Impact of application methods and doses of micronutrients on wheat' grain yield, nutrient content and their uptake

ABSTRACT

Various methodologies (soil or foliar application) and doses of zinc (Zn), iron (Fe) and manganese (Mn) either in conjunction with urea or in combination with one another were used to evaluate grain and straw production as well as nutrient concentration and their uptake in wheat. The experiment's findings showed that adding Zn, Fe and Mn significantly enhanced grain and straw production over control as well as available nitrogen (N), phosphorus (P) and potassium (K) content and their uptake. When 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 5 mg Mn kg^{-1} + 30 mg N kg^{-1} was applied, the maximum grain yield, straw yield, P uptake in grain and straw, as well as K concentration and uptake in grain and straw were found. Highest N content both in grain and straw was observed when 0.5% $FeSO_4$ + 3 % Urea were applied. Phosphorus content in grain was recorded highest when 0.5% $MnSO_4$ + 0.5% Citric acid was applied whereas in straw maximum concentration of phosphorus was noticed when 0.5% $ZnSO_4$ + 2% Urea were applied. Highest uptake of nitrogen in grain was found when 0.5% $MnSO_4$ + 2.5% Urea were applied and in straw when 0.5% $FeSO_4$ + 3 % Urea were applied. The experimental results also showed that micronutrient (Zn, Fe and Mn) concentration and uptake significantly increased as compared to control with micronutrient application (Zn, Fe and Mn).

Key Words: Grain and straw yield, Fe, Mn, Zn, N, P and K

INTRODUTION

The most valuable cereal crop in the world is wheat (*Triticum aestivum* L.), which is also the third most widely produced cereal after maize and rice. Since it is the nation's main source of food, it is one of India's most vital cereal crops (FAO, 2021). Wheat is a demanding crop that needs a lot of nutrients to produce higher yields. Wheat productivity in India is extremely low as a result of improper tillage and fertilization (more use of NPK fertilizers and limited use of manures and micronutrients, restricted recycling of plant residues). Although micronutrients are present in extremely small concentrations in soils and plants, they play an equally critical role to that of primary or secondary nutrients. Six essential micronutrients—Fe, Mn, Zn, Cu, B, and Mo—are among the most important (Steven, 2000). Due to our reliance on cereal crops, primarily wheat, rice and maize for their daily diet more than half of the world's population suffers from nutrient shortages, especially Zn and Fe (Kenzhebayeva *et al.* 2019). Micronutrient deficiencies, also known as hidden hunger are becoming a major problem for agricultural experts. Lack of iron, zinc, iodine, folate, vitamin A and zinc are the main causes of nutrient deficiency in diet (Jawaldeh *et al.* 2019).

Many enzymes that are employed in the metabolism of auxin and carbohydrates, in the production of proteins and in maintaining the integrity of membranes contain zinc as a structural component (Cakmak 2000; Rehman *et al.* 2018). Additionally, it also takes part in pollen development, fertilization and chlorophyll synthesis (Pandey *et al.* 2006). Iron plays a number of crucial roles in the growth and development of plants, including improving the efficiency of photosystems and contributing to chlorophyll biosynthesis. It is a crucial component of several enzymes. Iron also takes part in plant reactions that change nitrate into ammonium and the oxidation process that releases energy from sugars and starches. It is crucial for the metabolism of nucleic acids (Eskandari, 2011; Havlin *et al*., 2014). Moreover, Fe is constituent of ETC (electron transport chain) and cytochrome (Soetan *et al*. 2010). Manganese is required for enzyme activation, in electron transport and disease resistance (Zeidan *et al.*, 2010). Mn is crucial for the metabolism of phenolics, isoprenoids, chlorophylls and carotenoids. Mn^{+2} applied externally boosts yield, net assimilation, relative growth and photosynthetic activity. Additionally, Mn contributes to the development of root and shoots pathogen tolerance (Dimpka *et al.*, 2018). The water splitting enzymes connected to photosystem II depend heavily on manganese. It is a component of the enzyme superoxide dismutase (Mn-SOD). In addition, manganese helps in the production of quinines, sterols, gibberellic acid and chlorophyll (Singh and Patra, 2017).

Due to subpar crop management and degraded soil, the fall in micronutrient concentration is particularly pronounced in developing nations. The need for food is rising as the world's population rises. Since the 1960s, we have placed more emphasis on productivity than food quality (Cakmak *et al.* 2010). The quality of grains can be improved with the exogenous application of micronutrients, which can also increase wheat crop yield. Zn has a bioavailability of roughly 25% in wheat grains, while Fe is thought to have a bioavailability of 5%. Any breeding or biofortification effort should take into account enhancing the bioavailability of micronutrients in addition to their amount. Plants can more easily absorb and remobilize Fe and Zn thanks to certain nutrients. For instance, when applied to soil or leaves, nitrogen fertiliser combined with Zn and Fe boosts both the yield and uptake of these elements (Niyigaba *et al.*, 2019). The key to enhancing productivity, concentration, and nutrient uptake is to use the right amount of fertilisation, which can be achieved by carefully applying plant nutrients to wheat crops. With the aforementioned considerations in mind, it was deemed important to investigate the effects of Zn, Fe, and Mn treatment on wheat production, concentration, and nutrient uptake.

Method and material used

Experiment location:

A pot experiment was carried out at the screen house of the Department of Soil Science, CCSHAU, Hisar during the rabi season of 2017–18 to examine the impact of Zn, Fe and Mn application on wheat grain and straw yield as well as nutrient concentration and uptake in grain and straw.

Experimental design and treatments:

Basal application of recommended doses of N, P and K were applied by using 50 mg N kg^{-1} as urea, 50 mg P kg^{-1} as potassium dihydrogen phosphate, 15 mg K kg^{-1} soil through K_2SO_4. After mixing the soil thoroughly, all the pots were filled with this sandy soil and arranged in completely randomized design (CRD) with three different replications. Wheat variety WH 1105 was used for this experiment. Sixteen different combinations of Zn, Fe and Mn were used to investigate their effect on wheat yield, nutrient concentration and uptake. Treatments used were as follows: Control, 2.5 mg Zn kg^{-1} through $ZnSO_4$ (basal dose), 0.5% $ZnSO_4$ solution foliar spray at CRI, tillering and milking, 2.5 mg Zn kg^{-1} + 0.5% $ZnSO_4$ (basal + foliar spray), 0.5% $ZnSO_4$ + 0.2% Urea, 0.5% ZnSO4 + 0.5% Urea, 0.5% $ZnSO_4$ +

1% Urea, 0.5% $ZnSO_4$ + 1.5% Urea, 0.5% $ZnSO_4$ + 2% Urea, 0.5% $ZnSO_4$ + 2.5% Urea, 0.5% $ZnSO_4$ + 3% Urea, 0.5% $ZnSO_4$ + 0.1% citric acid. Similar treatments of Fe and Mn were applied using $FeSO_4$ and $MnSO_4$ except citric acid. In case of Fe and Mn, 0.5% of citric acid was used. Some combinations of Zn, Fe and Mn were also applied as 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1}, 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 30 mg N kg^{-1}, 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1} and 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1} + 30 mg N kg^{-1}. Separate pots were used to study the effect of Zn, Fe and Mn application.

Sampling and analysis:

Plants from the pots were picked after the crop achieved physiological maturity. Grain and straw that had been cleaned and threshed were weighed on an electric balance. The yields of grain and straw were expressed in gm pot^{-1}. After collecting from cleaned grains and straw, samples were ground. Different methods were used for analysis of different nutrients concentration as: colorimetric method using Nessler's reagent for nitrogen (by using spectrophotometer), Vanadomolybdate yellow colour method for phosphorus (by using spectrophotometer), flame photometer for potassium and atomic absorption spectrophotometer for micronutrient analysis. Uptake of nutrients was calculated by using the formula Nutrient concentration in grain or straw (%) × grain or straw yield (kg ha^{-1})/100.

Statistical analysis:

The whole data of the investigation was analysed using completely randomized (CRD) design. Critical difference ($p = 0.05$) was used to compare treatment effects.

Result and Discussion:

Impact on grain and straw yield of wheat:

Grain and straw yield increased significantly as compared to control with the application of Zn, Fe and Mn (Table 1, Table 2 and Table 3). Maximum grain (15.60 g pot^{-1}) and straw (19.70 g pot^{-1}) yield of wheat were recorded where 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 5mg Mn kg^{-1} + 30 mg N kg^{-1} was applied. Increase in grain yield followed the order Zn + Fe + Mn + N application > foliar as well as basal application > basal application of Zn, Fe and Mn. Maximum increase in yield was recorded with the application of Zn > Mn > Fe. Grain and straw yield of wheat varied from 8.03 to 15.60 g pot^{-1} and 10.02 to 19.70 g pot^{-1}, respectively. The results of present findings are in agreement with Singh *et al.* (2015), Khattak *et al.* (2015) and Choudhary *et al.* (2017). The fact that the initial status of available Zn, Fe and Mn in the soil was low and that increased supply of these micronutrients to the crop resulted in increased yield due to better growth and development of the crop may help to explain the increase in wheat yield due to application of micronutrients. Due to its role in the production of indole acetic acid, zinc is particularly important for the beginning of primordia for reproductive parts and the partitioning of photosynthates towards them, which improved flowering and fruiting (IAA). Similar results were reported by Singh *et al.* (2015) and Arshad *et al.* (2016). The improved transport of protein and carbohydrate metabolites to the site of grain production may be the reason why iron application to the soil increases wheat yield.

According to Gill and Walia (2014), the application of iron significantly increased grain and straw yield.

Impact on macronutrient content and uptake in grain and straw of wheat:

The results of the investigation also revealed that with the application of Zn, Fe and Mn, macronutrient content of wheat grain and straw increased significantly as compared to control (Table 7, Table 8 and Table 9). Maximum (1.95 % and 0.74 %) content of total N in grain and straw was recorded where Fe was applied @ 0.5% $FeSO_4$ + 3% urea as foliar spray. In case of P, maximum grain content was recorded when 0.5% $MnSO_4$ + 0.5% citric acid was applied and in straw maximum of P content was recorded when 0.5% $ZnSO_4$ + 2% urea was applied. Total K content in grain and straw was found maximum where 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1} + 30 mg N kg^{-1} was applied. In general, more concentration of N and P in grain and straw were recorded where nutrients were applied as foliar spray as compared to their basal application, reverse was true for concentration of K. Nitrogen content in grain and straw varied from 1.39 to 1.95% and from 0.39 to 0.74%, respectively. Whereas, P content in grain ranged from 0.18 to 0.30% and in straw from 0.015 to 0.035%. The K content in grain and straw varied from 0.17 to 0.76% and 1.01 to 1.50% respectively. The increased concentration of N, P and K in grain and straw as compared to control might be due application of Zn, Fe and Mn in conjugation with various N combination enhanced the uptake of macronutrients as a result of better crop growth. Increase in macronutrient content of wheat might be due to improved growth and development of crop. Increased metabolic and physiological activities, chlorophyll content might be another reason for improved growth and development of wheat plants. These results were in agreement with the findings of Shivay (2010), Khalifa *et al.* (2011) and Choudhary *et al.* (2017).

Similar results were obtained when effect of micronutrients on uptake of N, P and K was studied. It also showed that N, P and K uptake in grain and straw also increased significantly with the application of micronutrients. Highest uptake in wheat grain was recorded when 0.5% $MnSO_4$ + 2.5% Urea was applied. Whereas, uptake in straw it was found maximum where 0.5% $FeSO_4$ + 3 % Urea was applied. Phosphorus and potassium uptake in both grain and straw were recorded highest when 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1} + 30 mg N kg^{-1} was applied. These findings were in accordance with the results reported by Choudhary *et al.* (2017), Shivay (2010), Khalifa *et al.* (2011) and Abbas *et al*. (2011). This may be due to the wheat crop's improved nutrient uptake in response to micronutrient fertilization coupled with recommended levels of N, P and K. Comparing the balanced fertilization to nutrient use in alone or in combination the balanced fertilization had demonstrated favorable impacts on crop growth, development and nutrients content.

Impact on micronutrient content and uptake in grain and straw of wheat:

The concentration and uptake of micronutrients in grain and straw increased significantly with the application of Zn, Fe and Mn (Table 4, Table 5 and Table 6). Comparatively, more concentration of micronutrients both in grain and straw were recorded in treatments where nutrients were applied as foliar spray as compared to their basal application. The concentration of Zn in grain ranged from 19.6 to 37.4 mg kg^{-1} and in straw it varied from 9.2 to 27.6 mg kg^{-1}. Whereas, Fe content ranges from 27.3 to 62.2 mg kg^{-1} and 39.5 to 93.1 mg kg^{-1} in grain and straw respectively. The Mn content in grain and straw ranged from 12.3 to 25.7 mg kg^{-1} and 9.5 to 26.3 mg kg^{-1} respectively. The rise in micronutrients in grain and straw may be attributable to their greater absorption when Zn, Fe and Mn are applied with different levels of N. Similar results were reported by Wang *et al.* (2015), Narwal *et al.* (2012).

Uptake of Zn varied from 159.8 to 486.9 g pot^{-1} and 101.1 to 447.3 g pot^{-1} in grain and straw respectively (Table 10, Table 11 and Table 12). The Fe uptake ranged from 219.0 to 738.6 g pot^{-1} in grain and 450.5 to 1322.3 g pot^{-1} in straw. A variation from 98.8 to 323.4 g pot^{-1} and 102.1 to 355.2 g pot^{-1} was recorded for Mn content in wheat grain and straw, respectively. In micronutrients deficient soil, application of micronutrients increased their availability in rhizosphere. The favorable effect of micronutrients in raising the root's capacity for exchanging cations contributed to the improved uptake of nutrients from the soil. Similar findings were reported by Choudhary *et al.* (2017), Shivay (2010), Khalifa *et al.* (2011).

Conclusion:

This study shows that the application of micronutrients, either alone or in combination, significantly boosted grain production, straw yield, N, P and K content as well as their uptake. Foliar application showed a greater increase in macronutrient content than basal application in terms of magnitude. When basal dose was provided either alone or in combination, the N, P and K content under foliar spray increased significantly over their basal application of nutrients. The application of micronutrients also boosted their concentration and absorption in the order of foliar application > basal application.

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Table 1 Effect of mode and doses of Zn application on yield (g pot^{-1}) and NPK content (%) in wheat

Treatments	Yield		N	P	K	N	P	K
	Grain	Straw	Grain			Straw		
T_1- Control	10.80	13.46	1.39	0.21	0.20	0.42	0.017	1.03
T_2* - 2.5 mg Zn kg^{-1}	13.87	17.38	1.42	0.23	0.35	0.44	0.018	1.34
T_3**- 0.5% $ZnSO_4$ solution	11.50	14.45	1.45	0.21	0.45	0.45	0.020	1.38
T_4- T_2* + T_3**	15.30	19.13	1.47	0.22	0.50	0.47	0.021	1.39
T_5** - 0.5% $ZnSO_4$+ 0.2% Urea	11.97	15.00	1.55	0.24	0.53	0.50	0.018	1.40
T_6** - 0.5% $ZnSO_4$+ 0.5% Urea	12.50	15.62	1.60	0.23	0.44	0.53	0.021	1.37
T_7**- 0.5% $ZnSO_4$+ 1% Urea	12.60	15.79	1.72	0.25	0.62	0.56	0.024	1.40
T_8** -0.5% $ZnSO_4$+ 1.5% Urea	12.80	16.04	1.78	0.27	0.36	0.61	0.029	1.48
T_9** -0.5% $ZnSO_4$+ 2% Urea	12.87	16.17	1.81	0.26	0.45	0.64	0.035	1.44
T_{10}**- 0.5% $ZnSO_4$+ 2.5% Urea	13.00	16.21	1.89	0.24	0.36	0.69	0.026	1.47
T_{11}**-0.5% $ZnSO_4$+ 3% Urea	12.20	15.22	1.93	0.26	0.43	0.73	0.021	1.43
T_{12}**- 0.5% $ZnSO_4$+ 0.1% citric acid	10.97	13.78	1.30	0.29	0.29	0.46	0.028	1.49
T_{13}*- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1}	13.80	15.80	1.44	0.23	0.57	0.43	0.025	1.34
T_{14}*- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 30 mg N kg^{-1}	14.00	17.30	1.46	0.22	0.63	0.49	0.033	1.33
T_{15}*- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 5mg Mn kg^{-1}	15.40	18.00	1.43	0.24	0.69	0.44	0.031	1.48
T_{16}*- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 5mg Mn kg^{-1} + 30 mg N kg^{-1}	15.60	19.70	1.48	0.23	0.85	0.51	0.029	1.50
CD (p= 0.05)	1.19	1.51	0.16	0.02	0.06	0.05	0.003	0.14

**Basal application, ** foliar spray at CRI, tillering & milking stage*

Table 2 Effect of mode and doses of Fe application on yield (g pot^{-1}) and NPK content (%) in wheat

Treatments	Yield		N	P	K	N	P	K
	Grain	Straw	Grain			Straw		

T_1 – Control	8.03	10.02	1.42	0.19	0.17	0.39	0.015	1.01
T_2* - 5 mg Fe kg^{-1}	9.10	11.41	1.43	0.20	0.40	0.42	0.019	1.37
T_3**- 0.5% $FeSO_4$ solution	9.50	11.94	1.44	0.20	0.36	0.43	0.020	1.27
T_4 – T_2* + T_3**	13.67	17.09	1.46	0.21	0.23	0.46	0.018	1.34
T_5** - 0.5% $FeSO_4$ + 0.2% Urea	10.13	12.70	1.53	0.23	0.55	0.51	0.021	1.40
T_6** - 0.5% $FeSO_4$+ 0.5% Urea	10.60	13.25	1.58	0.22	0.49	0.52	0.022	1.33
T_7** - 0.5% $FeSO_4$+ 1% Urea	10.80	13.54	1.68	0.24	0.36	0.57	0.019	1.35
T_8** - 0.5% $FeSO_4$+ 1.5% Urea	11.07	13.88	1.71	0.23	0.62	0.62	0.022	1.31
T_9** - 0.5% $FeSO_4$+ 2% Urea	11.83	14.87	1.80	0.25	0.39	0.63	0.018	1.35
T_{10}** - 0.5% $FeSO_4$ + 2.5% Urea	11.33	14.13	1.87	0.27	0.59	0.68	0.023	1.41
T_{11}** - 0.5% $FeSO_4$+ 3 % Urea	12.67	15.79	1.95	0.23	0.43	0.74	0.020	1.49
T_{12}** - 0.5% $FeSO_4$+ 0.5% Citric acid	11.03	13.86	1.32	0.28	0.71	0.44	0.019	1.39
T_{13}* - 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1}	13.40	16.60	1.45	0.21	0.74	0.40	0.024	1.31
T_{14} *- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 30 mg N kg^{-1}	14.20	17.70	1.48	0.23	0.56	0.47	0.028	1.29
T_{15}* - 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1}	15.00	18.50	1.44	0.20	0.69	0.43	0.027	1.25
T_{16}* - 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1} + 30 mg N kg^{-1}	15.30	19.10	1.49	0.24	0.78	0.49	0.025	1.27
CD (p= 0.05)	1.56	1.98	0.16	0.02	0.06	0.05	0.002	0.13

**Basal application, ** foliar spray at CRI, tillering & milking stage*

Table 3 Effect of mode and doses of Mn application on yield (g pot^{-1}) and NPK content (%) in wheat

Treatments	Yield		N	P	K	N	P	K
	Grain	Straw	Grain			Straw		
T_1 – Control	10.00	13.50	1.40	0.18	0.26	0.41	0.019	1.16
T_2* - 5 mg Mn kg^{-1}	10.80	11.90	1.41	0.19	0.29	0.43	0.022	1.30
T_3** - 0.5%$MnSO_4$ solution	9.50	12.80	1.43	0.21	0.36	0.44	0.024	1.33
T_4 – T_2* + T_3**	9.80	13.50	1.49	0.20	0.56	0.42	0.028	1.31
T_5** - 0.5% $MnSO_4$ + 0.2% Urea	11.80	12.20	1.56	0.22	0.50	0.47	0.022	1.35
T_6** - 0.5% $MnSO_4$+ 0.5% Urea	10.20	11.80	1.61	0.22	0.29	0.49	0.024	1.45
T_7** - 0.5% $MnSO_4$+ 1% Urea	11.50	12.50	1.69	0.23	0.50	0.53	0.025	1.43
T_8** - 0.5% $MnSO_4$+ 1.5% Urea	12.50	13.50	1.75	0.24	0.73	0.57	0.020	1.48
T_9** - 0.5% $MnSO_4$+ 2% Urea	13.50	15.50	1.83	0.26	0.66	0.60	0.026	1.33
T_{10}** - 0.5% $MnSO_4$ + 2.5% Urea	13.80	14.50	1.86	0.26	0.76	0.65	0.027	1.36
T_{11}** - 0.5% $MnSO_4$+ 3 % Urea	11.20	13.50	1.90	0.23	0.29	0.69	0.026	1.30
T_{12}** - 0.5% $MnSO_4$+ 0.5% Citric acid	11.20	13.20	1.28	0.30	0.36	0.48	0.023	1.20
T_{13}* - 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1}	13.20	16.30	1.42	0.22	0.65	0.42	0.021	1.27
T_{14}* - 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 30 mg N kg^{-1}	14.00	16.90	1.49	0.23	0.67	0.45	0.027	1.34
T_{15}* - 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1}	15.20	19.00	1.40	0.21	0.68	0.41	0.025	1.39
T_{16}* - 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1} + 30 mg N kg^{-1}	15.50	19.40	1.47	0.21	0.63	0.47	0.029	1.41
CD (p= 0.05)	0.96	1.17	0.16	0.02	0.06	0.05	0.002	0.14

**Basal application, ** foliar spray at CRI, tillering & milking stage*

Table 4 Effect of mode and doses of Zn application on Zn, Fe and Mn content (mg kg^{-1}) in grain and straw

Treatments	Grain			Straw		
	Zn	**Fe**	**Mn**	**Zn**	**Fe**	**Mn**
T_1 – Control	19.6	26.4	11.9	9.2	40.4	10.8
T_2* - 2.5 mg Zn kg^{-1}	21.9	30.2	12.8	13.7	42.0	11.4
T_3**- 0.5% $ZnSO_4$ solution	27.5	31.6	13.4	14.0	42.8	12.0
T_4- T_2* + T_3**	28.5	31.9	13.7	16.3	43.7	12.6
T_5** - 0.5% $ZnSO_4$+ 0.2% Urea	29.9	33.2	14.9	17.5	42.6	13.8
T_6** - 0.5% $ZnSO_4$+ 0.5% Urea	32.8	35.4	15.5	18.8	43.5	13.9
T_7**- 0.5% $ZnSO_4$+ 1% Urea	33.2	35.9	16.2	20.5	45.2	14.3
T_8** -0.5% $ZnSO_4$+ 1.5% Urea	31.9	36.8	17.6	21.3	47.2	15.9
T_9** -0.5% $ZnSO_4$+ 2% Urea	32.7	37.1	18.3	22.0	47.5	16.0
T_{10}**- 0.5% $ZnSO_4$+ 2.5% Urea	37.4	38.3	18.8	27.6	48.1	17.1
T_{11}**-0.5% $ZnSO_4$+ 3% Urea	34.2	38.7	19.1	27.0	49.2	17.3
T_{12}**- 0.5% $ZnSO_4$+ 0.1% citric acid	29.9	37.4	18.0	16.1	42.3	12.5
T_{13}*- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1}	25.9	40.5	14.2	13.9	53.7	11.8
T_{14}*- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 30 mg N kg^{-1}	26.2	42.2	14.8	14.2	54.0	12.0
T_{15}*- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 5mg Mn kg^{-1}	26.7	43.3	15.3	14.6	54.2	12.4
T_{16}*- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 5mg Mn kg^{-1} + 30 mg N kg^{-1}	27.5	44.6	15.7	15.7	54.7	13.1
CD (p= 0.05)	2.9	3.9	1.6	1.8	4.9	1.4

**Basal application, ** foliar spray at CRI, tillering & milking stage*

Table 5 Effect of mode and doses of Fe application on Zn, Fe and Mn content (mg kg^{-1}) in grain and straw

Treatments	Grain			Straw		
	Zn	**Fe**	**Mn**	**Zn**	**Fe**	**Mn**
T_1 – Control	19.9	27.3	12.3	10.1	45.0	10.2
T_2* - 5 mg Fe kg^{-1}	20.2	38.8	13.2	11.3	53.1	11.2
T_3**- 0.5% $FeSO_4$ solution	22.0	41.2	14.9	11.9	57.3	11.3
T_4 – T_2* + T_3**	22.4	47.0	15.4	13.7	70.6	11.7
T_5** - 0.5% $FeSO_4$ + 0.2% Urea	22.7	40.4	14.3	10.4	71.0	11.4
T_6** - 0.5% $FeSO_4$ + 0.5% Urea	23.5	46.4	14.5	12.3	71.2	12.2
T_7** - 0.5% $FeSO_4$ + 1% Urea	24.2	46.3	15.3	14.9	74.3	12.8
T_8** - 0.5% $FeSO_4$ + 1.5% Urea	24.5	52.3	15.6	15.6	74.7	13.4
T_9** - 0.5% $FeSO_4$ + 2% Urea	24.9	53.8	16.0	15.9	79.9	15.2
T_{10}** - 0.5% $FeSO_4$ + 2.5% Urea	25.1	55.9	17.5	16.1	93.1	15.5
T_{11}** - 0.5% $FeSO_4$ + 3 % Urea	25.6	58.3	17.7	16.3	83.8	17.5
T_{12}** - 0.5% $FeSO_4$ + 0.5% Citric acid	22.1	62.2	18.8	15.1	41.0	14.9
T_{13}* - 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1}	21.4	43.4	14.1	13.2	56.2	12.1
T_{14} *- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1}+ 30 mg Nkg^{-1}	21.7	44.1	14.4	13.6	56.6	12.4
T_{15}* - 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1}	22.1	44.8	14.7	13.9	58.3	12.8
T_{16}* - 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1} + 30 mg N kg^{-1}	22.5	45.2	15.3	14.5	58.5	13.5
CD (p= 0.05)	2.3	4.7	1.5	1.4	6.7	1.3

**Basal application, ** foliar spray at CRI, tillering & milking stage*

Table 6 Effect of mode and doses of Mn application on Zn, Fe and Mn content (mg kg^{-1}) in grain and straw

Treatments	Grain			Straw		
	Zn	Fe	Mn	Zn	Fe	Mn
T_1 – Control	20.6	25.7	12.0	10.9	39.5	9.5
T_2* - 5 mg Mn kg^{-1}	21.4	29.6	14.1	9.2	41.4	12.7
T_3** - 0.5%Mn SO_4 solution	21.6	29.8	15.0	11.3	42.0	13.3
T_4 – T_2* + T_3**	21.9	30.8	15.5	12.5	43.2	13.2
T_5** - 0.5% $MnSO_4$ + 0.2% Urea	22.5	31.3	17.9	11.6	43.5	14.9
T_6** - 0.5% $MnSO_4$ + 0.5% Urea	22.9	33.6	18.0	11.5	44.9	15.6
T_7** - 0.5% $MnSO_4$ + 1% Urea	23.4	34.1	18.4	12.4	44.5	16.7
T_8** - 0.5% $MnSO_4$ + 1.5% Urea	24.0	34.7	19.4	14.2	46.3	17.8
T_9** - 0.5% $MnSO_4$ + 2% Urea	24.4	35.3	20.1	14.9	47.4	19.1
T_{10}** - 0.5% $MnSO_4$ + 2.5% Urea	25.2	36.8	23.4	15.8	47.9	24.3
T_{11}** - 0.5% $MnSO_4$ + 3 % Urea	25.8	37.9	25.7	16.0	49.5	26.3
T_{12}** - 0.5% $MnSO_4$ + 0.5% Citric acid	20.6	38.9	18.4	15.4	43.1	20.5
T_{13}* - 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1}	21.3	41.3	14.0	12.9	53.4	11.9
T_{14}* - 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 30 mg N kg^{-1}	21.5	41.5	14.3	13.7	53.8	12.2
T_{15}* - 2.5mg Zn kg^{-1}+ 5mg Fe kg^{-1} + 5mg Mn kg^{-1}	22.8	42.2	15.4	14.2	54.0	12.6
T_{16}* - 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1} + 30 mg Nkg^{-1}	23.0	43.6	16.2	14.7	54.3	13.4
CD (p= 0.05)	2.4	3.7	1.7	1.4	5.0	1.5

**Basal application, ** foliar spray at CRI, tillering & milking stage*

Table 7 Effect of mode and doses of Zn application on macronutrient uptake (g pot^{-1}) by grain and straw

Treatments	Grain			Straw		
	N	P	K	N	P	K
T_1 – Control	15.0	2.3	2.2	5.7	0.18	13.9
T_2* - 2.5 mg Zn kg^{-1}	19.7	3.2	4.9	7.7	0.25	23.3
T_3**- 0.5% $ZnSO_4$ solution	16.6	2.4	5.2	6.5	0.21	19.9
T_4- T_2* + T_3**	22.5	3.4	7.6	9.0	0.31	26.6
T_5** - 0.5% $ZnSO_4$+ 0.2% Urea	18.5	2.9	6.3	7.5	0.20	21.0
T_6** - 0.5% $ZnSO_4$+ 0.5% Urea	20.0	2.9	5.5	8.3	0.26	21.4
T_7**- 0.5% $ZnSO_4$+ 1% Urea	21.7	3.2	7.8	8.8	0.31	22.1
T_8** -0.5% $ZnSO_4$+ 1.5% Urea	22.8	3.5	4.6	9.8	0.36	23.7
T_9** -0.5% $ZnSO_4$+ 2% Urea	23.3	3.3	5.8	10.4	0.50	23.3
T_{10}**- 0.5% $ZnSO_4$+ 2.5% Urea	24.6	3.1	4.7	11.2	0.33	23.8
T_{11}**-0.5% $ZnSO_4$+ 3% Urea	23.6	3.2	5.2	11.1	0.24	21.8
T_{12}**- 0.5% $ZnSO_4$+ 0.1% citric acid	14.3	3.2	3.2	6.4	0.32	20.6
T_{13}*- 2.5 mg Zn kg^{-1}+ 5 mg Fe kg^{-1}	19.4	3.1	7.7	7.0	0.33	21.7
T_{14}*- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 30 mg N kg^{-1}	20.5	3.1	8.9	8.5	0.50	23.0
T_{15}*- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 5mg Mn kg^{-1}	21.7	3.6	10.5	8.1	0.47	27.4
T_{16}*- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 5mg Mn kg^{-1} + 30 mg N kg^{-1}	22.9	3.6	13.2	9.9	0.47	29.1
CD (p= 0.05)	3.0	0.5	1.0	1.3	0.06	3.3

**Basal application, ** foliar spray at CRI, tillering & milking stage*

Table 8 Effect of mode and doses of Fe application on macronutrient uptake (g pot^{-1}) by grain and straw

Treatments	Grain			Straw		
	N	P	K	N	P	K
T_1 – Control	11.4	1.5	1.4	3.9	0.15	10.1
T_2* - 5 mg Fe kg^{-1}	13.0	1.8	3.6	4.8	0.22	15.7
T_3**- 0.5% Fe SO_4 solution	13.7	1.9	3.4	5.1	0.24	15.1
T_4 – T_2* + T_3**	19.9	2.9	3.1	7.9	0.31	22.9
T_5** - 0.5% $FeSO_4$ + 0.2% Urea	15.5	2.3	5.6	6.5	0.27	17.7
T_6** - 0.5% $FeSO_4$ + 0.5% Urea	16.7	2.3	5.2	6.9	0.29	17.6
T_7** - 0.5% $FeSO_4$ + 1% Urea	18.1	2.6	3.9	7.7	0.26	18.3
T_8** - 0.5% $FeSO_4$ + 1.5% Urea	18.7	2.5	6.8	8.5	0.30	18.0
T_9** - 0.5% $FeSO_4$ + 2% Urea	21.4	3.0	4.6	9.4	0.27	20.1
T_{10}** - 0.5% $FeSO_4$ + 2.5% Urea	21.2	3.1	6.7	9.6	0.33	19.9
T_{11}** - 0.5% $FeSO_4$ + 3 % Urea	24.7	2.9	5.4	11.7	0.32	23.5
T_{12}** - 0.5% $FeSO_4$ + 0.5% Citric acid	14.5	3.1	7.8	6.1	0.26	19.2
T_{13}* - 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1}	19.5	2.8	10.0	6.5	0.38	21.3
T_{14} *- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1}+ 30 mg N kg^{-1}	20.8	3.2	7.9	8.1	0.49	22.3
T_{15}* - 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1}	21.9	3.0	10.5	8.0	0.50	23.1
T_{16}* - 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1} + 30 mg N kg^{-1}	23.1	3.7	12.1	9.5	0.49	24.7
CD (p= 0.05)	2.9	0.4	1.0	1.2	0.05	3.0

**Basal application, ** foliar spray at CRI, tillering & milking stage*

Table 9 Effect of mode and doses of Mn application on macronutrient uptake (g pot^{-1}) by grain and straw

Treatments	Grain			Straw		
	N	P	K	N	P	K
T_1 – Control	14.0	1.8	2.6	5.5	0.25	15.7
T_2* - 5 mg Mn kg^{-1}	15.3	2.1	3.1	5.1	0.26	15.5
T_3** - 0.5% $MnSO_4$ solution	13.6	2.0	3.4	5.6	0.31	17.1
T_4 – T_2* + T_3**	14.7	2.0	5.5	5.7	0.38	17.8
T_5** - 0.5% $MnSO_4$ + 0.2% Urea	18.4	2.6	5.9	5.7	0.27	16.5
T_6** - 0.5% $MnSO_4$ + 0.5% Urea	16.5	2.2	3.0	5.8	0.28	17.2
T_7** - 0.5% Mn SO_4 + 1% Urea	19.4	2.6	5.8	6.6	0.31	17.9
T_8** - 0.5% $MnSO_4$+ 1.5% Urea	22.0	3.0	9.2	7.7	0.27	20.1
T_9** - 0.5% $MnSO_4$+ 2% Urea	24.8	3.5	8.9	9.3	0.40	20.7
T_{10}** - 0.5% $MnSO_4$ + 2.5% Urea	25.7	3.6	10.5	9.4	0.39	19.7
T_{11}** - 0.5% $MnSO_4$+ 3 % Urea	21.3	2.6	3.2	9.3	0.35	17.6
T_{12}** - 0.5% $MnSO_4$+ 0.5% Citric acid	14.4	3.4	4.0	6.3	0.30	15.9
T_{13}* - 2.5 mg Zn kg^{-1}+ 5 mg Fe kg^{-1}	19.1	3.0	8.8	6.8	0.34	20.6
T_{14}* - 2.5 mg Zn kg^{-1}+ 5 mg Fe kg^{-1} + 30 mg N kg^{-1}	21.0	3.2	9.4	7.8	0.47	23.2
T_{15}* - 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1}+ 5mg Mn kg^{-1}	21.3	3.2	10.3	7.6	0.46	25.7
T_{16}* - 2.5mg Zn kg^{-1}+ 5mg Fe kg^{-1} + 5mg Mn kg^{-1}+ 30 mg N kg^{-1}	22.7	3.2	9.7	9.1	0.56	27.4
CD (p= 0.05)	3.4	0.5	1.2	1.3	0.06	3.4

**Basal application, ** foliar spray at CRI, tillering & milking stage*

Table 10 Effect of mode and doses of Zn application on Zn, Fe and Mn uptake (µg pot^{-1}) by wheat grain and straw

Treatments	Grain			Straw		
	Zn	Fe	Mn	Zn	Fe	Mn
T_1 – Control	210.1	285.5	128.7	124.0	544.4	145.5
T_2* - 2.5 mg Zn kg^{-1}	303.0	418.9	177.5	238.2	730.3	198.2
T_3**- 0.5% $ZnSO_4$ solution	313.9	364.3	153.8	201.9	617.2	173.1
T_4- T_2* + T_3**	434.4	487.9	209.5	311.7	835.7	241.0
T_5** - 0.5% $ZnSO_4$+ 0.2% Urea	357.4	396.5	178.1	262.2	638.2	206.7
T_6** - 0.5% $ZnSO_4$+ 0.5% Urea	409.8	442.5	193.8	293.8	679.7	217.3
T_7**- 0.5% $ZnSO_4$+ 1% Urea	417.2	452.7	204.2	323.7	713.8	225.9
T_8** -0.5% $ZnSO_4$+ 1.5% Urea	408.4	471.0	225.3	341.7	757.3	255.1
T_9** -0.5% $ZnSO_4$+ 2% Urea	421.1	477.2	235.4	355.8	768.2	258.6
T_{10}**- 0.5% $ZnSO_4$+ 2.5% Urea	486.9	497.8	244.5	447.3	779.6	277.1
T_{11}**-0.5% $ZnSO_4$+ 3% Urea	418.4	469.8	234.4	411.0	741.7	263.3
T_{12}**- 0.5% $ZnSO_4$+ 0.1% citric acid	327.7	410.0	197.6	222.3	582.5	172.4
T_{13}*- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1}	349.1	545.9	191.1	225.6	872.4	191.7
T_{14}*- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 30 mg N kg^{-1}	368.7	593.8	208.3	245.8	934.5	207.4
T_{15}*- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 5mg Mn kg^{-1}	406.0	658.5	232.7	270.1	1003.9	229.4
T_{16}*- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 5mg Mn kg^{-1} + 30 mg N kg^{-1}	425.6	690.2	242.8	304.8	1060.7	254.1
CD (p= 0.05)	54.6	66.1	32.5	44.5	97.7	32.5

**Basal application, ** foliar spray at CRI, tillering & milking stage*

Table 11 Effect of mode and doses of Fe application on Zn, Fe and Mn uptake (µg pot^{-1}) by wheat grain and straw

Treatments	Grain			Straw		
	Zn	Fe	Mn	Zn	Fe	Mn
T_1 – Control	159.8	219.0	98.8	101.1	450.5	102.1
T_2* - 5 mg Fe kg^{-1}	184.0	353.2	120.3	129.1	606.7	128.0
T_3**- 0.5% $FeSO_4$ solution	208.7	391.7	141.3	141.9	683.0	134.7
T_4 – T_2* + T_3**	306.0	642.8	210.4	234.1	1206.2	199.9
T_5** - 0.5% $FeSO_4$ + 0.2% Urea	229.5	407.7	144.6	131.8	899.6	144.4
T_6** - 0.5% $FeSO_4$+ 0.5% Urea	248.7	490.4	153.5	162.7	942.1	161.4
T_7** - 0.5% $FeSO_4$+ 1% Urea	261.4	498.5	165.3	201.7	1005.8	173.3
T_8** - 0.5% $FeSO_4$+ 1.5% Urea	267.9	573.6	170.6	213.9	1024.2	183.7
T_9** - 0.5% $FeSO_4$+ 2% Urea	295.4	636.1	189.8	237.0	1190.9	226.6
T_{10}** - 0.5% $FeSO_4$ + 2.5% Urea	284.1	633.1	198.1	227.2	1313.7	218.7
T_{11}** - 0.5% $FeSO_4$+ 3 % Urea	324.0	738.6	224.0	257.2	1322.3	276.1
T_{12}** - 0.5% $FeSO_4$+ 0.5% Citric acid	243.5	685.4	207.2	209.4	567.7	206.3
T_{13}* - 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1}	288.4	584.9	190.0	214.2	912.0	196.3
T_{14} *- 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 30 mg N kg^{-1}	305.3	620.5	202.6	235.4	979.9	214.7
T_{15}* - 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1}	336.1	681.3	223.5	256.9	1078.5	236.5
T_{16}* - 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1}+ 30 mg N kg^{-1}	348.2	699.5	236.8	281.5	1135.8	261.7

CD (p= 0.05)	41.9	87.5	27.5	33.3	156.7	28.3

**Basal application, ** foliar spray at CRI, tillering & milking stage*

Table 12 Effect of mode and doses of Mn application on Zn, Fe and Mn uptake (µg pot^{-1}) by wheat grain and straw

Treatments	Grain			Straw		
	Zn	Fe	Mn	Zn	Fe	Mn
T_1 – Control	206.5	257.7	120.3	147.5	534.6	128.6
T_2* - 5 mg Mn kg^{-1}	231.7	320.5	152.3	109.8	493.9	151.5
T_3** - 0.5% $MnSO_4$ solution	205.7	283.8	142.1	145.0	538.9	170.7
T_4 – T_2* + T_3**	215.7	303.4	152.4	168.6	586.2	179.1
T_5** - 0.5% $MnSO_4$ + 0.2% Urea	264.9	370.0	211.6	141.8	529.5	182.1
T_6** - 0.5% $MnSO_4$+ 0.5% Urea	234.1	343.6	184.1	136.0	531.1	184.5
T_7** - 0.5% $MnSO_4$+ 1% Urea	268.8	392.3	211.7	155.0	556.5	208.8
T_8** - 0.5% $MnSO_4$+ 1.5% Urea	300.6	435.5	243.5	191.5	627.6	241.3
T_9** - 0.5% $MnSO_4$+ 2% Urea	329.0	477.8	272.1	230.4	736.6	296.8
T_{10}** - 0.5% $MnSO_4$ + 2.5% Urea	347.2	508.6	323.4	229.7	695.5	352.8
T_{11}** - 0.5% $MnSO_4$+ 3 % Urea	288.9	424.7	288.0	216.2	667.5	355.2
T_{12}** - 0.5% $MnSO_4$+ 0.5% Citric acid	231.0	436.2	206.2	203.6	569.9	270.9
T_{13}* - 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1}	287.1	556.6	188.5	209.3	866.1	193.1
T_{14}* - 2.5 mg Zn kg^{-1} + 5 mg Fe kg^{-1} + 30mg N kg^{-1}	302.5	584.0	201.1	237.2	929.7	211.2
T_{15}* - 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1}	346.7	641.7	234.2	262.7	999.9	232.8
T_{16}* - 2.5mg Zn kg^{-1} + 5mg Fe kg^{-1} + 5mg Mn kg^{-1} + 30 mg N kg^{-1}	355.9	674.7	250.6	285.2	1052.9	259.8
CD (p= 0.05)	41.5	75.9	35.2	29.1	109.7	38.4

**Basal application, ** foliar spray at CRI, tillering & milking stage*