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Studies on the effect of iron and zinc fertilization on yield and quality of wheat under dry land agriculture

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Abstract
A field experiment on "Studies on the effect of iron and zinc fertilization on yield and quality of wheat under dry land agriculture" was conducted at College of Agriculture, Vijayapura during *rabi* 2020-21. The experiment was laid out in randomized complete block design with ten treatments and three replications. Apart from the recommended dose of fertilizers (RDF), the treatments included the application of ferrous sulphate @ 10, 20 and 30 kg ha^{-1} and zinc sulphate @ 5, 10 and 15 kg ha^{-1} in various combinations along with RDF. The effect of these treatments on yield and quality of wheat was studied. The application of different levels of ferrous sulphate and zinc sulphate in combinations along with RDF (@ 50:25:0:: N: P_2O_5: K_2O kg ha^{-1}) resulted in significant increase in growth and yield of wheat over RDF alone. Among the different treatments, application of RDF + 30 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1} has resulted in significantly higher plant height (95.59 cm), grain test weight (49.66 g) and grain (1,793 kg ha^{-1}) and straw (3134 kg ha^{-1}) yield of crop. The treatment also resulted in higher uptake of major (N, P, K and S) and micro (Fe, Zn, Cu and Mn) nutrients by wheat crop. Similarly, the application of RDF + 30 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1} resulted in higher iron and zinc content in both grain and straw of wheat, higher protein content in grains and significantly higher available Fe and Zn status in soil after harvest of crop. Thus, the combined application of 30 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1} along with RDF (50:25:0:: N: P_2O_5: K_2O kg ha^{-1}) was found to be a better means of balanced nutrition of wheat crop to ensure higher productivity.

Keywords: Wheat, iron, protein, uptake, yield, zinc

Introduction

Cereal grain crops are grown in greater quantities and provide more food energy worldwide than any other type of crop and are therefore staple crops. Cereals play a vital role to satisfy the global food demand of growing population, particularly in developing nations where cereal-based production system is the only predominant source of nutrition and calorie intake.

Wheat (*Triticum aestivum* L.) is the world's most important staple crop. It is one of the most important cereal crops of India. Wheat is called as **'**King of Cereals**'** and improved productivity has played a key role in making the country self-sufficient in food production. It is grown on a fairly wide range of soil and climatic conditions. Wheat is a major source of carbohydrates and protein for both humans and animals. It contains starch (60-90%), protein (11.0-16.5%), fat (1.5-2.0%), mineral ions (1.2-2.0%) and vitamins B-complex and E (Ayala *et al*., 2011) [56].

In India, wheat is the second most important food crop next to rice. Wheat was grown over an area of 30.79 million hectare with the total production of 98.51 million tones and productivity of 3200 kg per hectare which shares 12.43% of total production in the world (Anon, 2018) [5]. Major wheat producing states in India are Uttar Pradesh, Punjab, Haryana, Madhya Pradesh and Rajasthan. In Karnataka, wheat is grown in *rabi* season. The major wheat growing areas in Karnataka are Vijayapura, Belagavi, Dharwad, Gadag and Bagalkot districts.

Micronutrients are nutrients required by plants, humans and other organisms throughout their life in small quantities for a range of physiological functions. Many researchers reported that the use of micronutrients has a promising role in the growth and development of crop plants which resulted in improved quality and quantity of the agricultural produce. Micronutrients are important in the production of wheat in terms of quantity, quality, and human health.

Micronutrients have been well documented to be involved in photosynthesis, N-fixation, respiration and other biochemical pathways of plants and increasing crop yield. Micronutrients have prominent effects on dry matter, grain yield and straw yield in wheat (Asad and Rafique, 2000) [8]. Therefore, by supplying plants with micronutrients, either through soil application, foliar spray or side dressing, the quality and yield of crops are improved (Malakouti, 2008) [32].

Iron plays a role in the biological redox system, enzyme activation and oxygen carrier in N-fixation (Romheld and Marschner, 1991) [42]. Iron (Fe) promotes the formation of chlorophyll as well as enzyme mechanism, which operates the respiratory systems of cells and involved in reactions of cell division and growth (Ronen). Zn is important to membrane integrity and phytochrome activities (Shkoinik, 1984) [45]. Zn is known to have an important role as a metal component of enzymes or as a functional, structural or regulatory cofactor of a wide number of enzymes (Hotz and Braun, 2004; Esfandiari *et al*., 2016) [24, 15].

Fe and Zn are essential for plants as well as humans and animals who consume plant produce. Zn and Fe pose critical nutritional issues as their deficiencies cause severe impairment of human and animal health. Therefore, Fe and Zn can control plant growth, grains yield and determine the quality of food consumed by humans and animals. The concept of bio-fortification is attractive not only for improving the growing conditions of crops but also for exploiting a plant's potential for micronutrient mobilization and utilization. In plants, Zn is required for the synthesis of tryptophan, a precursor for indole-3-acetic acid (IAA). Fe is also a part of protein ferrodoxin which is required in nitrate and sulphate reduction (Marschner, 2012) [33].

Nutrients deficiency in the soils is one of the key factors limiting crop production in dry lands. Increased removal of micro-nutrients as a consequence of adopting high yielding varieties and intensive cropping together with a shift towards high analysis NPK fertilizers has caused a decline in the level of micronutrients in the soil below that required for normal productivity of crops. A rampant increase in Zn and Fe deficiencies has been noticed across the country. Deficiency of Zn (48%) and Fe (12%) has been noticed in the Indian soils and Zn deficiency is further expected to increase by 49 to 63 per cent by the year 2025 (Singh, 2009) [47]. However, the nature and extent of deficiencies vary with soil types, crop genotypes, management and agroecological situations. The availability of the micronutrients is affected by common factors such as alkaline pH, low organic matter content, $CaCO_3$ content, soil moisture and interaction with the other nutrients. Among the micronutrients, Fe, Zn and B improved the yield appreciably through foliar spray and soil application proved to be economical (Savithri. 2001) [44]. The deficiency symptoms, once resolved, can be corrected through supplementation of Zn and Fe carriers either by soil or foliar application (Shukla *et al*., 2016) [46].

Increased use of high analysis fertilizers for enhancing food grain production has resulted in the deficiencies of micronutrients due to their continued removal from soil. A sharp decline in the availability of these nutrients with continuous cropping at the recommended dose of NPK application has been widely reported in Indian soils. Application of Fe and Zn fertilizers not only improves nutritional quality but also contributes significantly to grain production in Zn deficient soils. Zn fertilizers are used in the prevention of Zn deficiency and in the biofortification of cereal grains (Alloway, 2008) [3]. In wheat grains, the bioavailability of Zn is about 25 percent, while that of Fe is assumed to be 5 percent. The bioavailability of Fe and Zn is associated with the presence of anti-nutrients, such as phytate and a lack of promoter substances in grains. Any breeding or biofortification programme should consider increasing not only the quantity of micronutrients, but also their bioavailability.

The deficiency of iron and zinc is observed in most of the soils of northern dry zone of Karnataka. It is necessary for agricultural systems to ensure proper products, which will balance quantity of nutrients to support healthy life. However, in many developing countries, agriculture does not meet these requirements. In the context of above observation, present field experiment was carried out on the studies on the effect of iron and zinc fertilization on yield and quality of wheat under dry land agriculture.

Material and Methods

Experimental Site and Design

The field experiment was carried out in a field at College of Agriculture, Vijayapura during *rabi* 2020-21. Vijayapura is situated in the Northern Dry Zone (Zone no.3) of Karnataka. Geographically it is located in the northern part of the state at 16° 49'N latitude and 75° 43' E longitude and at an altitude of 593.8 m above the mean sea level. Before sowing, the soil samples were taken for physico-chemical analysis. The soil is black in colour and clay in texture with 18.3, 15.3 and 59.2 per cent sand, silt and clay, respectively. The soil is alkaline in reaction (pH 8.30) and low in soluble salts (0.38 dS m^{-1}). The soil was low in organic carbon (3.40 g kg^{-1}) and available nitrogen (225 kg ha^{-1}) and medium in available P (15.30 kg ha^{-1}), while it was high in K (410 kg ha^{-1}) and sulphur (15.30 kg ha^{-1}). The free calcium carbonate content was 13.4 per cent. The DTPA extractable micronutrient content viz., zinc, iron, copper and manganese were 0.42, 2.52, 1.10 and 8.10 mg kg^{-1}, respectively. The content of Zn and Fe in soil was below the critical limit. The experiment was laid out in RCBD design with ten treatments and three replications including RDF, application of iron @ 10, 20, 30 kg ha^{-1} and zinc @ 5, 10, 15 kg ha^{-1} in combinations. RDF @ 50:25:00::N:P_2O_5 :K_2O kg ha^{-1} was applied to all the treatments. Fe and Zn were applied through $FeSO_4$. $7H_2O$ (19%Fe) and $ZnSO_4$.7 H_2O(21% Zn), respectively. $FeSO_4$. $7H_2O$ and $ZnSO_4$. $7H_2O$ were chelated with vermicompost at 1:1 ratio for 15 days before sowing. Treatments included were, T_1 : Recommended dose of fertilizers (RDF), T_2 : RDF + 10 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}, T_3 : RDF + 10 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}, T_4 : RDF + 10 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}, T_5 : RDF + 20 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}, T_6 : RDF + 20 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}, T_7 : RDF + 20 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}, T_8 : RDF + 30 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}, T_9 : RDF + 30 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1} and T_{10} : RDF + 30 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}. The weather data during the experimental period are given in Table 1.

Planting and Cultural practices

The land was ploughed with bullock pair after harvest of previous crop and harrowed twice to crush the clods at optimum soil moisture state. Stubbles and weeds were removed from experimental field and soil was brought to fine tilth condition. Recommended dose of nitrogen (50 kg N ha^{-1}) and phosphorus (25 kg P_2O_5 ha^{-1}) were applied through urea and diammonium phosphate. The entire quantity of fertilizer was applied as basal dose for each treatment. Fertilizers were mixed and thoroughly covered with soil. After the onset of monsoon wheat seeds were sown in the plot by line sowing at the spacing of 45cm × 10 cm. The crop was sown on 09.10.2020. Gap filling was done after complete emergence of crop to ensure uniform plant population. Thinning was carried out at 20 days after sowing keeping one healthy plant per hill to maintain optimum plant population. Hand weedings followed by hoeings were done at 20, 40 and 60 DAS to keep the plots free from weeds, to improve aeration and to conserve the soil moisture. Timely plant protection measures were taken to control pests and diseases as and when required.

Harvesting and Data Collection

Crop was harvested on 22.01.2020 when it attained complete physiological maturity. The crop in net plot area was harvested separately in each treatment. Grains were separated and cleaned manually. Weight of grains and straw were recorded separately as per the treatment after they were dried under sun. The observations recorded were plant height, panicle length, number of effective tillers per plant test weight (1000- grain weight), grain and straw yield. The protein content in grain was determined as mentioned by AOAC, (1984) [6]. The grain and straw samples were analysed in laboratory to determine the uptake of macro and micro nutrients were calculated. Finally the total uptake of nutrients by wheat crop was computed. The soil samples after the harvest of crop were analysed for iron and zinc content as mentioned by Page *et al*., (1982) [37].

Statistical analysis and interpretation of data

The data obtained from the experiment was subjected to statistical analysis adopting Fischer's method of analysis of variance as outlined by Gomez and Gomez (1984) [19]. The level of significance used in "F" was at P = 0.05. Critical difference (CD) values were calculated for the P = 0.05 whenever "F" test was found significant.

Results and Discussion

Yield parameters

Test weight (1000 Grain weight)

The results obtained in the experiment revealed that the application of different levels of iron and zinc along with RDF significantly influenced the test weight of wheat grains. Significantly higher test weight was recorded in the treatment (T_{10}) which received RDF + 30 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1} and it was on par with the treatment (T_9) which received RDF + 30 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1} (Fig 4.) The lower test weight was recorded in the treatment (T_1) which received RDF only. The better growth and development of the crop observed in the present study could be due to proper nourishment of crop with nutrient supply. The increase in test weight due to zinc and iron application may be attributed to their role in various physiological processes and improvement in growth components and better partitioning of carbohydrates from leaf to reproductive parts resulting in increased yield. It could also be ascribed to improvement in metallo enzymes system regulatory function and growth promoting auxin production. Besides, increased Zn content and its uptake in grains help in the production of bolder grains, thus increasing 1000-grain weight in wheat (Alloway, 2008) [3]. Ananda and Patil (2007) [4] reported that application of zinc resulted in maximum 1000 grain weight in wheat. These results are in agreement with the findings of Hosseini (2006) [22], Zeidan *et al*. (2010) [55], Genc *et al*. (2006) [17], Sarkar (2014) [43], Moghadam *et al*. and Kharub and Gupta (2003) [30] in wheat.

Grain yield of wheat

The results obtained in the present study revealed that the application of different levels of iron and zinc along with RDF significantly influenced the grain yield of wheat. Significantly higher grain yield of wheat was recorded in the treatment (T_{10}) which received RDF + 30 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1} and it was on par with the treatment (T_9) that received RDF + 30 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1} (Fig. 4). The lower grain yield was recorded in the treatment (T_1) which received RDF only. The increase in the yield could be due to continuous supply of micronutrients (Fe and Zn) to the crop through the soil application and their combinations. The increase in the yield could be due to continuous supply of micronutrients (Fe and Zn) to the crop through the soil application and their combinations. Iron and zinc are part of the photosynthesis, assimilation and translocation of photosynthates from source (leaves) to sink (ear head) (Singh *et al.,* 1995) [48]. Combination of zinc with iron improved the photosynthetic attributes and had a positive effect on reproductive organs to produce more grain yield (Zayed, 2011) [53]. Chaure *et al*. (2019) [13] recorded higher grain yield over the control in wheat due to application of RDF + $ZnSO_4$ @ 30 kg ha^{-1}. These results are in confirmity with the findings of Habib (2009) [21], Riffat *et al*. (2007) [41], Ozturk *et al*. (2006) [36], Kalidasu *et al*. (2008) [27], Dhaliwal *et al*. (2012) [14], Chandrakumar *et al*. (2004) [12] in wheat and Ghafoor *et al*. (2015) [18] in wheat.

Straw yield of wheat

The results obtained in the experiment revealed that the application of different levels of iron and zinc along with RDF significantly influenced the straw yield of wheat. Significantly higher straw yield was recorded in the treatment (T_{10}) which received RDF + 30 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1} and it was on par with the treatment (T_9) that received RDF + 30 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1} (Fig. 4). The lower straw yield was recorded in the treatment (T_1) which received RDF only. Combined application of micronutrients increased straw yield due to favourable effect of Zn and Fe on the proliferation of roots and thereby increasing the uptake of the plants nutrients from the soil and supplying then to the aerial parts of the plant and ultimately enhancing the vegetative growth of the plant (Barua and Sakia, 2018) [9]. Being an essential component of several enzymes, iron and zinc are involved in nitrogen metabolism, cellular proteins and nucleic acid synthesis and encouraged the meristematic activities and increased uptake of all the nutrients which in turn helped in dry matter production by increasing the straw yield of crop. Jat *et al*. (2011) [25] reported higher straw yield over control in wheat due to application of iron and zinc each @ 3 kg ha^{-1}. These results are in close conformity with the findings of Singh *et al*. (2012) [49], Nadim *et al.* (2012), Singh *et al*. (2015) [50], Arshad *et al*. (2016) [7] and Goswami (2007) in wheat. [20]

Quality parameters

Iron and zinc content in wheat grain

There was a no significant difference among quality parameter (iron and zinc content) in wheat grain due to application of different levels of iron and zinc in combination along with RDF. However, numerically higher iron and zinc content in wheat grain was recorded in the treatment (T_{10}) with RDF + 30 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1} followed by the treatment (T_9) with RDF + 30 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}. The lower iron and zinc content in wheat grain was recorded in the treatment (T_1) with RDF only. Increase in iron and zinc content in grain could be attributed to the higher utilization of micronutrients by crops as a result of external application of iron and zinc. Plants can absorb and accumulate higher concentration of soil applied micronutrients in their different parts. Mobilization of these nutrients from vegetative tissues into the grain resulting in increased grain iron and zinc concentration in wheat. Prasad *et al*. (1983) [39] noted an increase in Fe content with increasing level of Fe in wheat grain. Yilmaz *et al*. (1997) [52] reported use of Zn in soil amendments and as foliar sprays increased Zn concentration in wheat grain. These results are confirmed with the findings of Khattab *et al*. (2016) [29] and Ranjbar and Bahmaniar (2007) [40] in wheat.

Protein content in wheat grain

Significant difference was not noticed in protein content in wheat grain due to application of different levels of iron and zinc in combination with RDF. However, the higher protein content in wheat grain (13.19 %) was recorded in the treatment (T_{10}) with RDF + 30 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1} followed by the treatment (T_9) with RDF + 30 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1} (13.04 %) (Fig. 4). Increase in protein content could be attributed to iron and sulphur role in the enzyme activities and amino acids synthesis. It helps in conversion of amino acids to high quality protein. As iron and zinc helps in the translocation of N to grain resulted in increased protein content in grain. The increase in grain Zn increased the protein content in wheat grains. Strongly positive correlations between grain protein and Zn indicate that grain proteins represent a sink for Zn. Zinc is required as structural and catalytic components of protein and enzymes for normal growth and development (Broadley *et al*., 2007) [10]. Zeidan *et al*. (2010) [55] indicated that application of Zn and Fe elements increased the protein content in grain. Uppal *et al*. (2002) [51] also indicated that increasing levels of nitrogen increases protein content in wheat grain. Similar findings were reported by Kharub and Gupta (2003) [30], Pallavi and Sudha and Singh *et al*. (2002) [51] in wheat.

Uptake of iron and zinc by wheat crop at harvest

Similarly significant uptake of iron also noticed among the treatments with the application of different levels of iron and zinc in combination along with RDF. The highest iron uptake was recorded in the treatment (T_{10}) with the application of RDF + 30 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1} (Fig. 8). The uptake of iron by wheat increased due to the increased availability of iron due to chelation effect as it is applied after chelation with vermicompost. There by the fixation of iron reduced and availability of iron to plant increased, due to this the uptake of iron increased. It was also due to the synergetic effect between iron and zinc in plants and higher dry matter production. Similar results were reported by Ziaeian and Malakouti (2001) [54] they found that Fe and Zn fertilization significantly increased the concentration and total uptake of Fe in grain, flag leaves and grain protein contents of wheat. Abbas *et al*. (2009) [1] also reported that increasing the dose of Zn up to 8 kg ha^{-1} showed increase in Fe uptake by wheat. Similar results were also reported by Cakmak *et al*. (2010) [11] and Kutman *et al*. (2011) [31] in wheat.

The uptake of zinc was significantly influenced by the application of different levels of iron and zinc in combination along with RDF. The highest zinc uptake was recorded in the treatment (T_{10}) with the application of RDF + 30 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1} (Fig. 8). The increase in the uptake of zinc by crop is due to the synergetic effect of iron and zinc in plant (Mousavi *et al*., 2012) [34]. So, as the dose of iron and zinc increases the uptake of zinc also increases. The uptake of iron by wheat increased due to the increased availability of iron as a result of chelation effect as it is applied after chelation with vermicompost. There by availability of zinc increased, due to this the uptake of iron increased. It also may due be to the higher dry matter production by the application of iron and zinc to the deficient soil. Zinc concentrations and uptake in grain and straw in wheat increased with the zinc rate particularly in soil with below 0.60 ppm DTPA- Zn. Similar findings were reported by Khattab *et al*. (2016) [29] observed that dry matter of wheat increased by increasing rates of Zn and the uptake of Zn by the plants was higher as dry matter yield was higher. Similar findings were also reported by Riffat *et al*. (2007) [41] and Abbas *et al*. (2010) [2] in wheat.

Effect of iron and zinc on soil fertility status after the harvest of crop

The availability of DTPA extractable iron and zinc content in soil significantly increased due to the application of iron and zinc at different levels along with the RDF. Treatment (T_{10}) with the application of RDF + 30 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1} recorded higher iron and zinc content in soil (Fig. 9). This was due to the application of higher doses of iron and zinc to the soil deficient in iron and zinc. These findings are consistence with the previous researches of Keram *et al*. (2012) [28], Jat *et al*. (2015) [26], Hussain (2015) [23] in wheat.

Table 1: Monthly metrological data during the cropping period 2020-21

Month	Air Temp. (°C)		Relative Humidity (%)		Wind Speed (kmph)	Sunshine Duration (h)	Rainfall (mm)	Rainy Days (no.)	Pan Evaporation (mm day^{-1})
	Max	Min	AM	PM					
April-2020	38.8	23.3	64	24	7.0	8.9	19.1	3	8.1
May	39.5	24.2	75	28	10.4	9.0	112.9	4	9.2
June	33.0	22.6	88	54	11.5	7.0	93.4	7	5.5
July	30.9	22.0	91	63	9.8	-	187.6	12	3.9
August	29.7	21.7	91	66	12.4	-	58.4	5	3.6
September	30.4	21.7	92	67	7.1	5.6	267.3	13	3.5
October	30.2	20.7	91	59	5.0	5.7	112.6	6	2.9
November	29.9	16.5	84	44	4.3	7.7	4.0	0	3.9
December	29.8	13.4	82	35	3.6	9.1	0.0	0	3.9
January-2021	30.9	15.9	82	41	3.8	7.7	10.2	1	3.9
February	31.7	15.3	64	25	4.6	9.1	0	0	5.3
March	36.5	19.9	53	20	4.9	9.3	0	0	7.3
Total							865.5	51	

Table 2: Effect of different levels of iron and zinc application on test weight, grain yield and straw yield of wheat

Treatments	Test weight (1000-grains weight) (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1: Recommended dose of fertilizers (RDF)	38.51	1,159	2,251
T_2: RDF + 10 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}	42.79	1,312	2,538
T_3: RDF + 10 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}	43.33	1,364	2,639
T_4: RDF + 10 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}	44.00	1,437	2,720
T_5: RDF + 20 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}	44.66	1,473	2,732
T_6: RDF + 20 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}	45.29	1,511	2,796
T_7: RDF + 20 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}	45.66	1,552	2,863
T_8: RDF + 30 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}	46.59	1,623	2,884
T_9: RDF + 30 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}	49.66	1,793	3,134
T_{10}: RDF + 30 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}	51.33	1,813	3,341
S.Em. ±	0.95	50.89	81.24
C.D. (*P*=0.05)	2.85	151.21	241.38

Table 3: Effect of different levels of iron and zinc application on iron and zinc content in wheat grain

Treatments	Iron content in grain (mg kg^{-1})	Zinc content in grain (mg kg^{-1})
T_1: Recommended dose of fertilizers (RDF)	95.16	44.53
T_2: RDF + 10 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}	95.67	44.60
T_3: RDF + 10 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}	98.00	45.33
T_4: RDF + 10 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}	110.00	45.67
T_5: RDF + 20 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}	110.57	45.93
T_6: RDF + 20 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}	111.00	47.20
T_7: RDF + 20 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}	111.47	49.10
T_8: RPDF + 30 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}	112.33	50.73
T_9: RDF + 30 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}	113.03	51.37
T_{10}: RDF + 30 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}	114.73	52.17
S.Em. ±	6.82	2.85
C.D. (*P*=0.05)	NS	NS

NS- Non- significant

Table 4: Effect of different levels of iron and zinc application on nitrogen content and protein content in wheat grain

Treatments	Protein content in grain (%)
T_1: Recommended dose of fertilizers (RDF)	11.79
T_2: RDF + 10 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}	12.00
T_3: RDF + 10 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}	12.10
T_4: RDF + 10 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}	12.25
T_5: RDF + 20 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}	12.50
T_6: RDF + 20 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}	12.67
T_7: RDF + 20 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}	12.79
T_8: RPDF + 30 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}	12.92
T_9: RDF + 30 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}	13.04
T_{10}: RDF + 30 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}	13.19
S.Em. ±	0.96
C.D. (*P*=0.05)	NS

NS- Non- significant

Table 5: Effect of different levels of iron and zinc iron and zinc application on uptake of cationic micronutrients by wheat crop

Treatments	Uptake cationic micronutrients (g ha^{-1})	
	Iron	Zinc
T_1: Recommended dose of fertilizers (RDF)	319.18	140.26
T_2: RDF + 10 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}	385.67	173.48
T_3: RDF + 10 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}	400.83	176.48
T_4: RDF + 10 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}	424.29	180.48
T_5: RDF + 20 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}	434.97	184.73
T_6: RDF + 20 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}	445.60	189.21
T_7: RDF + 20 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}	454.11	199.48
T_8: RPDF + 30 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}	465.97	202.39
T_9: RDF + 30 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}	542.49	249.77
T_{10}: RDF + 30 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}	572.94	257.91
S.Em. ±	15.10	8.11
C.D. (*P*=0.05)	44.87	24.09

Table 6: DTPA extractable micronutrient status of soil after harvest of crop as influenced by different levels of iron and zinc application

Treatments	DTPA extractable micronutrients (mg kg^{-1})	
	Iron	Zinc
T_1: Recommended dose of fertilizers (RDF)	2.41	0.39
T_2: RDF + 10 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}	2.83	0.44
T_3: RDF + 10 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}	2.89	0.44
T_4: RDF + 10 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}	3.24	0.47
T_5: RDF + 20 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}	3.55	0.50
T_6: RDF + 20 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}	3.77	0.51
T_7: RDF + 20 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}	3.95	0.54
T_8: RDF + 30 kg $FeSO_4$ ha^{-1} + 5 kg $ZnSO_4$ ha^{-1}	4.27	0.58
T_9: RDF + 30 kg $FeSO_4$ ha^{-1} + 10 kg $ZnSO_4$ ha^{-1}	4.62	0.64
T_{10}: RDF + 30 kg $FeSO_4$ ha^{-1} + 15 kg $ZnSO_4$ ha^{-1}	4.85	0.66
S.Em. ±	0.11	0.02
C.D. (*P*=0.05)	0.32	0.06

Conclusion

The results of field experiment revealed that, the application of different levels of iron and zinc in combinations resulted in significant increase in yield, iron and zinc uptake by wheat, residual iron and zinc content in soil and it also recorded higher protein content in grain over RDF alone. The significantly higher results were recorded in the treatment which received RDF + 30 kg $FeSO_4$ ha^{-1} +10 kg $ZnSO_4$ ha^{-1}. Finally it can be concluded that the application of fertilizers containing iron and zinc helps to increase crop yield and nutrient uptake by wheat and also improves iron and zinc status in soil after crop harvest.

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