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# Using of Ferrihydrite and Some Ionic Compounds as a Potential Amendment in Calcareous Soils

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**Abstract:** Greenhouse experiment was conducted to evaluate using of synthetic ferrihydrite and some ionic compound formed between urea and essential micronutrient through complexation reaction. Results revealed that the addition of complexes metal salt urea with citric acid increased fresh and dry weight of wheat plant at different stages of plant growth than without citric acid. Higher value of fresh, dry weight, grain and straw of wheat plant were recorded in the presence of citric acid due to improving of the fertilizer complexing salt urea mechanisms. It was noticed that increasing levels of Fe from 40 to 120mg $Kg^{-1}$ soil gradually increased the yield production. Ferrihydrite products added to soil gave a remarkable effect on Fe and N uptake. Results also showed that, increasing ratio of Fe/ Si had a positive effect for both Fe and N uptake as well as total content. The application of complexing metal salt urea and ferrhydrite had a positive effect for maintaing Fe in an active form as $Fe^{+2}$ in leaves of wheat plant reflecting on the increasing of total chlorophyll content to an extent of healthy plants. It evident that poorly crystalline materials had a good scope of residual effects which seems to substantial the slow release of these was immobilized.

**Key words:** Ferrihydrite, ionic compound, wheat plants and calcareous soil.

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## INTRODUCTION

Iron deficiency is still one of the major problems in calcareous soils, the dynamic of iron (Fe) in calcareous soils is largely controlled by the dissolution- precipitation equilibrium of more or less crystalline iron oxides[22]. These minerals are characterized by a poor solubility product that is decreasing which increasing pH[9]. The total concentration of soluble Fe in solution is thus always far below the level required for adequate growth of crop species[15]. Unless pH is very low as occurs in the reducing conditions of waterlogged soils (Hinsinger, 1998). In calcareous soils, because of high pH, Fe concentrations in soil solution are very low and plants often develop severe symptoms of Fe chlorosis[21,15].

From iron chemistry thermodynamics, it is well known that Fe depends on the specific surface of the solid[24]. Amorphous materials dissolve very fast whereas crystalline materials are quite slow. These factors may act to mobilize labile Fe from solid phase Fe containing compounds in the soil. The most readily available labile sources of Fe are likely the poor crystalline Fe oxides, i.e. ferrihydrite, which have high reactive surface areas. This most corroborated in the recent study by Loeppert and Hallmark[[13] El-Aila[6] in which a high negative correlation was observed between incidence of chlorosis and the amorphous Fe oxide content.

Also, recently some metal salt-urea complexes have been successfully prepared[1,7]. Since the urea can be effective when complexed with certain metal salts to form new anhydrous coordination complexes. Such approach may prepare urea- based fertilizers, which contain micronutrients and still maintain good physical properties during storage.

The objective of this study was to evaluate the effectiveness of ferrihydrite and some ionic compounds as fertilizers values particularly in calcareous soil and their effects on growth and some chemical composition of wheat plants.

## MATERIALS AND METHODS

**Properties and perpetration of Siliceous ferrihydrite and ionic compounds:** The poorly crystalline Fe oxide was prepared by addition of NaOH to a Fe (III) salt as is summarized in the following equation:

$$Fe^{+3} + OH^{-} \xrightarrow[PH\ 8.2]{SiO_3^{-2}} \text{Siliceious ferrihydrate}$$

The presence of silicate influences the poorly crystalline product to have smaller crystal sizes and a

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higher surface area[4,27]. The rate of transformation of ferrihydrite to goethite is inversely related to silica content[6,25]. Ferrihydrite (without and silica) transforms rapidly at room temperature and high pH into a crystalline phase, e.g., goethite, but it has been observed that in the presence of silicate the transformation of these materials is inhibited due to silicate anion sorption at the surface of the crystal nuclei and the retardation of crystal growth processes. Therefore, in the soil it is likely that silicate anions in the ferrihydrite structure will inhibit the transformation to more crystalline phase and thus will enable the to maintain the labile pool of Fe for subsequent crops.

The preparation of ferrihydrate and ionic compound were discussed previously by El- Aila[6] and El-Aila *et al*[7].

**Greenhouse experiment:** Pot experiment was conduct in the National Research Center and designed as randomized complete block with three replicates in plastic pots 40cm height, 25 cm diameter, each one containg 10Kg of air-dried soil. The investigated soil was characterized by pH 8.72, E.C. 0.36 dsm$^{-1}$, CaCO$_3$ 11.3% organic matter 0.12%, total N 0.012% available Fe 5.3 ppm, Clay 1.73%, silt 6.58% and sand 91.69%. Soil were treated with ferrous sulfate (Fe$^{+2}$), ferric sulfate (Fe$^{+3}$), ferrihydrite, Fe (urea)$_6$ SO$_4$ and Fe (urea)$_6$ SO$_4$.CA with three doses 40,80,120 mg Fe Kg$^{-1}$. The investigated treatments were use as follows: (table 1)

| Treatment | mg Fe Kg$^{-1}$ | Treatment | mg Fe Kg$^{-1}$ |
|---|---|---|---|
| Control | - | - | - |
| Fe$^{+3}$ | 40 | Fe- 1.0 Si | 40 |
| Fe$^{+3}$ | 80 | Fe- 1.0 Si | 80 |
| Fe$^{+3}$ | 120 | Fe- 1.0 Si | 120 |
| Fe$^{+2}$ | 40 | Fe (urea)$_6$ SO$_4$ | 40 |
| Fe$^{+2}$ | 80 | Fe (urea)$_6$ SO$_4$ | 80 |
| Fe$^{+2}$ | 120 | Fe (urea)$_6$ SO$_4$ | 120 |
| Fe- 0.25 Si | 40 | Fe (urea)$_6$ SO$_4$. CA | 40 |
| Fe- 0.25 Si | 80 | Fe (urea)$_6$ SO$_4$. CA | 80 |
| Fe- 0.25 Si | 120 | Fe (urea)$_6$ SO$_4$. CA | 120 |

Nitrogen, phosphorous and potassium were applied at rates of 120mgN, 50mg P$_2$O$_5$ and 40 mg K$_2$O Kg$^{-1}$ as slow release nitrogen fertilizer, superphosphate and potassium sulphate respectively. Wheat (Triticum aestivum L.C.V. Sakha 69) were planted, after 10 days the plants were thinned to six plants per pot. Plants samples were taken at 30,45 and 60 days from seedling. Fresh, dry weight, total cholorophyll, ferrous (Fe$^{+2}$), nitrogen and iron were determine in plant as described by Cottenie *et al*.[5] and Black[2].

At physiological maturity, plants were harvested and separated into straw and grains, dry weight were recorded, and biomass ground and prepared for analysis. Total- N and iron were determined in grain and straw by the method described by Cotteni *et al*[5].

Soil samples were taken from each pot after harvesting and air-dried. Fractionation of iron was carried out according to the method described by Miller *et al*[17].

## RESULTS AND DISCUSSIONS

**Plant growth:** Table (1) observed that the addition of ferrihydrite increased both fresh and dry weight of wheat plants at different stages of plant growth. The ameliorative effect of ferrihydrite depends on the level of Si / Fe ratios and the rate of Fe application. For Fe-1.0 Si was more effective as compared with Fe-0.25 Si. This result may be due to the solubilization of the amorphous ferric hydroxide or ferrihydrite, which gave higher amounts of Fe in the soil solution than those, caused by crystalline hydroxide[11,20].

The addition of Fe$^{+2}$ or Fe$^{+3}$ slightly improved fresh and dry weight of plant growth as compared with the control. While the application of ionic compound Fe(urea)$_6$ SO$_4$ and Fe(urea)$_6$ SO$_4$. CA was more pronounced effect on fresh and dry weight of wheat plants than high level of Fe from Fe$^{+2}$ or Fe$^{+3}$ respectively. It was noticed that the addition of Fe (urea)$_6$ SO$_4$.CA gave the highest fresh and dry weight of wheat plants at different stages of plant growth. The ameliorative effect of citric acid (CA) depends on its reactions of urea with binding sorbing sites on the exchange complex to form stable complex with Fe and consequently, have a major functional acidic group product that maintain Fe more available through increasing its solubility groups. Similarly were noticed by Mora *et al*[18].

**Grain and straw Yield:** Data in table (1) show that the addition of Fe treatments increased grain and straw yield as compared with control. However the application of Fe$^{+2}$ and Fe$^{+3}$ does not effective as compared with ferrihydrite at different ratios or Fe(urea)$_6$SO$_4$ and Fe(urea)$_6$SO$_4$CA. This could be due to the sorption mechanisms particularly in calcareous soil which characterized by high both of pH and CaCO$_3$%.

The addition of Fe- 0.25 Si and Fe- 1.0 Si stimulate the yield production for both grain and straw yield as compared with Fe$^{+2}$ and Fe$^{+3}$. Increasing the levels of Fe from 40 to 120mg FeKg$^{-1}$ gradually increased the grain and straw yield production of wheat plants.

**Table 1:** Effect of ferrihydrite and ionic compound of iron on fresh, dry weight and total yield of wheat plant growing in calcareous soil (gm/plant).

| Treatments | Fe level mg Fe Kg$^{-1}$ | Fresh weight | | | Dry weight | | | Grain yield gm/plant | Straw yield gm/plant | Grain/straw ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 30 | 45 | 60 | 30 | 45 | 60 | | | |
| Control | | 7.24 | 11.96 | 17.50 | 2.19 | 4.95 | 7.26 | 1.62 | 7.26 | 0.22 |
| $Fe^{+3}$ | 40 | 7.95 | 12.68 | 19.44 | 2.3 | 5.31 | 9.93 | 2.90 | 9.34 | 0.31 |
| $Fe^{+3}$ | 80 | 8.08 | 14.94 | 20.30 | 2.55 | 5.63 | 7.95 | 3.28 | 10.02 | 0.34 |
| $Fe^{+3}$ | 120 | 8.22 | 14.54 | 20.93 | 2.65 | 5.69 | 8.03 | 3.45 | 10.35 | 0.38 |
| $Fe^{+2}$ | 40 | 8.05 | 13.94 | 20.65 | 2.3 | 5.63 | 8.0 | 3.48 | 10.53 | 0.33 |
| $Fe^{+2}$ | 80 | 8.42 | 14.83 | 21.30 | 2.78 | 5.66 | 8.18 | 3.93 | 11.30 | 0.34 |
| $Fe^{+2}$ | 120 | 9.10 | 15.41 | 21.75 | 3.05 | 5.75 | 8.64 | 4.43 | 11.63 | 0.38 |
| Fe- 0.25 Si | 40 | 8.69 | 14.16 | 23.17 | 2.70 | 6.32 | 9.61 | 5.47 | 14.44 | 0.37 |
| Fe- 0.25 Si | 80 | 9.33 | 16.5 | 24.41 | 3.47 | 6.50 | 9.71 | 5.68 | 14.98 | 0.37 |
| Fe- 0.25 Si | 120 | 9.93 | 17.57 | 25.57 | 3.61 | 6.79 | 10.26 | 6.08 | 15.99 | 0.38 |
| Fe- 1.0 Si | 40 | 10.46 | 19.34 | 27.04 | 4.16 | 7.53 | 10.24 | 6.10 | 19.12 | 0.32 |
| Fe- 1.0 Si | 80 | 10.74 | 20.28 | 28.30 | 4.26 | 7.96 | 10.60 | 6.73 | 19.75 | 0.34 |
| Fe- 1.0 Si | 120 | 12.07 | 21.04 | 29.78 | 4.72 | 8.11 | 11.45 | 6.81 | 20.53 | 0.33 |
| Fe (urea)$_6$SO$_4$ | 40 | 9.53 | 17.6 | 25.53 | 3.45 | 6.14 | 9.95 | 5.65 | 16.58 | 0.34 |
| Fe (urea)$_6$SO$_4$ | 80 | 10.06 | 19.22 | 26.53 | 3.70 | 7.03 | 10.36 | 6.31 | 17.16 | 0.36 |
| Fe (urea)$_6$SO$_4$ | 120 | 10.38 | 19.46 | 28.53 | 4.14 | 7.72 | 10.71 | 6.62 | 17.51 | 0.37 |
| Fe (urea)$_6$SO$_4$.CA. | 40 | 11.5 | 20.94 | 28.54 | 4.48 | 8.05 | 10.75 | 7.01 | 21.99 | 0.31 |
| Fe (urea)$_6$SO$_4$.CA. | 80 | 12.20 | 21.73 | 30.26 | 4.89 | 8.29 | 11.85 | 7.67 | 22.63 | 0.33 |
| Fe (urea)$_6$SO$_4$.CA. | 120 | 12.68 | 22.59 | 30.96 | 5.09 | 8.99 | 12.02 | 7.95 | 23.26 | 0.34 |

The addition of ionic compound was more pronounced effect for increasing the grain and straw yield of wheat plant but the highest rate of increase was recorded when citric acid was added as chelating compound.This phenomenon may be related to the structure of the ionic compound and the ability of citrate and urea to form stable complexes with Fe and urea through a ligand- exchange reaction[8,3].

Table (1) show that grain/straw ratio could be affected by the ferrihydrite, ionic compound of iron and the level of Fe addition. It has been noticed that Fe treated with silica and citric acid was markedly increased grain/straw ratio as compared with other treatment. Increasing levels of Fe increased the grain/ straw ratio of wheat plants. Therefore data in grain/ straw ratio confirmed that the forms of poorly crystalline Fe oxide and formation of ligand exchange reaction i.e., ferrihydrite and ionic compound of iron.

**Nutrient uptake:**

**a- N and Fe uptake at different stages of plant growth:** Data in table (2) show that the addition of ferrous sulfate increased the uptake of N and Fe than ferric sulfate. Whereas different ratios of Fe/ Si enhanced the N and Fe uptake by wheat plant as compared with $Fe^{+2}$ or $Fe^{+3}$ treated soil. This result may be due to forms and crystallinity of the precipitated Fe oxide.

It was noticed that the addition of Fe (urea)$_6$ SO$_4$. CA was more pronounced effect on the uptake of N and Fe of wheat plants than the other treatments. Increasing the level of Fe up to 120mgKg$^{-1}$ increased the uptake of N and Fe of wheat plants. The addition of Fe- 1.0 Si at a rate of 120mgKg$^{-1}$ gave a remarkable effect on N and Fe as compared with other treatments except the treatment of Fe (urea)$_6$ SO$_4$.CA. These results can be explained by the interactions of nitrogen with iron through changes in pH. When ammonium nitrogen is absorbed, plants release protons causing the growth medium to become more acid and iron availability is increased[16].

**b-N and Fe content in grain and straw:** Table (3) noticed that the addition of ferrihydrite at different ratios of silica gave a remarkable effect on N and Fe content in grain and straw. Wherease increasing the ratio of silicate were more

**Table 2:** Nitrogen and iron uptake (mg/plant) as affected by the addition of ferrihydrite and ionic compound of iron to wheat plant at different stages of plant growth

| Treatments | Fe level mg Fe $Kg^{-1}$ | N mg/plant | | | Fe mg/plant | | |
|---|---|---|---|---|---|---|---|
| | | 30 | 45 | 60 | 30 | 45 | 60 |
| Control | | 16.43 | 49.56 | 65.41 | 0.21 | 0.49 | 0.72 |
| $Fe^{+3}$ | 40 | 25.07 | 59.19 | 89.66 | 0.46 | 1.05 | 4.76 |
| $Fe^{+3}$ | 80 | 28.08 | 63.67 | 90.71 | 0.75 | 3.94 | 6.35 |
| $Fe^{+3}$ | 120 | 29.75 | 64.89 | 92.43 | 0.79 | 5.11 | 8.03 |
| $Fe^{+2}$ | 40 | 26.45 | 65.36 | 93.64 | 0.92 | 4.50 | 6.39 |
| $Fe^{+2}$ | 80 | 33.10 | 68.03 | 106.44 | 1.39 | 5.06 | 7.36 |
| $Fe^{+2}$ | 120 | 36.70 | 71.87 | 114.14 | 1.82 | 5.75 | 9.51 |
| Fe- 0.25 Si | 40 | 32.97 | 78.43 | 121.09 | 1.34 | 5.69 | 8.64 |
| Fe- 0.25 Si | 80 | 43.41 | 92.19 | 125.35 | 2.08 | 6.50 | 10.68 |
| Fe- 0.25 Si | 120 | 45.85 | 102.77 | 133.4 | 2.51 | 7.32 | 12.32 |
| Fe- 1.0 Si | 40 | 54.94 | 100.93 | 139.95 | 2.90 | 10.54 | 12.29 |
| Fe- 1.0 Si | 80 | 56.74 | 108.37 | 147.31 | 3.40 | 12.74 | 13.77 |
| Fe- 1.0 Si | 120 | 63.33 | 112.03 | 160.31 | 4.24 | 13.80 | 16.03 |
| Fe $(urea)_6SO_4$ | 40 | 44.50 | 81.17 | 131.45 | 2.07 | 6.14 | 10.94 |
| Fe $(urea)_6SO_4$ | 80 | 47.02 | 92.19 | 137.77 | 2.58 | 9.14 | 12.43 |
| Fe $(urea)_6SO_4$ | 120 | 53.82 | 102.77 | 144.67 | 3.31 | 11.59 | 13.92 |
| Fe $(urea)_6SO_4$. CA. | 40 | 60.54 | 110.28 | 149.38 | 3.58 | 12.88 | 13.97 |
| Fe $(urea)_6SO_4$. CA. | 80 | 66.61 | 114.41 | 168.36 | 4.39 | 14.91 | 16.59 |
| Fe $(urea)_6SO_4$. CA. | 120 | 69.27 | 124.89 | 180.43 | 6.25 | 17.07 | 18.04 |

**Table 3:** Nitrogen and iron uptake (mg/plant) in grain and straw of wheat plant as affected by ferrihydrite and ionic compound of iron treated soil.

| Treatments | Fe level mg Fe $Kg^{-1}$ | Grain | | Straw | |
|---|---|---|---|---|---|
| | | N | Fe | N | Fe |
| Control | | 30.80 | 2.71 | 36.34 | 1.05 |
| $Fe^{+3}$ | 40 | 61.96 | 3.62 | 41.50 | 1.18 |
| $Fe^{+3}$ | 80 | 70.38 | 4.17 | 43.74 | 1.74 |
| $Fe^{+3}$ | 120 | 74.17 | 4.53 | 45.77 | 2.21 |
| $Fe^{+2}$ | 40 | 75.61 | 4.34 | 46.80 | 1.92 |
| $Fe^{+2}$ | 80 | 90.45 | 6.10 | 48.99 | 2.04 |
| $Fe^{+2}$ | 120 | 102.98 | 6.64 | 52.85 | 3.04 |
| Fe- 0.25 Si | 40 | 123.62 | 6.25 | 65.43 | 3.93 |
| Fe- 0.25 Si | 80 | 130.06 | 7.83 | 72.10 | 4.42 |
| Fe- 0.25 Si | 120 | 139.61 | 8.00 | 75.90 | 4.49 |
| Fe- 1.0 Si | 40 | 144.09 | 10.95 | 93.49 | 6.16 |
| Fe- 1.0 Si | 80 | 161.0 | 11.73 | 99.13 | 6.79 |
| Fe- 1.0 Si | 120 | 163.64 | 12.36 | 101.89 | 7.25 |

**Table 3:** Continued.

| | | | | | |
|---|---|---|---|---|---|
| Fe $(urea)_6SO_4$ | 40 | 131.21 | 8.32 | 80.61 | 4.69 |
| Fe $(urea)_6SO_4$ | 80 | 147.08 | 9.56 | 87.74 | 5.31 |
| Fe $(urea)_6SO_4$ | 120 | 155.59 | 10.36 | 92.80 | 5.64 |
| Fe $(urea)_6SO_4$. CA. | 40 | 167.55 | 13.06 | 105.45 | 7.77 |
| Fe $(urea)_6SO_4$. CA. | 80 | 185.61 | 13.99 | 107.41 | 8.15 |
| Fe $(urea)_6SO_4$. CA. | 120 | 198.95 | 15.23 | 113.39 | 8.56 |

effective on N and particularly Fe content in grain and straw of wheat plant. This result may be probably due to, most soluble fraction of iron was depleted to some extent only in the rhizosphere, caused an increase systematically through mobilizing Fe from ferrihydrite and not only dissolved amorphous Fe but also some Fe from the ferrihydrite it self[22].

It was observed that the addition of Fe $(urea)_6$ $SO_4$ increased the N and Fe in content in grain and straw of wheat plant. Wherease the application of Fe $(urea)_6SO_4$ .CA was more pronounced effect on N and Fe grain and straw of wheat plant. This result suggested that the addition of citric acid during the preparation of the complexing materials was more effective than Fe $(urea)_6SO_4$ alone and other treatments for binding sorbing sites on the exchange complex and the ability of citrate to form stable complexes with Fe and urea of soils, and therefore regulate the release of total inorganic nitrogen similarly were observed by[8].

## Total chlorophyll and ferrous content:

**a-Total chlorophyll content:** Chlorophyll content as a measure of Fe- stress in plants is presented in Table (4). It was noticed that the addition of ferrihydrite with different ratios of silica increased the total chlorophyll as compared with ferrous or ferric treated soil. The addition of Fe-1.0 Si enhanced the chlorophyll content in wheat plants at different stages of plant growth. These phenomena may be due to the formation of poorly crystalline product to have smaller crystal size and higher surface area maintaining Fe in available forms[4,27,6].

It was observed that increasing the rate of ferrous sulfate form 40 to 120 mg $Kg^{-1}$ increased the total chlorophyll. Whereas the application of $Fe^{+3}$ treatments did not alleviate the Fe stress. Among the different treatments the addition of citric acid as ionic compound enhanced the chlorophyll of wheat plant at different stages of plant growth, due to as the availability of iron to the plant. This result may be due to when plant was allowed to take up $NH_4$, due to ammonification, a localized drop of pH occurred in the rhyzosphere zone due to $NH_4$ uptake. This change of pH in the rhyzosphere was sufficient to mobilize enough $Fe^{+2}$ near the root to allow Fe uptake by the plant[10].

**b-Ferrous content:** Concerning ferrous leaves content, the results in Table (4), also indicated that the addition of the $Fe(urea)_6SO_4$ complexing had positive effect on ferrous leaves content of wheat plants at different stages of the growth. The effect of citric acid as ligands which are capable to form stable availability of ferrous to the plant.

With respect to ferrihydrite, it was observed that increasing the levels of silicate had matching ameliorative effect in ferrous leaves content. However decreasing the level of Fe mg $Kg^{-1}$ decreased the ferrous content in the leaves of plant at 30,45 and 60 days. Results also observed that there is a good relation between the chlorophyll content and ferrous content in the plant tissue as noticed in Table (4).

It may be concluded that the application of ferrhydrite and ionic compound of iron had a positive effect for maintaing Fe in an active form as $Fe^{+2}$ in leaves of the wheat plants and furthermore, on the chlorophyll content to an extent of healthy plants. The ability to overcome the adverse effects of high pH particularly in calcareous soil and other ions and then correcting iron chlorosis.

**Fraction of Fe in soil:** Sequential extraction of Fe are presented in Table (5), were allowed to distinguish six fraction of Fe, which differ in mobility and plant availability. The most available forms of Fe in soils are the water soluble and exchangeable fraction[26]. This fraction contains Fe which is loosely held by surface associations and therefore is the most mobile. Water extractable fraction is very low in all treatments and does not exceed 1.7mg Fe $Kg^{-1}$ soil. The largest amounts of the most mobile Fe forms were observed in Fe $(urea)_6SO_4CA$. Existence of such low amounts of plant available Fe is related to high pH in $CaCO_3$[19].

In the second extracting step acid soluble Fe was determined through removing adsorbed and weakly bound of Fe, in calcareous soils only small amount of Fe is associated with carbonates. Fe concentration in this fraction is very low due to buffering capacity of the calcareous soil and ranged between 1.2 and 10.9 mg $Kg^{-1}$ soil.

**Table 4:** Total chlorophyll and ferrous content (mg/plant) as affected by different sources of iron fertilizers to wheat plants.

| Treatments | Fe level mg Fe Kg$^{-1}$ | Total chlorophyll mg/g F.W | | | Fe$^{+2}$ mg/plant | | |
|---|---|---|---|---|---|---|---|
| | | 30 | 45 | 60 | 30 | 45 | 60 |
| Control | | 0.56 | 0.33 | 0.27 | 0.21 | 0.17 | 0.14 |
| Fe$^{+3}$ | 40 | 0.79 | 1.01 | 1.04 | 0.23 | 0.36 | 0.38 |
| Fe$^{+3}$ | 80 | 0.81 | 1.01 | 1.06 | 0.26 | 0.37 | 0.38 |
| Fe$^{+3}$ | 120 | 0.84 | 1.02 | 1.06 | 0.27 | 0.38 | 0. 40 |
| Fe$^{+2}$ | 40 | 0.79 | 1.06 | 1.27 | 0.26 | 0.38 | 0.40 |
| Fe$^{+2}$ | 80 | 0.97 | 1.04 | 1.37 | 0.29 | 0.40 | 0.41 |
| Fe$^{+2}$ | 120 | 0.98 | 1.27 | 1.59 | 0.30 | 0.42 | 0.42 |
| Fe- 0.25 Si | 40 | 0.83 | 1.27 | 1.43 | 0.26 | 0.39 | 0.41 |
| Fe- 0.25 Si | 80 | 0.86 | 1.32 | 1.45 | 0.31 | 0.41 | 0.41 |
| Fe- 0.25 Si | 120 | 1.03 | 1.39 | 1.47 | 0.33 | 0.43 | 0.46 |
| Fe- 1.0 Si | 40 | 1.01 | 1.53 | 1.59 | 0.32 | 0.44 | 0.46 |
| Fe- 1.0 Si | 80 | 1.25 | 1.61 | 1.77 | 0.38 | 0.47 | 0.50 |
| Fe- 1.0 Si | 120 | 2.18 | 1.69 | 2.32 | 0.47 | 0.51 | 0.53 |
| Fe (urea)$_6$SO$_4$ | 40 | 0.83 | 1.38 | 1.44 | 0.29 | 0.40 | 0.43 |
| Fe (urea)$_6$SO$_4$ | 80 | 1.08 | 1.40 | 1.50 | 0.34 | 0.43 | 0.44 |
| Fe (urea)$_6$SO$_4$ | 120 | 1.32 | 1.47 | 1.56 | 0.36 | 0.47 | 0.49 |
| Fe (urea)$_6$SO$_4$. CA. | 40 | 1.35 | 1.54 | 1.62 | 0.40 | 0.49 | 0.50 |
| Fe (urea)$_6$SO$_4$. CA. | 80 | 1.79 | 2.14 | 2.49 | 0.42 | 0.45 | 0.54 |
| Fe (urea)$_6$SO$_4$. CA. | 120 | 2.27 | 2.60 | 2.89 | 0.53 | 0.56 | 0.60 |

**Table 5:** Effect of different sources of iron compound on iron fraction (ppm) in calcareous soil after harvesting of wheat plant.

| Treatments | Fe level mg Fe Kg$^{-1}$ | Fe-1 | Fe-2 | Fe-3 | Fe-4 | Fe-5 | Fe-6 |
|---|---|---|---|---|---|---|---|
| | | Soluble + exchange | Acid soluble | OM- bound | Amorphous | Crystalline | Residual |
| Control | | 0.24 | 1.2 | 103.3 | 65.6 | 20.4 | 250 |
| Fe$^{+3}$ | 40 | 0.31 | 2.5 | 112.0 | 150.3 | 38.2 | 340 |
| Fe$^{+3}$ | 80 | 0.33 | 2.6 | 117.1 | 162.4 | 40.6 | 360 |
| Fe$^{+3}$ | 120 | 0.34 | 3.7 | 122.3 | 196.2 | 47.2 | 382 |
| Fe$^{+2}$ | 40 | 0.33 | 2.7 | 137.4 | 220.1 | 45.2 | 408 |
| Fe$^{+2}$ | 80 | 0.35 | 3.0 | 144.1 | 241.6 | 48.3 | 415 |
| Fe$^{+2}$ | 120 | 0.36 | 4.0 | 152.6 | 270.3 | 50.4 | 426 |
| Fe- 0.25 Si | 40 | 0.66 | 3.1 | 195.3 | 280.4 | 50.3 | 440 |
| Fe- 0.25 Si | 80 | 0.70 | 3.7 | 222.7 | 302.5 | 57.2 | 452 |
| Fe- 0.25 Si | 120 | 0.79 | 4.9 | 231.4 | 321.4 | 60.6 | 459 |
| Fe- 1.0 Si | 40 | 0.82 | 6.3 | 270.6 | 410.1 | 79.1 | 506 |
| Fe- 1.0 Si | 80 | 0.47 | 7.0 | 280.6 | 425.9 | 80.6 | 523 |

**Table 4:** Continued.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Fe- 1.0 Si | 120 | 1.2 | 7.5 | 289.4 | 450.6 | 88.5 | 555 |
| Fe (urea)$_6$SO$_4$ | 40 | 0.71 | 4.2 | 242.4 | 350.6 | 60.2 | 462 |
| Fe (urea)$_6$SO$_4$ | 80 | 0.84 | 5.8 | 250.8 | 362.4 | 65.3 | 482 |
| Fe (urea)$_6$SO$_4$ | 120 | 0.96 | 6.9 | 269.9 | 380.4 | 73.4 | 495 |
| Fe (urea)$_6$SO$_4$. CA. | 40 | 0.95 | 7.3 | 250.7 | 460.7 | 41.2 | 529 |
| Fe (urea)$_6$SO$_4$. CA. | 80 | 1.4 | 8.5 | 282.4 | 485.8 | 44.4 | 542 |
| Fe (urea)$_6$SO$_4$. CA. | 120 | 1.7 | 10.9 | 301.9 | 493.3 | 99.1 | 560 |

Substantial amounts of iron were found in the organically- bound fraction (Fe-3) was determined by extraction with a complexing agent (e.g., potassium pyrophoshate at 0.1 M concentration). The amount of Fe associated with organically bound were in the range between 103.3 and 301.9 mg Kg$^{-1}$ soil. These data are in agreement with Shuman[26].

Soil extractable fraction of Fe was predominantly present in the amorphous Fe oxide fraction (Fraction -4). The amount of Fe in this fraction was ranged between 65.6 and 493.3 mg Fe Kg$^{-1}$ soil. Amorphous Fe oxide; ferrihydrite and poorly crystalline Fe phases have been identified as compounds that affect Fe solubility in near neutral, well aerated soils[24,14].

The crystalline Fe oxide fraction is smaller as compared to amorphous Fe oxides (Table 5). This phenomenon well explained by Schwertmann and Taylor[24], they reported that soil organic and particularly humic substances may interact with surface bound Fe and this process could inhibit the formation of crystalline Fe-oxides in favour of amorphous Fe- oxides. Also soil properties can play and important role for immobilization the Fe, under such condition with high pH and CaCO$_3$ content, iron is immobilized in form of hydroxide or hydrated oxides. It is believed that pH and CaCO$_3$ may be responsible for inhibit with formation of crystalline particularly in calcareous soil than organic matter effect. Since organic matter in our calcareous soil is quite low.

Iron held within silicate mineral structures, was extracted in the final step using an HF based method. The amounts of Fe that is fixed in the crystal lattice of minerals. This is in agreement with the results of Shuman[26].

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