.83, 7.58, 8.32 and 8.48mg kg^{-1}) was recorded in IW_2: Low saline water (EC < 1dS m^{-1}) at 10, 20, 40 and 60, respectively. The extent of increase in DTPA-Fe content in soil under IW_2: Low saline water (EC < 1dS m^{-1}) was 3.8, 8.5, 6.5 and 4.2 per cent over IW_1: High saline water (EC > 4dS m^{-1}).

Table 1. Effect of Fe nanoparticles and ferrous sulphate on periodical availability of DTPA-Fe at 10, 20, 40 and 60 days after incubation in soil under saline water condition

Treatment details		**DTPA-Fe (mg kg^{-1})**			
		Days after Incubation			
		10	**20**	**40**	**60**
IW Level					
IW_1	**High saline water (EC > 4 dS m^{-1})**	5.73	6.41	6.97	7.25
IW_2	**Low saline water (EC < 1 dS m^{-1})**	5.95	6.95	7.42	7.56
S.Em.±		0.07	0.10	0.09	0.11
CD at 5%		0.20	0.28	0.26	0.31
Fe Level					
Fe_1	**0.0 mg Fe kg^{-1} soil through nanoparticles**	5.08	5.28	5.38	5.44
Fe_2	**0.2 mg Fe kg^{-1} soil through nanoparticles**	5.16	6.23	6.55	6.75
Fe_3	**0.4 mg Fe kg^{-1} soil through nanoparticles**	5.40	6.44	6.80	6.94
Fe_4	**0.6 mg Fe kg^{-1} soil through nanoparticles**	5.51	6.54	7.13	7.22
Fe_5	**0.8 mg Fe kg^{-1} soil through nanoparticles**	5.61	6.66	7.30	7.39
Fe_6	**1.0 mg Fe kg^{-1} soil through nanoparticles**	5.79	6.76	7.40	7.58
Fe_7	**5.0 mg Fe kg^{-1} soil through nanoparticles**	6.50	7.18	7.76	8.19
Fe_8	**2.5 mg Fe kg^{-1} soil through $FeSO_4$**	5.91	6.86	7.52	7.99
Fe_9	**5.0 mg Fe kg^{-1} soil through $FeSO_4$**	6.59	7.30	7.82	8.11
Fe_{10}	**10.0 mg Fe kg^{-1} soil through $FeSO_4$**	6.83	7.58	8.32	8.48
S.Em.±		0.16	0.22	0.20	0.24
CD at 5%		0.46	0.63	0.58	0.69
IW x Fe (Interaction)					
S.Em.±		0.22	0.31	0.28	0.33
CD at 5%		NS	NS	NS	NS
CV %		6.55	7.92	6.76	7.82

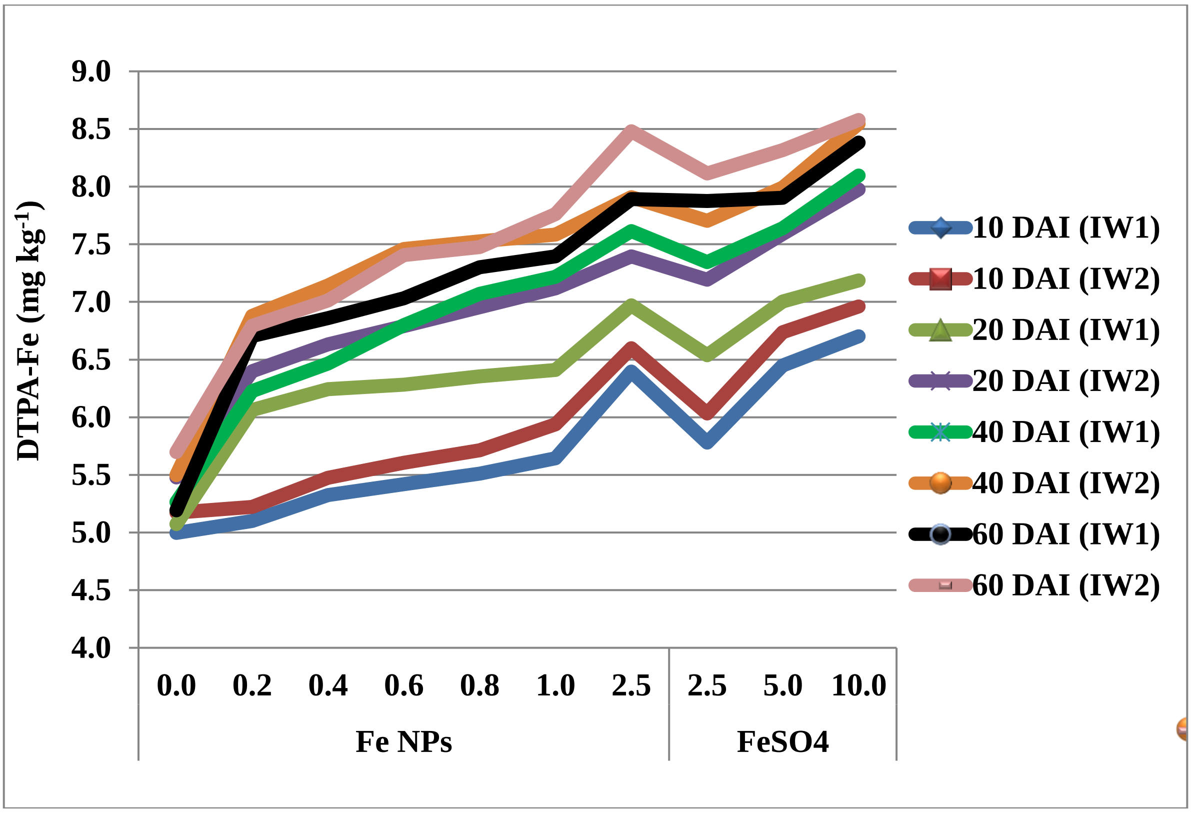

Fig. 1. The effect of Fe Nano particles on periodical availability of DTPA-Fe in soil under saline water condition

3.2 Effect of Fe Application

Various Fe applications in soil through Fe nanoparticles and ferrous sulphate (0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 5.0 mg Fe kg^{-1} soil through Fe nanoparticles and 2.5, 5.0 and 10 mg through $FeSO_4$ kg^{-1} soil). Significantly higher DTPA-Fe content was recorded 6.83, 7.58, 8.32 and 8.48 mg kg^{-1} in soil with application of Fe_{10}: 10.0 mg kg^{-1} soil through $FeSO_4$ at 10, 20, 40 and 60, respectively. The treatment Fe_{10}: 10.0 mg kg^{-1} soil through $FeSO_4$ application remained at par with treatments Fe_7: 5.0 mg Fe kg^{-1} soil through nanoparticles and Fe_9: 5.0 mg Fe kg^{-1} soil through $FeSO_4$. The maximum improvement in DTPA-Fe content in soil was 34.4, 43.5, 54.6 and 55.8 per cent observed under Fe_{10}: 10.0 mg kg^{-1} soil through $FeSO_4$application over Fe_1: 0.0 mg Fe kg^{-1} soil through nanoparticles.

3.3 Interaction Effect

Interactive effect among high and low saline water condition and various Fe applications in soil through Fe nanoparticles and ferrous sulphate on DTPA-Fe at 10, 20, 40 and 60 days after incubation in soil was found non-significant.

Overall, the changes due to application of Fe nanoparticles and ferrous sulphate on periodical availability of DTPA-Fe at 10, 20, 40 and 60 days after incubation in soil under saline water condition were found significant (Table 1 and Fig. 1).
The Fig. 1 showed that the soil DTPA-Fe content increased with the increasing in the level of Fe through nanoparticles and ferrous sulphate under low saline water (EC < 1dS m^{-1}) condition. The data pertaining to the DTPA-Fe in soil showed that the decreased DTPA-Fe content in soil in saline condition (High saline water: EC > 4dS m^{-1}). Therefore, result showed high salinity adversely affected DTPA Fe content in soil.

4. CONCLUSION

The DTPA extractable Fe content was adversely affected under high saline water condition at 10, 20, 40 and 60 days after incubation over the low saline water condition at 5.0 and 10.0 mg kg^{-1} soil through FeSO4 and 5.0 mg Fe kg^{-1} soil through Fe nanoparticles.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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