International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
www.chemijournal.com
IJCS 2020; 8(3): 266-270

Received: 22-03-2020
Accepted: 24-04-2020

Shalini
Department of Agronomy, Dolphin (PG) College of Science and Agriculture, Chunni Kalan, Fatehgarh Sahib Punjab, India

Atik Ahamad
Subject Matter Specialist (Soil Science), KVK, Bharari, Jhansi, Banda University of Agriculture & Technology, Banda, Uttar Pradesh, India

Agyapal Singh
Department of Agronomy, Dolphin (PG) College of Science and Agriculture, Chunni Kalan, Fatehgarh Sahib Punjab, India

Adyant Kumar
Assistant Professor, Ramakrishna Mission Vivekananda Educational and Research Institute, Morabadi, Ranchi, Jharkhand, India

Corresponding Author:
Shalini
Department of Agronomy, Dolphin (PG) College of Science and Agriculture, Chunni Kalan, Fatehgarh Sahib Punjab, India

Effect of zinc fortification on growth, yield and economics of wheat (*Triticum aestivum* L.) under irrigated condition of Punjab

Shalini, Atik Ahamad, Agyapal Singh and Adyant Kumar

DOI: https://doi.org/10.22271/chemi.2020.v8.i3d.9239

Abstract
A field experiment was carried out during the *Rabi* season of 2016-17 at Research Farm of Dolphin (PG) College of Science and Agriculture, Chunni Kalan, Fatehgarh Sahib Punjab. The experiment was designed in randomized block design with three replications and eight treatments. The results revealed that maximum plant height 23.20, 55.74, 91.07 and 96.07 cm and dry matter accumulation 57.88, 575.81, 1138.65 and 1396.40 g m^{-2} at 30,60,90 DAS and at harvest respectively, were recorded treatment T_8 (T_4 + 0.2% foliar spray with zinc sulphate at heading stage) which was significantly higher over all the treatments and at par with T_6, T_9 and T_4 treatments. The number of spikes per plant (6.60), number of grains per spike (41.00), grain yield (5.30 t ha^{-1}) and straw yield (6.43 t ha^{-1}) were recorded significantly highest under the treatment T_8 (T_4 + 0.2% foliar spray with zinc sulphate at heading stage) as comparison to other treatments and was statistically at par with T_6, T_9 and T_7 while the treatment T_1 recorded significantly lowest grain and straw yield. The application of T_8 (T_4 + 0.2% foliar spray with zinc sulphate at heading stage) was recorded highest organic carbon (0.67 %) available Nitrogen (414.19 kg ha^{-1}), Phosphorus (20.80 kg ha^{-1}), Potassium (227.67 kg ha^{-1}) and zinc (0.671 ppm) in soil and statistically at par with the treatments T_6 (T_2 + 0.2% foliar spray with zinc sulphate at heading stage) and T_9 (T_5 + 0.2% foliar spray with Zinc Sulphate at heading stage).

Keywords: Growth, yield, nutrients availability, economics, zinc fortification

Introduction
Zinc deficiency affects more than one-third of the human population in the world, Stein (2010) [25]. Its deficiency in soils of India is widespread (Cakmak, 2008) [3] and crops grown in these soils suffer from poor or no yield. A close relationship exists among soils, crops and human health nutrition (Welch, 2008) [28]. According to the World Health Organization, about 8 lakh people die annually due to zinc malnutrition, among which more than 50% are children below five years of age. Cereal grains are inherently low both in concentration and bioavailability of Zn, particularly when grown on potentially Zn-deficient soils (Welch and Graham, 2004) [29]. Zinc deficiency has been associated with poor growth, depressed immune function, increased susceptibility to and severity of infection, adverse outcomes of pregnancy, and neurobehavioral abnormalities. There is a close geographical overlap between global distribution of zinc deficiency in soil and humans which highlights the core linkage among agriculture, food crops and human health (Alloway, 2008; Welch, 2008) [1, 28]

Wheat is one of the most grown and consumed worldwide crop and plays a crucial role in food security. It is growing under 220 Mha of area with 729 MT of production throughout the world. India, ranks first in area (30.5 Mha.) and second in production (95.9 MT), which is 24.5 Mha 157 MT respectively, in case of China (FAOSTAT, 2016) [8]. Wheat is responsible up to 70 per cent of daily calorie intake of the population living in rural regions and an important source for zinc for human beings living in the developing world (Cakmak, 2008) [3].

Fortification is the practice of deliberately increasing the content of an essential micro-nutrient, *i.e.* vitamins and minerals (including trace elements) in a food, so as to improve the nutritional quality of the food supply and provide a public health with minimal risk to health. There are basically two ways to increase zinc concentration in food grains, namely genetically breeding crop cultivars that absorb and transmit more zinc to grains biofortification or fertilizing crops with zinc ferti-fortification. Zinc biofortification is the process by which the nutritional quality of food crops is improved through agronomic practices, conventional plant breeding or modern biotechnology. Ferti-fortification is a solution to increase zinc concentration in wheat grains. It involves the application of fertilizers to grain, soil and foliage for maximum yield to increase the uptake of nutrients into the plants and its translocation into grains. So as to increase the zinc concentration in wheat is the best way on agronomic level is ferti-fortification. Application of zinc fertilizer in soil having low zinc increased the grain yield in wheat up to 6.4-50%. Now-a-days, the requirement is high wheat yield together with high zinc content in wheat grain.

Material and methods

A fixed plot field experiment was carried out at the Agronomy Research Farm of Dolphin (PG) College of Science and Agriculture, Chunni Kalan, District Fatehgarh Sahib, Punjab, affiliated to Punjabi University, Patiala during *Rabi* season of 2016–17. This region comes under sub-tropical, sub-humid climate with moderate rainfall. The maximum rainfall (36.60 mm) was found in the month of February, 2017, while in case of relative humidity, it was ranged from 82.00 to 51.00%. The average annual temperature and precipitation is about 24.03 ºC and 692 mm, respectively. The mean temperature in the month of June attains the higher value of 33.6 ºC and lowest average temperature of 13.3 ºC is recorded in the month of January. The maximum temperature 36 °C and minimum temperature 7.10 °C recorded during the period of experimentation.

The soil of the experimental site falls under alluvial soil which is alkaline in nature and clay loam in texture. Being alluvial in origin, the soil is well drained and moderately fertile with good facility of irrigation through tube-wells. Initially, soil sample (0-15 cm depth) was taken from different places of the experimental site and was mixed further to form a composite sample to determine physico-chemical properties. The experimental soil are with soil pH (8.07), EC (0.66 dSm^{-1}), organic carbon (0.48 %), available nitrogen (388.86 kg ha^{-1}), phosphorus (20.90 kg ha^{-1}), potassium (219.32 kg ha^{-1}), and Zn (0.43 ppm). It was laid out in a Randomized Block Design with three replications and eight zinc treatments were applied along with control (Table-1) with a gross plot size of 5m x 3 m and net plot size of 4 m x 2.2 m. The application of recommended dose of fertilizers (120:60:40 N:P_2O_5:K_2O kg ha^{-1}), half dose of nitrogen and full dose of phosphorus and potassium were applied in the form of urea (130.5 kg ha^{-1}), SSP (375 kg ha^{-1}) and MOP (67 kg ha^{-1}), respectively. Remaining dose of nitrogen in the form of urea (130.5 kg ha^{-1}) was applied in 3 equal split doses after 30, 55 and 85 day after sowing. Application of zinc fertilizer, total eight zinc treatments were applied along with control during experimentation. The zinc fertilizers applied as both soil as well as foliar were $ZnSO_4.7H_2O$ (Zinc sulphate heptadate) and ZnO (Zinc oxide). Post-harvest soil samples analyzed for available N by alkaline permanganate method (Subbiah and Asija, 1956), available phosphorus (P) by 0.5 M $NaHCO_3$. Extractable Olsen's Colorimetric method (Olsen's, 1954) [20], available potassium (K) by neutral normal ammonium acetate method (Jackson, 1973), and zinc analysis was carried out by AAS. The data was analyzed by the method of analysis of variance as described by Cochran and Cox (1957) [6]. The level of significance used in "F" test was given at 5%.

Table 1: Treatment details

T_1	:	Control Plot (0% Zn + Recommended dose of NPK ha^{-1})
T_2	:	5 kg Zn through Zinc Sulphate ($ZnSO_4.7H_2O$) + Recommended dose of NPK ha^{-1}
T_3	:	5 kg Zn through Zinc Oxide (ZnO) + Recommended dose of NPK ha^{-1}
T_4	:	2% Zn enriched urea (Recommended N) through Zinc Sulphate + Recommended dose of PK ha^{-1}
T_5	:	2% Zn enriched urea (Recommended N) through Zinc Oxide + Recommended dose of PK ha^{-1}
T_6	:	T_2 + 0.2% foliar spray with Zinc Sulphate at heading stage (75 DAS)
T_7	:	T_3 + 0.2% foliar spray with Zinc Sulphate at heading stage (75 DAS)
T_8	:	T_4 + 0.2% foliar spray with Zinc Sulphate at heading stage (75 DAS)
T_9	:	T_5 + 0.2% foliar spray with Zinc Sulphate at heading stage (75 DAS)

Results and discussion

Plant height (cm)

Highest plant height (23.20 cm) at 30 DAS, was recorded with treatment T_8 in comparison to other zinc fortified treatments (Table-2) while, the statistically lowest plant height of (17.90 cm) was recorded under the treatment T_1 (RDF alone), where zinc was not applied. The plant height (55.74 cm) at 60 DAS was recorded significantly higher in T_8 (2% Zn enriched urea (Recommended N) through Zinc Sulphate + Recommended dose of PK ha^{-1} + 0.2% foliar spray with zinc sulphate at heading stage) which was at par with T_6 treatment. At 90 days of crop growth and at maturity, the significantly highest plant height (91.07 cm and 96.07 cm) were observed with the treatment T_8 (T_4 + 0.2% foliar spray with zinc sulphate at heading stage) which was statistically at par with T_2, T_4, T_6, T_7 and T_9. The increase in plant height was due to more availability and absorption of Zn from soil solution which results in fastens the auxin metabolism, synthesis of cytochrome and stabilization of ribosomal fractions, faster the cell division and cell elongation (Maurya *et al.* 2012) and there was also increase in the rate of photosynthesis and chlorophyll formation due to the Zn, which led to the increase in internode length (Mehandi *et al.* 2012) [16].

Dry matter accumulation (g m^{-2})

Dry matter accumulation increased with the advancement of the crop age and the conspicuous increase was observed between 60 and 90 DAS (Table-2). Different zinc fortification treatments significantly influenced the dry matter accumulation of wheat crop at different periodic intervals. At 30 DAS, highest dry matter accumulation (57.88 gm^{-2}) was recorded with T_8 (T_4 + 0.2% foliar spray with zinc sulphate at heading stage) which showed superiority among all other zinc fortified treatments. At 60, 90 day after sowing and at harvest of wheat, the highest dry matter accumulation 575.81, 1138.65 and 1396.40 gm^{-2} respectively, were recorded in T_8 (T_4 + 0.2% foliar spray with zinc sulphate at heading stage) and lowest in control. This is because Zn accumulates dry matter at faster rate per unit leaf area per unit time which results in reducing the death of tillers and senescence of leaves at different days after sowing of the wheat crop (Ram *et al.* 2012).

Number of spikes per plant

The members of spikes per plant as affected by different treatments have been summarized (Table-3). The outcome of different soil and soil + foliar applied treatments was found significant. The number of spike per plant was recorded significantly maximum (6.60) under the treatment T_8 (T_4 + 0.2% foliar spray with zinc sulphate at heading stage) in comparison to other zinc fortified treatments and statistically at par with the treatments T_2 (5.87), T_6 (6.23), T_9 (6.00) and T_7 (5.96). The number of spikes was greatly affected by zinc foliar application because of the higher number of fertile tillers per plant at vegetative stage, and zinc application also reduces the weakness of the stems which further led to formation of more fertile spikes (Zoz *et al.* 2012 and Davidson *et al.* 1990) [31, 7].

Number of grains per spike

The members of grain per spikes as affected by different treatments have been summarized (Table-3). The outcome of different soil and soil + foliar applied treatments was found significant. Members of grain per spikes was recorded significantly maximum (46.23) under the treatment T_8 (T_4 + 0.2% foliar spray with zinc sulphate at heading stage) in comparison to other zinc fortified treatments and statistically at par with the treatments T_7 (45.20) and T_9 (46.07). This was due to the application of Zn + K through soil as well as foliar which results in the reduction of adverse effects of salinity stress at both vegetative and reproductive stages of wheat (Zafar *et al*., 2016) [30].

Test weight (g)

The treatment T_8 recorded the maximum value of test weight (39.01 g) in comparison to other zinc fortified treatments (Table-3). Lowest test weight was found in control (36.45 g). The N and Zn fertilization is directly responsible for higher test weight because N increased the crude protein content in grains (Naik and das, 2008) [18].

Grain and straw yield (t ha^{-1})

Maximum grain yield (5.30 t ha^{-1}) and straw yield (6.43 t ha^{-1}) of wheat were recorded with T_8 (T4 + 0.2% foliar spray with zinc sulphate at heading stage) which was significantly superior over all treatments accept control plot (Table-3). The application of (T_8) 2% Zn enriched urea (Recommended N) through Zinc Sulphate + Recommended dose of PK ha^{-1} + 0.2% foliar spray with Zinc Sulphate at heading stage, the grain yield of wheat was increased 28.26%, 17.36%, 21.89%, 15.28%, 19.81%, 7.35%,12.26%, and 10.57% over T_1 (Control Plot (0% Zn + Recommended dose of NPK ha^{-1}, T_2 5 kg Zn through Zinc Sulphate ($ZnSO_4.7H_2O$) + Recommended dose of NPK ha^{-1}), T_3 (5 kg Zn through Zinc Oxide (ZnO) + Recommended dose of NPK ha^{-1}), T_4 (2% Zn enriched urea (Recommended N) through Zinc Sulphate + Recommended dose of PK ha^{-1}), T_5 (2% Zn enriched urea (Recommended N) through Zinc Oxide + Recommended dose of PK ha^{-1}), T_6 (T_2 + 0.2% foliar spray with Zinc Sulphate at heading stage 75 DAS), T_7 (T_3 + 0.2% foliar spray with Zinc Sulphate at heading stage 75 DAS), and T_9 (T_5 + 0.2% foliar spray with Zinc Sulphate at heading stage 75 DAS) respectively. The soil applied zinc oxide treatments recorded statistically lowest grain yield in comparison to soil applied zinc sulphate treatments. Foliar application of nutrients is an important crop management strategy to maximize crop yields and concentrations of micronutrients in edible parts. Several studies have demonstrated that foliar application of micronutrients, including Zn and Fe, showed good behaviour in increasing their concentration in wheat grain Chattha, *et al*. 2017. Mixed Zn-fertilization methods, i.e. soil + foliar application, were found superior to single fertilization approach. Imran and Rehim (2016) [9] also reported that combined application of Zn (soil + foliar) is more promising in improving plant growth and yield than the other fertilization approaches.

Availability of nutrients in soil

The organic carbon, availability of available nitrogen, phosphorus and potassium in soil after harvesting as affected by different treatments have been summarized in Table-4. The application of T_8 (T_4 + 0.2% foliar spray with zinc sulphate at heading stage) was recorded highest available nitrogen (414.19 kg ha^{-1}), Phosphorus (20.80 kg ha^{-1}) and potassium (227.67 kg ha^{-1}) in soil and statistically at par with the treatments T_6 (T_2 + 0.2% foliar spray with Zinc Sulphate at heading stage) and T_9 (T_5 + 0.2% foliar spray with Zinc Sulphate at heading stage). This might have happened due to the higher growth and development of wheat plants with Zn application resulting into higher root biomass production, which recycled these nutrients into the soil. Pooniya *et al.* (2012) [21] also reported the similar findings. Mathews *et al.* (2006) [14] also reported that residual N, P, K and Zn in soil were found to be highest with Zn fertilization compared with no Zn application.

Availability of Zn in soil

The increase in available zinc (ppm) was observed in all the zinc fortified treatments either through soil or soil and foliar spray when compared with control (Table-4). All the zinc fortified treatments varied significantly for available zinc in comparison to sole application of 100% RDF. The treatment T_8 recorded the highest quantity of available zinc (0.671 ppm) which was statistically at par with the zinc fortified treatments through zinc sulphate *viz*., T_4 (0.668 ppm), T_6 (0.660 ppm) and T_2 (0.658 ppm). While among the zinc fortified treatments, the soil application of zinc through zinc oxide treatments showed the inferior results in comparison to soil applied zinc sulphate treatments. The treatment T_8 recorded 55.50% increase in available zinc over the application of 100% RDF only and was closely followed by T_6 (54.81%), T_4 (52.96%) and T_2 (52.49%). This increment in available zinc in the zinc fortified treatments might be due to that the soil applied zinc through zinc fertilizers (either zinc sulphate or zinc oxide) makes the bio-availability of zinc in the soil potentially through the soluble, exchangeable and organically-bound zinc pools. The gradual solubility of zinc fertilizers increases the chance of zinc being received by plant roots while decreases the chance of bounding to other insoluble complexes. Cakmak *et al*., 2010a [4]; Narteh and Sahrawat, 1999 [19] were also expressed the similar views. Among the different zinc fertilizers applied, the availability of soil zinc was found more in case of the zinc sulphate applied treatments in comparison to zinc oxide applied treatments. This might be due to the reason that the solubility of zinc sulphate was found more in case of alkaline soil for longer period of time in comparison to zinc oxide. These findings were similar to the findings of Brennan and Bolland, 2006 [2].

Economics

The treatment T_8 observed significantly maximum value of net return (Rs.84711 ha^{-1}) and B:C ratio (3.75) which was closely followed by treatment T_6 (Rs. 76042), T_9 (Rs. 73383).

However, lowest net returns (Rs. 53796 ha^{-1}) and B: C ratio (2.43) was obtained in control (Table-5). This may be due to the proper growth and development of the crop as well as highest grain and straw yield obtained and proportionally higher gross return than that of the cost of cultivation. Similar results were also reported by Khattak *et al*., 2015 and Singh *et al.*, 2015. Another possible reason that can be ascertained to these findings is that this could have happened due to the fact that all treatments associated with zinc fortification were more remunerative than control with regard to net monetary returns. Similar findings were also observed by Shivay *et al.* (2008) [23], Jat *et al*. (2011) [11] and Naik and Das (2008) [18].

Conclusion

It may be concluded that the treatment 2% Zn enriched urea (recommended N) through zinc sulphate + recommended dose of PK followed by 0.2% foliar spray with zinc sulphate at heading stage (75 DAS) was found to be the best treatment in terms of growth and yield parameters of wheat. The application of zinc sulphate has increased the availability of zinc as well as other nutrients especially nitrogen in the alkaline soil; which enhanced the growth and development of the crop, made the crop more vigorous, improved the grain filling and thus, increased the yield of wheat as well as maintained the economics by increasing the net return and B:C ratio to the maximum.

Table 2: Effect of different zinc fortification treatments on Plant Height and Dry Matter Accumulation at various growth stages

Treatments	Plant height (cm)				Dry Matter Accumulation (g m^{-2})			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
T_1	17.90	47.69	79.68	87.27	34.55	393.13	617.58	824.44
T_2	20.55	51.24	88.90	92.36	38.12	422.55	715.58	925.25
T_3	19.03	50.12	83.50	89.27	36.74	414.45	679.44	888.38
T_4	20.57	51.90	89.49	92.36	38.98	429.16	720.36	934.51
T_5	19.10	50.90	86.24	91.86	37.58	416.54	698.25	907.79
T_6	21.37	53.69	90.93	94.87	49.25	512.54	958.32	1198.17
T_7	20.68	52.45	90.53	92.98	44.25	451.81	792.24	1014.62
T_8	23.20	55.74	91.07	96.07	57.88	575.81	1138.65	1396.40
T_9	21.33	53.10	90.53	93.98	45.63	473.11	850.55	1078.56
SEm (±)	0.30	0.74	1.25	1.31	0.65	6.75	12.28	15.48
CD (*p=0.05*)	0.89	2.22	3.74	3.93	1.94	20.23	36.81	46.42

Table 3: Effect of different zinc fortification treatments on yield and yield attributing characters of wheat crop

Treatments	Number of spike per plant	Number of grains per spike	Test weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
T_1	5.40	39.13	36.45	3.77	4.47
T_2	5.87	42.55	37.90	4.38	5.26
T_3	5.82	39.53	36.87	4.14	4.91
T_4	5.91	42.74	38.12	4.49	5.41
T_5	5.83	41.98	37.45	4.25	5.15
T_6	6.23	43.29	38.83	4.90	5.90
T_7	5.96	45.20	38.43	4.65	5.60
T_8	6.60	46.23	39.01	5.30	6.43
T_9	6.00	46.07	38.61	4.74	5.72
SEm(±)	0.09	0.62	0.54	0.07	0.08
CD (*p=0.05*)	0.25	1.85	NS	0.20	0.24

Table 4: Effect of different zinc fortification treatments on soil properties of the field after harvesting of wheat crop

Treatments	Soil OC (%)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Available Zn (ppm)
T_1	0.48	394.78	17.55	208.81	0.419
T_2	0.60	402.58	18.55	216.13	0.658
T_3	0.50	395.74	17.88	212.27	0.567
T_4	0.60	403.92	18.75	217.79	0.668
T_5	0.58	399.55	18.01	214.37	0.591
T_6	0.65	409.13	20.35	222.36	0.660
T_7	0.61	406.87	18.74	218.26	0.570
T_8	0.67	414.19	20.80	227.67	0.671
T_9	0.62	407.51	19.20	218.85	0.594
SEm(±)	0.01	2.55	0.41	2.39	0.009
CD (*p=0.05*)	0.03	7.65	1.23	7.15	0.026

Table 5: Effect of different zinc fortification treatments on relative economics of wheat crop

Treatments	Cost of cultivation (Rs. ha^{-1})	Gross Returns (Rs. ha^{-1})	Net Returns (Rs. ha^{-1})	B:C Ratio
T_1	22133	75929	53796	2.43
T_2	22966	88434	65467	2.85
T_3	22645	83379	60734	2.68
T_4	22533	90695	68161	3.02
T_5	22379	86065	63686	2.85
T_6	23001	99043	76042	3.31
T_7	22680	93974	71293	3.14
T_8	22568	107280	84711	3.75
T_9	22414	95798	73383	3.27

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