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Full Research Article

Enhancement of Growth Parameters and Productivity of Basmati Rice through Summer Green Manuring and Zinc Fertilization

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Abstract

Field experiments were conducted during summer and rainy (*kharif*) seasons (April-November) of 2009 and 2010 for two consecutive years at the research farm of the Indian Agricultural Research Institute, New Delhi, to evaluate the effects of summer green manuring crops and zinc (Zn) fertilizer sources on growth and physiological development of *Basmati* rice (*Oryza sativa* L.). Summer green manure residue incorporation and zinc fertilization significantly enhanced the growth and physiological development of *Basmati* rice. Incorporation of *Sesbania aculeata* (Dhaincha) led to a significant increase in growth parameters, yield attributes and grain and straw yields of succeeding *Basmati* rice. EDTA-chelated Zn (12% Zn) application significantly improved the growth parameters, yield attributes and grain and straw yields of succeeding *Basmati* rice over other zinc sources as well as control (no zinc application). *Sesbania aculeata* (Dhaincha) residue incorporation and EDTA-chelated Zn (12% Zn) treatments were found to be a better combination with respect to *Basmati* rice growth and physiological development. The correlation among the various yield attributes and yield indicated that all the yield attributes were highly correlated with yield. Thus, adequate Zn fertilization along with green manure incorporation can lead to better growth and physiological development for higher productivity of *Basmati* rice.

1. Introduction

Rice (*Oryza sativa* L.) is the most important food for more than 50% of the world's population, and it is grown on almost 163 million ha of the world's surface. World rice production in 2011 was approximately 722 million tonnes (mt), with more than 90% produced in Asia (Fertiliser Statistics, 201213). At least 114 countries grow rice. China is the world's largest rice producer, accounting for 28% of total world production, followed by India (22%), Indonesia (9%), and Bangladesh (7%). India is first in terms of area (44 million ha) and second in production (157.9 m t) of paddy, next only to China. However, the average productivity of paddy in India is only 3.59 t ha^{-1} compared with a world average of 4.43 t ha^{-1}, still well below the world average, although increasing marginally (Fertiliser Statistics, 2012-13). *Basmati* rices are premier rices grown in north-western India and Pakistan. These rice cultivars are preferred for their long and slender kernels which expand to 3-4 times their original length and remain fluffy on cooking.

Paddy (rice) soils are usually deficient in organic matter because of high temperature and moisture, which causes rapid decomposition of organic matter (Mohammed et al., 2005). The application of green manures to soil is considered a good management practice in any agricultural production system because it can increase cropping system sustainability by reducing soil erosion and ameliorating soil physical properties, by increasing soil organic matter and fertility levels (Mandal et al., 2003), by increasing nutrient retention and by reducing global warming potential (Robertson et al., 2000). In northern India some farmers, after harvesting of their wheat crop in the month of April, grow short-duration summer green-manuring crops to add nutrients to the soil by incorporating residue before transplanting *Basmati* rice. Typically, green manuring crops are grown for a specific-period, and then ploughed and incorporated into the soil. Green manures usually perform multiple functions including soil improvement and soil protection, as well as enhancing soil microbial biomass and enzymatic activity.

The low availability of zinc (Zn) in soils is one of the widest ranging abiotic stresses in rice production areas throughout the world, especially in India, Pakistan, China, Australia, Turkey and USA. On average, 50% of the Indian soils are deficient in Zn, particularly rice soils due to the formation of insoluble Zn hydroxide and its carbonate (Singh and Abrol, 1986 and Rattan and Shukla, 1991). However, Zn was one of the first micronutrients known to be essential for plants, animals, and man (Kabata-Pendias, 2000), and yet, in spite of that knowledge, Zn deficiencies still plague us today (Prasad, 2006; Prasad et al., 2014). Zn plays an important role in different plant metabolism processes like the development of cell walls, respiration, carbohydrates metabolism and gene expression and its regulation (Klug and Rhodes, 1987). Zn deficiency is the most widespread micronutrient disorder among different crops (Dobermann and Fairhurst 2000; Cakmak 2004; Prasad 2009; Prasad 2010; Shivay et al., 2014). The deficiency of this micronutrient frequently occurs in rice which is very sensitive to low Zn supply in submerged rice soils (Fageria, 2001; Karak et al., 2005; Naik and Das, 2008). Crop response to Zn fertilization varies with the Zn fertilizer source (Karak et al., 2005). Zn deficiency is usually corrected through the application of inorganic salts, mainly $ZnSO_4.7H_2O$, $ZnSO_4.H_2O$ or ZnO. Other sources are the chelated forms of Zn such as Zn-EDTA, which supplies substantial amount of Zn to the plants without interacting with soil components because the central metal ion Zn^{2+} is surrounded by chelate ligands (Mortvedt, 1979). Further, the application of different Zn fertilizer sources along with green manure crop residue incorporation in soil may exhibit their differential efficiency by interacting with soil components resulting in varying Zn availability to rice plants, this ultimately affect the growth and development of plants.

Therefore, considering the above-mentioned facts, field experiments were undertaken to study the effect of green-manuring crops and Zn fertilizer sources on the growth, yield attributes and yields of *Basmati* rice under summer green manure-*Basmati* rice cropping sequence. The results may be helpful in planning an efficient management strategy for improved Zn nutrition especially for rice crop grown in intensive cropping systems for its better growth and development.

2. Materials and Methods

Field experiments were conducted for two consecutive years at the research farm of the Indian Agricultural Research Institute, New Delhi, India during summer-*kharif*/rainy- seasons of 2009 and 2010 on a sandy clay-loam soil (*typic Ustochrept*). The experiments in both the years were conducted with a fixed lay-out plan on the same site. The institute farm is located at a latitude of 28°38' N, at a longitude of 77°10' E and at an altitude of 228.6 meters above the mean sea level. The mean annual rainfall of New Delhi is 650 mm and more than 80% generally occurs during the south-west monsoon season (July-September) with mean annual evaporation of 850 mm. The soils of experimental field had 135.75 kg ha^{-1} alkaline permanganate oxidizable nitrogen (N) (Subbiah and Asija, 1956), 16.04 kg ha^{-1} available phosphorus (P) (Olsen et al., 1954), 292.10 kg ha^{-1} 1 *N* ammonium acetate exchangeable potassium (K) (Hanway and Heidel, 1952) and 0.53% organic carbon (C) (Walkley and Black, 1934). The *p*H of soil was 7.5 (1: 2.5 soil and water ratio) (Prasad et al., 2006) and diethylene triamine penta acetic acid (DTPA)-extractable Zn (Lindsay and Norvell, 1978) in soil was 0.67 mg kg^{-1} of soil. The critical level of DTPA-extractable Zn for rice grown on alluvial soils in the rice-wheat belt of North India varies from 0.38-0.90 mg kg^{-1} soil (Takkar et al., 1997) and thus, the response of *Basmati* rice to Zn application was expected on the experimental field.

The experiment was conducted in a split plot design, keeping three green manuring crops viz. *Sesbania aculeata* (Dhaincha), *Crotalaria juncea* (Sunhemp), and *Vigna unguiculata* (Cowpea) and one summer fallow treatment as main-plot treatments and five Zn sources viz. $ZnSO_4.7H_2O$ (21% Zn), $ZnSO_4.H_2O$ (33% Zn), ZnO (82% Zn), $ZnSO_4.7H_2O$+ZnO (50%+50%), EDTA-chelated Zn (12% Zn) and a control (no Zn application) in sub-plots and was replicated thrice. After 42-days the summer green manuring crops were incorporated into the soil before transplanting of rice. The experimental field was disk-ploughed twice, puddled three times with a puddler in standing water and levelled. At final puddling 26 kg P ha^{-1} as single superphosphate and 33 kg K ha^{-1} as muriate of potash was broadcasted. Nitrogen @ 120 kg ha^{-1} as prilled urea was applied into two equal splits, half at the time of transplanting and remaining half at panicle initiation stage (40 DAT). In all the Zn treatments uniformly 5 kg Zn ha^{-1} was applied to *Basmati* rice. Three 25-day-old seedlings of *Basmati* rice variety 'Pusa *Basmati* 1' was transplanted at 20×10 cm in the first fortnight of July in both the years of study. Rice crop was grown as per recommended package of practices and was harvested in the second fortnight of October in both the years of experimentation.

Plant height for the *Basmati* rice was measured at periodic intervals of 30 days till harvest from the base of the plant at ground surface to the tip of the tallest leaf/panicle using a standard meter scale and was expressed in cm. Numbers of tillers were noted by counting from the sampling unit periodically at 30 days interval and was expressed on tillers $hill^{-1}$ basis. Five hills were selected periodically at 30 days interval for recording of total dry matter accumulation by *Basmati* rice. These plants were then air dried and further dried in a hot air oven at 60±2°C till constant weight was obtained. Dry weight was recorded and was expressed on grams hill^{-1} basis. Leaf area was measured by separating leaves from the stem, cleaning the leaves with deionized water and drying them with tissue paper. The area of fresh green leaves for each treatment was measured by using a leaf area meter (Model LICOR 3000, USA) and was expressed in cm^2 plant^{-1}. Leaf area index (LAI) was calculated at the 30, 60 and 90 DAT stage using the formula as suggested by Evans (1972). From the ten selected panicles, grains were separated and cleaned. The grain weight per panicle was recorded. The filled and unfilled grains were separated. The number of filled and unfilled (chaffy) grains was counted with the help of a seed counter (Numigral II). The mean value of filled and unfilled (chaffy) grains per panicle was computed and was expressed as numbers of filled and unfilled (chaffy) grains per panicle. From the total number of filled grains and unfilled grains per panicle, the fertility percentage was worked out as:

Fertility (%)=(Number of filled grains per panicle/Total grains per panicle)×100

The 1,000-filled grains, taken from sampled panicles, were first counted by a seed counter and then weighed to compute the 1,000-grain weight.

Harvesting of *Basmati* rice was undertaken as soon as it attained the harvest maturity. The harvesting was done with sickles after leaving the border area. Net plots were demarcated at first from the portion of the plot kept for recording grain yield. Plants from the demarcated net plot area were harvested, tied in bundles and taken to the threshing floor for drying and threshing. The harvested plants were dried for 3-4 days to bring down the moisture content to around 14%. After threshing, the seeds were cleaned, sun-dried and their weight was recorded. The yields in kg plot^{-1} were converted to t ha^{-1}. The weight of the harvested plants after sun drying and before threshing was recorded. Straw yield was obtained by deducting the seed weight from the total weight. The grain and straw yields were expressed in t ha^{-1}.

All the replicated data obtained from the experiments for consecutive two years of study were statistically analysed using the F-test as per the procedure given by Gomez and Gomez (1984). Least significant difference (LSD) values at p=0.05 were used to determine the significance of differences between treatment means. Correlation and regression analysis was done by using SPSS 11.5 package of statistical analysis.

3. Results and Discussion

3.1. Fresh and dry matter accumulation by summer green manuring crops

Among the summer green manuring crops, dhaincha recorded significantly higher total fresh and dry matter accumulation compared with sunhemp and cowpea in 2009 and 2010 (Figures 1 and 2). Further, sunhemp recorded significantly higher fresh and dry matter over cowpea, but was significantly lower than dhaincha during both the years. The increase in biomass (fresh/dry) accumulation of dhaincha can be due to its fast and determinate growth habit leading to enhanced biomass incorporation/addition and nutrient availability in soil.

3.2. Basmati rice growth parameters

In general, all the growth parameters of *Basmati* rice got significantly influenced by green manure crop residue incorporation and Zn fertilization during 2009 and 2010. Among different Zn fertilizer sources used, EDTA-chelated Zn (12% Zn) resulted into significantly higher plant height and leaf area index (LAI) (Table 1), numbers of tillers hill^{-1} and dry matter accumulation (Table 2) of *Basmati* rice at all the growth stages during both the years. Application of $ZnSO_4.7H_2O$ (21% Zn) were next best treatment with respect to growth parameters, but was significantly lower than EDTA-chelated Zn (12% Zn). However, application of ZnO (82% Zn) was least effective with respect to growth parameters, although it significantly increased growth parameters compared to the control (no Zn application). The lowest values of growth parameters were

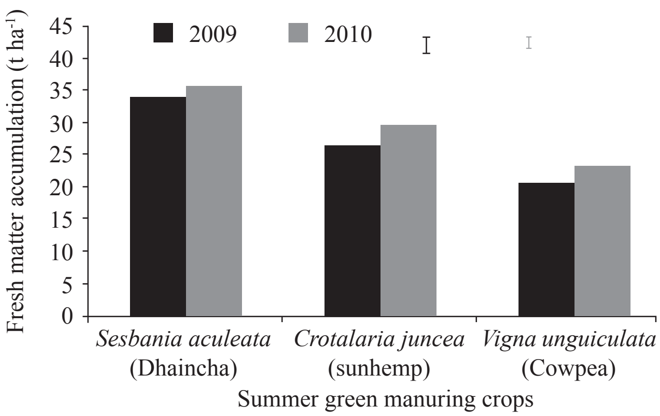

Figure 1: Fresh matter accumulation by summer green manuring crops. The vertical bars represent LSD0.05 values.

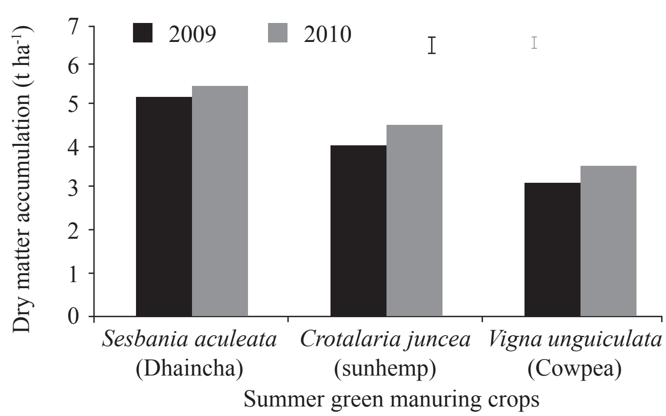

Figure 2: Dry matter accumulation by summer green manuring crops. The vertical bars represent LSD0.05 values.

recorded in control (no Zn application) followed by ZnO (82% Zn) application. In both years of the study, the tallest plants were recorded with EDTA-chelated Zn (12% Zn) and shortest with control (no Zn application). There was a 93.6 and 100%

Table 1: Effect of summer green manuring crops and Zn fertilizer sources on the plant height and leaf area index (LAI) of *Basmati* rice

Treatment	Plant height (cm)								Leaf area index (LAI)					
	30 DAT*		60 DAT		90 DAT		Harvest		30 DAT		60 DAT		90 DAT	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Summer-green manuring crops														
Sesbania aculeata (Dhaincha)	65.0	67.5	86.0	91.9	110.9	115.0	118.6	120.8	3.2	3.3	5.9	6.1	4.7	4.8
Crotalaria juncea (Sunhemp)	63.4	65.7	83.9	89.3	106.8	109.0	115.8	117.2	2.8	2.9	5.7	5.9	4.5	4.6
Vigna unguiculata (Cowpea)	60.9	63.5	80.6	85.7	103.0	106.5	112.8	114.1	2.5	2.6	5.4	5.6	4.3	4.4
Summer fallow	58.4	59.7	77.3	81.3	99.8	101.2	109.6	110.1	2.3	2.4	5.2	5.4	4.1	4.3
SEm±	0.63	1.11	0.81	1.47	1.13	1.16	0.87	0.93	0.03	0.03	0.04	0.07	0.04	0.04
LSD (p=0.05)	2.19	3.84	2.81	5.09	3.90	4.00	3.02	3.22	0.11	0.12	0.14	0.25	0.14	0.13
Zinc sources														
Control	58.0	59.8	76.4	80.2	97.7	100.5	109.4	108.9	2.2	2.3	5.1	5.3	4.0	4.2
$ZnSO_4.7H_2O$ (21% Zn)	64.5	66.1	84.7	91.0	109.5	112.2	116.8	119.9	3.0	3.1	5.8	6.1	4.6	4.7
$ZnSO_4.H_2O$ (33% Zn)	62.4	64.4	82.8	87.9	106.1	109.1	114.5	115.8	2.8	2.9	5.6	5.8	4.4	4.6
ZnO (82% Zn)	59.7	61.5	79.2	82.5	100.8	103.6	110.9	111.3	2.4	2.5	5.3	5.4	4.2	4.3
$ZnSO_4.7H_2O$+ZnO (50%+50%)	60.8	63.3	81.1	85.3	103.6	105.6	113.4	113.7	2.6	2.7	5.4	5.6	4.3	4.4
EDTA-chelated Zn (12% Zn)	66.2	69.4	87.4	95.4	113.1	116.7	120.3	123.6	3.1	3.4	6.1	6.3	4.8	5.0
SEm±	0.43	0.42	0.55	0.80	0.81	0.77	0.52	0.81	0.04	0.04	0.04	0.05	0.03	0.03
LSD (p=0.05)	1.23	1.20	1.57	2.30	2.31	2.21	1.47	2.30	0.11	0.12	0.13	0.14	0.09	0.10

DAT*: Days after transplanting

Table 2: Effect of summer green manuring crops and Zn fertilizer sources on the number of tillers hill^{-1} and dry matter accumulation of *Basmati* rice

	Tillers hill^{-1}						Effective tillers hill^{-1}		Dry matter accumulation (g hill^{-1})					
	30 DAT*		60 DAT		90 DAT		Harvest		30 DAT		60 DAT		90 DAT	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Summer-green manuring crops														
Sesbania aculeata (Dhaincha)	19.0	21.7	22.0	25.6	19.3	21.6	16.6	18.6	7.9	9.5	15.7	17.6	41.0	45.3
Crotalaria juncea (Sunhemp)	17.3	19.3	19.3	22.8	17.2	19.4	14.7	16.9	7.3	8.3	14.3	15.6	38.3	41.4
Vigna unguiculata (Cowpea)	15.7	16.4	17.6	19.8	15.1	16.5	12.9	14.4	6.7	7.7	12.5	13.5	35.9	38.5
Summer fallow	14.2	15.1	15.9	17.4	13.6	14.3	11.1	12.6	6.3	6.9	11.2	11.8	32.6	35.6
SEm±	0.46	0.59	0.62	0.81	0.60	0.80	0.63	0.76	0.09	0.15	0.41	0.66	0.76	0.73
LSD (p=0.05)	1.59	2.03	2.13	2.79	2.06	2.75	2.17	2.62	0.32	0.51	1.42	2.27	2.63	2.51
Zinc sources														
Control	12.0	12.9	13.9	15.2	11.9	13.0	9.4	10.7	5.8	6.6	10.7	10.6	31.8	32.9
$ZnSO_4.7H_2O$ (21% Zn)	19.0	21.0	21.7	24.8	19.2	21.2	16.3	18.7	7.9	8.7	14.8	16.8	39.8	43.6
$ZnSO_4.H_2O$ (33% Zn)	17.4	18.7	19.6	22.2	17.3	18.2	14.7	16.2	7.2	8.1	13.6	15.1	37.0	40.7
ZnO (82% Zn)	14.2	15.2	16.1	17.7	13.6	14.6	11.5	12.3	6.3	7.2	11.8	12.3	34.1	36.5
$ZnSO_4.7H_2O$+ZnO (50%+50%)	15.9	17.3	17.4	20.2	15.0	16.8	12.9	14.6	6.8	7.6	12.7	13.6	35.5	38.6
EDTA-chelated Zn (12% Zn)	20.7	23.7	23.5	28.3	20.8	23.8	18.2	21.4	8.4	10.3	16.8	19.3	43.4	49.0
SEm±	0.44	0.52	0.46	0.63	0.50	0.58	0.50	0.61	0.12	0.13	0.28	0.49	0.49	0.75
LSD (p=0.05)	1.25	1.49	1.31	1.81	1.42	1.66	1.44	1.74	0.33	0.37	0.80	1.39	1.39	2.15

DAT*: Days after transplanting

increase in the number of effective tillers hill^{-1} and 36.7 and 48.9% increase in dry matter (at 90 DAT) of *Basmati* rice over control (no Zn application) in 2009 and 2010, respectively. A similar trend was observed with respect to LAI. The LAI at 60 DAT was highest (varied from 5.1 to 6.3) compared with 30 and 90 DAT. This might be due to the fact that, at this stage, the leaves are fully functional and expanded compared with 30 and 90 DAT. Among the different summer green manure crops, incorporation of dhaincha resulted in significantly higher values of growth parameters of *Basmati* rice over sunhemp, cowpea and summer fallow. The lowest values of growth parameters at all growth stages were observed when *Basmati* rice was grown after summer fallow treatment. Incorporation of dhaincha residue resulted into 25.7 and 27.2% increase in dry matter of *Basmati* rice over summer fallow at 90 DAT in 2009 and 2010, respectively. But, the incorporation of cowpea resulted into the values of dry matter which remained at par with summer fallow at 60 DAT, however was significantly higher at harvest.

All the growth parameters, viz. plant height, dry matter accumulation, number of tillers and LAI of *Basmati* rice, were significantly influenced by the incorporation of summer green-manuring crops' residues and Zn fertilization. This might be due to higher nutrient availability and better physico-chemical soil properties under green manure incorporated plots and because of higher Zn availability to the rice plants from applied zinc fertilizers. This could be attributed to the higher supply of N and other micronutrient cations through the incorporation of legumes into soil (Bisht et al., 2006). In addition to N contribution, the biomass of these summer green manures also recycled considerable quantities of P, K and other nutrients; and thus might have improved fertility build-up, physical and biological properties of the soil (Sharma and Prasad, 1999; Jensen and Hauggaard-Nielsen 2003; Kirkegaard et al., 2008). Similar findings were also reported by Pooniya and Shivay (2012). The increased availability of Fe and other micronutrients in soil with regular summer green manuring crops every year before transplanting of rice was responsible for higher growth and development of rice plants in the green manuring plot compared with the non-green manuring plot (Nayyar and Chhibba, 2000). The increase in the growth parameters of rice with Zn fertilization may also be due to higher Zn availability to plants in Zn applied plots compared to control (no Zn application). Increase in plant height with Zn application could be due to higher synthesis of auxins as Zn is required for its normal production (Alloway, 2008). The relatively higher maintenance of available Zn in soil due to applied EDTA-chelated Zn (12% Zn) may be attributed from the very little or no interaction between soil components preventing various harmful reactions occurring in soil as compared to soil treated with other Zn sources, which enhances greater fixation, adsorption etc, resulting from the greater interaction between soil components. Ortiz and Garcia (1998) also reported that the chelated-Zn is fixed less in soil than the sulphate source. Srivastava et al. (1999) also studied the comparative efficiency of different sources of Zn for low land rice production and reported that out of various sources, the chelated-Zn (Zn-EDTA) was the most efficient sources of Zn for low land rice production. The performance of Zn sources in our studies was in the order; EDTA-chelated Zn (12% Zn)>$ZnSO_4.7H_2O$ (21% Zn)>$ZnSO_4.H_2O$ (33% Zn)>$ZnSO_4.7H_2O$+ZnO (50%+50%)>ZnO (82% Zn). The results obtained are in accordance with Karak et al. (2005) and Naik and Das (2008). The better performance of $ZnSO_4 \cdot 7H_2O$ and $ZnSO_4.H_2O$ (33% Zn) over ZnO is due to its water solubility. Water solubility of Zn sources is considered an important criterion for Zn availability (Slaton et al., 2005a and Slaton et al., 2005b). The lower values of growth parameters of *Basmati* rice reported under control (no Zn application) could be because, when soils are submerged, the availability of Zn to plants decreases. In submerged condition, there is a formation of large amounts of very insoluble Zn compounds, which results in lower Zn uptake. Brar and Sekhon (1976), Mandal et al. (1993) and Singh et al. (1999) also reported the decrease in the Zn availability to rice plants under submerged conditions, resulting into decrease in growth and development of plants.

3.3. Yield attributes of Basmati rice

The incorporation of summer green-manuring crop residue and various Zn fertilization treatments significantly influenced the panicle length and panicle weight (Table 4), filled, unfilled (chaffy) and total grains panicle^{-1} (Table 3), fertility percentage, grain weight panicle^{-1} and 1,000-grain weight (Table 3) of *Basmati* rice during both the years. The number of unfilled (chaffy) grains got significantly reduced with summer green manure residue incorporation and with Zn fertilization (Table 3). The significantly higher values of the yield attributes were recorded when *Basmati* rice was grown after dhaincha incorporation compared with sunhemp, cowpea and summer fallow treatments. The highest and lowest values of all these yield attributes were recorded with dhaincha and summer fallow treatments, respectively. Fertility percentage was significantly influenced by both the green manure residue incorporation as well as Zn fertilization. Dhaincha residue incorporation and EDTA-chelated Zn (12% Zn) were statistically superior over all other green manure and Zn fertilization treatments including controls (summer fallow and no Zn application), respectively in both the years.

Among the Zn fertilization treatments, application of EDTA-chelated Zn (12% Zn) resulted into statistically higher values of yield attributes compared with all Zn fertilizer sources and control (no Zn application). $ZnSO_4$. Application of $7H_2O$ (21% Zn) was second best treatment with respect to all these yield attributes after EDTA-chelated Zn (12% Zn), but was statistically inferior to it. The lowest values of all these yield attributes were observed with no Zn application (control).

3.4. *Grain and straw yields of Basmati rice*

In general, the grain and straw yields were higher during the second year of experimentation (Table 4). The yields of

Table 3: Effect of summer green manuring crops and Zn fertilizer sources on the yield attributes of Basmati rice

Treatment	Filled grains panicle^{-1} (A)		Unfilled (Chaffy) grains panicle^{-1} (B)		Total grains panicle^{-1} (A+B)		Fertility percentage (%)		Grain weight (g) panicle^{-1}		1,000-grain weight (g)	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Summer-green manuring crops												
Sesbania aculeata (Dhaincha)	86.9	87.6	34.8	35.1	121.7	122.9	71.2	71.3	2.48	2.63	25.37	25.88
Crotalaria juncea (Sunhemp)	81.9	83.2	36.1	36.2	118.1	119.4	69.1	69.7	2.34	2.47	24.95	25.13
Vigna unguiculata (Cowpea)	75.8	76.6	37.2	38.0	113.4	114.6	66.5	66.5	2.17	2.33	24.25	24.63
Summer fallow	68.6	70.7	39.8	38.3	108.4	109.0	62.9	64.4	2.02	2.14	23.47	24.01
SEm±	1.39	1.60	0.42	0.41	1.03	1.34	0.69	0.71	0.031	0.038	0.132	0.162
LSD (p=0.05)	4.78	5.52	1.44	1.42	3.57	4.61	2.39	2.47	0.108	0.130	0.456	0.558
Zinc sources												
Control	62.4	63.7	42.7	42.1	105.1	105.8	59.2	60.1	1.89	1.93	22.54	22.69
$ZnSO_4.7H_2O$ (21% Zn)	86.8	87.4	34.1	34.9	120.9	122.3	71.7	71.4	2.48	2.62	25.71	26.14
$ZnSO_4.H_2O$ (33% Zn)	80.7	81.9	36.3	36.2	117.2	118.1	68.7	69.1	2.28	2.43	24.82	25.21
ZnO (82% Zn)	71.3	72.5	38.8	38.4	110.1	110.9	64.5	65.2	2.06	2.17	23.33	23.96
$ZnSO_4.7H_2O$+ZnO (50%+50%)	75.6	77.6	37.8	37.2	113.8	114.8	66.2	67.4	2.18	2.31	24.07	24.69
EDTA-chelated Zn (12% Zn)	93.0	93.8	32.3	32.6	125.4	126.8	74.1	74.7	2.63	2.88	26.59	26.77
SEm±	0.94	0.99	0.22	0.25	0.82	1.00	0.41	0.41	0.025	0.034	0.153	0.148
LSD (p=0.05)	2.68	2.84	0.62	0.70	2.35	2.85	1.16	1.18	0.070	0.098	0.438	0.422

Table 4: Effect of summer green manuring crops and Zn fertilizer sources on the yield attributes and grain and straw yields of *Basmati* rice

Treatment	Panicle length (cm)		Panicle weight (g)		Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
	2009	2010	2009	2010	2009	2010	2009	2010
Summer-green manuring crops								
Sesbania aculeata (Dhaincha)	28.8	29.5	3.00	3.07	4.89	5.56	9.04	10.21
Crotalaria juncea (Sunhemp)	27.3	28.0	2.82	2.89	4.74	5.34	8.83	10.02
Vigna unguiculata (Cowpea)	26.0	26.4	2.63	2.74	4.58	5.12	8.64	9.82
Summer fallow	25.1	24.6	2.38	2.50	4.30	4.86	8.36	9.63
SEm±	0.36	0.62	0.025	0.029	0.041	0.026	0.039	0.031
LSD (p=0.05)	1.25	2.16	0.087	0.100	0.141	0.091	0.135	0.105
Zinc sources								
Control	24.2	23.1	2.34	2.40	4.09	4.75	8.13	9.39
$ZnSO_4.7H_2O$ (21% Zn)	28.3	29.3	2.93	3.05	4.92	5.41	9.04	10.18
$ZnSO_4.H_2O$ (33% Zn)	27.2	27.4	2.77	2.85	4.74	5.27	8.81	10.02
ZnO (82% Zn)	25.3	25.3	2.50	2.57	4.32	4.98	8.40	9.61
$ZnSO_4.7H_2O$+ZnO (50%+50%)	26.2	26.8	2.61	2.72	4.54	5.15	8.61	9.85
EDTA-chelated Zn (12% Zn)	29.7	30.7	3.09	3.19	5.15	5.76	9.30	10.48
SEm±	0.24	0.43	0.028	0.032	0.043	0.027	0.046	0.032
LSD (p=0.05)	0.69	1.24	0.079	0.090	0.123	0.077	0.131	0.090

Basmati rice were significantly influenced by incorporation of summer green manuring crop residue and Zn sources. The significantly higher grain and straw yields of *Basmati* rice were recorded when it was grown after dhaincha incorporation compared with sunhemp, cowpea and summer fallow treatments. With the incorporation dhaincha, sunhemp and cowpea, about 5.46 and 5.77, 4.16 and 4.76, 3.00 and 3.77 t ha^{-1} of dry biomass was added to the soil during first and second year of experimentation, respectively (Figure 2). Dhaincha supplied significantly higher amount of readily decomposable organic materials, which improved soil organic matter and nutrient status. It leads to recycling of nutrients into the soil and increased availability of nutrients and thus improved the yield attributes and yields of *Basmati* rice.

Among the Zn fertilization treatments, application of EDTA-chelated Zn (12% Zn) resulted into statistically higher values of grain (5.15 and 5.76 t ha^{-1}) and straw yields (9.30 and 10.48 t ha^{-1}) compared with all other Zn fertilizer sources and control (no Zn application), respectively during 2009 and 2010. Application of $ZnSO_4.7H_2O$ (21% Zn) was second best treatment with respect to grain (4.92 and 5.41 t ha^{-1}) and straw yields (9.04 and 10.18 t ha^{-1}) after EDTA-chelated Zn (12% Zn), but was statistically inferior to it. The lowest values of grain, straw and biological yields were recorded with control (no Zn application). The performance of Zn sources in terms of yields of *Basmati* rice was in the order; EDTA-chelated Zn (12% Zn)>$ZnSO_4.7H_2O$ (21% Zn)>$ZnSO_4.H_2O$ (33% Zn)>$ZnSO_4.7H_2O$+ZnO (50%+50%)>ZnO (82% Zn). Percent increase in grain and straw yields with EDTA-chelated Zn (12% Zn) application over control (no Zn application) was 25.91, 21.26% and 14.39, 11.60%, respectively during 2009 and 2010. The increase in grain and straw yields due to incorporation of summer green-manuring crops and Zn fertilization can be explained on the basis of increase in the yield attributes, namely panicle length, panicle weight, number of grains per panicle and 1,000 grain weight of *Basmati* rice.

Increase in yield attributes and yields of *Basmati* rice with Zn application might be due to higher Zn uptake with Zn fertilization, resulting into higher biomass production (Shivay et al., 2008 and Pooniya et al., 2012) and photosynthates translocation to reproductive parts (Ozkutlu et al., 2006; Alloway, 2008). The increase in yield attributes and yields of *Basmati* rice with application of EDTA-chelated Zn (12% Zn) might be due to the relatively greater amount of Zn uptake compared with other Zn sources. These results are in agreement with the findings of Karak et al. (2005) who reported that chelated Zn was the most efficient source of Zn for lowland rice production. Further, the incorporation of green manuring crops before transplanting of *Basmati* rice improves the organic matter content in soil. The applied Zn might have been complexed with the humic substances present in soil due to organic matter addition and there might have been lesser Zn fixation by the formation of insoluble Zn complexes. Thus resulting into increase in the availability of soil applied Zn to rice plants. Improvement in the nutrient use efficiency of the applied fertilizers by transplanted rice after green manure incorporation was also reported by Yadvinder-Singh et al. (1991). The correlation among the various yield attributes and yield were estimated (Table 5), which indicated that all the yield attributes were highly correlated with yield.

Table 5: Correlation coefficients of yield attributes and yield of Basmati rice

	Yield		Effective tillers		Panicle length		Panicle weight		Number of grains panicle^{-1}		Grain weight panicle^{-1}		1,000-grain weight		Number of filled grains panicle^{-1}	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Yield	1.00**	1.00**	0.98**	0.97**	0.97**	0.98**	0.96**	0.97**	0.98**	0.98**	0.97**	0.97**	0.98**	0.94**	0.98**	0.98**
Effective tillers			1.00**	1.00**	0.98**	0.96**	0.97**	0.97**	0.99**	0.97**	0.99**	0.98**	0.97**	0.96**	0.99**	0.97**
Panicle length					1.00**	1.00**	0.98**	0.99**	0.98**	0.99**	0.98**	0.97**	0.97**	0.97**	0.98**	0.99**
Panicle weight							1.00**	1.00**	0.98**	0.98**	0.97**	0.98**	0.96**	0.97**	0.98**	0.98**
Number of grains panicle^{-1}									1.00**	1.00**	0.98**	0.98**	0.98**	0.98**	1.00**	1.00**
Grain weight panicle^{-1}											1.00**	1.00**	0.97**	0.98**	0.98**	0.98**
1,000-grain weight													1.00**	1.00**	0.98**	0.98**
Number of filled grains panicle^{-1}															1.00**	1.00**

4. Conclusion

Results showed that the incorporation of dhaincha green manure before transplanting of *Basmati* rice and application of EDTA-Chelated Zn (12% Zn) improved the growth and physiological development of *Basmati* rice compared to rest of green manuring crops and Zn fertilizer sources. Dhaincha and EDTA-Chelated Zn (12% Zn) were found to be the best to obtain higher grain and straw yields of *Basmati* rice and thus enhanced its productivity. Adequate Zn fertilization of *Basmati* rice along with incorporation of summer green manure crops can thus lead to better growth and development of rice plants, which in turn leads to higher crop productivity.

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