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# Composting of Rice Straw and its Influences on Iron Availability in Calcareous Soil

F. A. Hellal

Plant Nutrition Dept., National Research Centre, Dokki, Giza, Egypt.

**Abstract**: Composting incubation and pot experiment were conducted to evaluate the nutritional status of composted rice straw mixed with organic raw materials and assess the combined effect of compost and iron supply on growth, yield, and iron status of barley plant grown in calcareous soil. Results indicated that, the determination of humification parameters (HA, FA and DH), C/N ratio and temperature could be used to evaluate the quality of composted rice straw mixed with different raw material. The compost of rice straw mixture *($M_2$)* with chicken manure registered the best regarding its nutritional values and narrower in C/N ratio and humification degree. The C/N ratio showed very high positive significant correlation with TOC and HA indicating their role for narrowing the C/N ratio for the composted materials. Whereas, the degree of humification had highly positive significant correlation with soluble and available iron by releasing chelated compounds during composting. Results of pot experiment clarified that, the effectiveness of application of composted rice straw with chicken manure *($M_2$)* gave the highest grain, straw yield of barley in calcareous soil. Iron uptake and ferrous iron increased significantly due to compost supply *($M_2$)* and foliar spray of 0.25 % citric acid over other treatments. Successive extraction of iron at 40 days in calcareous soil of barley plant showed significant effect from compost application on water soluble, exchangeable, acid soluble and organically bound iron. This increment of iron fraction in soil and iron uptake by plant was associated with a predominate increase in chlorophyll content of barley leaves correcting the iron deficiency symptoms in calcareous soil.

**Keywords:** Rice straw, C/N ratio, humic acid, ferrous-Fe, iron fraction , grain yield

## INTRODUCTION

Composting is an attractive prospective in a policy of waste recycling to produce humus-like compounds to be used for improvement both soil and plant growth. Composting is an aerobic process in which microorganisms convert a mixed organic substrate into carbon dioxide, water, minerals and stabilized organic matter under controlled condition, particularly of moisture and aeration are required to yield temperatures conductive to the microorganisms involved in the composting process[1]. This process has many advantages including sanitation, mass and bulk reduction and decrease of C/N ratio. The stabilized compost produced should benefit the plant growth and be suitable for agricultural applications[2]. Rice straw is rich in carbon and poor in nitrogen, which limits the composting process. This high C/N can be decreased by increasing the basal nitrogen content of rice straw by adding different organic raw materials including farmyard manure and chicken manure.

Rashid *et al.*[3] compared mixtures of rice straw and nitrogen materials (cow dung + soybean plants) at ratios from 70 to 100 % rice straw. The mixture containing 70 % rice straw produced the most suitable compost in terms of maturity and nutrient status. Composting of rice straw with poultry manure and oilseed rape cake and its application at 20-200 g pot$^{-1}$ to *faba bean* plants improved selected soil chemical (increased total N and CEC), physical (decreased particle density) and biological ( increased soil respiration rate) properties and significantly increased yield and yield components of *faba bean* plants[4]. Lee[5] reported that, the mixture containing 70 to 80 % rice straw and 60 to 70 % hardwood bark were produced the most suitable compost in terms of nutrients and maturity.

Humic acids are very important, not only on the biological activity in soils but also on the availability of most nutrients to the growing plants[6]. Mackwiak[7] studied the effect of humic acid on the plant growth and nutrient uptake in wheat. He concluded that, humic acid application improved Fe bioavailability.

Iron deficiency chlorosis is a widespread in higher plants grown in calcareous soil. Soil amendments and foliar sprays of iron are important to overcome iron deficiency. Singh *et al.*[8] indicated that application of iron alone up to 10 mg kg$^{-1}$ soil significantly increased the grain and straw yield and the uptake of nutrients. Likewise, application of farmyard manure (FYM)

**Corresponding Author:** F. A. Hellal, Plant Nutrition Dept., National Research Centre, Dokki, Giza, Egypt.

significantly enhanced the yield and uptake of N, P, K and Fe by the crop. Iron and FYM showed a synergistic interaction effect on the uptake of N, P, K and Fe and ultimately on the grain and straw production of wheat.

The main objective of the current work is to evaluate the nutritional status of composted rice straw mixed with organic raw materials, assess the combined effect of compost, and iron supply on growth, yield, and iron status of barley plants grown in calcareous soil.

## MATERIALS AND METHODS

**Composting Experiment:** Five kilograms of three mixtures of organic materials prepared in a polyvinyl house in plastic container of size 35 x 50 x 30 cm (weight x length x height) were used for the experiment with three replicates. The mixtures used were arranged at different ratios as follows: $M_1$: 50 % Rice straw + 30 % FYM, $M_2$: 50 % Rice straw + 30 % Chicken manure, $M_3$: 50 % Rice straw + 15 % FYM + 15 % Chicken manure. Additives of lentil hay and potato tops were added to the compost mixtures at levels of 10 % as a nitrogen source and to accelerate the rate of decomposition at the initial stages of composting. The initial properties of rice straw, FYM, and chicken manure were 7.21, 7.75, and 8.32 pH; 2.05, 1.41 and 3.87 dS $m^{-1}$ EC; 0.74, 1.21 and 4.30 % total nitrogen and 60.8, 26.4 and 14.3 C/N ratios, respectively. Moisture content was maintained at 50-60 % throughout the active composting period by frequent checking and temperature was measured periodically at 0, 1, 2, 3, 7, 15, 30,45, 60 and 90 days. The mixtures were turned at three-day intervals to maintain porosity. The samples were collected at zero, 15, 30, 45, 60 and 90 days of the composting process and analyzed for pH, EC, and iron by the standard methods[9]. Humic acids (HA), Fulvic acids (FA), Total organic carbon (TOC), and Total extractable carbon (TEC) were assayed in composts by dichromate oxidation methods[10]. Degree of humification (DH) was calculated after Govi *et al.*[11] as follows: DH % = HA+ FA / TEC x 100.

**Pot Experiments:** A greenhouse pot experiment was carried out at National Research Center and designed in a split plot design with three replication. Pots measured 25 cm in diameter and 30 cm in height were filled with ten Kg of air-dry calcareous soil characterized by 11.6 % $CaCO_3$, 8.17 pH, 1.24 dS $m^{-1}$ EC and 1.21 % organic matter. Treatments applied were consisted of sixteen treatment combinations involving three iron forms applied as foliar spray were ($Fe_1$: 10 ppm Fe as iron citrate, Fe2: 10 ppm Fe as Fe-EDTA and $Fe_3$: iron reducer as 0.25 % Citric acid applied as foliar spray), three composted mixtures ($M_1$, $M_2$ and $M_3$) obtained from the composting experiment and control without iron and compost ($Fe_0$ and $M_0$) were involved. The compost was applied at (2 % wb) level before sowing and mixed thoroughly with the soil of each pot. Recommended rates of Nitrogen (35 kg/fed), $P_2O_5$ (15 kg/fed) and $K_2O$ (24 kg/fed) in the form of Ammonium sulfate, super phosphate and potassium sulfate were added as basic dose to all pots. Barley (*Hordium vulgar* L. Giza 2000) was sown on November 15th 2005 and thinned to five uniform seedlings in each pot and the soil moisture was maintained at field capacity by weighting twice a week. Plant samples were collected at 40 day after sowing (DAS) for estimation of chlorophyll and $Fe^{2+}$ iron in the fresh leaves and dry weight. Iron fractions in soil were also determined. At 110 days, the plants were harvested, washed twice with distilled water then dried at 70 $^0$C and grinded for analysis.

Ferrous iron analyzed by the methods reported by Katyal and Sharma.[12]. Chlorophyll was also estimated according to Lichtenthalar and Wellborn.[13]. Iron fractions were estimated by sequential extraction as described by Miller *et al.*[14]. Obtained data were subjected to statistical analysis according to SAS institute [15].

## RESULTS AND DISCUSSIONS

**Composting Experiment:**

**Changes of Temperature, pH, EC and C/N Ratio During Composting:** Temperature of compost increased rapidly within the first three days of composting process (Fig.1), then gradually decline and finally stabilize near ambient level within 30 to 60 day

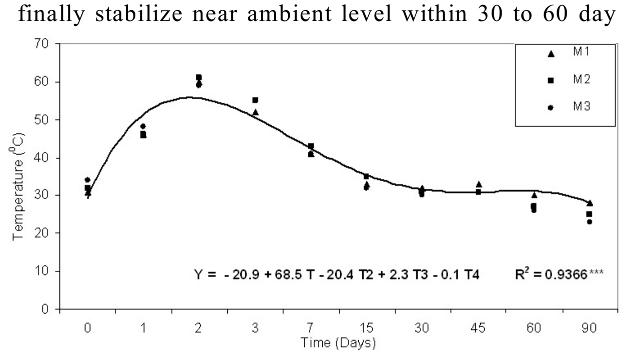


**Fig 1:** Changes in temperature of organic waste mixtures during composting.

of composting. Rice straw with chicken manure ($M_2$) gave the highest values of temperature at earlier stages of composting. Whereas, decreasing trend in temperature levels near to the incubation end may be due to decreasing the microbial activity and the greater

**Table 1:** Changes of pH, EC and C/N of organic waste mixtures during composting.

| Time period (days) | Organic waste mixtures | pH (1:20) | EC dS m-1 | TEC | TOC (%) | TN | C/N Ratio |
|---|---|---|---|---|---|---|---|
| Zero | $M_1$ | 6.76 | 1.9 | 10.25 | 42.5 | 1.58 | 26.6 |
| | $M_2$ | 7.38 | 1.6 | 11.03 | 43.1 | 1.61 | 26.8 |
| | $M_3$ | 6.93 | 2.1 | 10.97 | 42.2 | 1.56 | 27.2 |
| 15 | $M_1$ | 7.41 | 1.2 | 9.2 | 46.9 | 1.72 | 23.8 |
| | $M_2$ | 7.36 | 1.35 | 9.59 | 41.6 | 1.69 | 24.6 |
| | $M_3$ | 7.4 | 0.8 | 9.03 | 39.9 | 1.63 | 24.5 |
| 30 | $M_1$ | 7.65 | 1.4 | 8.91 | 40.9 | 1.83 | 22.4 |
| | $M_2$ | 7.51 | 1.35 | 8.96 | 41.7 | 1.92 | 21.7 |
| | $M_3$ | 7.5 | 1.4 | 9.24 | 38.2 | 1.88 | 20.3 |
| 45 | $M_1$ | 7.87 | 1.75 | 8.24 | 33.8 | 1.87 | 18.1 |
| | $M_2$ | 7.87 | 1.8 | 8.38 | 30.2 | 1.83 | 16.5 |
| | $M_3$ | 7.95 | 1.64 | 8.43 | 35.9 | 1.92 | 18.7 |
| 60 | $M_1$ | 7.9 | 2 | 8.7 | 30.5 | 2.09 | 14.6 |
| | $M_2$ | 8.03 | 1.9 | 9.14 | 26.1 | 2.23 | 11.7 |
| | $M_3$ | 8.08 | 1.98 | 8.92 | 28.4 | 2.15 | 13.2 |
| 90 | $M_1$ | 8.17 | 2.24 | 8.94 | 29.3 | 2.24 | 13.1 |
| | $M_2$ | 8 | 2.11 | 9.91 | 24.7 | 2.4 | 10.3 |
| | $M_3$ | 8.03 | 2.16 | 9.11 | 27.6 | 2.21 | 12.5 |

TOC: Total organic carbon, TEC: Total extractable carbon, TN: total nitrogen.

resistance to decomposition of remaining carbon compounds (lignin and cellulose)[16].

Polynomial regression equation was estimated to describe the relationship between periods and composting temperature of the studied mixtures. Data on hand revealed that $R^2$ was very highly significant (***). In addition, one can notice there was a drop in curve after 60 days and the pile temperature had cooled to ambient level indicating maturity of the composting mixtures.

Data in Table (1) presented the changes in pH, EC, total organic carbon content (TOC) and C/N ratio during composing process. As organic acid released at the first stages of composting pH was around 7.0 to7.5. Then, the pH frequently rises, as ammonia is librated during protein degradation[17]. Similar trend was observed with EC values.

It was noticed that, the initial values of the TOC of $M_2$ mixture were higher than other mixtures. The differences in TOC of composts at zero time are due to the source of organic materials and the mixing ratio between these materials. At the end of composting process the lowest value of TOC in the composts was (24.7 %) for Rice straw + chicken manure ($M_2$) and the highest value was 29.3 % for Rice straw + FYM ($M_1$). This decrease in TOC during composting may be due to mineralization of carbonic materials thus, the TOC of composting materials decreased. These data are in accordance with that reported by Eghball *et al.*,[18] who found that the carbon loss during composting ranged from 46 to 62 % for beef cattle feedlot manure.

Total nitrogen (TN) of different organic wastes during composting process are recorded in Table (1). At the beginning of composting of organic wastes ($M_1$, $M_2$ and $M_3$) were 1.58, 1.61 and 1.56 %, respectively. The initial values of TN of different mixtures were depending upon the ratio between the raw materials in the treatment. The highest TN content mixtures that are contain chicken manure, while the lowest one that is containing FYM only. There was an increase in TN during composting process for all composted materials.

The increase in TN of different composted materials may be due to concentration effect because of bio-oxidation of OC during composting. In this respect,

**Table 2:** Changes of humification parameters and iron availability of organic waste mixtures during composting.

| Time period (days) | Organic waste mixtures | FA (%) | HA (%) | Humus (FA+HA) | DH ( %) | Soluble iron (ppm) | Available iron (ppm) |
|---|---|---|---|---|---|---|---|
| Zero | $M_1$ | 2.63 | 3.12 | 5.75 | 56.1 | 2.52 | 10.5 |
| | $M_2$ | 2.87 | 3.26 | 6.13 | 55.6 | 2.63 | 10.8 |
| | $M_3$ | 2.70 | 3.19 | 5.89 | 53.7 | 2.59 | 10.3 |
| 15 | $M_1$ | 2.70 | 2.94 | 5.64 | 61.3 | 3.16 | 10.1 |
| | $M_2$ | 2.97 | 3.08 | 6.05 | 63.1 | 3.38 | 11.4 |
| | $M_3$ | 2.91 | 2.84 | 5.75 | 63.7 | 3.23 | 10.7 |
| 30 | $M_1$ | 2.80 | 2.91 | 5.71 | 57.1 | 4.04 | 10.7 |
| | $M_2$ | 3.01 | 2.84 | 5.85 | 58.5 | 4.08 | 11.8 |
| | $M_3$ | 2.89 | 2.86 | 5.84 | 58.4 | 4.02 | 10.9 |
| 45 | $M_1$ | 3.22 | 2.12 | 5.34 | 64.8 | 4.47 | 15.8 |
| | $M_2$ | 3.44 | 2.15 | 5.59 | 66.7 | 4.13 | 16.2 |
| | $M_3$ | 3.18 | 2.40 | 5.58 | 66.2 | 4.07 | 18.1 |
| 60 | $M_1$ | 3.63 | 2.31 | 5.94 | 68.3 | 4.22 | 16.1 |
| | $M_2$ | 3.87 | 2.26 | 6.13 | 67.1 | 5.11 | 24.0 |
| | $M_3$ | 3.73 | 2.33 | 6.06 | 67.9 | 4.73 | 20.5 |
| 90 | $M_1$ | 4.06 | 2.23 | 6.29 | 70.3 | 4.54 | 18.6 |
| | $M_2$ | 4.81 | 2.01 | 6.82 | 68.8 | 5.97 | 27.2 |
| | $M_3$ | 4.20 | 2.15 | 6.35 | 69.7 | 4.89 | 21.7 |

HA:Humic acids, FA: Fulvic acids, DH: Degree of humification

Khater *et al.*[19] reported that the increase in TN during composting may be due to the higher oxidation of non-nitrogenous organic materials and partially to the $N_2$-fixation by non-symbiotic nitrogen fixers as indexed by the increase in organic nitrogen.

Carbon to nitrogen ratio is one of the parameters used as an index of compost maturity. The initial C/N ratios of the raw materials used were 26.6, 26.8, and 27.2, respectively. During the composting process, the TN gradually increased due to the mineralization of organic matter and simultaneously the TOC were decreased due to the humification through the degradability of the organic carbon. These processes minimize the difference between C and N and finally the C/N ratio decreased. At the end of composting, almost all the composted substrates are reached to value about 11, which will be in suitable form for application to the soil. Jimenez and Garcia[20] considered that a C/N ratio lower than 12 for municipal solid waste compost indicates a good degree of maturity.

**Changes of humification and Fe solubility during composting:** Changes in Humic acids (HA), Fulvic acids (FA) and degree of humification (DH) and soluble and available iron are presented in Table 2. In order to evaluate the maturity level of the organic matter composted through the composting process, humification parameters have been used to discriminate stabilized form. The amount of HA changed considerably during composting period. At the begining of composting, the values of HA content of organic wastes $M_1$, $M_2$ and $M_3$ were 3.12, 3.26 and 3.19, respectively.

Data also noticed that the HA content gradually diminished through the composting period. The rapid decrease in the HA content was more evident in the first month of composting period. This decrease may be attributed to the degradation of the coating materials of HA (interference materials) such as proteins, carbohydrates, lipids, waxes and cellulose, which co-extracted with the alkaline solutions; this nucleus of HA called true humic acid or core humic acid [21].

Data showed that, at the beginning of composting time the values of the FA content of organic wastes $M_1$, $M_2$ and $M_3$ were 2.63, 2.87, and 2.70 % respectively. It was observed that the FA content decrease in the early phase of composting

**Table 3:** Correlation analysis of the estimated parameters of composting experiment.

| | C/N ratio | TN | TOC | TEC | EC | pH | FA | HA | FA+HA | DH | Sol- Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TN | -0.965 | | | | | | | | | | |
| TOC | 0.960 | -0.894 | | | | | | | | | |
| TEC | 0.523 | -0.411 | 0.407 | | | | | | | | |
| EC | -0.594 | 0.581 | -0.684 | 0.133 | | | | | | | |
| pH | -0.919 | 0.872 | -0.846 | -0.676 | 0.393 | | | | | | |
| FA | -0.925 | 0.932 | -0.925 | -0.251 | 0.659 | 0.803 | | | | | |
| HA | 0.935 | -0.840 | 0.919 | 0.653 | -0.533 | -0.902 | -0.846 | | | | |
| FA+HA | -0.493 | 0.627 | -0.509 | 0.372 | 0.511 | 0.311 | 0.734 | -0.260 | | | |
| DH | -0.882 | 0.802 | -0.850 | -0.616 | 0.402 | 0.877 | 0.837 | -0.900 | 0.366 | | |
| Sol-Fe | -0.952 | 0.938 | -0.870 | -0.666 | 0.439 | 0.938 | 0.832 | -0.900 | 0.372 | 0.826 | |
| Aver-Fe | -0.945 | 0.905 | -0.955 | -0.373 | 0.680 | 0.856 | 0.937 | -0.906 | 0.540 | 0.863 | 0.844 |

TN: total nitrogen, TOC: Total organic carbon and TEC: Total extractable carbon, FA: Fulvic acids, HA:Humic acids, DH: Degree of humification, Sol-Fe:,soluble iron, Ava-Fe: available iron.

(about 30 days) and then it showed a slight increase at intermediate phase of composting for all mixtures. While at the maturity phase, the increase of FA content was profound high. The decrease in FA fraction in the first phase could be explained either by the consumption of the FA by the microbial activity or transformation of this fraction to create stable compounds of HA [11].

Data also showed that the FA content were higher than the HA content of all mixtures in the maturity phase. These results could be explained by the degradation of organic matter through the composting period. At the end of composting the humic substances (HA+FA) content were increased for most organic wastes and their mixtures. These results are in agreement with Michel *et al.,*[22]. The highest values of humic substances content (6.82 %) was recoded for $M_2$ followed by 6.35 % for $M_3$ compost treatment.

The trend of degree of humification in the successive phases of composting indicated the same difference among the compost mixtures used. The values of DH of all the compost mixtures decreased during the first 30 days of maturity and then increased progressively. The compost mixture ($M_1$) seems to have the highest values of DH at the maturity stage; 70.3 %. $M_3$ comes in the second order (69.7 %), while $M_2$ was the lowest one (68.8 %). Data also showed that the final DH values of all mixtures were higher than the initial values. This could be explained by the degradation of organic matter during the composting period. These results are in consonance with Govi *et al.*[11]. They stated that, the DH increased during composting of pig manure with air-dried poultry manure. It can be concluded that, the determination of humification parameters (HA, FA and DH) could be used to evaluate the quality of organic waste mixtures related to the stabilization level.

Data in Table (2) showed that, composting of rice straw with N rich materials creates a product that supplies nutrients to plants through increasing their availability in soil. The soluble and available iron was gradually low in the initial stages of composting period. Later on increased by mineralization of organic matter in the organic waste mixtures. The mixture of rice straw with 30% of chicken manure ($M_2$) registered the highest in soluble and available iron over other composted organic waste mixtures indicating its importance for increasing iron availability in soil and its uptake by plants. Zhengqian *et al.*[23] conducted laboratory experiment to determine the influence of three types of composting of fresh organic materials (pig manure, astagalus sinicus and alternanthera philoxeroides on dissolution of Fe and Zn. Results indicated that levels of Fe and Zn concentrations in composting solution changed with composting time.

Simple correlation coefficients of different estimated parameters of composted mixtures are recorded in Table 3.

The C/N ratio showed very high positive significant correlation with TOC (0.960**) and HA (0.935**) and negative correlation with TN, pH, FA, soluble and available iron. This indicates the importance of TOC and HA for narrowing the C/N ratio for the composted materials. The degree of humification (DH) had highly positive significant correlation with soluble and available iron as a result of increasing chelated compounds like Humic and Fulvic acid which play an important role in increasing iron solubility and availability for the growing plants.

**Table 4:** Influence of compost and iron application on dry weight, ferrous-Fe and chlorophyll of barley at 40 day after sowing.

| Treatments | | Dry weight (g/plant) | Chlorophyll (mg/g fresh weight) | | | Plant Iron (ppm) | |
|---|---|---|---|---|---|---|---|
| Compost | Iron | | a | b | Total | Ferrous | Total |
| $M_0$ | $Fe_0$ | 8.32 | 0.521 | 0.286 | 0.882 | 19.18 | 191.5 |
| | $Fe_1$ | 8.52 | 0.613 | 0.358 | 1.018 | 20.44 | 196.9 |
| | $Fe_2$ | 9.23 | 0.634 | 0.367 | 1.062 | 20.84 | 212.4 |
| | $Fe_3$ | 9.80 | 0.639 | 0.391 | 1.075 | 25.31 | 234.1 |
| | Mean | 8.97 | 0.606 | 0.351 | 1.009 | 21.44 | 208.7 |
| $M_1$ | $Fe_0$ | 8.76 | 0.562 | 0.32 | 0.906 | 21.04 | 276.1 |
| | $Fe_1$ | 8.85 | 0.631 | 0.367 | 1.076 | 24.71 | 279.5 |
| | $Fe_2$ | 9.63 | 0.647 | 0.369 | 1.108 | 23.62 | 291.6 |
| | $Fe_3$ | 9.67 | 0.656 | 0.394 | 1.117 | 26.17 | 306.2 |
| | Mean | 9.23 | 0.624 | 0.363 | 1.052 | 23.89 | 288.4 |
| $M_2$ | $Fe_0$ | 9.40 | 0.591 | 0.341 | 0.952 | 25.26 | 282.3 |
| | $Fe_1$ | 10.48 | 0.652 | 0.39 | 1.125 | 25.73 | 291.6 |
| | $Fe_2$ | 11.07 | 0.673 | 0.405 | 1.148 | 28.14 | 311.2 |
| | $Fe_3$ | 11.21 | 0.698 | 0.432 | 1.211 | 30.17 | 318.5 |
| | Mean | 10.53 | 0.654 | 0.392 | 1.109 | 27.33 | 300.9 |
| $M_3$ | $Fe_0$ | 9.53 | 0.571 | 0.353 | 0.921 | 23.1 | 265.8 |
| | $Fe_1$ | 9.85 | 0.634 | 0.376 | 1.113 | 24.92 | 281.4 |
| | $Fe_2$ | 10.19 | 0.663 | 0.403 | 1.136 | 28.63 | 304.2 |
| | $Fe_3$ | 10.75 | 0.671 | 0.411 | 1.180 | 25.86 | 301.3 |
| | Mean | 10.08 | 0.635 | 0.386 | 1.088 | 25.63 | 288.2 |
| LSD (5%) | *M* | 0.65 | NS | NS | 0.074 | 1.37 | 10.7 |
| | *Fe* | 0.65 | NS | NS | 0.074 | 1.37 | 10.7 |
| | Interaction | NS | NS | NS | NS | 2.84 | NS |

**Pot Experiments:**

**Dry Weight, Ferrous-Fe and Chlorophyll Content:** Data presented in Table 4 revealed that, dry weight, ferrous-Fe and chlorophyll content of barley at 40 day after sowing increased significantly due to compost and iron application. Application of $M_2$ compost and $F_3$ iron treatments markedly increased dry weight by 17.4 and 18.1 % relative to control treatment and it was significantly superior over other treatments.

Regarding to ferrous-Fe and chlorophyll content, application of 2 % of composted rice straw with chicken manure ($M_2$) recorded the highest ferrous iron (27.33 ppm) and total chlorophyll content (1.109 mg $g^{-1}$ fr.wt.) and it was significantly superior over rest of the treatments.

The variation in the forms of foliar applied iron (Ferric citrate, Fe-EDTA and citric acid) distinctly influenced ferrous iron and chlorophyll content of barley. The treatment $Fe_3$ (0.25 % Citric acid) significantly increased ferrous iron and chlorophyll content by (21.4 and 25.2 %) over no $Fe_0$ applied followed by $Fe_2$ and $Fe_1$ and the lowest values was obtained in control treatment. The combination between compost and foliar iron application were significant with respect to ferrous iron in plant leaves at 40 days. The beneficial effect of compost application along with foliar spray of iron increased iron availability in soil and ferrous iron uptake by plant leaves resulted in increased chlorophyll formation and various growth parameters of barley. This confirms the

**Table 5:** Influence of compost and iron application on iron fractions (ppm) in soil of barley.

| Treatments | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Compost | Iron | Water soluble | Exchan-geable | Acid soluble | Organically bound | Pb-displ-aceable | Mn-oxide occluded | Amor-Phous |
| $M_0$ | $Fe_0$ | 1.01 | 2.49 | 3.31 | 314.7 | 8.54 | 818.4 | 1195.0 |
| | $Fe_1$ | 1.02 | 2.73 | 4.16 | 318.2 | 8.67 | 861.1 | 1101.6 |
| | $Fe_2$ | 1.01 | 2.55 | 3.82 | 318.6 | 9.37 | 910.2 | 1156.3 |
| | $Fe_3$ | 1.02 | 2.65 | 4.09 | 324.1 | 9.71 | 917.6 | 1135.9 |
| | Mean | 1.01 | 2.60 | 3.85 | 318.9 | 9.07 | 876.8 | 1147.2 |
| $M_1$ | $Fe_0$ | 1.13 | 2.65 | 4.41 | 362.7 | 9.15 | 877.0 | 1128.2 |
| | $Fe_1$ | 1.14 | 2.76 | 4.86 | 381.5 | 10.33 | 821.7 | 1136.4 |
| | $Fe_2$ | 1.15 | 2.94 | 5.23 | 357.9 | 10.17 | 908.5 | 1132.8 |
| | $Fe_3$ | 1.21 | 2.98 | 5.17 | 388.0 | 10.02 | 912.9 | 1129.9 |
| | Mean | 1.21 | 2.83 | 3.63 | 372.5 | 9.29 | 880.0 | 1131.8 |
| $M_2$ | $Fe_0$ | 1.25 | 2.76 | 5.06 | 413.2 | 10.37 | 916.3 | 1188.1 |
| | $Fe_1$ | 1.24 | 2.96 | 5.63 | 433.9 | 12.05 | 917.8 | 1131.6 |
| | $Fe_2$ | 1.32 | 3.21 | 5.70 | 414.6 | 10.81 | 908.7 | 1125.7 |
| | $Fe_3$ | 1.27 | 3.03 | 5.41 | 421.3 | 11.71 | 997.3 | 1193.4 |
| | Mean | 1.27 | 2.99 | 5.45 | 420.8 | 11.33 | 935.0 | 1159.7 |
| $M_3$ | $Fe_0$ | 1.13 | 2.71 | 4.61 | 385.2 | 10.13 | 846.1 | 1138.2 |
| | $Fe_1$ | 1.11 | 2.86 | 4.85 | 391.2 | 11.68 | 929.0 | 1123.5 |
| | $Fe_2$ | 1.19 | 2.96 | 5.11 | 411.0 | 10.54 | 886.3 | 1121.1 |
| | $Fe_3$ | 1.13 | 3.01 | 5.28 | 412.8 | 11.51 | 925.4 | 1175.1 |
| | Mean | 1.14 | 2.89 | 4.96 | 400.1 | 10.97 | 896.7 | 1139.5 |
| LSD (5%) | *M* | 0.06 | 0.27 | 0.90 | 19.7 | NS | NS | NS |
| | *Fe* | NS | NS | NS | NS | NS | NS | NS |
| | Interaction | NS | NS | NS | NS | NS | NS | NS |

finding of Katyal and Sharma[12]. The interaction effects were not significant regarding total chlorophyll content at 40 days of barley plant. The results also indicated that the effect of compost and iron application and their interactions did not differ significantly with respect to chlorophyll *a* and chlorophyll *b* of barley at 40 days.

**Iron Fraction in Soil of Barley:** Several attempts have been made to fractionate the nutrients present in different forms in order to have a better understanding of their chemistry and availability in soils. Iron fractions existed in different distinct pools in the soils which apply to iron also, water soluble, exchangeable, Pb-displaceable, acid soluble, Mn oxide occluded, organically bound, amorphous Fe oxide occluded, iron held in secondary clay minerals and in metal oxides by occlusion, iron held within the primary minerals. Water soluble, exchangeable, and chelated iron are in reversible equilibrium with each other and the iron in these pools are readily available to plants [14].

Results of iron fractions status in soil of barley at 40 days after sowing are shown in Tables (5). Significant differences among the treatments were noticed regarding to water soluble iron, exchangeable iron, acid soluble iron and organically bound iron due to applied compost. Application of $M_2$ composted mixture recorded the highest iron fractions in soil and the lowest value was registered in control.

**Table 6:** Influence of composted materials and iron nutrition on DTPA-Fe and iron uptake and yield of barley plant.

| Treatments | | DTPA-Fe (ppm) | | Fe uptake (mg pot$^{-1}$) | | Yield (g pot$^{-1}$) | |
|---|---|---|---|---|---|---|---|
| Compost | Iron | 40 days | At harvest | 40 days | At harvest | Straw | Grain |
| $M_0$ | $Fe_0$ | 2.46 | 2.21 | 1.59 | 2.31 | 14.70 | 6.03 |
| | $Fe_1$ | 2.48 | 2.35 | 1.68 | 4.01 | 15.06 | 7.11 |
| | $Fe_2$ | 2.46 | 2.28 | 1.96 | 4.08 | 15.52 | 7.16 |
| | $Fe_3$ | 2.52 | 2.31 | 2.29 | 4.70 | 17.01 | 8.25 |
| | Mean | 2.48 | 2.29 | 1.88 | 3.77 | 15.57 | 7.14 |
| $M_1$ | $Fe_0$ | 3.17 | 2.48 | 2.45 | 4.24 | 14.81 | 6.86 |
| | $Fe_1$ | 3.05 | 2.61 | 2.45 | 5.19 | 15.66 | 7.63 |
| | $Fe_2$ | 3.28 | 2.73 | 2.81 | 5.72 | 16.81 | 7.91 |
| | $Fe_3$ | 3.25 | 2.71 | 2.96 | 6.89 | 17.98 | 8.87 |
| | Mean | 3.19 | 2.63 | 2.67 | 5.51 | 16.32 | 7.82 |
| $M_2$ | $Fe_0$ | 4.11 | 3.14 | 2.65 | 4.31 | 15.32 | 7.38 |
| | $Fe_1$ | 5.21 | 3.45 | 3.06 | 5.72 | 16.26 | 8.51 |
| | $Fe_2$ | 5.86 | 3.36 | 3.45 | 6.22 | 17.13 | 8.98 |
| | $Fe_3$ | 5.61 | 3.47 | 3.57 | 8.12 | 18.38 | 9.75 |
| | Mean | 5.20 | 3.36 | 3.18 | 6.09 | 16.77 | 8.66 |
| $M_3$ | $Fe_0$ | 4.26 | 2.86 | 2.53 | 4.44 | 14.34 | 7.01 |
| | $Fe_1$ | 4.11 | 2.81 | 2.77 | 5.77 | 17.53 | 7.96 |
| | $Fe_2$ | 4.63 | 2.96 | 3.10 | 6.45 | 17.85 | 8.31 |
| | $Fe_3$ | 4.66 | 3.15 | 3.24 | 7.37 | 18.10 | 9.03 |
| | Mean | 4.42 | 2.95 | 2.91 | 6.01 | 16.96 | 8.08 |
| LSD (5%) | *M* | 0.57 | 0.20 | 0.15 | 0.23 | 1.04 | 0.82 |
| | *Fe* | NS | NS | NS | 0.23 | 1.04 | 0.82 |
| | Interaction | NS | NS | NS | 0.45 | NS | NS |

The water soluble, exchangeable, acid soluble and organically bound increased by 25.3, 15.1, 41.6, and 24.2 % in the treatment $M_2$ as compared to other treatments over control ($M_0$), respectively. The lowest water soluble, exchangeable, acid soluble and organically bound obtained in the treatment receiving no compost (control). This may be due to increased total dry matter production, yield and yield components of barley as result of increased iron availability in calcareous soil by high acidulation effect of compost and its role for maintaining soil fertility in soil. Thus, addition of composted mixtures increased water soluble, acid soluble, exchangeable, and Pb-displaceable iron in soil. Amending soil with compost may lead to accumulation of metals and their fractions at various concentrations in soil profile [24].

However, the iron fractions like, Pb displaceable iron, Mn oxide occluded and amorphous Fe oxide occluded did not differ significantly due to application of composted mixtures or the foliar spray of iron. In addition, the interaction effects between compost and iron sources were not significant with respect to iron fractions.

**DTPA-Fe and Iron Uptake:** Data presented in Table 6 indicated that, significant differences in available Fe fraction in soil were recorded due to application of composted mixtures. Data revealed that, the application of composted mixture of rice straw plus chicken manure ($M_2$) gave the highest available Fe (5.20 and 3.36 ppm) at 40 day and at harvest over control followed by $M_3$ (4.42 and 2.95 ppm) and $M_1$ (3.19 and 2.63 ppm), respectively.

The treatment $M_2$ recorded the highest percent increase in DTPA-extractable Fe (109.7 and 46.7 %) over the control one at 40 days and at harvest, respectively. Natural chelating agents isolated from various organic materials are more effective in micronutrients availability in soil. The organic acids which is released into the soil such as humic and fulvic acids from a stable complexes with metal ions is undoubtedly due to their high content of oxygen-containing functional groups, including COOH, phenolic, alcoholic, enolic-OH and C=O structures.

The available Fe fraction extracted by DTPA did not varied significantly by the foliar application of iron. The interaction effects between compost and iron supply were not significant. This could be due to more vegetative growth and root growth which release hydrogen ions, phenolic compounds and organic acids helped in increased availability and uptake of iron by barley plants. A study conducted by Srikanth[25] on the enriched and un-enriched compost revealed that there was significant increase in the DTPA extractable micronutrients and their contents in the ragi-cowpea crop. Regarding iron uptake by barley plant, iron uptake increased markedly because of compost and foliar iron application. Foliar application of iron had profound influence on iron uptake by barley. The pots receiving $Fe_3$ treatment of foliar application of 0.25 % citric acid registered significantly highest iron uptake (30.16 and 67.68 g pot$^{-1}$) over control treatment ($Fe_0$) at 40 day and at harvest. This trend of higher uptake of iron in the treatments receiving foliar application of citric acid could be due to increased iron reduction and mobility in plant leaves resulting in higher production of chlorophyll, dry matter, and higher uptake of iron by plants.

Addition of composted rice straw with chicken manure ($M_2$) treatment recorded significant increase in iron uptake by (69.1 and 61.4 %) at 40 day and at harvest, respectively over no compost applied ($M_0$) followed by $M_3$ (54.8 and 59.2 %) and $M_1$ (41.7 and 45.9 %). The combined effects of compost and iron application were significantly affected on iron uptake by plant. This may be due to increased iron availability in soil by high nutrient content of applied compost and its role in improving chemical and physical characteristic of soil resulting in increasing iron uptake by barley. Similar observations were made by Kalyan Singh *et al.*[26] in wheat.

**Yield of Barley:** The yield determining components of barley crop such as straw and grain yield were significantly influenced by compost and iron application (Table 6). The treatment $Fe_3$ significantly increased straw and grain yield by 20.8 and 31.7 %, respectively and it was significantly superior over no iron applied ($F_0$). Foliar spray of citric acid increased iron assimilation in plants and grains and availability of iron through leaves of plant resulted in increase grain yield of barley.

With respect to the effect of applied composted mixtures, the highest percent increase in straw yield (7.7 %) and grain yield (21.3 %) was recorded in the treatment $M_2$ as compare with $M_0$ followed by $M_3$ and $M_1$, respectively. The lowest values recorded in the treatment receiving no compost ($M_0$). This might be due to various physiological characters in plants, one can exploit full genetic potential of a crop, when it is grown under favorable conditions and well balanced supply of nutrients to the crop especially under usage of composted mixtures. The results of the present study are in conformity with the findings of Srinivas and Raju[27].

Regression equations were obtained between grain and straw yield from one side and iron forms and chlorophyll from the other side and the equitation were:

Grain yield = - 0.146 + 3.636 Total chlorophyll + 0.091 Ferrous-Fe - 0.153 DTPA-Fe at 40 days + 0.449 DTPA-Fe at harvest + 0.085 Fe uptake at 40 days + 0.199 Fe uptake at harvest.
$R^2$ = 0.949**

Straw yield = 7.676 + 6.277 Total chlorophyll + 0.136 Ferrous-Fe + 0.086 DTPA-Fe at 40 days – 1.659 DTPA-Fe at harvest + 0.589 Fe uptake at 40 days + 0.272 Fe uptake at harvest.
$R^2$ = 0.901**

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