

## Effect of green manuring and zinc fertilization on productivity and nutrient uptake in *Basmati* rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system

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### ABSTRACT

Field experiments were conducted during *kharif* and *rabi* of 2008-09 and 2009-10 for two consecutive years at New Delhi; to study the effect of summer green manuring crops in conjunction with zinc (Zn) fertilization on productivity and nutrient uptake of *Basmati* rice (*Oryza sativa* L.) - wheat [*Triticum aestivum* (L.) emend. Fiori & Paol] cropping sequence. Among the summer green manuring crops, *dhaincha* (*Sesbania aculeata*) Pers accumulated significantly higher dry matter (7.41 t/ha) and N (180.5 kg/ha) than mungbean [*Vigna radiata* (L.) Wilczek]. Significantly higher grain yield (3.64 t/ha), N and Zn uptake of *Basmati* rice recorded when it was grown after incorporation of *Sesbania aculeata* as compared with cowpea [*Vigna unguiculata* (L.) Walp], mungbean [*Vigna radiata* (L.) Wilczek] and summer fallow. Application of 2.0% zinc-enriched urea (ZEU) 'ZnSO<sub>4</sub>.H<sub>2</sub>O' recorded the highest grain yield (3.79 t/ha) of *Basmati* rice as compared to remaining treatments closely followed by 2.0% ZEU (ZnO). The highest N (159.7 kg/ha) and Zn (3085.3 g/ha) uptake in *Basmati* rice was recorded with 2.0% ZEU (ZnSO<sub>4</sub>.H<sub>2</sub>O) followed by 2.0% ZEU (ZnO) and 0.2% foliar spray of ZnSO<sub>4</sub>.H<sub>2</sub>O. Wheat recorded significantly higher grain yield (3.09 and 3.20 t/ha), N and Zn uptake due to residual effect of summer green manuring crops and Zn fertilization. Significantly higher available nutrients (NPK and Zn) in soil after harvest of *Basmati* rice was recorded with *Sesbania aculeata* green manuring and 2.0% ZEU (ZnSO<sub>4</sub>.H<sub>2</sub>O) Zn fertilization treatment under *Basmati* rice-wheat cropping system. The highest productivity of *Basmati* rice-wheat cropping system was recorded after incorporation of *Sesbania aculeata* and application of 2.0% ZEU (ZnSO<sub>4</sub>.H<sub>2</sub>O).

**Key words :** *Basmati* rice, Fertilization, Green manuring, Nitrogen uptake, Wheat, Yield, Zinc enriched urea

Rice and wheat are the world's most important cereal crops, contributing 45% of the digestible energy and 30% of total protein in the human diet, as well as a substantial contribution to feeding of livestock (Timsina and Connor, 2001). This system accounts for about one-fourth of total food grain production of South-East Asia and about 31% of the total food grain production of India (Prasad, 2005). India and Pakistan are the largest cultivators and exporters of *Basmati* rice. The productivity of *Basmati* rice depends on environmental conditions and agronomic management practices of the area (Oo *et al.*, 2007).

In northern India some farmers, after harvesting of their wheat crop in April, grow short-duration green-manuring crops to improve soil health. Incorporation of *Sesbania* green manuring over the years before transplanting of rice helps in improving DTPA-extractable micro-nutrient cations of the soil (Nayyar and Chhibba, 2000). It may be due to recycling of the micro-nutrients from subsurface layer to the surface layer of the soil and the build-up of organic

carbon in the surface soil layer. Currently, millions of hectares of cropland are affected by Zn deficiency and approximately one-third of the human population suffers from an inadequate intake of Zn. Low Zn content in grains and straw results in poor Zn nutrition of human beings and animals, which has recently received considerable attention (Cakmak, 2008). The recommendation of Zn, which is generally marketed as Zn sulphate monohydrate (ZnSO<sub>4</sub>.H<sub>2</sub>O) varies from 15 to 45 kg/ha/yr, depending on the crop, environment and soil conditions. Therefore, good quality ZEU will be require for Zn and N application to rice crop, this is ideal one from viewpoint of quality and also cost effective. Attempts are therefore being currently made by the fertilizer companies in India to produce ZEU (2.0% Zn either through ZnSO<sub>4</sub>.H<sub>2</sub>O or ZnO), that would allow farmers to apply Zn to crops along with N for increase productivity and N or Zn uptake of *Basmati* rice and succeeding wheat.

### MATERIALS AND METHODS

Field experiments were conducted during the rainy

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(*kharif*) and winter (*rabi*) seasons of 2008-09 and 2009-10 on sandy-clay-loam soil of New Delhi (Ustochrept) having pH 7.5, available N 139.5 kg/ha, P 16.0 kg/ha, K (275 kg/ha) and organic carbon 0.53%. The available DTPA-extractable Zn in soil was 0.68 mg/kg of soil. The summer green manuring crops comprising *viz.*, cowpea 'Pusa Komal', mungbean 'Pusa Vishal', *Sesbania aculeata* and summer fallow were incorporated in main plots before transplanting of Basmati rice in both the years and soil samples were drawn from the plough soil layer to analyze the organic carbon (%), available N-P-K (kg/ha) and Zn (mg/kg). Eight treatments of Zn fertilization *viz.*, absolute control (no N and no Zn), control (only N), 2.0% zinc-enriched urea (ZEU) as  $ZnSO_4 \cdot H_2O$ , 2.0% ZEU as ZnO, 5 kg Zn/ha through  $ZnSO_4 \cdot H_2O$  as soil application, 5 kg Zn/ha through ZnO as soil application, ZnO slurry for dipping rice seedling roots before transplanting of rice and 0.2% foliar spray ( $ZnSO_4 \cdot H_2O$ ) at maximum tillering, pre-flowering and flowering stage, respectively were applied in sub-plots and replicated thrice in split plot design. Twenty five day-old *Basmati* rice 'Pusa Sugandh 4' ('Pusa 1121') seedlings were transplanted at 20 × 10 cm spacing with two seedlings/hill.

The experimental field was disk-ploughed thrice, puddled twice with a heavy puddler in standing water and levelled. At final puddling 26.2 kg P and 33 kg K/ha were broadcast uniformly. N @ 120 kg/ha as prilled urea (PU) or ZEU was applied into two equal splits; half at the time of transplanting and remaining half at panicle initiation stage in all the treatments except absolute control (no N and no Zn) in *Basmati* rice. All the Zn fertilization treatments either by ZEU (2.0% ZEU as  $ZnSO_4 \cdot H_2O$  or ZnO) or direct soil application (as  $ZnSO_4 \cdot H_2O$  or ZnO) supplied 5.0 kg Zn/ha, ZnO slurry and 0.2% foliar spray ( $ZnSO_4 \cdot H_2O$ ) supplied 0.5 and 1.0 kg Zn/ha, respectively. After harvest of *Basmati* rice, wheat 'HD 2851' ('Pusa Vishesh') was sown in the second fortnight of November in both the years at a row spacing of 22.5 cm with a seed rate of 100 kg/ha. Since the objective of this study was to quantify the residual effect of summer green manuring crops and Zn applied to *Basmati* rice on succeeding wheat, no fertilizers (NPK or Zn) was added to succeeding wheat. Yield attributing characters and productivity of *Basmati* rice as well as succeeding wheat were recorded by standard procedure. The concentrations of N and Zn in plant and soil samples were estimated by modified Kjeldahl, alkaline permanganate ( $KMnO_4$ ), di-acid digestion and DTPA-extractable methods. Similarly, the N and Zn uptake by *Basmati* rice and succeeding wheat were determined by multiplying dry matter accumulation with their respective concentrations in grain and straw of *Basmati* rice and succeeding wheat. All the data obtained from

*Basmati* rice and succeeding wheat crop for consecutive two years were statistically analyzed using the *F*-test.

## RESULTS AND DISCUSSION

### *Fresh/dry matter and nutrients accumulation*

Among the summer green manuring crops, *Sesbania aculeata* accumulated significantly higher fresh/dry matter, N, P and K over mungbean and it remained statistically on par to cowpea green manuring crop. The fresh matter accumulated by *Sesbania aculeata* was 8.9 and 71.5% higher over cowpea and mungbean (Table 1). The increase in biomass (fresh/dry) accumulation of *Sesbania aculeata* might be due to its fast and determinate growth habit as compared to cowpea and mungbean. As regard to Zn accumulation, non-significant differences were observed among the green manuring crops while, *Sesbania aculeata* accumulated highest Zn *viz.*, 470.15 g/ha in their dry matter. The increase in N and Zn accumulation with *Sesbania aculeata* was 27.1; 45.2 and 15.0; 22.8% over cowpea and mungbean green manuring.

### *Soil fertility after incorporation of summer green manuring crops*

The total amount of N added in the soil through green manuring crops varied from 132.8 to 188.6 kg/ha and the highest amount was added through *Sesbania aculeata*. Among the summer green manuring crops, *Sesbania aculeata* incorporated plots recorded significantly higher available N and which was 35.2% higher than the initial status of N (Table 2). *Sesbania aculeata* remained on par with cowpea and mungbean green manuring crops and significantly superior to summer fallow with respect to available N. As regard to OC, available P, K and Zn, non-significant variation observed among the green manuring crops as well as summer fallow. However, initial soil fertility was lower than the nutrient status of soil after incorporation of green manuring crops with respect to OC, available N, P, K and Zn. Incorporation of *Sesbania aculeata* residue into soil, fixed more atmospheric N biologically in the soil and also added higher amount of organic matter which is good indicator of soil fertility and improved status of available nutrients in the soil (Dwivedi *et al.*, 2005). Nayyar and Chhibba (2000) also reported significant increase in Zn content after incorporation of *Sesbania aculeata* green manuring.

### *Basmati rice*

#### *Yield attributes*

*Basmati* rice due to *Sesbania aculeata* recorded significantly more number of effective tillers/hill, panicle length and number of grains/panicle when compared with rest of green manuring crops as well as summer fallow (Table 3).

Residue of *Sesbania aculeata* accumulated highest N viz., 180.5 kg/ha (Table 1), P, K and Zn as compared to cowpea and mungbean, finally these nutrients recycled into soil and increase availability of nutrients into soil and led to increased number of effective tillers, panicle length and panicle weight of Basmati rice. Increase in yield attributes might be due to more residual effect of biological N-fixed in the root nodules of previous green manuring crops (Meena and Shivay, 2010).

Zinc fertilization showed significant effect on all the yield attributing characters of Basmati rice. Application of 2.0% ZEU through  $ZnSO_4 \cdot H_2O$  recorded the highest number of grains/panicle, panicle weight and grain weight/panicle and it remained statistically on par with 2.0% ZEU (ZnO) and 5 kg Zn/ha ( $ZnSO_4 \cdot H_2O$ ) as soil application (Table 3). Application of 2.0% ZEU ( $ZnSO_4 \cdot H_2O$ ) remained statistically on par to 5 kg Zn/ha (ZnO) as soil application and 0.2% foliar spray of  $ZnSO_4 \cdot H_2O$  with respect to grain weight/panicle. Significantly highest number of panicle bearing tiller/hill and panicle length also recorded with 2.0% ZEU ( $ZnSO_4 \cdot H_2O$ ). This could be attributed due to the proper supply of Zn and N up to harvesting stages and longer supply of mineralized nitrogen through zinc-enriched urea to the plants (Shivay *et al.*, 2008a).

#### Yield

Significantly higher grain yield of Basmati rice re-

corded when it was grown after incorporation of *Sesbania aculeata*. *Sesbania aculeata* remained on par to cowpea with respect to grain yield of Basmati rice. The grain yield of Basmati rice grown after incorporation of *Sesbania aculeata* was 2.2, 4.3 and 11.0% higher over that after cowpea, mungbean and summer fallow treatments, respectively (Table 3). This was due to the higher dry matter (7.41 t/ha) and N (180.5 kg/ha) accumulated by *Sesbania aculeata* summer green manuring crop which led to also increased grain and straw yield (Porpavai, 2009). The harvest index of Basmati rice was recorded the highest (18.6%), with cowpea green manuring and it remained on par with mungbean and *Sesbania aculeata*, but significantly superior over summer fallow.

Zn fertilization showed significant effect on grain as well as harvest index of Basmati rice. Application of 2.0% ZEU ( $ZnSO_4 \cdot H_2O$ ) recorded significantly higher grain yield over rest of the Zn fertilization treatments except 2.0% ZEU (ZnO). The grain yield of Basmati rice with 2.0% ZEU ( $ZnSO_4 \cdot H_2O$ ) was 40.9 and 12.8% higher over absolute control (no N and no Zn) and control (only N), respectively (Table 3). Increase due to in yield might be to slow release of applied N and Zn from ZEU (Ozkutlu *et al.*, 2006), which might have led to increased photosynthetic activity for longer period and finally increased dry matter accumulation. On other hand, ZnO was inferior to  $ZnSO_4$  with respect to grain yield of rice. Hence, due to better solubility, Zn sulphate-enriched urea produced more

**Table 1.** Fresh/dry matter and total (shoot + root) nutrients accumulated by summer green manuring crops (Pooled data of 2 years)

Treatment	Fresh matter accumulation (t/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Zn (g/ha)
<i>Summer green manuring crops</i>					
Cowpea	35.38 (5.38)*	142.1	18.0	218.4	408.95
Mungbean	22.45 (5.08)	124.3	12.7	130.8	382.90
<i>Sesbania aculeata</i>	38.56 (7.41)	180.5	22.6	267.8	470.15
SEm±	2.25 (0.40)	10.1	1.2	14.4	28.5
CD (P=0.05)	8.81 (1.58)	39.6	4.8	56.4	NS

\*, dry matter accumulation

**Table 2.** Organic carbon (OC) content and available nutrients in soil after residue incorporation of summer green manuring crops (Pooled data of 2 years)

Treatment	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Zn (mg/kg)
<i>Summer green manuring crops</i>					
Cowpea	0.55	177.8	16.2	286.7	0.70
Mungbean	0.55	167.5	15.6	278.3	0.69
<i>Sesbania aculeata</i>	0.57	188.6	16.7	293.5	0.69
Summer fallow	0.52	132.8	15.1	275.7	0.67
SEm±	0.03	10.2	0.94	16.6	0.04
CD (P=0.05)	NS	35.1	NS	NS	NS
Initial status	0.53	139.5	16.0	275.0	0.68

grain yield than ZnO-enriched urea at the same level of Zn enrichment (Shivay *et al.*, 2008b). In present study, foliar spray 0.2% ZnSO<sub>4</sub>.H<sub>2</sub>O was significantly less effective than 2.0% ZEU (ZnSO<sub>4</sub>.H<sub>2</sub>O) and 2.0% ZEU (ZnO) in improving the yield of Basmati rice. The highest harvest index of Basmati rice was recorded with application of 5 kg Zn/ha (ZnSO<sub>4</sub>.H<sub>2</sub>O) as soil application and it remained on par with remaining Zn fertilization treatments except absolute control (no N and no Zn). Harvest index of Basmati rice is controlled by partition of photosynthates between harvesting and non-harvesting organs during crop growth period. The variation in harvest index of rice might be due to variation in partitioning of photosynthates in grain and vegetative organs of the different treatments.

#### Nutrient uptake

The highest N uptake (grain + straw) by Basmati rice was recorded when it was grown after incorporation of *Sesbania aculeata* and it was remained superior than the rest of the green manuring crops as well as summer fallow. Percent increase in N uptake with *Sesbania aculeata* was 5.4, 8.4 and 22.4% over cowpea and mungbean green manuring as well as summer fallow (Table 3). This might be due to increase in the N availability through synchronized released from the ZEU which increased the N concentration proportionately in grain and straw and finally led to higher N uptake with highest level of N (Mhaskar and Thorat, 2005). Green manuring crops also signifi-

cantly influenced the Zn uptake in grain and straw of Basmati rice (Table 3). Incorporation of *Sesbania aculeata* before transplanting recorded significantly higher Zn uptake in grain and straw of Basmati rice over rest of the green manuring crops and summer fallow.

Application of 2.0% ZEU (ZnSO<sub>4</sub>.H<sub>2</sub>O) recorded significantly higher N uptake by Basmati rice as compared to rest of the Zn fertilization treatments including absolute control (no N and no Zn) and control (only N). The highest Zn uptake by Basmati rice was recorded with 2.0% ZEU (ZnSO<sub>4</sub>.H<sub>2</sub>O) and it was significantly superior to the rest of Zn fertilization treatments. The percent increase in Zn uptake with 2.0% ZEU (ZnSO<sub>4</sub>.H<sub>2</sub>O) was in the order of 85.7, 31.6, 27.5 and 5.1 over absolute control (no N and no Zn), control (only N), ZnO slurry and 0.2% foliar spray of ZnSO<sub>4</sub>.H<sub>2</sub>O (Table 3). A single foliar spray of 0.2% ZnSO<sub>4</sub> was not as good as soil application of ZnSO<sub>4</sub>, ZnO and Zn-coated PU for increasing Zn concentrations and their uptake. Therefore, application of N and Zn either through ZEU or through PU increased Zn uptake significantly over absolute control (no N and no Zn).

#### Soil fertility after Basmati rice

*Sesbania aculeata* recorded significantly higher OC, available N, P and K as compared to mungbean and summer fallow. *Sesbania aculeata* was remained statistically on par to cowpea green manuring with respect to available N, P and K in soil (Table 4). Non-significant variation was

**Table 3.** Effect of summer green manuring crops and zinc (Zn) fertilization on yield attributes, yield, N and Zn uptake of Basmati rice (Pooled data of 2 years)

Treatment	Effective tillers/hill	Panicle length (cm)	Panicle weight (g)	Number of grains/panicle	Grain weight/panicle (g)	Grain yield (t/ha)	Harvest index (%)	N uptake (kg/ha)	Zn uptake (g/ha)
<i>Summer green manuring crops</i>									
Cowpea	12.1	24.8	1.94	64.7	1.73	3.56	18.6	145.5	2640.1
Mungbean	11.7	24.5	1.89	64.0	1.71	3.49	18.5	141.4	2587.3
<i>Sesbania aculeata</i>	12.7	25.6	1.98	67.1	1.75	3.64	18.3	153.4	2764.5
Summer fallow	11.4	23.6	1.83	62.0	1.64	3.28	17.6	125.3	2360.4
SEm±	0.10	0.13	0.02	0.60	0.02	0.03	0.16	1.0	27.0
CD (P=0.05)	0.34	0.43	0.07	1.98	0.06	0.08	0.54	3.4	90.0
<i>Zn fertilization</i>									
Absolute control (no N and no Zn)	8.3	22.3	1.68	49.5	1.53	2.69	17.2	102.9	1661.0
Control (only N)	11.3	23.6	1.79	57.0	1.63	3.36	18.1	131.6	2344.0
2.0% ZEU* (ZnSO <sub>4</sub> .H <sub>2</sub> O)	14.2	26.0	2.01	70.1	1.79	3.79	18.3	159.7	3085.3
2.0% ZEU* (ZnO)	12.7	25.7	1.99	69.0	1.78	3.70	18.4	154.0	2909.1
5 kg Zn/ha (ZnSO <sub>4</sub> .H <sub>2</sub> O)	12.5	25.3	1.99	69.2	1.76	3.67	18.6	149.9	2824.2
5 kg Zn/ha (ZnO)	12.4	24.8	1.94	67.2	1.75	3.59	18.5	144.7	2526.5
ZnO slurry	11.9	24.0	1.88	65.2	1.68	3.54	18.5	140.7	2420.1
0.2% Foliar spray (ZnSO <sub>4</sub> .H <sub>2</sub> O)	12.7	25.2	1.97	68.4	1.75	3.60	18.5	147.8	2934.2
SEm±	0.15	0.11	0.01	0.49	0.01	0.04	0.13	1.4	26.9
CD (P=0.05)	0.42	0.32	0.04	1.37	0.04	0.10	0.38	4.1	76.1

ZEU\*; zinc-enriched urea

observed with respect to available Zn content in soil but highest amount of available Zn after harvest of Basmati rice was recorded with cowpea green manuring. The OC content and available N, P, K and Zn increased significantly with the application of Zn fertilization irrespective of Zn sources.

Application of 2.0% ZEU ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ ) recorded highest OC, available N, P, K and Zn content in soil as compared to rest of Zn fertilization treatments. However, application of 2.0% ZEU (ZnO) and 5 kg Zn/ha ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ ) were remained on par to 2.0% ZEU ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ ) with respect to available N (Table 4). Synergistic effect of Zn and N are mainly attributed to increased availability of Zn in soil due to acid forming effect of N (Prasad, 2005). The available P and K in soil after harvest of Basmati rice with application of 2.0%  $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$  was 2.5 and 5.5% higher than the initial status of these nutrients. The highest available Zn content in soil was recorded with 2.0% ZEU ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ ) and this treatment significantly superior when compared with absolute control (no N and no Zn) and control (only N) and remained on par with rest of the Zn fertilization treatments. Significantly higher OC content was recorded with 2.0% ZEU ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ ) when compared with rest of the Zn fertilization treatments. Incorporation of green manure crops into the soil had shown to increase soil organic carbon and high OC responsible for higher nutrient availability by accumulating higher nutrients (Nayyar and Chhibba, 2000).

### Succeeding wheat

#### Yield attributes

Pooled data (2008-09 and 2009-10) on yield attributes and yield of succeeding wheat are given in Table 5. Number of tiller/m<sup>2</sup> and 1,000-grain weight of succeeding wheat recorded significantly higher, when it was grown in the residual of *Sesbania aculeata* as compared to mungbean and summer fallow treatments. Among the Zn fertilization treatments, residual of 2.0% ZEU ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ ) had significant effect on number of tillers/m<sup>2</sup>, spike length and 1,000-grain weight. Application of 2.0% ZEU ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ ) in rice was remained on par to residual of 2.0% ZEU (ZnO), 5 kg Zn/ha ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ ) and 5 kg Zn/ha (ZnO) with respect to spike length and 1,000-grain weight of succeeding wheat. Similar findings were also reported by Shivay *et al.* (2008b).

#### Yield

Wheat recorded the highest grain yield when it was grown in the residual of *Sesbania aculeata* and significantly superior than mungbean and summer fallow. The grain yield of succeeding wheat grown in the residual of *Sesbania aculeata* was 3.0 and 16.6% higher over that after mungbean and summer fallow treatment, respectively (Table 5). However, harvest index recorded significantly higher when it was grown in the residual of cowpea and mungbean as compared to *Sesbania aculeata* and summer fallow treatments.

**Table 4.** Effect of summer green manuring crops and zinc (Zn) fertilization on available nutrients in soil after harvest of Basmati rice (Pooled data of 2 years)

Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	Zn (mg/kg)	OC (%)
<i>Summer green manuring crops</i>					
Cowpea	129.5	15.7	282.7	0.72	0.57
Mungbean	126.3	15.5	275.8	0.71	0.55
<i>Sesbania aculeata</i>	131.2	16.3	283.9	0.71	0.58
Summer fallow	121.5	13.4	267.5	0.66	0.53
SEm±	0.8	0.2	2.2	0.02	0.002
CD (P=0.05)	2.8	0.6	7.2	NS	0.007
<i>Zinc fertilization</i>					
Absolute control (no N and no Zn)	122.1	14.3	265.5	0.65	0.54
Control (only N)	123.8	15.0	270.6	0.68	0.55
2.0% ZEU* ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ )	130.9	16.4	290.2	0.74	0.57
2.0% ZEU* (ZnO)	130.8	15.3	283.9	0.72	0.56
5 kg Zn/ha ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ )	129.1	15.1	279.3	0.73	0.56
5 kg Zn/ha (ZnO)	126.6	15.2	276.9	0.72	0.56
ZnO slurry	125.5	15.1	272.2	0.70	0.56
0.2% Foliar spray ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ )	128.3	15.4	281.2	0.69	0.56
SEm±	0.8	0.2	2.2	0.02	0.002
CD (P=0.05)	2.3	0.4	6.3	0.05	0.006
Initial status	139.5	16.0	275.0	0.68	0.53

ZEU\*; zinc-enriched urea

The highest grain yield of succeeding wheat was recorded with application of 2.0% ZEU ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ ) and it was significantly better than absolute control (no N and no Zn), control (only N), 5 kg Zn/ha (ZnO), ZnO slurry and 0.2% foliar spray of  $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ . The grain yield of succeeding wheat with the residual of 2.0% ZEU ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ ) on an average was 24.0, 11.5, 10.3 and 11.1% increase over absolute control (no N and no Zn), control (only N), ZnO slurry and 0.2% foliar spray of  $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ , respectively. The residual effect of Zn applied to Basmati rice on succeeding wheat yield can be partially explained on the basis of yield attributes. Harvest index of succeeding wheat was not influenced significantly due to residual of various Zn fertilization treatments.

#### Nutrient uptake

Residuals of green manuring crops had a significant effect on N and Zn uptake in grain and straw by succeeding wheat. The increase in N uptake by succeeding wheat with the residual of *Sesbania aculeata* was 3.9, 10.0 and 34.5% over cowpea, mungbean as well as summer fallow treatments (Table 5). Among the green manuring crops, residual of *Sesbania aculeata* recorded significantly higher Zn uptake in grain and straw of succeeding wheat as compared to rest of the treatments. The Zn uptake by succeeding wheat with residual of *Sesbania aculeata* was

2.9, 6.7 and 21.6% higher over cowpea, mungbean and summer fallow treatments, respectively.

Application of 2.0% ZEU ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ ) to Basmati rice increased N and Zn uptake by succeeding wheat when compared with rest of the Zn fertilization treatments (Table 5). The increase in Zn uptake by succeeding wheat with the residual of 2.0% ZEU ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ ) was 42.8, 20.8, 19.2 and 18.3% over absolute control (no N and no Zn), control (only N), 0.2% foliar spray of  $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$  and ZnO slurry treatments, respectively.

#### System Productivity

As regards, the system productivity of Basmati rice-wheat cropping system, the highest productivity (Basmati rice + wheat) of the system was recorded with *Sesbania aculeata* incorporated plots and 2.0% ZEU ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ ) (Table 5). It remained on par with cowpea green manuring and 2.0% ZEU (ZnO). The increase in productivity (Basmati rice + wheat) of system with 2.0% ZEU ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ ) over control (only N) was 1.72 t/ha. It is important to note that if one such material (2.0% ZEU) become available, the farmers will apply both to Basmati rice and succeeding wheat and this is one of the alternative for enhanced the Zn uptake in grain and straw as well as productivity of system (Shivay *et al.*, 2008a).

It is concluded that incorporation of *Sesbania aculeata* green manuring crop before transplanting of Basmati rice

**Table 5.** Effect of summer green manuring crops and zinc (Zn) fertilization on yield attributes, yield, N and Zn uptake of succeeding wheat and system productivity of Basmati rice-wheat cropping system (Pooled data of 2 years)

Treatment	Tillers/ m <sup>2</sup>	Spike length (cm)	1,000-grain weight (g)	Grain yield (t/ha)	Harvest index (%)	N uptake (kg/ha)	Zn uptake (g/ha)	System productivity (t/ha)
<i>Summer green manuring crops</i>								
Cowpea	481	8.0	39.7	3.09	43.1	72.0	571.4	6.65
Mungbean	479	8.1	39.3	3.00	43.1	68.0	551.4	6.49
<i>Sesbania aculeata</i>	484	8.1	40.1	3.09	42.6	74.8	588.3	6.73
Summer fallow	431	7.6	38.2	2.65	42.1	55.6	483.7	5.93
SEm±	0.7	0.1	0.1	0.01	0.06	0.4	1.2	0.04
CD (P=0.05)	2.2	0.3	0.3	0.02	0.20	1.3	4.0	0.10
<i>Zn fertilization</i>								
Absolute control (no N and no Zn)	437	7.3	37.2	2.58	42.5	51.9	436.1	5.27
Control (only N)	464	7.9	39.1	2.87	42.5	64.1	515.6	6.23
2.0% ZEU* ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ )	494	8.3	40.5	3.20	43.1	77.4	622.6	6.99
2.0% ZEU* (ZnO)	477	8.1	40.0	3.11	42.8	73.1	593.8	6.81
5 kg Zn/ha ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ )	477	8.2	40.0	3.10	42.8	73.5	598.9	6.77
5 kg Zn/ha (ZnO)	472	8.1	39.6	3.05	43.0	70.5	574.1	6.64
ZnO slurry	466	7.9	39.2	2.90	42.5	65.8	526.5	6.44
0.2% Foliar spray ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ )	464	7.9	39.1	2.88	42.6	64.7	522.4	6.48
SEm±	2.2	0.2	0.4	0.05	0.40	1.0	8.2	0.09
CD (P=0.05)	6.3	0.5	1.0	0.13	NS	2.7	23.1	0.23

ZEU\*; zinc-enriched urea

and application of 2.0% ZEU ( $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ ) increased and productivity of Basmati rice-wheat cropping system found to be best to enrich the grain and straw of Basmati rice and succeeding wheat with N and Zn.

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