

## Effect of zinc application on productivity, nutrient uptake and economics of wheat (*Triticum aestivum*) varieties under different sowing conditions

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### ABSTRACT

A field experiment was conducted during the winter seasons of 2013–14 and 2014–15 at the Indian Agricultural Research Institute, New Delhi, to study the effects of sowing time and zinc application on productivity, nutrient uptake and economics of wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] varieties. The experiment was laid out in a split-plot design, replicated thrice with sowing times (normal and very late) and wheat varieties ('HD 2967', 'WR 544' and 'HD 3059') in mainplots and ZnSO<sub>4</sub>·7H<sub>2</sub>O application (control; 25 kg/ha soil application, 3 foliar sprays @ 0.5% at boot, anthesis and grain-filling stage; 25 kg/ha soil application + 1 foliar spray @ 0.5% at anthesis) in subplots. Very late sowing reduced the yield attributes, grain and straw yields (9.2 and 29.1%), total N, P, K, Zn uptake, net returns (22.9%) and benefit: cost ratio (23.3%) of wheat. 'HD 2967' wheat gave higher grain and straw yields and showed higher total N, P, Zn uptake, net returns and benefit: cost ratio. However, it showed the highest grain yield reduction (18%) with the late planting. Application of Zn did not significantly alter yield attributes, grain and straw yields, net returns and benefit: cost ratio, though this treatment increased the total N, K and Zn uptake (6.8, 5.4, and 9.9% respectively) over the control under 1.45 mg/kg soil available Zn.

**Key words :** Late sowing, Net returns, Wheat varieties, Zinc application

Wheat is one of the most important staple food crop of the world including India. The country has the largest area under wheat (31.2 M ha), with a production of 95.9 Mt and productivity of 3.08 t/ha (DES, 2014). Growing of rice during the rainy (*kharif*) season delays sowing of wheat beyond mid-November which coincides reproductive phase of wheat to high temperature. The Eastern Gangetic Plains under the rice–wheat cropping system (RWCS) are prominent heat-stressed locations of South Asia besides, central and peninsular India. Heat stress is comparatively moderate in north western parts of the Indo-Gangetic Plains. Heat stress during the reproductive phase decreases grain yield due to accelerated development, reduced photosynthesis, increased respiration and decreased starch synthesis in developing grain. In wheat, high temperature (>30°C) after anthesis reduces grain-filling rate.

In plants, under heat stress, over-production of reactive oxygen species (ROS) like superoxide radicals, hydroxyl radicals and hydrogen peroxide changes cell-membrane structure which results in loss of function and increases cell-membrane leakiness (Wahid *et al.*, 2007).

Plants employ enzymatic and non-enzymatic antioxidant defence systems to scavenge the ROS. The enzymatic antioxidant defence system includes enzymes like ascorbate peroxidase, dehydroascorbate reductase, glutathione-S-transferase, superoxide dismutase, catalase and glutathione reductase. Zinc (Zn) is an integral part of the antioxidant enzyme Cu-Zn superoxide dismutase (Cu-Zn SOD) that first breakdowns the harmful superoxide radical produced in the cell. Thus, it provides structural and functional integrity of bio-membranes. Zn is also required for other cellular functions like protein metabolism, gene expression, photosynthetic C metabolism and IAA metabolism (Marschner, 1997). Different genotypes of wheat respond differently to the natural and modified growing environments and thus studying their responses to the Zn application under normal and delayed sowing conditions is important. Thus, keeping the above facts in view, the present investigation was conducted to find out the effect of Zn application on productivity, nutrient uptake and eco-

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nomics of wheat varieties grown under timely and very late-sown conditions.

### MATERIALS AND METHODS

A field experiment was conducted during the winter (*rabi*) seasons of 2013–14 and 2014–15 at the Indian Agricultural Research Institute, New Delhi (28°40' N, 77°12' E, 228.6 m above mean sea-level). On an average of 2 years, crop received 206.7 and 204.7 mm rainfall and the highest average growing temperature of 24.5 and 27.0°C for normal and very late sowing respectively. The soil was sandy clay loam, low in organic C (0.43%) and available N (182.5 kg/ha), medium in available P (17.3 kg/ha), high in available K (320.5 kg/ha) and medium in available Zn (1.45 mg/kg). The pH of soil was 7.6. Two sowing times, normal (19 November in 2013–14 and 25 November in 2014–15) and very late (26 December in 2013–14 and 2 January in 2014–15), 3 wheat varieties ('HD 2967', 'WR 544' and 'HD 3059') and 4 levels of  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$  application (control, 25 kg/ha soil application, 3 foliar sprays of  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$  @ 0.5% at booting, anthesis and grain-filling stage, 25 kg/ha soil application + 1 foliar spray of  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$  @ 0.5% at anthesis stage) were taken for investigation. Thus, there were 24 treatment combinations, set in a 3 times replicated split-plot design with 2 factors (sowing time and variety) in the main-plot, third factor ( $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$  application) in sub-plot. A pre-sowing irrigation was applied to the field to ensure the adequate moisture in the soil profile at the time of wheat sowing. The field was cultivated twice with the disc harrow followed by rotavator and a fine seed-bed was obtained by 2 operations by cultivator followed by planking. Recommended package of practices were followed for cultivation of normal and late sown wheat crop.

Soil application of  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$  was done as per treatment before sowing of wheat except in the control (no Zn application). Foliar sprays of  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$  were made as per the treatment and a spray volume of 500 litres/ha was used. The irrigations were applied as per crop need and weather conditions. All yield attributes were recorded as per the standard procedures at the maturity stage of crop. The net-plot area was harvested and total biomass weight was measured for each plot. Threshing of crop was done with thresher and yield per plot was finally expressed in terms of t/ha. The weight of wheat straw was obtained by subtracting the grain weight from total biomass yield and was expressed in t/ha. The nutrient uptake by the crop (straw and grain) was worked out by multiplying nutrient content in crop part (straw and grain) with the respective straw and grain yield and expressed in kg/ha (NPK) and g/ha (Zn). The total nutrient uptake was computed by adding the grain and straw uptake. Economics was computed

using the prevailing market prices of inputs and outputs. Gross returns were calculated based on the grain and straw yields of the crop and their prevailing market prices during the respective crop seasons. Net returns were calculated by subtracting cost of cultivation from gross returns. The benefit: cost ratio was calculated by dividing the net returns with cost of cultivation. The statistical analysis of data was done using analysis of variance (ANOVA) technique for split-plot design at 0.05 probability level.

### RESULTS AND DISCUSSION

#### *Yield attributes and grain and straw yields*

Very late sowing significantly reduced effective tillers/m<sup>2</sup>, grains/spike, 1,000-grain weight, spike length, spike weight, grain weight/spike, grain and straw yields, the reduction being 4.9, 9.3, 6.2, 5.3, 9.9, 8.6, 9.2 and 29.1%, respectively, as compared to normal sowing (Table 1). The reduction in the above traits may be ascribed to high temperature environment under late sowing. Heat stress reduces photosynthesis through disruption in the structure and function of chloroplasts and reductions in chlorophyll content (Wahid *et al.*, 2007). A reduction in photosynthesis under heat stress leads to reduced growth, accelerated leaf senescence and decreased grain yield in wheat (Wang *et al.*, 2011). Heat stress not only reduces grain number, but also shortens the grain-filling duration (Dias and Lidon, 2009), limits supply of photo-assimilates for grain filling (Talukder *et al.*, 2013) through reduced activity of enzymes involved in starch accumulation in wheat grains (Zhao *et al.*, 2008). Significantly higher harvest index (16.2%) was found with the late-sown crop. This is mainly ascribed to accelerated phenological development of crop under high temperature. The accelerated development leads to reduction in overall biomass accumulation, thus increased harvest index.

'HD 2967' showed the maximum number of effective tillers/m<sup>2</sup>, grains/spike, grain and straw yields, though the highest 1,000-grain weight was noted with 'HD 3059'. No significant effect of the variety factor was seen on the harvest index. The interaction between sowing time and variety on grain yield of wheat was found significant (Table 2). Under normal sowing, 'HD 2967' recorded the highest grain yield followed by 'HD 3059' and least was attained with 'WR 544'. The highest grain yield reduction of 18% was recorded in 'HD 2967', though 'WR 544' and 'HD 3059' also showed 5.4 and 2.3% reductions, respectively, due to late planting.

Application of Zn, on an average, increased 1,000-grain weight, grains/spike, grain and straw yields by 1.7, 2.9, 3.5 and 3.6%, respectively, over the control, though the difference was non-significant (Table 1). This might be due to adequate Zn absorption by the crop as per its need under

the sufficient level of soil-available Zn (1.45 mg/kg). In a long-term experiment on the rice–wheat system, no significant increase in the grain yields of rice and wheat were obtained with P, K, Zn and S applications due to adequate native supply of these nutrients (Gami *et al.*, 2001). However, in Zn-deficient soil (0.54 mg/kg), significantly higher grain and straw yields of wheat were reported with the Zn applications (Keram *et al.*, 2013).

#### Nutrient uptake

The uptake of nitrogen (N), phosphorus (P), potassium (K) and Zn in straw was reduced to the extent of 26.2, 43.5, 26.1 and 34.0%, respectively, due to very late sowing (Table 3). Likewise in grains, uptake of N, P and Zn was reduced due to very late sowing by 16.8, 25.5 and 14.0%, respectively, compared to that recorded with normal sowing. The K uptake by the grain increased (9.7%), though the total uptake of all the nutrients was reduced significantly under late planting. The reduced nutrient uptake could be attributed to late planting-created forced crop maturity. Forced maturity decreases biomass yield and time span for nutrient absorption from soil. In addition, particularly during the later growth stages (flowering to maturity) of late-sown wheat atmospheric demand for water (evapo-transpiration) increases due to increasing temperatures. This leads to soil drying which reduces nutrient movement to roots. It has also been reported that

growth and development of wheat roots stop and their degeneration start after anthesis.

Significantly higher N, P and Zn uptake in grain and straw and total uptake were recorded with ‘HD 2967’ wheat followed by ‘HD 3059’. This main effect may be owing to long growing period of both these varieties (140–145 days for normal; 110–115 days for very late), higher root growth, *viz.* root length density, root dry weight density and root volume density (data not shown here) in the 0–15 cm soil depth, higher nutrient content in plant (data not shown here), higher grain and straw yields. The least uptake of all the nutrients was found with ‘WR 544’. This was due to short-duration of variety (120 days for normal; 100–105 days for very late), lower root

**Table 2.** Interaction effect between sowing time and variety on grain yield of wheat (mean of 2 years)

| Treatment   | Grain yield (t/ha) |                  |      |
|-------------|--------------------|------------------|------|
|             | Normal sowing      | Very late sowing | Mean |
| ‘HD 2967’   | 4.98               | 4.14             | 4.56 |
| ‘WR 544’    | 3.68               | 3.52             | 3.60 |
| ‘HD 3059’   | 4.34               | 4.17             | 4.25 |
| Mean        | 4.34               | 3.94             |      |
| SEm±        | 0.05               |                  |      |
| CD (P=0.05) | 0.16               |                  |      |

**Table 1.** Yield attributes, grain yield, straw yield and harvest index of wheat as influenced by sowing time, variety and Zn application (mean of 2 years)

| Treatment                                           | Effective tillers/m <sup>2</sup> | Spike weight (g) | Spike length (cm) | Grains/spike | Grain weight/spike (g) | 1,000-grain weight (g) | Grain yield (t/ha) | Straw yield (t/ha) | Harvest index (%) |
|-----------------------------------------------------|----------------------------------|------------------|-------------------|--------------|------------------------|------------------------|--------------------|--------------------|-------------------|
| <i>Sowing time</i>                                  |                                  |                  |                   |              |                        |                        |                    |                    |                   |
| Normal                                              | 364                              | 2.8              | 10.1              | 50.2         | 2.3                    | 38.4                   | 4.3                | 7.85               | 35.8              |
| Very late                                           | 346                              | 2.5              | 9.5               | 45.5         | 2.1                    | 36.0                   | 3.9                | 5.56               | 41.6              |
| SEm±                                                | 4                                | 0.04             | 0.1               | 0.6          | 0.02                   | 0.2                    | 0.03               | 0.21               | 0.7               |
| CD (P=0.05)                                         | 14                               | 0.12             | 0.2               | 1.9          | 0.1                    | 0.6                    | 0.1                | 0.66               | 2.1               |
| <i>Variety</i>                                      |                                  |                  |                   |              |                        |                        |                    |                    |                   |
| ‘HD 2967’                                           | 365                              | 2.8              | 9.9               | 51.2         | 2.3                    | 37.4                   | 4.6                | 7.23               | 38.9              |
| ‘WR 544’                                            | 339                              | 2.3              | 9.5               | 42.8         | 2.1                    | 35.7                   | 3.6                | 5.70               | 39.3              |
| ‘HD 3059’                                           | 361                              | 2.9              | 9.9               | 49.5         | 2.2                    | 38.4                   | 4.3                | 7.19               | 37.9              |
| SEm±                                                | 5                                | 0.05             | 0.1               | 0.8          | 0.03                   | 0.2                    | 0.04               | 0.26               | 0.8               |
| CD (P=0.05)                                         | 17                               | 0.15             | 0.2               | 2.4          | 0.09                   | 0.8                    | 0.1                | 0.81               | NS                |
| <i>ZnSO<sub>4</sub>·7H<sub>2</sub>O application</i> |                                  |                  |                   |              |                        |                        |                    |                    |                   |
| Control                                             | 353                              | 2.6              | 9.8               | 46.8         | 2.2                    | 36.7                   | 4.03               | 6.53               | 38.7              |
| SA 25 kg/ha                                         | 355                              | 2.7              | 9.8               | 47.8         | 2.2                    | 37.0                   | 4.1                | 6.74               | 38.4              |
| 3 FS @ 0.5%                                         | 354                              | 2.7              | 9.8               | 48.3         | 2.3                    | 37.2                   | 4.2                | 6.75               | 38.9              |
| SA 25 kg/ha + 1 FS @ 0.5%                           | 356                              | 2.7              | 9.8               | 48.4         | 2.2                    | 37.8                   | 4.2                | 6.81               | 38.8              |
| SEm±                                                | 6                                | 0.04             | 0.1               | 0.7          | 0.02                   | 0.3                    | 0.05               | 0.10               | 0.6               |
| CD (P=0.05)                                         | NS                               | NS               | NS                | NS           | NS                     | NS                     | NS                 | NS                 | NS                |

SA, Soil application; 3 FS, 3 foliar sprays at booting, anthesis and grain-filling stage; 1 FS, 1 foliar spray at anthesis

growth, grain and straw yields and nutrient content. The highest total K uptake by 'HD 3059' may be attributed to higher K content in plant parts and its heat stress-resistant character.

On an average, Zn application caused 8.2% increase in grain N and 6.8% increase in the total N uptake by wheat crop over the control. The higher uptake of N might be owing to synergistic interaction of N with Zn. Under Zn-deficiency, the uptake of  $\text{NO}_3^-$  N is lowered due to enhanced plasma-membrane permeability that favours the net efflux of  $\text{NO}_3^-$  through membranes (Cakmak and Marschner, 1990).

Non-significant effect of zinc application was found in improving the grain as well as total uptake of P. On an average, 6.7% reduction in P uptake by straw was recorded as compared with the control. The significantly lower P uptake in straw was found with 3 foliar sprays of 0.5%  $\text{ZnSO}_4$  at booting, anthesis and grain-filling stage and with the soil application of  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$  @ 25 kg/ha followed by foliar spray of 0.5%  $\text{ZnSO}_4$  at anthesis stage. The lower uptake of P in straw could be due to Zn-mediated reduction in the P concentration of shoot and more remobilization of phosphate from shoot to developing grains. It has also been observed that Zn sufficient plants have capacity to down regulate expression of genes encoding high affinity phosphate transporters in plant roots, thus may regulate the absorption of phosphate ion from the soil

solution (Huang *et al.*, 2000).

Application of Zn increased the grain K uptake by 4.4% and total K uptake by 5.4% over control. Among the Zn treatments, soil application of  $\text{ZnSO}_4$  @ 25 kg/ha + foliar spray of 0.5%  $\text{ZnSO}_4$  at anthesis registered the highest grain and total K uptake. The higher K uptakes might be owing to synergistic interaction between Zn and K. The appreciable level of available K in the experimental field along with Zn fertilization might have created a favourable environment for K absorption by the roots, thus improved K content in plant. The higher grain K content could be attributed to higher translocation of K to grain in zinc-applied plots. Keram *et al.* (2013) also reported similar results.

All Zn application treatments significantly increased the straw, grain and total zinc uptakes by the crop as compared to the control. An increase in Zn uptake of 9.6, 10.5 and 9.9% was noted with Zn application over the control in straw, grain and total (grain and straw), respectively. The highest Zn uptake was noticed with 3 foliar sprays of 0.5%  $\text{ZnSO}_4$  at boot, anthesis and grain-filling stage, though it was found at par with soil application of  $\text{ZnSO}_4$  @ 25 kg/ha + foliar spray of 0.5%  $\text{ZnSO}_4$  at anthesis. The highest uptake of zinc in foliar-fertilized plots might be attributed to increased concentration of Zn in plant tissues that were directly exposed to zinc supply. Three foliar sprays of 0.5%  $\text{ZnSO}_4$  at boot, anthesis and grain-filling

**Table 3.** Nitrogen, phosphorus, potassium and zinc uptake of wheat as influenced by sowing time, variety and zinc application (mean of 2 years)

| Treatment                                           | N uptake<br>(kg/ha) |       | Total N uptake<br>(kg/ha) | P uptake<br>(kg/ha) |       | Total P uptake<br>(kg/ha) | K uptake<br>(kg/ha) |       | Total K uptake<br>(kg/ha) | Zn uptake<br>(g/ha) |       | Total Zn uptake<br>(g/ha) |
|-----------------------------------------------------|---------------------|-------|---------------------------|---------------------|-------|---------------------------|---------------------|-------|---------------------------|---------------------|-------|---------------------------|
|                                                     | Straw               | Grain |                           | Straw               | Grain |                           | Straw               | Grain |                           | Straw               | Grain |                           |
| <i>Sowing time</i>                                  |                     |       |                           |                     |       |                           |                     |       |                           |                     |       |                           |
| Normal                                              | 34.7                | 87.5  | 122.1                     | 4.6                 | 12.9  | 17.6                      | 103.0               | 13.4  | 116.4                     | 260.2               | 180.0 | 440.2                     |
| Very late                                           | 25.6                | 72.8  | 98.4                      | 2.6                 | 9.6   | 12.2                      | 76.1                | 14.7  | 90.8                      | 171.7               | 154.8 | 326.5                     |
| SEm±                                                | 1.0                 | 0.8   | 1.2                       | 0.1                 | 0.1   | 0.2                       | 2.9                 | 0.1   | 2.9                       | 6.8                 | 1.4   | 6.8                       |
| CD (P=0.05)                                         | 3.3                 | 2.6   | 3.7                       | 0.5                 | 0.4   | 0.6                       | 9.3                 | 0.5   | 9.1                       | 21.5                | 4.4   | 21.3                      |
| <i>Variety</i>                                      |                     |       |                           |                     |       |                           |                     |       |                           |                     |       |                           |
| ‘HD 2967’                                           | 32.5                | 87.9  | 120.4                     | 4.1                 | 12.6  | 16.7                      | 92.0                | 17.1  | 109.1                     | 243.4               | 191.3 | 434.7                     |
| ‘WR 544’                                            | 25.9                | 71.9  | 97.8                      | 2.7                 | 9.7   | 12.3                      | 72.5                | 11.2  | 83.7                      | 169.2               | 136.6 | 305.8                     |
| ‘HD 3059’                                           | 32.0                | 80.7  | 112.6                     | 4.0                 | 11.5  | 15.5                      | 104.2               | 13.9  | 118.1                     | 235.2               | 174.2 | 409.4                     |
| SEm±                                                | 1.3                 | 1.0   | 1.4                       | 0.2                 | 0.2   | 0.2                       | 3.6                 | 0.2   | 3.5                       | 8.4                 | 1.7   | 8.3                       |
| CD (P=0.05)                                         | 4.0                 | 3.2   | 4.5                       | 0.6                 | 0.5   | 0.7                       | 11.4                | 0.6   | 11.2                      | 26.3                | 5.3   | 26.1                      |
| <i>ZnSO<sub>4</sub>·7H<sub>2</sub>O application</i> |                     |       |                           |                     |       |                           |                     |       |                           |                     |       |                           |
| Control                                             | 29.3                | 75.5  | 104.9                     | 3.7                 | 11.2  | 14.9                      | 86.0                | 13.6  | 99.6                      | 201.4               | 155.2 | 356.6                     |
| SA 25 kg/ha                                         | 33.4                | 80.8  | 114.3                     | 3.8                 | 11.4  | 15.2                      | 90.5                | 13.9  | 104.4                     | 214.3               | 163.0 | 377.3                     |
| 3 FS @ 0.5%                                         | 29.5                | 81.3  | 110.8                     | 3.5                 | 11.2  | 14.7                      | 90.0                | 14.2  | 104.3                     | 225.9               | 177.1 | 403.0                     |
| SA 25 kg/ha + 1 FS @ 0.5%                           | 28.2                | 82.9  | 111.1                     | 3.4                 | 11.1  | 14.6                      | 91.7                | 14.5  | 106.2                     | 222.1               | 174.3 | 396.4                     |
| SEm±                                                | 1.1                 | 1.3   | 1.4                       | 0.1                 | 0.2   | 0.2                       | 1.6                 | 0.2   | 1.6                       | 4.3                 | 2.4   | 5.0                       |
| CD (P=0.05)                                         | 3.2                 | 3.7   | 4.1                       | 0.2                 | NS    | NS                        | NS                  | 0.6   | 4.5                       | 12.3                | 7.0   | 14.4                      |

SA, Soil application; 3 FS, 3 foliar sprays at booting, anthesis and grain-filling stage; 1 FS, 1 foliar spray at anthesis

**Table 4.** Influence of sowing time, variety and zinc application on economics of wheat (mean of 2 years)

| Treatment                                           | Cost of cultivation<br>( $\times 10^3$ ₹/ha) | Gross returns<br>( $\times 10^3$ ₹/ha) | Net returns<br>( $\times 10^3$ ₹/ha) | Benefit:<br>cost ratio |
|-----------------------------------------------------|----------------------------------------------|----------------------------------------|--------------------------------------|------------------------|
| <i>Sowing time</i>                                  |                                              |                                        |                                      |                        |
| Normal                                              | 31.7                                         | 79.3                                   | 47.5                                 | 1.50                   |
| Very late                                           | 31.9                                         | 68.6                                   | 36.6                                 | 1.15                   |
| SEm $\pm$                                           | -                                            | 0.5                                    | 0.5                                  | 0.02                   |
| CD (P=0.05)                                         | -                                            | 1.7                                    | 1.7                                  | 0.05                   |
| <i>Variety</i>                                      |                                              |                                        |                                      |                        |
| 'HD 2967'                                           | 31.8                                         | 81.2                                   | 49.4                                 | 1.55                   |
| 'WR 544'                                            | 31.8                                         | 63.8                                   | 31.9                                 | 1.00                   |
| 'HD 3059'                                           | 31.8                                         | 76.8                                   | 45.0                                 | 1.41                   |
| SEm $\pm$                                           | -                                            | 0.7                                    | 0.7                                  | 0.02                   |
| CD (P=0.05)                                         | -                                            | 2.1                                    | 2.1                                  | 0.07                   |
| <i>ZnSO<sub>4</sub>·7H<sub>2</sub>O application</i> |                                              |                                        |                                      |                        |
| Control                                             | 30.9                                         | 72.1                                   | 41.2                                 | 1.34                   |
| SA 25 kg/ha                                         | 32.1                                         | 73.7                                   | 41.6                                 | 1.30                   |
| 3 FS @ 0.5%                                         | 31.8                                         | 74.7                                   | 42.8                                 | 1.35                   |
| SA 25 kg/ha + 1 FS @ 0.5%                           | 32.4                                         | 75.2                                   | 42.8                                 | 1.32                   |
| SEm $\pm$                                           | -                                            | 0.7                                    | 0.7                                  | 0.02                   |
| CD (P=0.05)                                         | -                                            | 2.0                                    | NS                                   | NS                     |

SA, Soil application; 3 FS, 3 foliar sprays at booting, anthesis and grain-filling stage; 1 FS, 1 foliar spray at anthesis

improved the straw Zn content by 8.3% and grain Zn content by 10.1%. Hussain *et al.* (2012) reported that foliar application of Zn both at jointing and heading gave 25% higher Zn concentration in wheat grain than the soil application.

### Economics

Economic analysis showed that late sowing increased the cost of cultivation, reduced the gross returns by 13.5%, net returns by 22.9% and benefit: cost ratio by 23.3% compared to the normal sowing (Table 4). The higher cost of cultivation was mainly due to 25% extra seed rate used under the delayed sowing over the normal sowing. Likewise, reduction in the gross and net returns and benefit: cost ratio was mainly due to the high grain and straw yields of crop under timely sowing. 'HD 2967' recorded significantly higher gross and net returns and benefit: cost ratio than the other varieties. This could be owing to its higher grain and straw yields than the other 2 varieties. The significantly lowest benefit: cost ratio was observed with 'WR 544' mainly due to its genetically lower yield potential.

The highest cost of cultivation and gross returns were found with the soil application of ZnSO<sub>4</sub> @ 25 kg/ha + foliar spray of 0.5% ZnSO<sub>4</sub> at anthesis. This was ascribed to comparatively more cost incurred in above treatment owing to more amount of Zn addition into the field and its application cost. The higher gross returns under same treatment was owing to comparatively higher grain and

straw yields. The Zn application treatments did not differ significantly among themselves with respect to net returns and benefit: cost ratio.

Thus, it can be concluded that late sowing has a net negative effect on the yield attributes, grain and straw yields, total nutrient uptake, net returns and finally benefit: cost ratio of wheat. Zinc application not only improved Zn status of wheat under sufficient soil Zn conditions, but also increased the content and uptake of N and K. These findings indicate the critical role of Zn in N absorption, translocation and protein synthesis in wheat and other plants.

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