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Foliar zinc application affects yield associated traits, zinc response curve and zinc utilization efficiency in wheat

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Abstract
Excessive and imprecise application of a limited range of macronutrients in wheat has resulted in a stark deficit of micronutrients, particularly zinc, making zinc insufficiency a major constraint in wheat production worldwide. A field study was conducted at the N.E. Borlaug Crop Research Centre, GBPUA&T, Pantnagar, India during the wheat cropping season of 2019–20 with the objectives of evaluating the effects of different concentrations as well as spray frequencies of foliar-applied $ZnSO_4$ on yield attributes, zinc response curve and utilization efficiency in wheat. Wheat variety PBW343 was used in the study. Results indicate that foliar $ZnSO_4$ application significantly increased panicle number per meter square and biological yield; straw and grain yield; as well as test weight and harvest index. Three sprays of 0.75% $ZnSO_4$ was found to be most effective combination towards increasing all the yield associated parameters except biological yield and straw yield maximum values of which were observed with a single spray of 1% $ZnSO_4$. The maximum grain yield (5.25 t/ha), amounting to an increase of 19.4% over the control plants was observed with three sprays of 0.75% $ZnSO_4$.Foliar zinc application significantly affected total zinc uptake and highest total zinc uptake summing up to about 40% increment over control plants was recorded under three sprays of 1% $ZnSO_4$. Among the different zinc efficiency indices Partial Factor Productivity (PFP) and Agronomic efficiency (AE) were significantly affected by foliar $ZnSO_4$ application. When compared to 0.5% $ZnSO_4$ an increase of 20-32% and 55-65% in AE and Physiological Efficiency (PE) respectively was observed with 0.75% $ZnSO_4$ application.

Keywords: Foliar zinc, utilization zinc, response zinc

Introduction

Wheat is an important staple crop, especially in developing countries, where it provides more than 60% of daily calorific needs. With 13.53 percent of global wheat production, India is the world's second largest wheat producer (Dhanda *et al.*, 2022) [4]. Wheat cropping systems have been continuously intensified in terms of utilisation of macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) to meet rising demands. The small increments in yield achieved through crop intensification, however, have come at the expense of a greater decline in productivity and nutritive value. The growth and yield of a plant are determined by the availability of some specific mineral nutrients that are absolutely essential for the completion of their life cycle. Crop intensification necessitates the application of these essential nutrients to plants in the form of chemical fertilizers. However, when only one or a few mineral nutrients are used in excess, the other nutrients become limiting in nature, even when present in sufficient concentrations in the rhizosphere. Thus, overuse of macronutrients has resulted in a micronutrient deficiency problem in the majority of the world's cultivable soils leading to a stagnation in productivity (Jalal *et al.*, 2020) [12]. Among the various micronutrients essential for plant growth, zinc deficiency has emerged as a worldwide nutritional constraint for crop production. Wheat is an exhaustive cereal crop that leads to significant depletion of soil nutrients and zinc deficiency in wheat is further aggravated when narrow variety of fertilizers are used in greater quantities (Dhanda *et al.*, 2022) [4].

Zinc is an essential micronutrient for plant growth and it is absorbed by the plant roots as divalent zinc cation. It is involved in a variety of metabolic activities, including hydrogenase and carbonic anhydrase activity, cytochrome synthesis, ribosomal fraction stabilisation, and auxin metabolism pollen function and fertilization (Das *et al.*, 2020) [3] Plants with zinc deficiencies show poor growth, interveinal chlorosis, and necrosis of lower leaves. Reddish or brownish spots are common on older leaves, and seed production is drastically reduced as a result of its deficiency (El-Dahshouri, 2017) [5]. Despite the fact that zinc plays numerous roles in plant growth and development, only trace amounts of zinc are required to support normal plant growth and development. Even so, more than half of cultivable soils are zinc deficient. Rhizospheric factors such as high lime content, high pH, low moisture, low organic carbon content, and imbalanced fertiliser use reduce Zinc bioavailability in the rhizosphere making it a limiting factor in crop production (Nasharty *et al*., 2013) [7]. Foliar application of micronutrients is an effective strategy to overcome these edaphic factors that tend to reduce zinc bioavailability in soil. Several studies have demonstrated that foliar application of micronutrients increases yield in wheat on account of their quick absorption and reduced losses through leaching and fixation. Bameri *et al*., (2012) [1]; El-Habbasha *et al*. (2015) [6] and Esfandiari *et al*. **(**2016**)** [8] reported that foliar application of Zn had positive significant effect on wheat grain yield and its components, as well as quality of grains. Similar results were obtained by El-Dahshouri, **(**2017**)** [5], Ramzan *et al*. **(**2020**)** [15] and Zulfiqar *et al*. **(**2020**)** [18]. Foliar application of fertilizers requires lesser quantity of fertilizers and is more productive as compared to soil application of micronutrients. Moreover, Zn application is one of the important approaches for agronomic biofortification of valuable crops for human health (Cakmak, 2010) [2]. Gomaa *et al.* (2015) [9] reported increased grain yield with foliar application of micronutrient as compared to soil application. Nasiri *et al.* **(**2010**)** [13] reported that foliar Zn application at both stem elongation and flowering stages had more beneficial effects on these characters as compared with spray at only one stage. In view of the above, the present study was carried out to determine the effect of foliar zinc application (at various spray concentrations and frequencies) on the yield response and zinc utilization by the crop.

Materials and Methods

The field study was conducted at the N.E. Borlaug Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India during the wheat cropping season of 2019-20. Wheat variety PBW343 was sown in early November and harvested in early April. The metrological data for the duration of experiment is presented in Figure 1. The experiment was conducted in split plot design with five different levels of

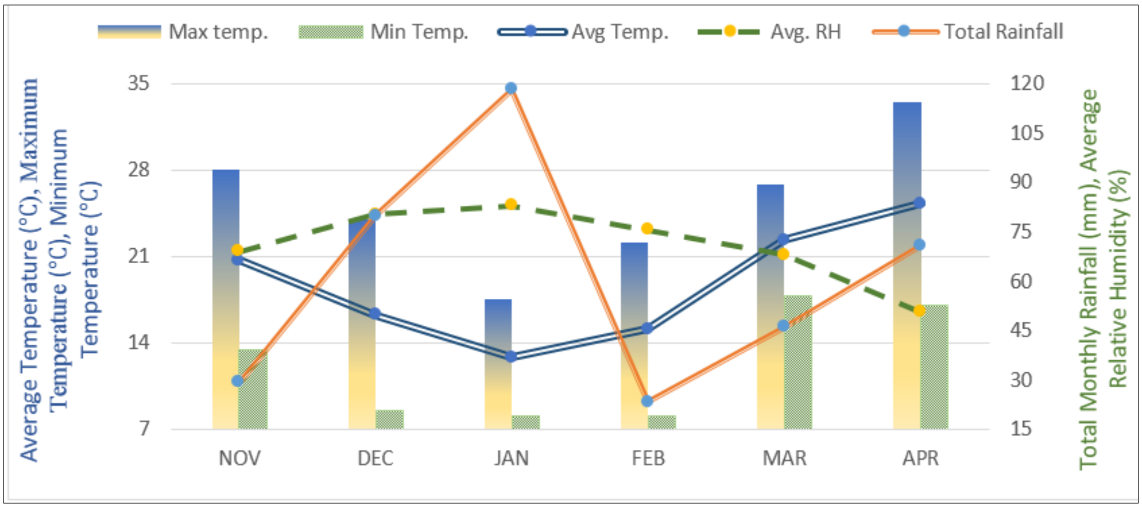

Fig 1: Metrological data for the duration of experiment (Source- Agro-meteorological observatory, N.E.B. Crop Research Centre, GBPUA&T, Pantnagar, Uttarakhand, India)

Zinc spray concentrations (0, 0.25, 0.50, 0.75 and 1.0% $ZnSO_4 . 7H_2O$) as main plot treatments and three levels of spray frequencies (S1: One spray at 30 days after emergence; S2: Two sprays, one each at 30 and 45 days after emergence (DAE); S3: Three sprays, one each at 30, 45 and 60 days after emergence) as subplot treatments. Each treatment was laid out into four replications with a plot size of 5m x 3m. Recommended package of practices for wheat cultivation were followed and a handheld sprayer was used for foliar application of zinc sulphate. Grain yield, biological yield and other yield related attributes were recorded at the time of harvesting. Different zinc utilization efficiencies were calculated as per the following formulae (Shivay and Prasad, 2012) [16]:

$$\text{PFP} = \text{Y}_{\text{Zn}}/\text{Zn}_{\text{a}}$$
$$\text{AE} = (\text{Y}_{\text{Zn}} - Y_C)/\text{Zn}_{\text{a}}$$
$$\text{ARE/RE} = [(\text{U}_{\text{Zn}} - U_C)/\text{Zn}_{\text{a}}] \times 100$$
$$\text{PE} = (\text{Y}_{\text{Zn}} - Y_C)/(\text{U}_{\text{Zn}} - \text{U}_{\text{C}})$$

Where Y_{Zn} and Y_C denote the grain yield (Kg ha^{-1}) of Zn treated and control (without foliar zinc application) plots respectively; U_{Zn} and U_C denote the total zinc uptake (Kg ha^{-1}) of Zn treated and control plots respectively; Zn_a denotes Zn applied (Kg ha^{-1}). PFP and AE denote Partial Factor Productivity and Agronomic Efficiency respectively, while ARE/RE denotes Apparent/Recovery Efficiency. PE refers to Physiological Efficiency. IBM SPSS statistical package (Version 25) was used for statistical analysis and correlations were analyzed using linear models. Means were separated using Tukey’s honestly significant difference (HSD) test at 5% significance level ($p \leq 0.05$).

Results and Discussion

Yield associated attributes and yield response curve

Foliar application of zinc sulphate significantly increased panicle number per meter square and biological yield (Table 1); straw and grain yield (Table 2); as well as test weight and harvest index. (Table 3). Both spray concentration and frequency significantly affected number of panicles per square meter. Number of panicles/m^2 increased significantly for all concentrations ranging between 4.6% to 19.6%, 11% to

21.6% and 12.2% to 21.4% with one, two and three sprays respectively as compared to control. A second spray of zinc sulphate increased the number of panicles per meter square by about four percent, while a third spray resulted in marginal reduction (about 1%) in the number of panicles observed per meter square. Among the zinc treated plants maximum increase in number of panicles (21.6%) was observed with two sprays of 0.75% zinc sulphate solution and minimum increase (4.6%) was observed with a single spray of 0.25% solution.

Biological, straw and grain yield were significantly affected by spray concentrations only while spray frequency had no significant effect. Biological and straw yield increased significantly across all spray concentrations in the range of 3.5 to18.2%, 6.4 to 19.1%, and 6.4 to 19.4% with one two and three sprays respectively. On application of a second spray of zinc sulphate, biological and straw yield increased in the range of 1.5 to 3.0%, while subsequent spray had no effect towards increasing straw and biological yield. A single spray of 1% zinc sulphate resulted in maximum biological yield (11.34 t/ha) and straw yield (6.19 t/ha) which represented an 18% increased over control plants. Minimum increment (4-5%) in biological and straw yield was observed with a single spray of 0.25% zinc sulphate solution.

With a single spray of $ZnSO_4$ at 30 DAE grain yield increased significantly with all concentrations ranging from 6.5% to 19.4% as compared to control. A significant increase was further observed in grain yield from 0.25% to 0.75% $ZnSO_4$ ranging between 9.5% to 19.1% and 9.8% to 19.4% for two and three sprays respectively as compared to control. Application of 1% $ZnSO_4$ was less effective in increasing grain yield as compared to 0.75% $ZnSO_4$ for all the spray frequencies. The maximum grain yield (5.25 t/ha), amounting to an increase of 19.4% over the control plants was observed with three sprays of 0.75% $ZnSO_4$ and minimum (4.67 t/ha) with a single spray of 0.25% $ZnSO_4$

Table 1: Effect of different concentrations of $ZnSO_4$. On the number of panicles per meter square and biological yield of wheat cultivar PBW343

Foliar Applications	Number of panicles per meter square				Biological Yield (t/ha)			
	S1*	S2	S3	Mean	S1*	S2	S3	Mean
Control	334	331	334	333[D**]	9.62	9.54	9.60	9.59[C]
0.25% $ZnSO_4.7H_2O$	349	368	375	364[C]	10.09	10.30	10.38	10.25[B]
0.50% $ZnSO_4.7H_2O$	376	383	381	380[B]	10.44	10.54	10.59	10.53[B]
0.75% $ZnSO_4.7H_2O$	396	403	406	401[A]	11.02	11.09	10.91	11.01[A]
1.0% $ZnSO_4.7H_2O$	399	401	398	400[A]	11.34	11.23	11.20	11.26[A]
Mean	371[b]	377[a]	379[a]		10.50[a]	10.54[a]	10.54[a]	

* S1: One spray at 30 days after emergence; S2: Two sprays, one each at 30 and 45 days after emergence; S3: Three sprays, one each at 30, 45 and 60 days after emergence

**Values having same letters do not show significant differences at 5% level by Tukey's honestly significant difference (HSD) test

Table 2: Effect of different concentrations of $ZnSO_4$. On straw and grain yield of wheat cultivar PBW343

Foliar Applications	Straw Yield (t/ha)				Grain Yield (t/ha)			
	S1*	S2	S3	Mean	S1*	S2	S3	Mean
Control	5.24	5.16	5.21	5.20[D]	4.38	4.38	4.40	4.39C
0.25% $ZnSO_4.7H_2O$	5.42	5.49	5.54	5.49[C]	4.67	4.80	4.83	4.77[B]
0.50% $ZnSO_4.7H_2O$	5.66	5.69	5.74	5.70B[C]	4.78	4.85	4.86	4.83[B]
0.75% $ZnSO_4.7H_2O$	5.85	5.87	5.66	5.79[B]	5.17	5.22	5.25	5.21[A]
1.0% $ZnSO_4.7H_2O$	6.19	6.04	6.02	6.08[A]	5.15	5.19	5.18	5.17[A]
Mean	5.67[a]	5.65[a]	5.63[a]		4.83[a]	4.89[a]	4.90[a]	

* S1: One spray at 30 days after emergence; S2: Two sprays, one each at 30 and 45 days after emergence; S3: Three sprays, one each at 30, 45 and 60 days after emergence

**Values having same letters do not show significant differences at 5% level by Tukey's honestly significant difference (HSD) test

Table 3: Effect of different concentrations of $ZnSO_4$. On test weight and Harvest Index of wheat cultivar PBW343

Foliar Applications	Test weight (g)				Harvest Index (%)			
	S1*	S2	S3	Mean	S1*	S2	S3	Mean
Control	39.3	40.1	40.1	39.9[C]	45.6	45.9	45.8	45.7[B]
0.25% $ZnSO_4.7H_2O$	40.2	40.8	41.2	40.7[B]	46.3	46.7	46.6	46.5[AB]
0.50% $ZnSO_4.7H_2O$	40.4	41.4	41.5	41.1[B]	45.8	46.0	45.9	45.9[B]
0.75% $ZnSO_4.7H_2O$	41.9	42.0	42.5	42.1[A]	46.9	47.1	48.2	47.4[A]
1.0% $ZnSO_4.7H_2O$	41.8	42.0	42.2	42.0[A]	45.4	46.2	46.2	45.9[B]
Mean	40.7[b]	41.3[ab]	41.5[a]		46.0[a]	46.4[a]	46.5[a]	

* S1: One spray at 30 days after emergence; S2: Two sprays, one each at 30 and 45 days after emergence; S3: Three sprays, one each at 30, 45 and 60 days after emergence

**Values having same letters do not show significant differences at 5% level by Tukey's honestly significant difference (HSD) test

Based upon the statistical analysis of the yield data and fitting of quadratic equations over the range of grain yield versus zinc application rates as suggested by Gomez and Gomez **(**1984) [10], it was observed that three sprays of 0.75% $ZnSO_4$ was the optimum level of foliar zinc application without limiting wheat yield (Figure-2). In general, with different spray concentrations of $ZnSO_4$ the test weight of wheat seeds increased in the range of 2-6% while the harvest index marginally increased by 1-2% except for three sprays of 0.75% $ZnSO_4$ where a 5.2% increase in harvest index was observed. Increase in spray frequency had a significant effect towards increasing test weight. Among the treated plants, maximum (an increase of 6% over control) test weight and harvest index was observed with three sprays of 0.75% $ZnSO_4$. Minimum test weight (39.3g) and harvest index (45.4%) were observed with one spray of 0.25% $ZnSO_4$ and 1.0% $ZnSO_4$ respectively. A high and significant level of correlation was observed between $ZnSO_4$ spray concentration and all the yield associated parameters except for harvest index where the correlation value was low and statistically insignificant (Figure 3). In continuation with the above, the number of sprays was not directly correlated with any of the yield associated parameters except for test weight of the seeds.

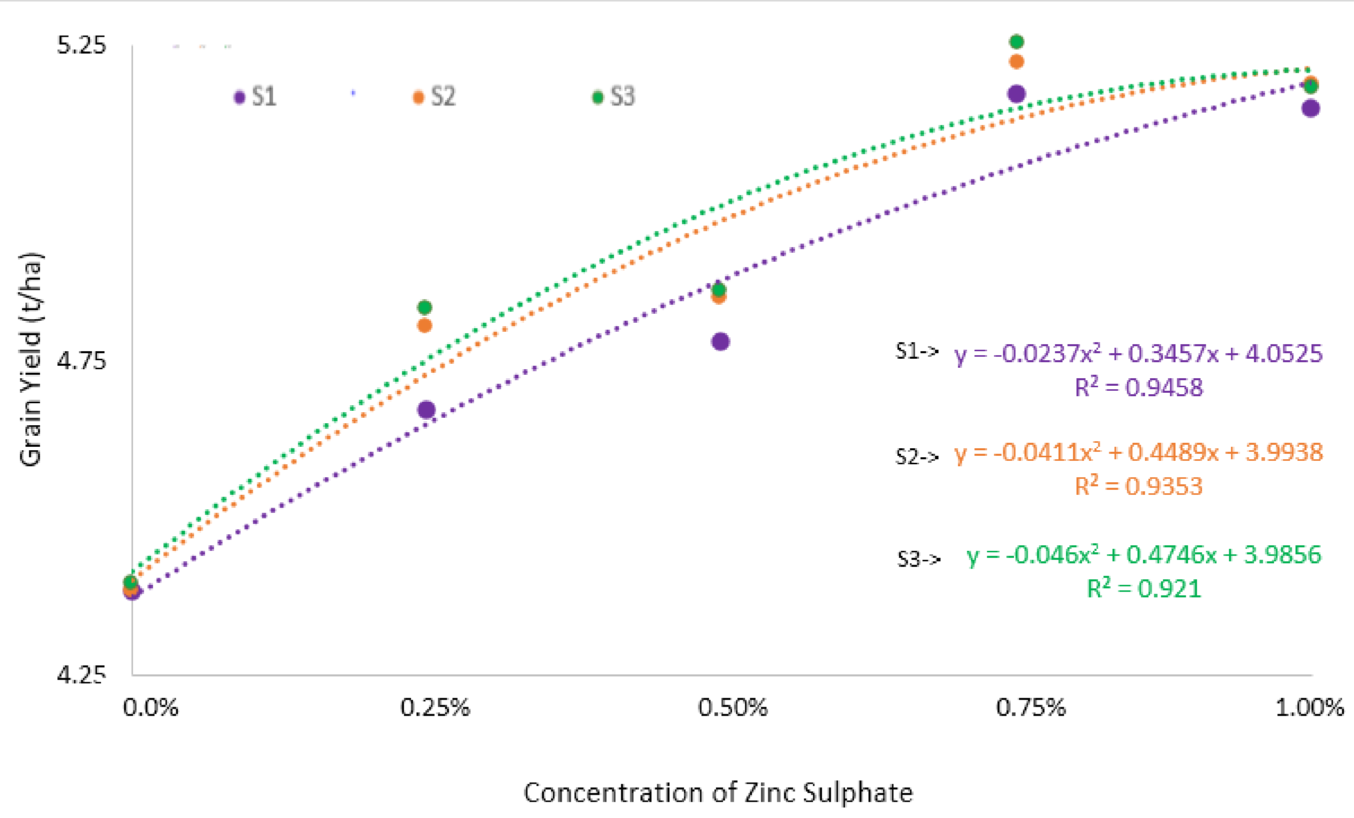

Fig 2: Zinc response curve of wheat cultivar PBW343 under various levels of $ZnSO_4$ application.

Total zinc uptake and various zinc utilization efficiencies

Zinc uptake was significantly affected by both $ZnSO_4$ spray concentration as well as frequency. Total zinc uptake increased in the range of 18-36%, 14-52% and 22-56% with one two and three sprays respectively as compared to control (Figure 4). Application of 1% $ZnSO_4$ spray concentration was found most effective in increasing total zinc uptake, under which zinc uptake increased by about 55% as compared to control while minimum increase in zinc uptake (14% over control) was observed with two sprays of 0.25% $ZnSO_4$. A third spray was relatively more enriching in terms of increasing total zinc uptake and increased zinc uptake by 5-6% when compared with two sprays. A significant correlation with high positive values of correlation coefficient (R^2 = 0.4985**) were observed for grain yield and total zinc uptake (Figure 5). Zinc use efficiency was quantified in terms of Partial Factor Productivity (PFP), Agronomic efficiency (AE, Apparent Recovery Efficiency (ARE/RE) and Physiological Efficiency (PE) (Fig. 6). As expected PFP and ARE decreased with increase in concentration from 0.25% to 1.0% $ZnSO_4$ while discontinuous trends were observed for AE and PE. Nevertheless, maximum values for PFP, AE, ARE and PE were observed with one spray of 0.25% $ZnSO_4$.AE decreased in the range of 30-45% with increase in $ZnSO_4$ concentration from 0.25-0.5%. However, plants with 0.75% $ZnSO_4$ recorded better AE (20-32%) as compared to plants treated with 0.5% $ZnSO_4$ for all the spray frequencies. A further increase in $ZnSO_4$ again decreased the AE. Similarly, plants sprayed with 0.75% $ZnSO_4$ resulted in better PE in the range of 55-65% as compared to plants treated with 0.5% $ZnSO_4$ and PE decreased with further increase in spray concentration.

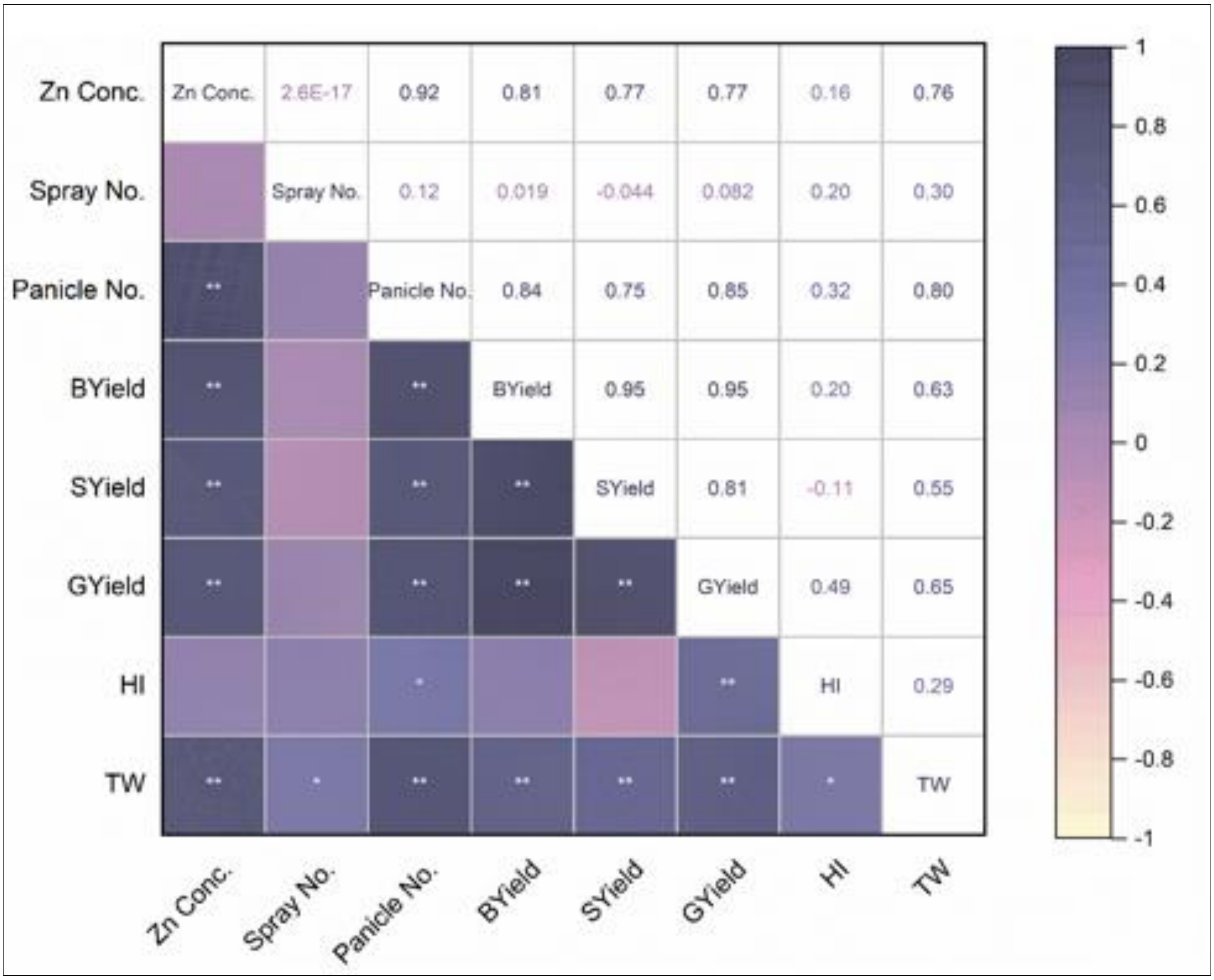

Fig 3: Relationship between different yields associated traits observed under various levels of $ZnSO_4$ application. * $p<=0.05$ ** $p<=0.01$

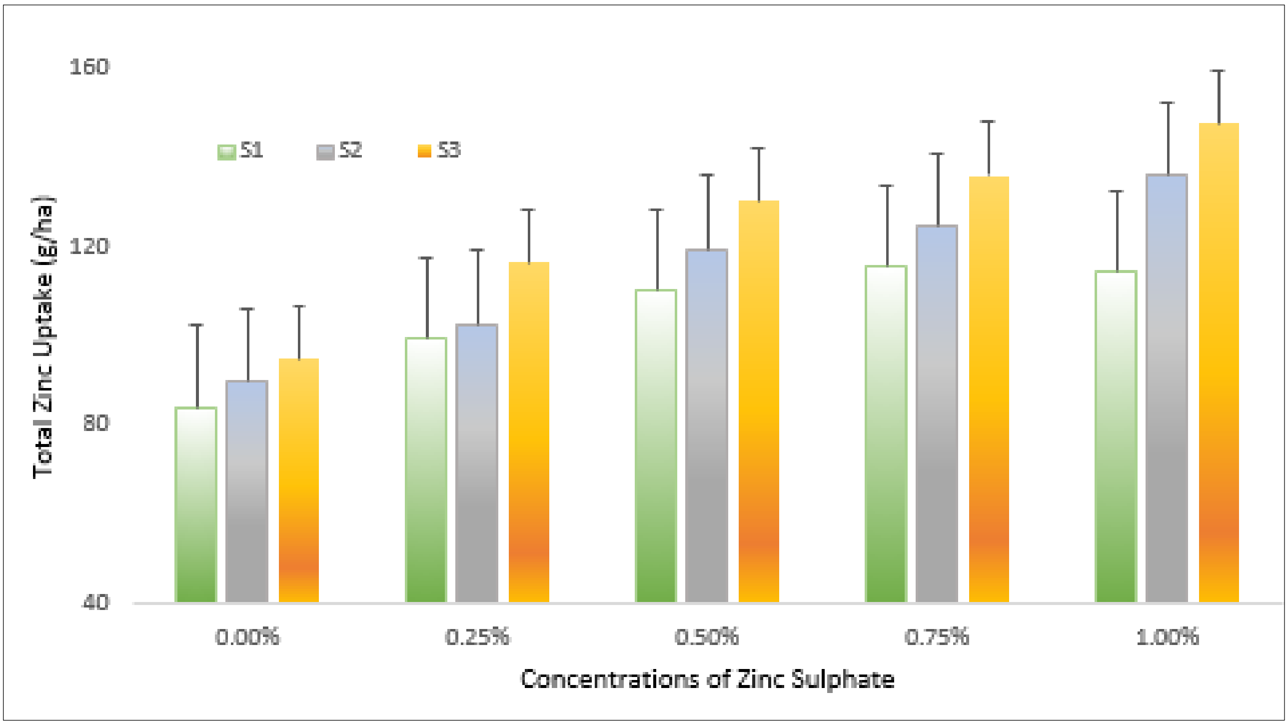

Fig 4: Effect of different conch. of $ZnSO_4$. On total zinc uptake of wheat cultivar PBW343

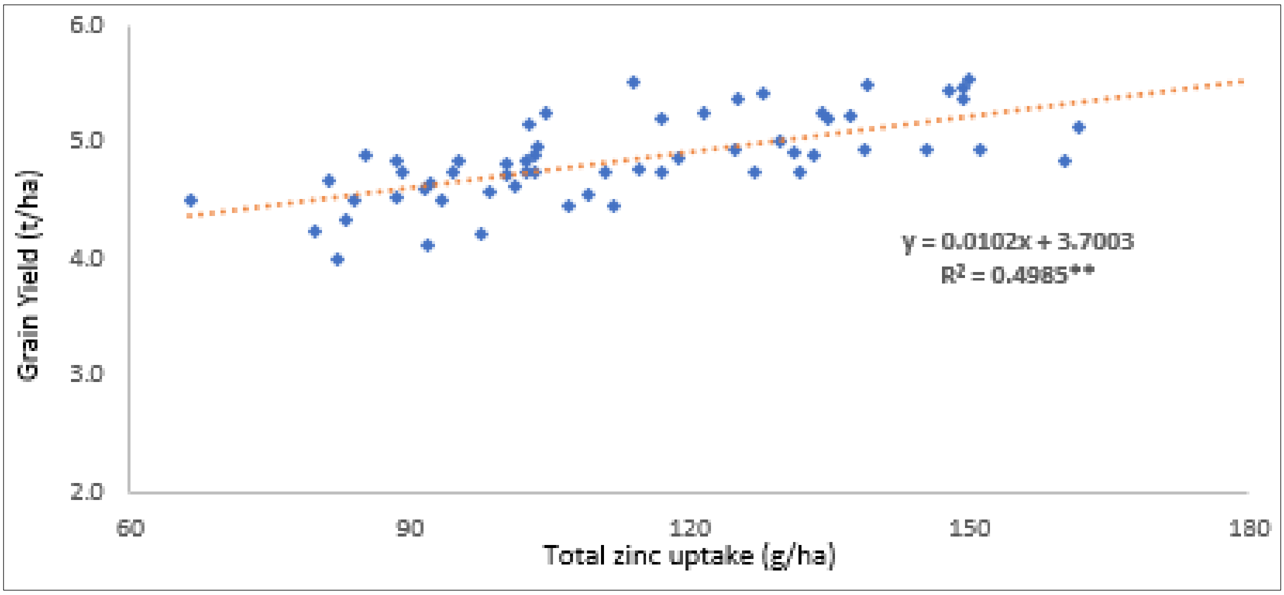

Fig 5: Relationship between Total zinc uptake and Grain yield for different concn. of $ZnSO_4$. **Significant at p<=0.01

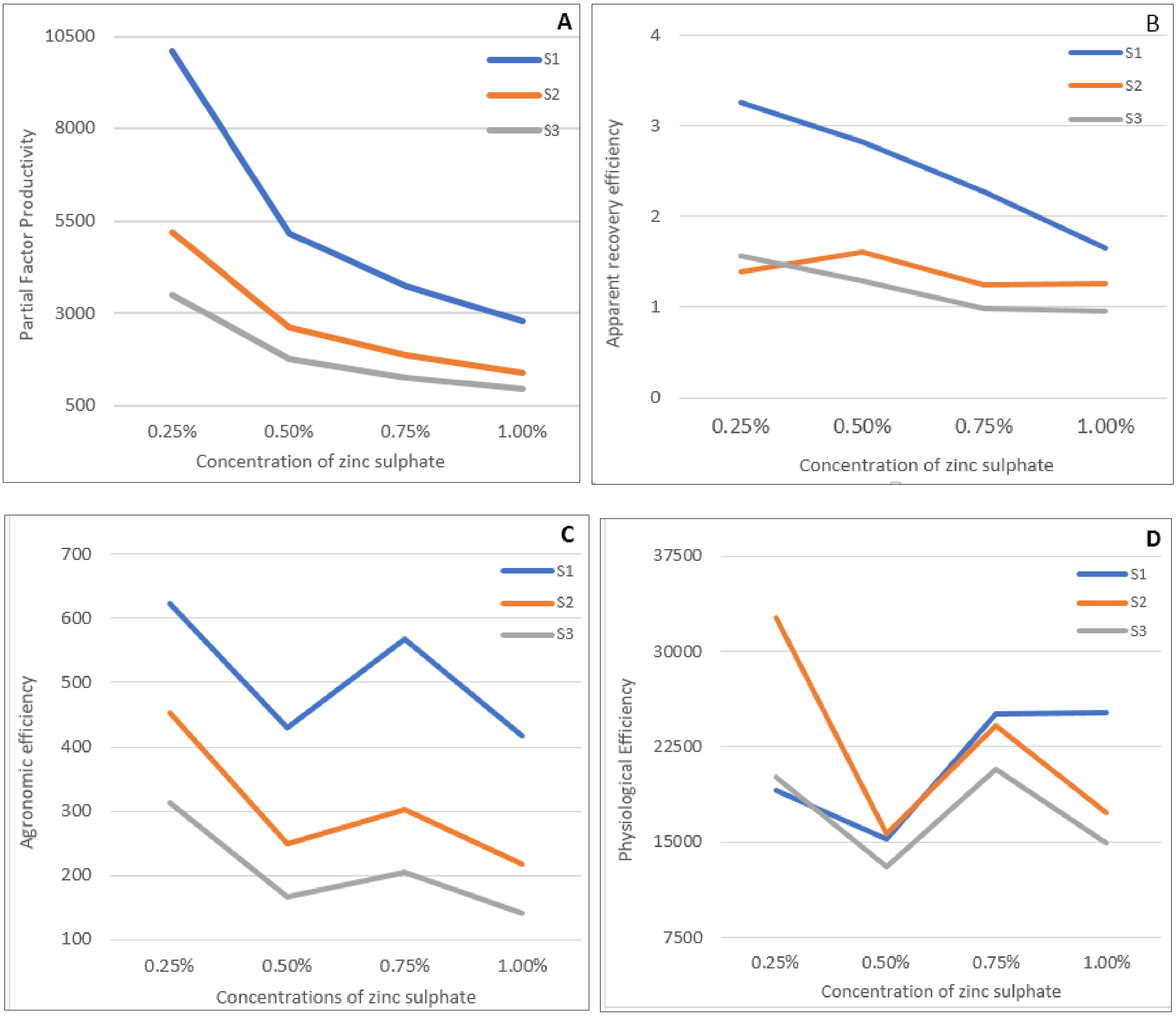

Fig 6: Effect of different concentrations of $ZnSO_4$ on Partial Factor Productivity (A), Apparent Recovery Efficiency (B), Agronomic Efficiency(C) and Physiological Efficiency (D) of wheat cultivar PBW343

Discussion

As the intensity and productivity of wheat crop has increased, soil fertility has declined and deficiencies of some micronutrients noticeably Zn has emerged in most of the wheat cultivated areas. Since zinc is an indispensable micronutrient required in trace amounts, even a minor deviation from the critical limit can make it the most significant constraint in wheat growth and yield. In majority of the cases, edaphic factors such as low moisture, low organic carbon and high pH reduce the rhizospheric bioavailability of zinc. In view of the above, the present study was conducted to evaluate the effect of different Zinc sulphate concentrations and spray frequencies on the yield components, yield response curve and zinc utilization efficiency in wheat. It follows from the results that foliar zinc application significantly increased panicle number per meter square and biological yield (Table NO. 1); straw and grain yield (Table No.2); as well as test weight and harvest index. (Table 3). The collective inputs of numerous growth and yield contributing characteristics, which are influenced by diverse agronomic methods under a specific set of ecological conditions, result in final grain yield. The increase in yield and associated components found in the study could be attributed to role of Zinc as a catalyst in many growth processes and other physiological activities. Zn is required for the production of IAA as well as the formation of primordia for propagative parts, which results in abundant tillering and shoot growth. This explains the increase in panicle number as well as the increase in grain and biological yield observed in the current study. Zinc applied to the leaf epidermis is more rapidly absorbed and retranslocated as compared to soil application, making it easily available to the plant for metabolism. Zn is believed to affect carbohydrate metabolism through its effects on photosynthesis and sugar conversions. Better photosynthate partitioning and starch consumption resulted in larger, well developed grains, which could explain the increase in test weight and harvest index observed. The results are in accordance with the findings of Niyigaba *et al*. (2019) [14], Sultana *et al*. (2016) [17], Hassan *et al*. (2019) [11] and Shilpi das *et al* (2020) [3]. Productivity of the cropping system vis-à-vis applied input and the amount of nutrient taken up by the plant are given by the indices PFP and ARE respectively. Although foliar application compensates for leaching and fixation losses, absorption of spray solution through the cuticle is a sluggish process that limits nutrient recovery. This explains the decrease in ARE observed in the study. The decrease in PFP and ARE observed in the study are in accordance with the findings of Shivay and Prasad (2012) [16]. The observed increase in AE at 0.75% $ZnSO_4$ as compared to 0.5% $ZnSO_4$ is attributed to the productivity improvement gained by the additional nutrient input. A similar trend observed in PE is due to a greater transformation of additional nutrient input into economic yield rather than biological yield.

Conclusion

Foliar zinc application increased the yield associated traits as well as total zinc uptake in wheat. Among the various spray concentrations (0.25% to 1% $ZnSO_4$) and frequencies (one at 30DAE, two at 45DAE and three at 60DAE), three sprays of 0.75% $ZnSO_4$ led to the maximum increase in grain yield and most of the yield associated traits. An increase in concentration upto 1.0% $ZnSO_4$ caused a marginal decline in grain yield. The yield response curve also suggested 0.75% $ZnSO_4$ to be the best fit. Moreover, application of 0.75% $ZnSO_4$ led to better values of AE and PE when compared with 0.5% $ZnSO_4$. Thus, foliar application of 0.75% $ZnSO_4$ can be recommended for enhancing grain yield in wheat.

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