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Agronomic bio-fortification of wheat (*Triticum aestivum L.*) through iron and zinc enriched organics

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Abstract

The short-term agricultural tools like agronomic bio-fortification of available nutrient resources as a complementary approach was initiated by applying iron and zinc as such as well as enriched with organics (FYM & Vermicompost) with two levels of recommended dose of nitrogen and phosphorus (RDNP). The RDNP with organics without iron and zinc (i.e. T_1) was treated as control. The soil under study was sandy loam having low organic carbon and medium in fertility with neutral soil reaction. A significant impact of iron & zinc enriched organics were found on soil properties as well as wheat quality and production. However, both the organic sources were found at par towards all the parameters under study. The application effect of Fe-Zn enriched organics with RDNP were increased both grain as well as biomass yield of the wheat by 2.3 to 6.6% as compared to direct and by 5.6 to 10.3% as compared to no application of the micronutrients. Similarly, an appreciable improvement in SOC (28%), available nitrogen (5%) and available phosphorus (22%) was observed which are equivalent or better than control. Although, the application effect of Fe-Zn enriched organics with RDNP didn't show any effect on nitrogen and phosphorus uptake by wheat. Therefore, these differences seem to be due to application of organics and RDNP. In contrary, the availability of Fe (5.9 to 18.4 %) & Zn (24.3 to 48.5 %) as well as their uptake (12.9 to 24.1 % for Fe and 13.4 to 28.8 % for Zn) by wheat were appreciably increased by application of Fe-Zn enriched organic as compared to direct and no application of these micronutrients. Further, it is interesting that availability (10 to 37%) as well as uptake (17 to 32%) of these micronutrients was considerably higher under 50% RDNP as compared to 100% RDNP possibly due to antagonistic effect of phosphorus. Hence, this approach would be able to conquer the micronutrient deficiency in the food and human.

Keywords: Agronomic bio-fortification, Wheat, Iron, Zinc, Organics

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Introduction

Zinc (Zn) and iron (Fe) deficiencies are well-documented public health issue affecting nearly half of the world population especially in developing countries like India. Zinc and Fe deficiencies are the common micronutrient deficiencies in light textured soils of North Gujarat limiting both crop production and nutritional quality. Further, very low concentrations and poor bioavailability of Zn and Fe in the commonly used cereals aggravated the micronutrient deficiencies. Breeding new cereal genotypes with high genetic capacity for grain accumulation of micronutrients is widely accepted and most sustainable solution to the problem. However, the breeding approach is a long-term process and may be affected from very low chemical solubility of Zn and Fe in soils due to high pH and low organic matter (Cakmak, 2008). Therefore, agronomy-related approaches offer short-term and complementary solutions to the Zn and Fe deficiency in crop production and human health. Soil amendments contributing to solubility of Zn and Fe in soil solution, cereal-legume intercropping systems, and soil and foliar application of micronutrient-containing fertilizers are well-documented agronomic tools which contribute to root uptake, shoot and grain accumulation of Fe and Zn. Addition of organic material had beneficial effect on crop growth, productivity by sustaining soil health. Mixing inorganic salts of micronutrients with different organic materials can enhance the efficacy of micronutrients. On decomposition of organic manures numerous compounds like humic acid and fulvic acid and biological substances like organic acid, amino acid and polyphenols are produced which act as chelating agents that form stable complexes with native micronutrients and also prevent added inorganic micronutrients from precipitation, fixation, oxidation and leaching resulted in improvement in efficiency of applied micronutrients. The enrichment of organics with micronutrients not only improve the quality of organics but also reduced the quantity of both inorganic chemicals and as well as quantity of organics. It is reported that addition of enriched organics in lower quantities had similar effects on soil properties to that of high quantity (without enrichment). The enriched organics are expected to provide beneficial effect on plant growth for longer time. The information on Fe and Zn enriched organics are lacking on Fe and Zn deficient soils of North Gujarat where wheat crop is mainly grown as cereal crop. Keeping this in view this experiment is planned with following objectives.

- To study the combative efficiency of organics for enrichment of Fe and Zn.
- To study the effect of Fe and Zn enriched organics on yield and yield attributes.
- To reduce the requirement of inorganic N, P, Fe and Zn fertilizers.
- To study the effect of Fe and Zn enriched organics on soil available nutrients at harvest.

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Materials and Methods

A field experiment was conducted on sandy loam soils during the winter (rabi) season of 2005-06 to 2007-08 at wheat research station, Vijapur (Gujarat). The soils had pH 8.03, EC 0.32 dS/m, organic carbon 0.315%, 178 kg/ha nitrogen, 42.51kg/ha phosphorus and 291kg/ha potash, DTPA extractable iron 5.6 & zinc 0.35 mg/kg. The ten treatment combinations namely T_1: RDNP* + FYM @ 5 t ha^{-1} (Control); T_2: RDNP + Fe @ 4 Kg ha^{-1} + Zn @ 2 Kg ha^{-1} ; T_3: FYM @ 2.5 t ha^{-1} + RDNP + Fe-Zn Enrichment** No. 1; T_4: FYM @ 2.5 t ha^{-1} + RDNP + Fe-Zn Enrichment No.2, T_5: FYM @ 2.5 t ha^{-1} + RDNP + Fe-Zn Enrichment No. 3 ; T_6: FYM @ 2.5 t ha^{-1} + RDNP + Fe-Zn Enrichment No. 4; T_7: FYM @ 2.5 t ha^{-1} + 50% RDNP + Fe-Zn Enrichment No. 1; T_8: FYM @ 2.5 t ha^{-1} + 50% RDNP + Fe-Zn Enrichment No. 2; T_9: FYM @ 2.5 t ha^{-1} + 50% RDNP + Fe-Zn Enrichment No. 3; T_{10}: FYM @ 2.5 t ha^{-1} + 50% RDNP + Fe-Zn Enrichment No. 4 were laid out in a randomized block design (RBD) with three replications. The enrichment no. 1 contains 500 kg/ha FYM with 1kg/ha $ZnSO_4.7H_2O$ + 2 kg/ha $FeSO_4.5H_2O$; enrichment no. 2 contains 500 kg/ha FYM with 2kg/ha $ZnSO_4.7H_2O$ + 4 kg/ha $FeSO_4.5H_2O$; enrichment no. 3 contain 500 kg/ha Vermicompost with 1kg/ha $ZnSO_4.7H_2O$ + 2 kg/ha $FeSO_4.5H_2O$ and enrichment no. 4 contain 500 kg/ha Vermicompost with 2 kg/ha $ZnSO_4.7H_2O$ + 4 kg/ha $FeSO_4.5H_2O$. The process of Fe-Zn enrichment with different organic sources was started about 45 days before their use. Required quantities of FYM/Vermicompost @ 500 Kg/ha was thoroughly mixed with the solution of $ZnSO_4.7H_2O$ (For @ 1.00 & 2.00 Kg Zn/ha) and $FeSO_4.5H_2O$ (For @ 2.00 & 4.00 Kg Fe/ha) as described in treatments. These mixtures were filled in the pre-dug polyethylene lined pits of appropriate size. The pits were covered with polyethylene sheets and allowed for decomposition. The mixture was turned weekly and moisture loss was maintained. The enrichment was completed within 5-6 weeks.

The treatments were applied as basal dressing during field preparation. Recommended dose of nitrogen i.e., 120 kg/ha (50% at the time of sowing and remaining 50% at first irrigation stage) and phosphorus i.e. 60 kg/ha (as basal dose at the time of sowing) through urea and DAP were applied. Bread wheat (*Triticum aestivum* L.) variety GW 322 was sown in rows at 22.5 cm apart using 120 kg/ha seed between 15^{th} to 25^{th} November every year. Representative soil samples were collected before sowing. However, the soil as well as plant samples were collected at harvest from each treatment plots. The soil samples were dried and sieved through 2 mm sieve before analysis. Similarly, the plant samples were ground and digested using di-acid mixture (HNO_3: $HClO_4$:: 9 : 4) except for analysis of nitrogen. The nitrogen was determined by nitrogen auto analyzer using di-acid (H_2SO4: $HClO_4$:: 9:1) for digestion followed by distillation and titration (Subbahia & Asejja, 1962). Different parameters like pH, EC, available nitrogen, available P_2O_5, available K_2O, in soil as well as plant samples were analyzed as described by Jackson (1973). Available micronutrients (i.e., iron & zinc) were determined by atomic absorption spectrophotometer using DTPA extractant as well as di-acid digestion for plant samples (Lindsay and Norvell, 1978).

Results and Discussion

Effect on wheat yield

The grain and biomass yield of the wheat were significantly (p=0.05) influenced among different treatments of FYM, RDNP & organic enriched Fe-Zn (Table 1). Although, the biomass yield of wheat was found non- significant during 2005-06. The treatment T_4 (i.e.100% RDNP along with 4 kg Fe + 2 Kg Zn/ha in 500 kg FYM/ha with pre-sowing application of 2.5 t FYM/ha) and T_6 (same to T_4 except 4KgFe+2KgZn in 500Kg Vermicompost) were gave highest grain & biomass yield of wheat, respectively.

Table 1 Response of wheat yield to Iron and Zinc enriched with different organic sources.

Treats.	Grain Yield (q/ha)				Biomass Yield (q/ha)			
	2005-06	2006-07	2007-08	Pooled	2005-06	2006-07	2007-08	Pooled
T_1	47.08	37.45	41.85	42.13	2005-06	2006-07	2007-08	95.11
T_2	49.71	35.85	41.72	42.43	102.36	77.90	105.07	97.22
T_3	49.55	36.01	48.44	44.67	110.51	79.71	101.45	104.17
T_4	51.25	35.85	51.49	46.20	104.17	88.77	119.57	102.96
T_5	42.70	38.08	50.29	43.69	103.26	82.43	123.19	105.74
T_6	39.96	37.86	52.36	43.39	105.98	90.58	120.65	106.58
T_7	42.64	34.89	42.08	39.87	106.88	57.86	125.00	98.31
T_8	45.56	31.34	45.40	40.77	111.41	76.65	106.88	99.03
T_9	44.18	34.95	43.03	40.72	110.51	70.65	115.94	99.09
T_{10}	40.36	31.50	46.45	39.44	108.70	78.80	109.78	98.01
CD(0.05)	5.72	4.36	7.30	3.58	103.26	73.37	117.39	6.53
SEm ±	1.92	1.85	2.46	1.26	NS	4.06	11.28	2.30
C.V.%	7.36	11.86	9.19	8.95	2.98	15.21	3.80	6.86
Y X T	-	-	-	S	4.83	10.92	5.74	S

The other treatment combinations of 100 % RDNP with and without Fe-Zn application were seems to be at par to treatment T_4 & T_6. However, the application of 50% RDNP with different levels of organic enriched Fe-Zn (i.e. T_7,T_8,T_9

& T_{10}) were found significant to treatment combinations of 100% RDNP both for grain as well as biomass yield of the wheat (Pooled results). Therefore, it is evident from the results that irrespective of the organic sources, application of organic enriched micronutrients were increased both grain as well as biomass yield of the wheat as compared to direct or no application of the micronutrients.

Under rainfed conditions, wheat plants derived from seeds containing 1.5 µg Zn per seed had better seedling establishment and twofold higher grain yields than the wheat plants that emerged from seeds containing only 0.4 µg Zn per seed (Yilmaz *et al.* 1998).

Effect on ancillary characters

All the ancillary characters except plant stand observed under this study like test weight, No. of tillers/m, plant height & grains per earhead (GPE) were significantly altered among different treatments during individual as well as in pooled analysis (Table 2).

Table 2 Response of ancillary characters of wheat to Iron and Zinc enriched with different organic sources (Pooled Results).

Treats.	Ancillary characters				
	Plant stand	Test wt.(g)	Tillers/m	Plant ht (cm)	Grain /Ear head
T_1	57.67	42.27	84.11	78.78	54.33
T_2	58.00	41.64	68.11	78.44	53.33
T_3	59.44	41.67	78.33	75.44	53.67
T_4	59.11	41.68	76.78	76.33	53.56
T_5	58.44	42.83	79.89	78.78	54.44
T_6	61.33	42.33	81.56	81.78	53.56
T_7	54.44	42.25	65.89	73.33	48.11
T_8	59.56	42.06	68.44	69.56	48.56
T_9	58.44	42.72	67.89	74.11	48.44
T_{10}	53.28	43.66	57.72	67.06	47.84
CD (5%)	**NS**	**0.62**	**6.90**	**3.46**	**2.76**
SEm ±	1.50	0.22	2.43	1.22	0.97
C.V.%	**7.78**	**1.54**	**10.01**	**4.85**	**5.66**
Y X T	NS	S	NS	NS	NS

A non- significant difference among different treatments was observed for number of tillers/m during 2006-07 only. However, the application effect of organic enriched Fe-Zn was observed mainly on plant height, GPE & number of tillers/m. These effects were mostly at par to 100% RDNP application and significant to application of 50% RDNP. Similar to results obtained in the field, Rengel and Graham (1995) showed in pot experiments that increasing seed-Zn contents from 0.25 µg per seed to 0.70 µg per seed significantly improved root and shoot growth of wheat plants under Zn deficiency, and concluded that high seed-Zn acts similarly to a starter-fertilizer effect. Recently, we found that during seed germination Zn concentration of newly developed radicle and coleoptile is extremely high (up to 200 mg kg–1), indicating critical physiological roles of Zn during early seedling development (Ozturk *et al.* 2006).

Effect on soil properties and nutrient uptake by wheat

The results presented in table 3 indicated that soil organic carbon (SOC) significantly influenced by application of different treatments in individual as well as in pooled analysis. Highest organic carbon was observed under T_1 treatment (100%RDNP + 5t FYM/ha) followed by T_3, T_4, T_5 & T_6 (i.e. organic enriched Fe-Zn with 2.5t FYM/ha) which were at par to each other. However, a significant decrease in SOC was observed under application of 50% RDNP plus organic enriched Fe-Zn with 2.5t FYM/ha with lowest SOC under no application of FYM (i.e. T_2). Similarly, significant effect of different treatments on available soil nitrogen was observed in pooled analysis. The treatment T_1, T_3, T_4, T_5 & T_6 was found at par to each other with highest available N under T_5. Which were statistically significant to rest of the treatments (i.e. T_2, T_7, T_8, T_9 & T_{10}) as under organic carbon. Further, the effect of different treatment on available soil phosphorus was found significant. The highest available P was observed under T_3 treatment. However, the treatments T_1, T_3, T_4, T_5, T_6 & T_7 were found at par to each other and significant to treatment no.T_2, T_7, T_8, T_9 & T_{10}.

The total nitrogen and phosphorus uptake (kg/ha) by the plants was higher under application of 100% RDNP which were statistically significant to 50% RDNP. The application effect of Fe-Zn enriched organics did not show any effect on nitrogen and phosphorus uptake. The difference among different treatments seems to be due to application of FYM.

Table 3 Effect of Iron and Zinc enriched with different organic sources on soil chemical properties under irrigated wheat (Pooled results)

Treatments	Soil Organic carbon (%)	Available N (kg/ha)	Available P_2O_5 (kg/ha)	N - uptake (kg/ha)	P_2O_5 uptake (kg/ha)
T_1	0.37	189.89	40.74	168.01	33.61
T_2	0.28	182.00	35.01	161.20	29.93
T_3	0.36	187.44	43.82	168.09	32.39
T_4	0.35	190.44	43.78	155.14	33.65
T_5	0.36	194.67	40.23	160.81	34.17
T_6	0.36	191.33	42.84	163.55	33.49
T_7	0.30	176.89	38.94	121.65	24.25
T_8	0.29	179.33	42.96	123.62	24.29
T_9	0.29	181.11	36.40	128.79	24.15
T_{10}	0.30	183.67	36.79	123.75	23.76
CD (5%)	0.03	6.91	2.83	7.26	2.05
SEm ±	0.01	2.43	1.00	2.56	0.72
C.V.%	8.20	3.93	7.46	5.20	7.37
Y X T	NS	NS	NS	NS	NS

Effect on availability of iron and zinc and their Uptake by wheat

The highest availability of both the micronutrients (i.e. Fe & Zn) was observed under treatments number T_8 during all the years as well as in pooled analysis followed by T_4, T_{10} & T_6 (Table 4 & 5). An appreciable increase in available Fe & Zn was observed under application of these micronutrients as compared to no application (i.e. 100% RDNP). However, these responses were higher under application of organic enriched micronutrients (i.e. T_3 to T_{10}) as compared to direct application of micronutrients (i.e. T_2).

The application effect of different micronutrients (i.e. Fe & Zn) enriched in organics was clearly evidenced on Fe & Zn uptake by plants which were statistically significant during individual as well as in pooled analysis (Table 4 & 5). The uptake of iron & zinc was higher under application of FYM enriched micronutrients as compared to Vermicompost enriched Fe & Zn. However, this difference was statistically at par to each other. The treatment number T_8 (i.e. 2.5t FYM + 50% RDNP + FYM enriched 4 Kg Fe + 2 Kg Zn/ha) was found best in terms of uptake of these micronutrients by the plants.

Table 4 Effect of Iron and Zinc enriched with different organic sources on availability of DTPA extractable Zn and its uptake by wheat plants

Treatments	Available Zn (mg/kg)				DTPA -Zn Uptake (g/ha)			
	2005-06	2006-07	2007-08	Pooled	2005-06	2006-07	2007-08	Pooled
T_1	0.58	0.69	0.69	0.66	145.60	117.20	188.33	130.38
T_2	0.70	0.74	0.77	0.74	155.02	128.70	147.00	143.24
T_3	0.82	0.88	0.85	0.85	172.62	141.83	157.71	157.38
T_4	0.99	1.05	1.03	1.02	175.56	151.49	174.00	167.02
T_5	0.83	0.88	0.77	0.86	172.30	140.70	163.66	158.89
T_6	0.94	0.95	0.97	0.96	179.74	150.62	168.93	166.43
T_7	0.87	0.88	0.93	0.89	178.06	143.08	164.92	162.02
T_8	1.02	1.06	1.05	1.04	179.00	159.67	179.40	176.02
T_9	0.91	0.96	0.95	0.94	177.04	141.99	167.94	162.32
T_{10}	0.99	1.04	1.03	1.02	183.64	154.73	174.33	171.57
CD (5%)	0.04	0.05	0.03	0.02	15.53	9.51	11.81	6.91
SEm ±	0.01	0.02	0.01	0.01	5.23	3.20	3.97	2.43
C.V.%	2.99	3.25	2.09	2.82	5.24	3.88	4.23	4.58
Y X T	-	-	-	NS	-	-	-	NS

Increasing number of evidence is available showing that soil and especially foliar application of Zn fertilizers results in impressive enhancements in grain Zn concentration. In contrast, soil and foliar application of Fe fertilizers is not effective in increasing grain Fe concentration. Little information is available in the literature about the effectiveness of various iron and zinc supplemented compound fertilizers/ organics and the type of their supplementation process (e.g., incorporation, coating or bulk-blending) on uptake and accumulation of these micronutrients in plants. Iron & zinc can be directly applied to soil as both organic and inorganic compounds. All type of these supplementation procedures (e.g., agronomic biofortification) were equally effective in increasing yield, but the fertilizers with Zn blending were more effective in increasing plant Zn concentration, most probably due to less reactions of the blended Zn with the NPK fertilizer and/or soil constituents (Mortvedt and Gilkes 1993). Increasing number of evidence is available showing that soil and especially foliar application of Zn fertilizers results in impressive enhancements in grain Zn concentration and increasing plant growth and yield (Martens and Westermann 1991; Mortvedt and Gilkes 1993; Rengel *et al.* 1999, Yilmaz *et al.* 1997, Ozturk *et al.* 2006)). In contrast, soil and foliar application of Fe fertilizers is not effective in increasing grain Fe concentration.

Table 5 Effect of Iron and Zinc enriched with different organic sources on availability of DTPA extractable Fe and its uptake by wheat plants

Treatments	Available Fe (mg/kg)				DTPA - Fe Uptake (g/ha)			
	2005-06	2006-07	2007-08	Pooled	2005-06	2006-07	2007-08	Pooled
T_1	3.94	4.09	4.03	4.02	1074.33	755.74	992.94	941.67
T_2	4.32	4.66	4.32	4.43	1090.53	798.49	1105.14	998.05
T_3	4.64	4.81	4.65	4.70	1178.00	854.25	1168.50	1066.91
T_4	4.74	4.93	4.77	4.82	1336.42	963.15	1267.12	1188.90
T_5	4.43	4.62	4.41	4.49	1227.67	864.64	1146.81	1079.71
T_6	4.79	4.89	4.71	4.76	1308.80	930.20	1274.15	1171.05
T_7	4.48	4.79	4.56	4.61	1265.12	891.19	1203.11	1119.81
T_8	4.89	5.05	4.89	4.67	1365.00	970.71	1324.22	1219.98
T_9	4.59	4.80	4.61	4.80	1288.33	924.94	1212.00	1141.74
T_{10}	4.75	4.90	4.75	0.70	1344.67	963.30	1266.03	1191.33
CD (5%)	0.30	0.38	0.26	0.03	50.72	47.03	65.92	30.41
SEm ±	0.10	0.13	0.09	3.96	27.07	15.83	22.18	10.72
C.V.%	3.78	4.60	3.34	NS	2.37	3.07	3.21	2.89
Y X T				NS				NS

Economics

The results presented in table 6 on economics of different treatments indicated that an application of 2.5t ha^{-1} FYM + 100% RDNP + 4 kg Fe & 2 Kg Zn enriched with 500 kg FYM/ha (Treatment T_4) recorded highest net realization (Rs. 30,426.00 per hectare with BCR 1.78) which was followed by application of 100% RDNP + 4.00kg Fe & 2.00Kg Zn/ ha (i.e. treatment T_2) earned net realization of Rs. 29,458.00 with BCR value of 1.88.

Table 6 Economics of Iron and Zinc enriched with different organic sources supplied to irrigated wheat

Treat.	Seed yield (q/ha)	Straw yield (q/ha)	Gross- realization (Rs./ha)	Cost of cultivation	Net realization	BCR
T1	42.13	52.98	14779	19656	25037	1.46
T2	42.43	54.79	45169	15669	29458	1.88
T3	44.67	59.50	47645	18291	29268	1.74
T4	46.20	56.76	49038	18562	30426	1.78
T5	43.69	62.05	46793	19391	27315	1.41
T6	43.39	63.19	46550	19662	26838	1.36
T7	39.87	58.44	42792	17140	25567	1.49
T8	40.77	58.26	43683	17417	26223	1.51
T9	40.72	58.37	43639	18240	25314	1.39
T10	39.44	58.57	42369	18517	23809	1.29

Conclusion

Agronomic practice mentioned (i.e. combination of inorganic and organic source of nutrients) is simple and easy in application with high correction of micronutrient deficiencies. The results available indicate high potential of this agronomic approach for improving grain Zn and Fe concentrations. The farmers of north Gujarat growing irrigated wheat (cv. GW 322) on light soils deficient in available iron and zinc are advised to apply Fe @ 4kg and Zn @ 2kg in the form of enriched FYM (500 kg) along with recommended dose of fertilizer (120-60-40kg NPK /ha) and 2.5t FYM/ha to get higher yield and economic return. The enrichment could be done before 45 days of sowing by composting of 4.0kg Fe/ha as FeSO4 (19% Fe) and 2.0kg Zn/ha as ZnSO4 (21% Zn) in 500kg FYM/ha.

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