

## Phenophase-based nitrogen and zinc scheduling for agronomic zinc biofortification and indices of wheat (*Triticum aestivum*)

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### ABSTRACT

A field experiment was conducted during winter (*rabi*) season of 2012–13 at Varanasi, Uttar Pradesh, to assess nitrogen and zinc management on wheat (*Triticum aestivum* L.) phenophase (*Zadoks scale*) to increase yield, grain zinc content (agronomic biofortification) and agronomic indices of wheat. The experiment was laid out in a randomized block design (factorial) with 4 nitrogen scheduling [0 kg N/ha, 50% recommended dose of nitrogen (RDN) at sowing + 50% RDN at Z<sub>20</sub>, 50% RDN at sowing + 25% RDN at Z<sub>20</sub> + 25% RDN at Z<sub>30</sub> and 50% RDN at sowing + 25% RDN at Z<sub>20</sub> + 25% RDN at Z<sub>37</sub>] and 4 zinc scheduling (0 kg Zn/ha, 0.5% Zn-EDTA spray at Z<sub>45</sub>, 0.25% Zn-EDTA spray at Z<sub>45</sub> + 0.25% Zn-EDTA spray at Z<sub>60</sub> and 0.25% Zn-EDTA spray at Z<sub>45</sub> + 0.25% Zn-EDTA spray at Z<sub>73</sub>). Nitrogen scheduling (50% RDN at sowing + 50% RDN at Z<sub>20</sub>) and zinc scheduling (0.5% Zn-EDTA spray at Z<sub>45</sub>) recorded significantly higher effective tillers, 1,000-grain weight, yield, zinc uptake, partial factor productivity (PEP), agronomic efficiency (AE) and recovery efficiency (RE) over the other treatments. Nitrogen and zinc management also positively interacted and recorded higher effective tillers, grain yield, and nitrogen and zinc uptake with N<sub>1</sub> × Zn<sub>1</sub>; however, the maximum grain zinc content (52.30 mg/kg) was recorded with N<sub>3</sub> × Zn<sub>2</sub> combination.

**Key words** : Nitrogen × zinc interaction, Nutrient enrichment, Zinc content, Zinc fertilization, Zinc malnutrition, Zinc-use efficiency

Wheat is the second most important cereal crop after rice in India and ranks first in dietary shares in northern India (Joshi *et al.*, 2007), play a key role in food and nutritional security. It contributes about 70% of daily calorie intake of the population living in rural regions and an important source of zinc (Zn) for human beings living in the developing world (Cakmak, 2008). Among the micronutrients, Zn is an essential mineral nutrient for all organisms. However, the widespread of Zn deficiency in soil causes low crop productivity and poor nutritional quality of crops and ultimately exacerbates the micronutrient malnutrition in the human population. Fertilization of food crops with

Zn for enhancing grain Zn content (Singh *et al.*, 2014) represents a short-term and complementary strategy of biofortification. Moreover, it also depends on various factors, of which nutrient interactions (Prasad *et al.*, 2014) as well as nitrogen (N) status of plants are important. Kutman *et al.* (2011) also stated that high N can increase the grain Zn concentrations by enhancing the grain protein concentration and thereby the sink strength of the grain for Zn and suggested that N management can be an effective agronomic tool to improve grain Zn concentration. Adequate and timely application of fertilizers is not only improved the crop yield but a prerequisite for improving the efficiency of applied nutrients (Dar and Ram, 2016). In order to address the Zn malnutrition, the agronomic approaches, i.e. scheduling of N and Zn fertilizer based on phenophase (*Zadoks scale*), was rarely tested, although a large number of studies are available on the role of soil and foliar applied Zn fertilizers in the correction of Zn deficiency and increasing plant growth and yield.

The field experiment was conducted during 2012–13 at the Banaras Hindu University, Varanasi (25°18' N, 83°03' E, 128.93 mean sea-level), India. The soil of the experi-

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mental field was Ustochrepts (Gangetic alluvium) of Inceptisols. It was low in organic carbon (0.42%), available nitrogen (210.0 kg/ha) and medium in available phosphorus (14.4 kg/ha) and potassium (172.1 kg/ha). The soil DTPA-extractable Zn in soil was 0.52 mg/kg with the pH 7.4. The total rainfall received during the growing season (5 November, 2012–30 April, 2013) was 86.6 mm and weekly mean maximum and minimum temperature ranged from 17.1 to 40.6°C and 5.8 to 24.0°C, respectively. The experiment was laid out in a randomized block design (factorial) with 3 replications. The treatments comprised 4 nitrogen scheduling [ $N_0$ , 0 kg N/ha;  $N_1$ , 50% recommended dose of nitrogen (RDN) at sowing + 50% RDN at  $Z_{20}$ ;  $N_2$ , 50% RDN at sowing + 25% RDN at  $Z_{20}$  + 25% RDN at  $Z_{30}$ ; and  $N_3$ , 50% RDN at sowing + 25% RDN at  $Z_{20}$  + 25% RDN at  $Z_{37}$ ] and 4 zinc scheduling ( $Zn_0$ , 0 kg Zn/ha;  $Zn_1$ , 0.5% Zn-EDTA spray at  $Z_{45}$ ;  $Zn_2$ , 0.25% Zn-EDTA spray at  $Z_{45}$  + 0.25% Zn-EDTA spray at  $Z_{60}$  and  $Zn_3$ : 0.25% Zn-EDTA spray at  $Z_{45}$  + 0.25% Zn-EDTA spray at  $Z_{73}$ ). The N and Zn were applied as per Zadoks scale (Z), i.e.  $Z_{20}$  (main shoots only),  $Z_{30}$  (pseudostem erection),  $Z_{37}$  (flag leaf just visible),  $Z_{45}$  (boot swollen),  $Z_{60}$  (beginning of anthesis) and  $Z_{73}$  (early milk stage). In addition to Zn spray, a uniform rate of Zn (5 kg/ha) was applied except the control plot. The source of basal zinc was zinc sulphate monohydrate ( $ZnSO_4 \cdot H_2O$ ). Nitrogen was applied @ 120 kg/ha, whereas uniform dose of  $P_2O_5$  (60 kg/ha) and  $K_2O$  (60 kg/ha) were also applied. The wheat variety 'HUW 468' was sown on 3 December 2012 under well-pulverized soil and harvested on 25 April 2013. At maturity, wheat crop was harvested manually. Grain and straw yields were recorded from a net area of 9.45 m<sup>2</sup> from the experimental plots. Grain and straw samples of wheat for chemical analysis collected from each plot, were air-dried at 70°C in a hot-air oven. The dried samples were crushed with mortar and pestle for analysis of Zn content in grain and straw. Agronomic indices of Zn i.e. agronomic efficiency (AE), partial factor productivity (PFP), recovery efficiency (RE) and physiological efficiency (PE), computed and data were statistically analyzed as per standard statistical procedure (Gomez and Gomez, 1984).

Scheduling of N fertilizer on Zadoks scale significantly improved the effective tillers, 1,000-grain weight, yield (grain and straw), N and Zn content and uptake in grain. Among the treatments, the 50% RDN at sowing + 50% RDN at  $Z_{20}$  recorded the maximum effective tillers, 1,000-grain weight and grain and straw yields (Table 1). The grain yield with  $N_1$  was 13.10, 20.39 and 40.59% higher than  $N_2$ ,  $N_3$  and  $N_0$  respectively. The adequate N at right stage (50% RDN at  $Z_{20}$ ) may enhance the rate of tillering and correspondingly increased the effective tillers, 1,000-grain weight, harvest index and grain yield. This was

might be owing to active participation of N in photosynthesis. Similar results were also reported by Mohanty *et al.* (2015). However, split application of N, i.e. 50% RDN at sowing + 25% RDN at  $Z_{20}$  + 25% RDN at  $Z_{37}$  recorded higher Zn content in grain than other treatments (Table 1). This indicates that the N application at late tillering ( $Z_{37}$ ) improves the Zn content in grain. Similar findings were also reported by Erenoglu *et al.* (2011). Further, the Zn uptake was recorded higher with 50% RDN at sowing + 50% RDN at  $Z_{20}$  and recorded 96.82% higher than the control (0 kg N/ha).

Zinc scheduling with  $Zn_1$  had significantly improved the effective tillers, yield (grain and straw), whereas  $Zn_3$  improved the Zn content (grain and straw) in wheat crop. Effective tillers recorded with  $Zn_1$  were 3.60, 4.50 and 20.14% higher than  $Zn_2$ ,  $Zn_3$  and  $Zn_0$ , respectively. Interestingly,  $Zn_1$  had 9.52, 18.03 and 28.00% higher grain yield than  $Zn_2$ ,  $Zn_3$  and  $Zn_0$  respectively. However, maximum Zn content in grain was recorded with 0.25% Zn-EDTA spray at  $Z_{45}$  + 0.25% Zn-EDTA spray at  $Z_{73}$  and was 13.47, 19.93 and 59.96% higher than  $Zn_2$ ,  $Zn_1$  and  $Zn_0$  respectively. This result indicates a synergistic effect of N and Zn, and also Zn spray at later booting stage  $Z_{45}$  (boot swollen) and  $Z_{73}$  (early milk) increased the Zn content in wheat grain. The increase in Zn content attributed to higher absorption and translocation of Zn applied through the foliar application (Yang *et al.*, 2011). Yang *et al.* (2011) also reported that foliar Zn application at grain filling, especially the early grain-filling stage, improves the Zn concentration in crop. But, in straw, the maximum Zn content was recorded with  $Zn_2$  followed by  $Zn_3$ ,  $Zn_1$  and  $Zn_0$ .

Agronomic indices i.e. partial factor productivity (PFP), agronomic efficiency (AE), physiological efficiency (PE) and recovery efficiency (RE) were significantly influenced by Zn management (Table 1). Maximum PFP, AE and RE were recorded with 0.5% Zn-EDTA spray at  $Z_{45}$  ( $Zn_1$ ), followed by 0.25% Zn-EDTA spray at  $Z_{45}$  + 0.25% Zn-EDTA spray at  $Z_{60}$  ( $Zn_2$ ) and 0.25% Zn EDTA spray at  $Z_{45}$  + 0.25% Zn EDTA spray at  $Z_{73}$  ( $Zn_3$ ). However, the maximum Zn recovery efficiency recorded with  $Zn_3$  and was 0.19 and 26.98% higher than  $Zn_2$  and  $Zn_1$  respectively. Zadoks scale-based Zn scheduling has merit in terms of Zn-use efficiency. In each treatment, equal amount of Zn was applied but Zn received at early stage ( $Z_{45}$ ) recorded higher PFP, AE and PE. This was might be efficient Zn utilization by crop that has also be reflected in higher grain yield and Zn uptake. This result also indicates that the PFP, AE and PE decreased as Zn spray was delayed. However, the RE increased when plot received Zn at latter growth stage ( $Z_{73}$ ).

Application of N and Zn on Zadoks scale interacts with

**Table 1.** Phenophase (Zadoks scale)-based nitrogen and zinc management in wheat

Treatment	Effective tillers/m <sup>2</sup>	1,000-grain wt (g)	Yield (t/ha)		Harvest index (%)	Grain nutrient content		Grain nutrient uptake		Agronomic indices of zinc			
			Grain	Straw		N (%)	Zn (mg/kg)	N (kg/ha)	Zn (g/ha)	PPF (kg/kg Zn)	AE (kg/kg Zn)	PE (kg/kg Zn)	RE (%)
<i>Nitrogen scheduling</i>													
N <sub>0</sub>	269.7	28.4	2.50	3.94	39.0	1.89	25.2	47.2	63.0	275.3	29.0	994.4	2.85
N <sub>1</sub>	376.7	35.7	3.51	4.81	42.2	2.06	35.3	72.6	124.0	395.8	66.2	1,349.1	4.39
N <sub>2</sub>	356.3	32.0	3.11	4.62	40.3	2.05	38.0	63.9	118.0	345.9	44.2	1,553.7	3.30
N <sub>3</sub>	336.2	33.0	2.91	4.28	40.6	2.10	40.2	60.9	117.0	324.8	41.2	990.4	3.84
<i>Zinc scheduling</i>													
Zn <sub>0</sub>	296.8	29.2	2.65	3.95	40.5	1.93	26.0	51.2	69.0	00.0	00.0	00.0	00.00
Zn <sub>1</sub>	356.6	35.0	3.40	4.81	41.4	2.01	34.6	68.8	120.0	486.2	93.0	2,953.4	4.07
Zn <sub>2</sub>	344.2	32.4	3.10	4.53	40.5	2.08	36.6	64.7	116.0	443.9	56.0	1,296.5	5.15
Zn <sub>3</sub>	341.3	32.4	2.88	4.36	39.8	2.07	41.5	59.9	123.0	411.9	28.0	637.9	5.16
SEm±	10.1	0.9	0.04	0.17	1.0	0.03	1.0	1.2	4.0	3.7	3.4	99.8	0.36
CD (P=0.05)	29.4	2.8	0.11	0.49	NS	0.09	2.7	3.6	11.0	10.8	10.0	288.4	1.03
N×Z	S	NS	S	NS	NS	NS	S	S	S	NS	NS	NS	NS

N<sub>0</sub>, 0 kg N/ha; N<sub>1</sub>, 50% recommended dose of nitrogen (RDN) at sowing + 50% RDN at Z<sub>20</sub>; N<sub>2</sub>, 50% RDN at sowing + 25% RDN at Z<sub>20</sub> + 25% RDN at Z<sub>30</sub>; and N<sub>3</sub>, 50% RDN at sowing + 25% RDN at Z<sub>20</sub> + 25% RDN at Z<sub>37</sub>; (Zn<sub>0</sub>, 0 kg Zn/ha; Zn<sub>1</sub>, 0.5% Zn-EDTA spray at Z<sub>45</sub>; Zn<sub>2</sub>, 0.25% Zn-EDTA spray at Z<sub>45</sub> + 0.25% Zn-EDTA spray at Z<sub>60</sub>; and Zn<sub>3</sub>, 0.25% Zn-EDTA spray at Z<sub>45</sub> + 0.25% Zn-EDTA spray at Z<sub>73</sub>); PFP, Partial factor productivity; AE, agronomic efficiency; PE, physiological efficiency; RE, recovery efficiency

**Table 2.** Interaction effect of nitrogen and zinc fertilization scheduling on effective tillers, grain yield, N uptake, zinc content and uptake in grain

Treatment	Effective tillers/m <sup>2</sup>																			
	Yield (t/ha)						N uptake (kg/ha)													
	Zn <sub>0</sub>	Zn <sub>1</sub>	Zn <sub>2</sub>	Zn <sub>3</sub>	Zn <sub>0</sub>	Zn <sub>1</sub>	Zn <sub>2</sub>	Zn <sub>3</sub>	Zn <sub>0</sub>	Zn <sub>1</sub>	Zn <sub>2</sub>	Zn <sub>3</sub>								
N <sub>0</sub>	216.7	265.2	297.8	299.3	2.29	2.81	2.41	2.48	21.81	22.5	24.6	30.9	42.7	51.9	47.5	47.0	46	63	59	77
N <sub>1</sub>	328.2	431.1	336.3	411.5	2.98	4.02	3.84	3.21	24.80	37.3	38.9	40.4	56.5	85.4	79.2	69.3	68	150	150	130
N <sub>2</sub>	323.2	389.6	373.3	339.3	2.75	3.49	3.20	2.98	27.06	38.4	41.0	45.8	50.9	70.8	70.2	64.0	67	135	132	137
N <sub>3</sub>	319.5	340.7	369.6	315.2	2.59	3.29	2.96	2.84	29.00	40.5	42.1	52.3	54.8	67.2	62.2	59.6	65	133	125	149
SEm±	20.36				0.08				1.82				2.54							8.00
CD (P=0.05)	58.80				0.27				5.42				7.35							32.00

N<sub>0</sub>, 0 kg N/ha; N<sub>1</sub>, 50% recommended dose of nitrogen (RDN) at sowing + 50% RDN at Z<sub>20</sub>; N<sub>2</sub>, 50% RDN at sowing + 25% RDN at Z<sub>20</sub> + 25% RDN at Z<sub>30</sub>; and N<sub>3</sub>, 50% RDN at sowing + 25% RDN at Z<sub>20</sub> + 25% RDN at Z<sub>37</sub>

each other for effective tillers, grain yield, zinc content and N and Zn uptake in grain (Table 2). Nitrogen and zinc application at  $N_1 \times Zn_1$  had recorded the maximum effective tillers, grain yield, N and Zn uptake compared to other treatment combination. However, effective tillers recorded with  $N_1 \times Zn_3$ ,  $N_2 \times Zn_1$  and  $N_2 \times Zn_2$  was statistically at par with  $N_1 \times Zn_1$ . The maximum grain yield was recorded with  $N_1 \times Zn_1$  and was varied from 4.54 to 74.91% from  $N_1 \times Zn_3$  to  $N_0 \times Zn_0$ . However,  $N_3 \times Zn_3$  recorded higher zinc content (52.30 mg/kg) and was varied from 21.81 to 45.80 mg/kg. The increase in zinc content was might be owing to positive interaction and the efficient translocation of zinc to grain at later stage of crop phenophase. Similar interaction of N  $\times$  Zn was also reported by Singh *et al.* (2014).

Based on present findings we conclude that phenophase (Zadoks scale)-based scheduling of nitrogen and zinc fertilizer not only improve grain yield and zinc content in grain but also improve the zinc-use efficiency. In case of zinc biofortification, 50% RDN at sowing + 25% RDN at  $Z_{20}$  + 25% RDN at  $Z_{37}$  and 0.25% Zn EDTA spray at  $Z_{45}$  + 0.25% Zn EDTA spray at  $Z_{73}$  significantly interact and recorded the maximum (52.30 mg/kg) zinc content in grain.

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