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Research Articles

Yield attributes, yields and nutrient uptake of *Basmati* rice (*Oryza sativa*) as influenced by *in-situ* and *ex-situ* green manuring crops and zinc fertilization

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ABSTRACT

A field experiment was conducted in a split plot design at the research farm of ICAR–Indian Agricultural Research Institute (IARI), New Delhi during summer and *kharif* seasons of 2015 and 2016 to study the influence of *in–situ* and *ex–situ* green manuring and zinc fertilization on nutrient uptake, yield attributes, correlation between yield and yield attributes, and yield of *Basmati* rice (*Oryza sativa* L.). Results of this study revealed that the incorporation of *Sesbania aculeata* green manure @ 33.8 and 35.6 t/ha prior to transplanting of *Basmati* rice during 2015 and 2016, respectively resulted in higher yield attributes and yield of *Basmati* rice compared with *Vigna umbellata*, *Leucaena leucocephala* and summer fallow during both the years. Foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 days after transplanting (DAT) was better than soil application of Zn with regard to yield attributes and yield of *Basmati* rice and uptake of nutrients by the crop. In general, there was significant and positive correlation of grain yield with yield attributes. The uptake of nutrients by the crop was highest with incorporation of *Sesbania aculeata* and lowest in summer fallow.

Key words: *Basmati* rice, *In–situ* and *ex–situ* green manuring, Nutrient uptake, Yield attributes, Zn–EDTA

The rice–wheat cropping system (RWCS) occupying 13.5 million ha (m ha) is important to meet the challenge of food security in the Indo–Gangetic Plains (Bisen and Rahangdale 2017). However, sustainability of this system is at risk due to deterioration of soil health, decrement in total factor productivity and increase in cultivation costs, and reduction in profit margins (Sarkar 2015). Combination of poor soil fertility and inadequate, unbalanced, and inefficient use of fertilizers contributes much to this problem (Singh *et al.* 2017). Consequently, maintaining long-term soil fertility under RWCS is greater concern for the farmers in present scenario. In this concern, green manuring has been known to improve soil fertility with increase in soil organic matter, available nitrogen, concentration of nutrients near the soil surface in available form and reduces the nutrient losses through leaching and soil erosion (Sultani *et al.* 2007, Singh and Shivay 2016).

The role of Zn is as much as important as that of major nutrients in improving productivity of rice (*Oryza sativa* L.) in present scenario (Ghasal *et al.* 2016, Pooniya and Shivay 2013, Shivay *et al.* 2016). Applying Zn fertilizer as soil and foliar spray offers an easy and highly effective ways to correct Zn deficiency problems in crops especially major cereals, viz. rice, wheat and corn, which are inherently low in Zn content (Stein *et al.* 2007, Prasad *et al.* 2014). Several past studies carried out on involvement of green manure and zinc nutrition in rice–wheat cropping system showed a positive impact, however in India such information is scanty. Therefore, a comprehensive study was carried out to study nutrient uptake, yield attributes and yield of *Basmati* rice as influenced by summer green manuring crops and zinc fertilization.

MATERIALS AND METHODS

The field experiment was conducted at the research farm of Division of Agronomy, ICAR-Indian Agricultural Research Institute (IARI), New Delhi during 2015 and 2016 of *kharif* seasons. The soil of the experimental field was sandy clay loam (*typic Ustochrept*) in texture with 51.4% sand, 22.2% silt and 26.4% clay. The soil was medium in organic C, low in available nitrogen and medium in available phosphorus and available potassium and had a *p*H of 7.7. The experiment was conducted in a split plot design, keeping two *in-situ* green manuring crops, viz. *Sesbania aculeata* (dhaincha) and *Vigna umbellata* (rice bean), one *ex-situ* green manuring crop, viz. *Leucaena leucocephala* (subabul) and summer fallow as main-plot treatments and

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four zinc (Zn) fertilization treatments, viz. 5 kg Zn through chelated Zn–EDTA as soil application, 2.5 kg Zn through chelated Zn–EDTA as soil application + 1 foliar application of 0.5% solution of chelated Zn–EDTA at flowering, foliar application of 0.5% solution of chelated Zn–EDTA at active tillering + flowering + grain filling, foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 days after transplanting (DAT) and a control (no Zn) in sub-plots and was replicated thrice. The rice crop was transplanted in the month of July during both years. Nitrogen, phosphorus and potassium were uniformly applied @ 130, 60 and 50 kg/ha respectively to all plots. In foliar spray treatments, 0.5% Zn–EDTA solution at the rate of 500 liters/ha was applied in each spray to supply the Zn.

Nutrient contents at harvest in the plant was determined by drying the samples in hot air oven at 60°C±2°C till a constant dry weight was obtained. Nitrogen in samples was analyzed by using Kjeldahl's apparatus (Piper 1966). The plant samples were digested in di-acid mixture (HNO_3 and $HClO_4$ in the ratio of 10:3) and P content was determined by using Vanado-molybdo-phosphoric acid yellow colour method (Piper 1966). The potassium content was determined by using the flame photometer (Jackson 1973). The Zn concentration in rice grain and straw was determined as per the procedure described by Prasad *et al.* (2006) using Atomic Absorption Spectrophotometry (AAS). The N, P, K and Zn uptake was computed by multiplying the nutrient content with plant biomass. Grain weight/panicle, numbers of grains/panicle and fertility percentage, grain and straw yield were recorded at harvest.

RESULTS AND DISCUSSION

Yield attributes and yields

Yield attributes of *Basmati* rice was significantly influenced by incorporation of *in-situ* and *ex-situ* green-manuring crops during both the years of experimentation (Table 1). The significantly higher values of grains weight/ panicle were recorded when *Basmati* rice was grown after *Sesbania aculeata* incorporation compared with *Leucaena leucocephala, Vigna umbellata*, and fallow treatments. *Sesbania aculeata* produced significantly higher number of grains/panicle compared to *Leucaena leucocephala* and summer fallow. However, it was statistically at par with *Vigna umbellata* during 2015 and 2016. *Sesbania aculeata* recorded higher fertility percentage in *Basmati* rice over *Vigna umbellata*, *Leucaena leucocephala* and summer fallow during both years. Among the Zn fertilization treatments, foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT resulted into higher grains weight/panicle, number of grains/panicle and fertility percentage than rest of Zn fertilization treatments and control (no Zn) during both years. Among the *in-situ* and *ex-situ* green-manuring crops and summer fallow treatment, *Sesbania aculeata* recorded significantly higher grain and straw yields over summer fallow and it was statistically at

Table 1 Effect of *in-situ and ex-situ* green manuring crops and Zn fertilization on yield attributes, grain and straw yields of *Basmati* rice

Treatment	Grains weight/ panicle (g)		Grains/panicle (Nos.)		Fertility percentage (%)		Grain yield (t/ha)		Straw yield (t/ha)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
In-situ and *ex-situ* green manuring crops										
Sesbania aculeata	2.19	2.31	78	82	90.7	92.2	4.63	4.68	9.04	9.14
Leucaena leucocephala	1.99	2.06	74	78	86.4	88.6	4.48	4.52	8.72	8.83
Vigna umbellata	2.07	2.15	78	80	88.4	90.2	4.60	4.64	8.88	8.98
Summer fallow	1.94	1.95	73	74	84.6	86.5	3.83	3.91	7.83	7.80
SEm±	0.014	0.016	1.29	0.7	0.49	0.62	0.055	0.160	0.150	0.107
CD (P=0.05)	0.054	0.063	3.82	2.7	1.92	2.42	0.217	0.627	0.590	0.419
Zn fertilization										
Control (no Zn)	1.54	1.56	73	74	83.2	85.2	3.68	3.71	7.43	7.47
5 kg Zn through chelated Zn–EDTA as soil application	2.06	2.13	76	78	85.4	87.5	4.15	4.21	8.70	8.85
2.5 kg Zn through chelated Zn–EDTA as soil application + 1 *foliar application at flowering	2.11	2.18	77	79	86.8	88.8	4.26	4.32	8.81	8.92
*Foliar application of chelated Zn–EDTA at active tillering + flowering + grain filling stages	2.23	2.31	77	80	90.1	92.0	4.85	4.91	8.87	8.97
*Foliar application of chelated Zn–EDTA at 20, 40, 60 and 80 DAT	2.31	2.41	77	80	92.0	93.4	4.98	5.04	9.27	9.24
SEm±	0.017	0.018	1.3	1.4	0.95	0.91	0.065	0.108	0.180	0.104
CD (P=0.05)	0.050	0.052	3.8	4.0	2.81	2.70	0.194	0.320	0.536	0.309

*0.5% solution of chelated Zn–EDTA (12% Zn) @ 500 litres/ha par with incorporation of *Vigna umbellata* and *Leucaena leucocephala* during 2015 and 2016. Foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT resulted into statistically higher grain and straw yields compared to other Zn fertilization treatments and control (no Zn). However, it remained statistically at par with foliar application of 0.5% solution of chelated Zn–EDTA at active tillering + flowering + grain filling during both years. The highest yield attributes viz. grains weight/panicle, number of grains/panicle and fertility percentage and yield of *Basmati* rice were recorded with incorporation of *Sesbania aculeata* and foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT. This might be due to higher organic matter production and higher supply and uptake of nutrients cations through the incorporation of *Sesbania aculeata*, resulting in more leaf area coverage and thereby producing more leaf dry weight and thus improved yield attributing characters and yield of rice. These observations were in agreement with the findings of Bisht *et al.* (2006) and Pooniya *et al.* (2012). Increase in yield attributes and yield of *Basmati* rice with foliar Zn application might be due to higher Zn uptake, resulting into higher biomass production (Shivay *et al.* 2008) and photosynthates translocation to reproductive parts. Yield attributes and yield of *Basmati* rice was higher with foliar application of 0.5% solution of Zn–EDTA than sole soil application of Zn, because of direct absorption of the Zn by the foliar spray. This proper and adequate supply of Zn increased the uptake of Zn during the grain formation stage and ultimately improved the yield attributes and yields.

Correlation between yield and yield attributes

The correlation between grain yield and yield attributes viz. filled grains/panicle and fertility percentage of *Basmati* rice during 2015 and 2016 are given in Fig 1. There was a positive and higher correlation between grain yield and yield attributes during both years of experimentation. The correlation between yield and filled grains/panicle was 80.9% and 88.6% and yield between and fertility percentage was 89.8% and 92.7% during 2015 and 2016, respectively. Incorporation of *Sesbania aculeata* along with Zn fertilization can lead to better growth, development and yield attributes of rice which resulted in to higher yields of *Basmati* rice.

Nutrient concentrations and uptake

The highest N concentration in grain and straw of *Basmati* rice was recorded when *Basmati* rice was grown

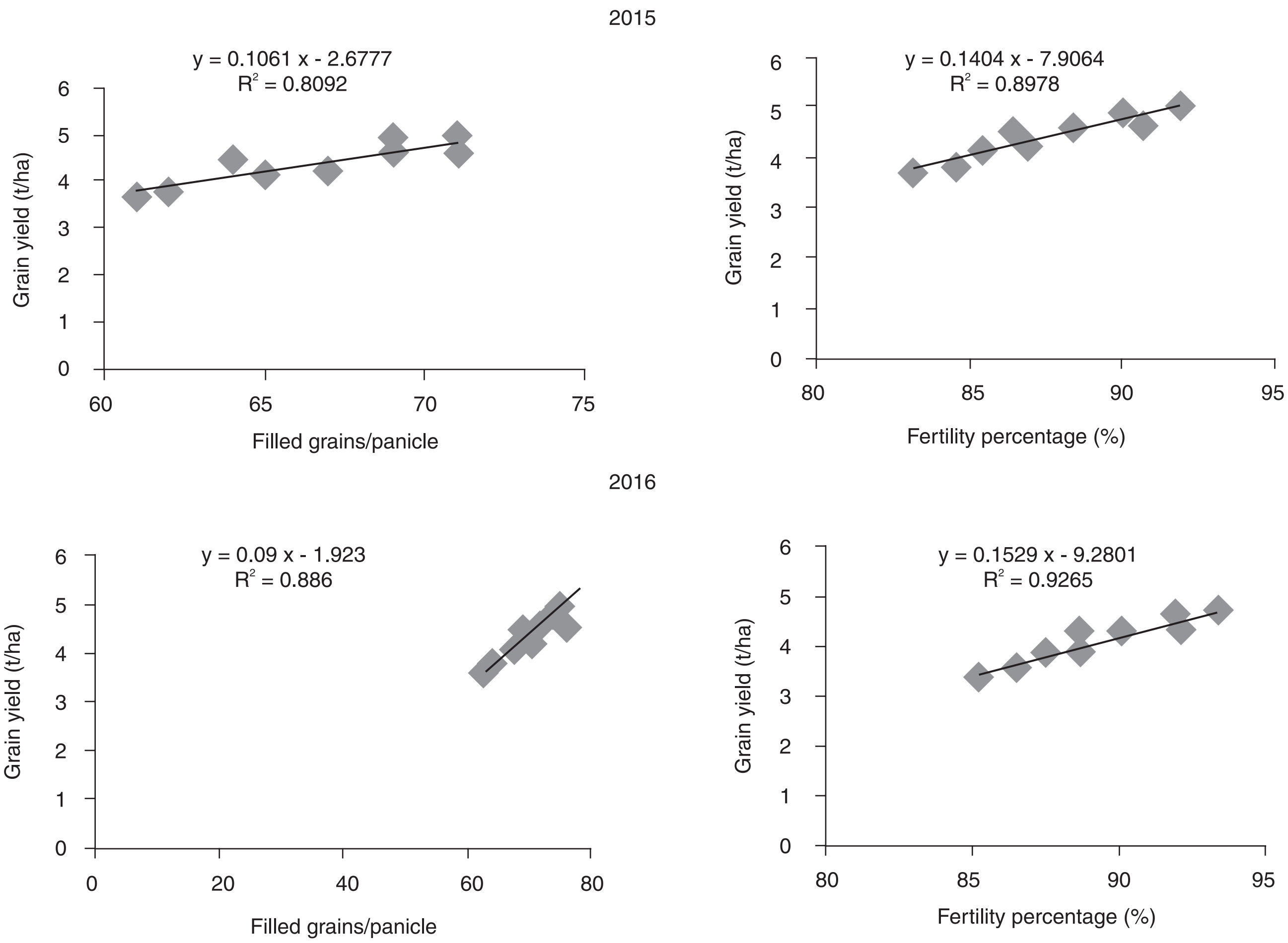

Fig 1 Effect of *in-situ* and *ex-situ* green manuring crops and Zn fertilization on correlation between yield and yield attributes of *Basmati* rice

after the incorporation of *Sesbania aculeata,* which was significantly higher than summer fallow but remained statistically at par with *Vigna umbellata* and *Leucaena leucocephala* during 2015 and 2016 (Table 2). The N uptake of *Basmati* rice grain and straw was highest with *Sesbania aculeata* followed by *Vigna umbellata*, *Leucaena leucocephala* and summer fallow during both years. The total N uptake was significantly higher with *Sesbania aculeata* which remained at par with *Vigna umbellata* and significantly higher than *Leucaena leucocephala* and summer fallow during both years. Among different soil and foliar Zn fertilization treatments, 0.5% solution of foliar application of chelated Zn–EDTA at 20, 40, 60 and 80 DAT resulted into higher nitrogen concentration in grain and straw than other soil and foliar Zn fertilization treatments and control (no Zn) during both years. The N uptake of *Basmati* rice grain and total uptake of N was recorded highest with foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT and it was significantly higher than other zinc fertilization treatments during 2015 and 2016. The N uptake of *Basmati* rice straw was significantly higher with foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT than other zinc fertilization treatments during 2015, while it was statistically at par with foliar application of chelated Zn–EDTA at active tillering + flowering + grain filling in 2016. Incorporation of *Sesbania aculeata* and foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT recorded the highest N concentration and uptake of *Basmati* rice which might be due to better physico–chemical soil properties and higher N availability which in turn resulted in higher N concentration and uptake by rice. Similar findings had also been recorded by Singh (2013) and Singh and Shivay (2016).

The highest P concentration in grain and straw of *Basmati* rice was recorded when it was grown after the incorporation of *Sesbania aculeata.* However there were non-significant differences with *Vigna umbellata*, *Leucaena leucocephala* and summer fallow during both years (Table 3). The P uptake of *Basmati* rice grain and straw and total P uptake was recorded highest with *Sesbania aculeata* among *in-situ* and *ex-situ* green manuring crops and summer fallow during both years. Among Zn fertilization, 0.5% solution of foliar application of chelated Zn–EDTA at 20, 40, 60 and 80 DAT recorded higher P concentration in grain and straw of *Basmati* rice over the other Zn fertilization treatments and it was only significantly higher over control (no Zn) during 2015 and 2016. The P uptake of *Basmati* rice grain and straw and total P uptake was recorded highest with foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT and it was significantly higher

Table 2 Effect of *in-situ* and *ex-situ* green manuring crops and Zn fertilization on N concentration and uptake in grain, straw and total N uptake of *Basmati* rice

Treatment	N concentration in grain (%)		N concentration in straw (%)		N uptake by grain (kg/ha)		N uptake by straw (kg/ha)		Total N uptake (kg/ha)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
In-situ *and* ex-situ *green manuring crops*										
Sesbania aculeata	1.33	1.36	0.57	0.59	62.0	64.0	51.7	54.2	113.7	118.2
Leucaena leucocephala	1.32	1.33	0.55	0.57	59.2	60.6	47.9	50.3	107.2	110.9
Vigna umbellata	1.33	1.35	0.56	0.58	61.2	63.0	49.7	52.1	111.0	115.1
Summer fallow	1.28	1.29	0.53	0.55	49.1	50.5	41.6	42.9	90.7	93.5
SEm±	0.008	0.010	0.006	0.007	0.51	1.99	0.49	0.63	0.72	1.73
CD (P=0.05)	0.033	0.041	0.023	0.028	2.02	7.82	1.93	2.49	2.83	6.77
Zinc fertilization										
Control (no Zn)	1.25	1.26	0.52	0.54	46.1	46.6	39.0	40.6	85.1	87.2
5 kg Zn through chelated Zn–EDTA as soil application	1.32	1.34	0.54	0.56	54.6	56.4	47.4	49.9	102.0	106.4
2.5 kg Zn through chelated Zn–EDTA as soil application + 1 *foliar application at flowering	1.32	1.35	0.55	0.57	56.4	58.2	48.8	51.1	105.2	109.4
*Foliar application of chelated Zn–EDTA at active tillering + flowering + grain filling stages	1.34	1.36	0.56	0.58	65.0	67.0	50.2	52.5	115.1	119.4
*Foliar application of chelated Zn–EDTA at 20, 40, 60 and 80 DAT	1.35	1.37	0.58	0.60	67.3	69.5	53.4	55.2	120.7	124.7
SEm±	0.007	0.008	0.010	0.011	0.36	0.63	0.92	0.94	1.00	1.04
CD (P=0.05)	0.020	0.022	0.031	0.032	1.07	1.87	2.74	2.79	2.98	3.10

*0.5% solution of chelated Zn–EDTA (12% Zn) @ 500 L/ha

Table 3 Effect of *in-situ* and *ex-situ* green manuring crops and Zn fertilization on P concentration and uptake in grain, straw and total P uptake of *Basmati* rice

Treatment	P concentration in grain (%)		P concentration in straw (%)		P uptake by grain (kg/ha)		P uptake by straw (kg/ha)		Total P uptake (kg/ha)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
In-situ *and* ex-situ *green manuring crops*										
Sesbania aculeata	0.142	0.144	0.122	0.124	6.6	6.8	11.1	11.4	17.7	18.2
Leucaena leucocephala	0.140	0.142	0.119	0.121	6.3	6.5	10.4	10.7	16.7	17.1
Vigna umbellata	0.141	0.143	0.121	0.123	6.5	6.7	10.8	11.0	17.3	17.7
Summer fallow	0.139	0.140	0.116	0.117	5.3	5.5	9.1	9.2	14.5	14.7
SEm±	0.0019	0.0011	0.0018	0.0019	0.06	0.21	0.13	0.11	0.23	0.30
CD (P=0.05)	NS	NS	NS	NS	0.22	0.82	0.53	0.43	0.90	1.16
Zn fertilization										
Control (no Zn)	0.127	0.127	0.111	0.112	4.7	4.7	8.3	8.4	12.9	13.1
5 kg Zn through chelated Zn–EDTA as soil application	0.143	0.145	0.120	0.122	5.9	6.1	10.4	10.8	16.4	16.9
2.5 kg Zn through chelated Zn–EDTA as soil application + 1 *foliar application at flowering	0.144	0.145	0.121	0.123	6.1	6.3	10.7	11.0	16.8	17.2
*Foliar application of chelated Zn–EDTA at active tillering + flowering + grain filling stages	0.145	0.146	0.122	0.124	7.0	7.2	10.8	11.1	17.9	18.3
*Foliar application of chelated Zn–EDTA at 20, 40, 60 and 80 DAT	0.146	0.148	0.123	0.126	7.3	7.5	11.5	11.6	18.7	19.1
SEm±	0.0018	0.0011	0.0011	0.0012	0.06	0.09	0.10	0.12	0.15	0.13
CD (P=0.05)	0.0053	0.0032	0.0033	0.0035	0.16	0.26	0.29	0.35	0.45	0.40

*0.5% solution of chelated Zn–EDTA (12% Zn) @ 500 litres/ha

compared to other zinc fertilization treatments during 2015 and 2016. Incorporation of *Sesbania aculeata* and foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT recorded the highest P concentration and uptake of *Basmati* rice which might be due to continuous supply of P to crop throughout growing season which resulted in to higher growth and development of plants, leading to higher P concentrations and their uptake. The present findings were quite similar with those of Shivay *et al.* (2015) and Pooniya and Shivay (2013).

The highest K concentration in grain and straw of *Basmati* rice was recorded when *Basmati* rice was grown after the incorporation of *Sesbania aculeata* which was non–significant with *Vigna umbellata*, *Leucaena leucocephala* and summer fallow during 2015 and 2016 (Table 4). The K uptake of rice grain was recorded highest with *Sesbania aculeata* which was significantly higher than summer fallow but remained statistically par with *Vigna umbellata* and *Leucaena leucocephala* during both years of experimentation. The K uptake by straw and total K uptake of rice were also recorded highest with *Sesbania aculeata* which was significantly higher than *Vigna umbellata, Leucaena leucocephala* and summer fallow during both years of experimentation. Among Zn fertilization, foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT recorded higher K concentration in *Basmati* rice grain but it was non-significant over other Zn fertilization treatments and control (no Zn) during both years. The K concentration in rice straw was highest with foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT during both years. The K uptake of *Basmati* rice grain was recorded highest with foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT. However, it remained at par with foliar application of 0.5% solution of chelated Zn–EDTA at active tillering + flowering + grain filling and significantly higher than rest of Zn fertilization treatments. The K uptake of *Basmati* rice straw and total K uptake was recorded highest with foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT and it was significantly higher than other zinc fertilization treatments during 2015 and 2016. Incorporation of *Sesbania aculeata* and foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT recorded the highest K concentration and uptake which might be due to higher organic matter produced by green manure crops. Organic matter is considered reservoir of several nutrients in soil which in turn resulted in to

Table 4 Effect of *in-situ* and *ex-situ* green manuring crops and Zn fertilization on K concentration and uptake in grain, straw and total K uptake of *Basmati* rice

Treatment	K concentration in grain (%)		K concentration in straw (%)		K uptake by grain (kg/ha)		K uptake by straw (kg/ha)		Total K uptake (kg/ha)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
In-situ *and* ex-situ *green manuring crops*										
Sesbania aculeata	0.28	0.30	1.60	1.62	13.2	14.2	145.1	148.6	158.3	162.8
Leucaena leucocephala	0.26	0.28	1.56	1.58	11.7	12.6	136.0	139.3	147.7	152.0
Vigna umbellata	0.27	0.29	1.59	1.61	12.5	13.5	141.2	144.7	153.8	158.2
Summer fallow	0.25	0.26	1.54	1.56	9.6	10.2	120.7	121.7	130.3	131.8
SEm±	0.009	0.011	0.016	0.010	0.55	0.65	0.73	0.64	1.02	0.94
CD (P=0.05)	NS	NS	NS	NS	2.17	2.56	2.88	2.53	4.00	3.68
Zinc fertilization										
Control (no Zn)	0.25	0.25	1.53	1.55	9.1	9.4	113.7	115.5	122.8	125.0
5 kg Zn through chelated Zn–EDTA as soil application	0.26	0.27	1.57	1.58	10.6	11.5	136.4	140.3	147.1	151.8
2.5 kg Zn through chelated Zn–EDTA as soil application + 1 *foliar application at flowering	0.27	0.28	1.57	1.60	11.3	12.3	138.8	142.5	150.1	154.7
*Foliar application of chelated Zn–EDTA at active tillering + flowering + grain filling stages	0.27	0.29	1.59	1.61	13.3	14.4	141.2	144.5	154.5	158.9
*Foliar application of chelated Zn–EDTA at 20, 40, 60 and 80 DAT	0.29	0.31	1.60	1.62	14.4	15.5	148.7	150.0	163.1	165.6
SEm±	0.013	0.012	0.017	0.009	0.56	0.59	0.81	0.99	1.02	1.09
CD (P=0.05)	NS	NS	0.051	0.027	1.66	1.75	2.40	2.94	3.02	3.24

*0.5% solution of chelated Zn–EDTA (12% Zn) @ 500 litres/ha

higher K uptake by rice. Singh (2013) also reported similar findings in his study.

The Zn concentration in grain and straw of *Basmati* rice was recorded highest when *Basmati* rice was grown after the incorporation of *Sesbania aculeata* and remained at par with *Vigna umbellata*, *Leucaena leucocephala* and summer fallow during 2015 and 2016 (Table 5). *Sesbania aculeata* incorporation before the transplanting of rice recorded the highest Zn uptake by grain and straw and total Zn uptake among *in-situ* and *ex-situ* green manuring crops and summer fallow during both years. These results were in the conformity with those of Pooniya and Shivay (2013). Foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT recorded the highest Zn concentration in grain and straw and it was significantly higher over control (no Zn) during 2015 and 2016. Zn uptake by grain with foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT was at par with foliar application of 0.5% solution of chelated Zn–EDTA at active tillering + flowering + grain filling and significantly higher over rest of Zn treatments and control during 2015 and 2016. However, foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT recorded significantly higher Zn uptake by straw and total Zn uptake than other Zn fertilization treatments and control during both years of experimentation. Incorporation of *Sesbania aculeata* and foliar application of 0.5% solution of chelated Zn–EDTA at 20, 40, 60 and 80 DAT recorded highest Zn concentration and uptake of rice which might be due to increase in the Zn availability to plants and higher yields of *Basmati* rice, which finally led to increased Zn uptake. Similar results were also observed by Pooniya and Shivay (2013) in their study.

It was concluded that incorporation of *Sesbania aculeata* as green manure crop before transplanting of rice and foliar Zn fertilization may be the better options in terms of nutrient uptake, yield attributes and yield of *Basmati* rice than other *in-situ* and *ex-situ* green manure crops and Zn fertilization strategy.

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Table 5 Effect of *in-situ* and *ex-situ* green manuring crops and Zn fertilization on Zn concentration and uptake in grain, straw and total Zn uptake of *Basmati* rice

Treatment	Zn concentration in grain (mg/kg grain)		Zn concentration in straw (mg/kg straw)		Zn uptake by grain (g/ha)		Zn uptake by straw (g/ha)		Total Zn uptake (g/ha)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
In-situ *and* ex-situ *green manuring crops*										
Sesbania aculeata	27.6	28.1	145.7	157.8	129.4	133.3	1321.6	1453.2	1451.1	1586.5
Leucaena leucocephala	26.7	27.1	144.4	155.5	121.0	124.2	1264.4	1381.1	1385.4	1505.3
Vigna umbellata	27.3	27.7	144.6	156.1	126.8	130.1	1289.2	1411.6	1416.1	1541.7
Summer fallow	23.3	23.5	139.0	151.6	89.4	92.2	1088.7	1184.9	1178.0	1277.0
SEm±	1.22	1.24	1.58	1.02	5.62	5.33	15.77	13.49	19.05	17.07
CD (P=0.05)	NS	NS	NS	NS	22.05	20.94	61.91	52.97	74.80	67.02
Zinc fertilization										
Control (no Zn)	21.7	21.6	135.1	131.8	79.9	80.2	1004.8	984.4	1084.6	1064.6
5 kg Zn through chelated Zn–EDTA as soil application	26.0	26.5	140.7	159.0	108.3	111.6	1224.5	1407.8	1332.8	1519.4
2.5 kg Zn through chelated Zn–EDTA as soil application + 1 *foliar application at flowering	27.1	27.6	140.8	160.1	115.9	119.7	1241.0	1429.2	1357.0	1548.8
*Foliar application of chelated Zn–EDTA at active tillering + flowering + grain filling stages	27.6	28.1	143.2	160.6	135.2	139.4	1272.0	1441.8	1407.2	1581.2
*Foliar application of chelated Zn–EDTA at 20, 40, 60 and 80 DAT	28.7	29.2	157.3	164.8	144.0	148.7	1462.7	1525.2	1606.6	1673.9
SEm±	0.84	0.81	1.18	0.84	3.97	4.20	12.95	9.38	13.58	11.84
CD (P=0.05)	2.49	2.42	3.50	2.48	11.79	12.47	38.47	27.88	40.36	35.19

*0.5% solution of chelated Zn–EDTA (12% Zn) @ 500 l/ha

REFERENCES

Bisen N and Rahangdale C P. 2017. Crop residues management option for sustainable soil health in rice–wheat system: A review. *International Journal of Chemical Studies* **5**(4): 1038–42.

Bisht P S, Pandey P C and Singh D K. 2006. Effect of different sources of nutrients on rice (*Oryza sativa*) yield and soil nutrient status in rice–wheat cropping. (*In*) *National Symposium on Conservation Agriculture and Environment*, October 26-28, Banaras Hindu University, Varanasi, India.

Ghasal P C, Shivay Y S, Pooniya V, Kumar P and Verma R K. 2016. Zinc fertilization enhances growth and quality parameters of aromatic rice (*Oryza sativa* L.) varieties. *Indian Journal of Plant Physiology* **21**(3): 323–32.

Jackson M L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Pvt Ltd, New Delhi.

Piper C S. 1966. *Soil and Plant Analysis*, pp 250-1. Hans Publishers, Bombay, Maharashtra.

Pooniya V and Shivay Y S. 2013. Enrichment of *Basmati* rice grain and straw with zinc and nitrogen through ferti-fortification and summer green manuring under Indo-Gangetic Plains of India. *Journal of Plant Nutrition* **36(**1): 91–117.

Pooniya V, Shivay Y S, Rana A, Nain L and Prasanna R. 2012. Enhancing soil nutrient dynamics and productivity of *Basmati* rice through residue incorporation and zinc fertilization. *European Journal of Agronomy* **41**: 28–37.

Prasad R, Shivay Y S and Kumar D. 2014. Agronomic biofortification of cereal grains with iron and zinc. *Advances in Agronomy* **125**: 55–91.

Prasad R, Shivay Y S, Kumar D and Sharma S N. 2006. *Learning by Doing Exercises in Soil Fertility (A practical manual for soil fertility)*, Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi, p 68.

Sarkar S. 2015. Management practices for enhancing fertilizer use efficiency under rice–wheat cropping system in the Indo-Gangetic Plains. *Innovare Journal of Agricultural Science* **3**(2): 5–10.

Shivay Y S, Kumar D and Prasad R. 2008. Relative efficiency of zinc sulfate and zinc oxide-coated urea in rice–wheat cropping system. *Communications in Soil Science and Plant Analysis* **39**(7 and 8): 1154–67.

Shivay Y S, Prasad R and Pal M. 2015. Effects of source and method of zinc application on yield, zinc bio-fortification of grain, and Zn uptake and use efficiency in chickpea (*Cicer arietinum* L.). *Communication in Soil Science and Plant Analysis* **46:** 2191–2200.

Shivay Y S, Prasad R, Kaur R and Pal M. 2016. Relative efficiency of zinc sulphate and chelated zinc on zinc biofortification of rice grains and zinc use-efficiency in *Basmati* rice. *Proceedings of the National Academy of Sciences, India, Section B Biological Sciences* **86**(4): 973–84.

Singh A and Shivay Y S. 2016. Effect of summer green manuring crops and zinc fertilizer sources on productivity, Zn-uptake and economics of *Basmati* rice. *Journal of Plant Nutrition* **39**(2): 204-18.

Singh A. 2013. Effect of summer green manuring crops and zinc fertilizer sources on productivity and quality of aromatic rice (*Oryza sativa* L.)–durum wheat (*Triticum durum* Desf.) cropping system. Ph D thesis, ICAR-Indian Agricultural Research Institute, New Delhi.

Singh S, Bohra J S, Singh Y V, Upadhyay A K, Verma S S, Mishra P K and Raghuveer M. 2017. Effect of integrated nutrient management on growth and development stages of rice under rice–wheat ecosystem. *International Journal of Current Microbiology and Applied Sciences* **6**: 2032–42.

Singh A and Shivay Y S. 2014. Enhancement of growth parameters and productivity of *Basmati* rice through summer green manuring and zinc fertilization. *International Journal of Bio-resource and Stress Management* **5(4):** 486–94.

Stein A J, Nestel P, Meenakshi J V, Qaim M, Sachdev H P S and Bhutta Z A. 2007. Plant breeding to control zinc deficiency in India: How cost-effective is bio-fortification? *Public Health and Nutrition* **10**: 492–501.

Sultani M I, Gill M A, Anwar M M and Athar M. 2007. Evaluation of soil physical properties as influenced by various green manuring legumes and phosphorus fertilization under rain fed conditions. *International Journal of Environmental Science and Technology* **4**(1): 109–18.