Indian Journal of Agronomy **58** (3): 327–333 (September 2013)

Research Paper

Residual effects of summer green manure crops and zinc applied to rice (*Oryza sativa*) on succeeding durum wheat (*Triticum durum*) under basmati rice–wheat cropping sequence

AMARPREET SINGH[1] AND YASHBIR SINGH SHIVAY[2]

Indian Agricultural Research Institute, New Delhi 110 012

Received : February 2013; Revised accepted : June 2013

ABSTRACT

Field experiments were conducted for two consecutive years (2009-11) at the research farm of Indian Agricultural Research Institute, New Delhi, to determine the direct and residual effects of summer green manuring crops [*Sesbania aculeata* (Dhaincha), *Crotalaria juncea* (Sunhemp) and *Vigna unguiculata* (Cowpea)] and zinc fertilizer sources [EDTA-chelated Zn (12% Zn), $ZnSO_4.7H_2O$ (21% Zn), $ZnSO_4.H_2O$ (33% Zn), ZnO (82% Zn) and $ZnSO_4.7H_2O$ + ZnO (50% + 50%)] on productivity, Zn uptake and economics of basmati rice (*Oryza sativa* L.)–durum wheat (*Triticum durum* Desf.) cropping sequence. In this paper information pertaining to residual effect of treatments on durum wheat is given. Significant residual effects of Zn fertilizer sources and summer green manuring crops were observed on durum wheat in comparison with control (no Zn application or summer fallow in preceding *Basmati* rice). With residual effect of *Sesbania* incorporation, grain and straw yields of durum wheat were 4.5 and 5.16 t/ha, which were 15.9 and 10.0% higher compared to fallow. Among the different Zn fertilizer sources, residual effect of EDTA-chelated Zn was found to be the best with respect to growth, yield attributes, grain, straw, Zn content and uptake and economics. The residual effect of application of EDTA-chelated Zn resulted in the highest durum wheat grain (4.78 t/ha) and straw yields (5.38 t/ha) compared to control. Highest Zn concentration in grain (43.0 mg/kg) and straw (126.6 mg/kg) and its uptake was recorded with residual effect of *Sesbania* incorporation compared with sunhemp, cowpea and summer fallow. Highest total Zn uptake (936.6 g/ha) in durum wheat was recorded with residual effect of EDTA-chelated Zn application, followed by $ZnSO_4.7H_2O$, $ZnSO_4.H_2O$, $ZnSO_4.7H_2O$ + ZnO (50% + 50%), ZnO and control. The best economical returns were obtained with residual effect of *Sesbania* incorporation and EDTA-chelated Zn combination.

Key words : Durum wheat, Economics, Residual effects, Summer green manure crops, Yields, Zinc concentration and uptake, Zinc sources

Wheat is mainly cultivated after harvesting of rice in rice-wheat cropping system, which covers about 24 million hectares in China, India, Pakistan, Nepal and Bangladesh (Prasad, 2005). Zinc (Zn) deficiency is widespread in rice-wheat belts of all these five countries. The sustainability of this system is at the stake because of declining factor productivity and it is due to continuous deprivation of addition of manures; however there is a scope to incorporate the summer green manure crops before rice transplanting, which act as a source of nutrients for improved productivity and maintenance of soil fertility. Also, the green manuring before rice transplanting improves the nutrient use efficiency of the applied fertilizer (Singh *et al.*, 1991).

In north India, some of the farmers after harvesting of their wheat crop in the month of April generally grow summer green manuring crops to add nutrients and organic matter to the soil before transplanting of *Basmati* rice. Typically, a summer green manure crop is grown for a specific period, and then ploughed under and incorporated into the soil. Green manure crops being leguminous in nature usually perform multiple functions that include improvement in nutrient content, organic matter addition in soil and soil protection as well as enhance microbial biomass and enzymatic activity in soil. Sharma *et al.* (1995) reported that *Sesbania* green manuring and mungbean residue incorporation in rice increased grain

Based on part of Ph.D. Thesis of first author submitted to IARI, New Delhi, during 2013.

[2]**Corresponding author Email:** ysshivay@hotmail.com

[1]Scientist, Division of Crop Production, Central Research Institute for Jute and Allied Fibres, Barrackpore, Kolkata, West Bengal 700 120, [2]Princiapl Scientist, Division of Agronomy, Indian Agricultural Research Institute, New Delhi 110 012

yield of succeeding wheat by 0.3-0.7 t/ha. Kumar and Sharma (2000) found that *Sesbania* and blackgram had significant positive effects on the growth and yield attributes of wheat which ultimately resulted in significantly higher grain yield of wheat than control. The varietal diversification of crops in the existing rice-wheat cropping system can be a good option in the present scenario. The newly developed varieties of durum wheat can effectively replace aestivum/bread wheat in Indo-Gangatic plains. The special features of durum wheat for making good quality products like macaroni, spaghetti, vermicelli, noodles and various other pasta products increases its export potential.

Zn in now recognized as the fifth leading risk factor in developing Asian countries (IFA, 2007) and efforts are underway for encouraging Zn fertilization not only from the view point of getting higher yields and quality produce, but also for increasing Zn concentration in grain and straw to improve human and animal Zn nutrition (Schardt, 2006). Also, the increased Zn concentration in wheat straw is of importance from the viewpoint of cattle nutrition, since in developing countries of Asia, wheat straw is the major feed for farm cattle (Shivay *et al.*, 2008) with most crops. The general way of correcting Zn deficiencies in soils is to apply Zn fertilizers (Brennan and Bolland, 2006 and Alvarez *et al.*, 2009). In India, Zn deficiency in crops is usually corrected through the application of zinc sulphate heptahydrate ($ZnSO_4.7H_2O$). Soil application of 5 kg Zn/ha (25 kg $ZnSO_4.7H_2O$/ha) is recommended for rice-wheat cropping system in India. However, the product is quite costly and generally not available to farmers', resulting in reduced yields. 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 (Karak *et al.*, 2005), because the central metal ion Zn^{2+} is surrounded by chelate ligands (Mortvedt, 1979). Shivay *et al.* (2008) reported significant improvement in the net return and B: C ratio of wheat under rice-wheat cropping system due to application of Zn over no Zn application to rice. They also reported significant increase in productivity, Zn uptake and Zn-use efficiencies in wheat under rice-wheat cropping system due to Zn application to rice over control.

It is expected that regular incorporation of green manure crops before transplanting of rice may improve not only physico-chemical properties of soil but also enhance availability of macro and micronutrients in soil and its uptake by durum wheat under *Basmati* rice-durum wheat cropping system. Selection amongst alternative sources of Zn and green manuring solely depends upon economic advantage of the system. Keeping these in view, the present investigation was taken up to quantify the residual effects of summer green manure crops and Zn fertilizer sources on productivity, economics and Zn uptake by succeeding durum wheat crop grown after *Basmati* rice in a basmati rice–wheat cropping system.

MATERIALS AND METHODS

Field experiments were conducted for 2 consecutive years at the research farm of the Indian Agricultural Research Institute, New Delhi, India during summer, rainy/*kharif* (mid June-mid November) and *rabi*/winter (mid November-mid April) seasons of 2009-10 and 2010-11 on a sandy clay loam soil (*Typic Ustochrept*). The experiments in both the years were conducted with a fixed lay out plan in the same field. The soils of experimental field had 135 kg/ha alkaline permanganate oxidizable nitrogen (N), 16 kg/ha available phosphorus (P), 292 kg/ha 1 *N* ammonium acetate exchangeable potassium (K) and 0.53% organic carbon (OC). The pH 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 in soil was 0.67 mg/kg of soil. The critical level of DTPA extractable Zn for crops grown on alluvial soils in the rice-wheat belt of north India varies from 0.38-0.90 mg/kg soil (Takkar *et al.*, 1997) and thus the response of *Basmati* rice and durum wheat to Zn application was expected in 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. $ZnSO_4.7\ H_2O$ (21% Zn), $ZnSO_4.H_2O$ (33% Zn), ZnO (82% Zn), $ZnSO_4.7\ H_2O$ + ZnO (50% + 50%), EDTA-chelated Zn (12% Zn) and control (no Zn application) in sub-plots and was replicated thrice. After 40-days the summer green manuring crops were incorporated into the soil before transplanting of rice. After incorporation of green manuring crops, each main plot (with green manure incorporation or otherwise) was divided into six sub-plots, which received the Zn-fertilization treatments. 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 as single superphosphate and 33 kg K/ha as muriate of potash was broadcasted. Nitrogen @ 120 kg/ha as prilled urea was applied into two equal splits, half at the time of transplanting of preceding *Basmati* rice and remaining half at panicle initiation stage (40 DAT). In all the Zn treatments 5 kg Zn/ha was applied uniformly only to rice crop.

After harvest of rice, plots were ploughed once and harrowed twice and durum wheat 'PDW 291' was sown 22.5 cm apart in rows using 100 kg seed/ha in middle of

November and harvested in the last week of April in both the years. The fixed layout plan of preceding *Basmati* rice was used for durum wheat also for both the years of experimentation. Since the objective of this study was to quantify the residual effects of summer green manuring crops' residue incorporation and Zn fertilization applied to preceding *Basmati* rice on succeeding durum wheat, therefore, only 40 kg N/ha was applied uniformly to all the treatments in wheat. However, all other recommended standard package of practices was followed to raise the wheat crop on residual soil fertility.

One metre row length was demarcated in each sub-plot for measuring plant height and fertile tillers/m^2 10 days before harvest. The fertile tillers of durum wheat were then converted to numbers per meter square and the average values were computed. Ten spikes were randomly selected from each plot for recording the data on yield attributes (spike length, spike weight, number of grains/spike and grains weight/spike). The 1,000-grains were counted randomly from each sub-plot, and their weight was recorded at 12% moisture and expressed in grams. Harvesting of the durum wheat was undertaken as soon as it attained the harvest maturity.

Plant samples of durum wheat crop for Zn analysis were collected at harvest. Plant samples were cut at ground level randomly from 50-cm row length. They were washed initially with tap water followed by dilute hydrochloric acid (0.05 N), deionised water and finally with Zn-free double distilled water and dried in an air oven at 60±2°C. The plants were separated into grain and straw and analysed for Zn concentration separately. The dried samples of durum wheat were ground with a milling machine and sieved to pass through 40 mesh sieve. The samples were digested using a di-acid [perchloric acid ($HClO_4$) + nitric acid (HNO_3) in 3:10 ratio] method. After digestion and extraction of samples, total Zn was estimated with the help of atomic absorption spectrophotometer (Perkin Elmer; Model-A. Analyst 100) as described by Prasad *et al.* (2006).

Economics of durum wheat cultivation was calculated based on the prevailing market prices during the respective crop seasons. The gross and net returns were calculated. Benefit-to-cost ratio (B: C) was calculated by dividing the net returns with total cost of cultivation. All the replicated data obtained from the experiments were statistically analysed for pooled analysis using the F-test as per the procedure given by Gomez and Gomez (1984). Critical difference (CD) 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.

RESULTS AND DISCUSSION

Plant height and number of tillers

Number of tillers/m^2 and plant height of durum wheat was significantly higher, when it was grown in *Sesbania* incorporated plots compared with sunhemp, cowpea and summer fallow (Table 1). There was 7.3% increase in the number of tillers, when durum wheat was grown in *Sesbania* incorporated plots compared to summer fallow. Sharma and Prasad (1999) also reported the improvement in wheat productivity, when it was grown after green ma-

Table 1. Residual effect of summer green manuring crops and Zn fertilizer sources on the growth and yield attributes of succeeding durum wheat under *Basmati* rice-durum wheat cropping system (Pooled data of two years)

Treatment	Plant height (cm)	Tillers/ m^2	Spike length (cm)	Spike weight (g)	Grains/ spike	Grains weight/ spike (g)	1,000-grain weight(g)
Summer-green manuring crops							
Sesbania aculeata (Dhaincha)	86.3	468.2	7.8	2.84	46.8	1.83	43.55
Crotalaria juncea (Sunhemp)	84.4	458.6	7.5	2.67	45.0	1.73	43.10
Vigna unguiculata (Cowpea)	82.6	448.5	7.2	2.58	42.4	1.63	42.21
Summer fallow	80.2	436.5	6.9	2.48	39.8	1.55	41.31
SEm±	0.57	2.84	0.05	0.028	0.74	0.015	0.286
CD (P=0.05)	1.98	9.79	0.18	0.090	2.57	0.052	0.988
Zn sources							
Control	79.5	431.1	6.7	2.40	39.2	1.48	40.77
$ZnSO_4.7H_2O$ (21% Zn)	85.6	464.5	7.7	2.77	45.6	1.81	43.48
$ZnSO_4.H_2O$ (33% Zn)	84.1	454.6	7.5	2.67	43.5	1.72	42.92
ZnO (82% Zn)	81.1	440.5	6.9	2.50	40.9	1.56	41.34
$ZnSO_4.7H_2O$+ZnO (50% + 50%)	82.6	448.1	7.2	2.59	42.4	1.64	42.19
EDTA-chelated Zn (12% Zn)	87.5	478.8	8.0	2.91	49.4	1.91	44.55
SEm±	0.34	1.39	0.04	0.018	0.47	0.016	0.145
CD (P=0.05)	0.97	3.96	0.12	0.051	1.36	0.046	0.413

nuring in rice-wheat cropping system. Among the Zn fertilizers, EDTA-chelated Zn recorded the highest plant height and number of tillers in wheat. $ZnSO_4.7H_2O$ was the second best treatment and was statistically inferior to EDTA chelated Zn. The lowest values were recorded with control. The performance of Zn sources in terms of residual effect on plant height and tillers at harvest was in the following order; EDTA-chelated Zn > $ZnSO_4.7H_2O$ > $ZnSO_4.H_2O$ > $ZnSO_4.7H_2O$ + ZnO (50% + 50%) > ZnO.

Yield attributes

Yield attributes of durum wheat were significantly higher, when it was grown in *Sesbania* incorporated plots compared with sunhemp, cowpea and summer fallow (Table 1). There was 14.5% and 17.6% increase in spike weight and number of grains/spike due to residual effect of *Sesbania* incorporation compared with summer fallow. Among the Zn fertilizer sources, residual effect of EDTA-chelated Zn most significantly influenced the yield attributes. The application of $ZnSO_4.7H_2O$ was second best treatment with respect to residual effect of Zn on yield attributes of durum wheat after EDTA-chelated Zn, but was statistically inferior to it. The lowest values were recorded with control. The performance of Zn sources in terms of residual effect was in the following order; EDTA-chelated Zn > $ZnSO_4.7H_2O$ > $ZnSO_4.H_2O$ > $ZnSO_4.7H_2O$ + ZnO (50% + 50%) > ZnO.

Yield and harvest index

Zn and summer green manure residue incorporation to rice significantly influenced the grain and straw yields and harvest index of succeeding wheat (Table 2). Wheat grain yield was 15.8% higher in *Sesbania* incorporated plot than summer fallow. Similarly, wheat straw yield was 10% higher in *Sesbania* incorporated plots than summer fallow. Similar trend was also recorded for harvest index. 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 and Pooniya and Shivay, 2011). The increased availability of Fe and other micronutrients in soil with regular summer green manuring every year before transplanting of rice in rice-wheat system was responsible for higher yields in the green manuring plot compared with the non-green manuring plot (Nayyar and Chhibba, 2000).

Residual effect of Zn fertilizers applied to rice produced significantly higher yields and harvest index of succeeding durum wheat compared to control. These results indicate that a part of Zn was left as residual in soil after harvesting *Basmati* rice, which influenced the growth and development of durum wheat plants. Among the Zn fertilizer sources, residual EDTA-chelated Zn produced significantly higher grain (4.78 t/ha) and straw (5.38 t/ha) compared to other Zn sources, including control. Application of $ZnSO_4.7H_2O$ was second best treatment which produced 4.47 t/ha of grain and 5.14 t/ha of straw. The lowest values were recorded with control. Similar trend was observed with respect to harvest index. The performance of Zn sources in terms of residual effect was in the order of; EDTA-chelated Zn > $ZnSO_4.7H_2O$ > $ZnSO_4.H_2O$ > $ZnSO_4.7H_2O$ + ZnO (50% + 50%) > ZnO. The results obtained might be due to the higher growth and develop-

Table 2. Residual effect of summer green manuring crops and Zn fertilizer sources on the productivity and economics of succeeding durum wheat under *Basmati* rice-durum wheat cropping system (Pooled data of two years)

	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Gross returns (×10 ₹/ha)	Net returns (×10 ₹/ha)	Net benefit : cost ratio
Summer-green manuring crops						
Sesbania aculeata (Dhaincha)	4.51	5.16	46.6	71.6	57.5	4.07
Crotalaria juncea (Sunhemp)	4.32	5.04	46.1	68.8	54.6	3.87
Vigna unguiculata (Cowpea)	4.10	4.88	45.6	65.5	51.4	3.64
Summer fallow	3.89	4.69	45.2	62.4	48.2	3.41
SEm±	0.014	0.020	0.03	0.24	0.24	0.016
CD (P=0.05)	0.048	0.070	0.10	0.82	0.82	0.054
Zn sources						
Control	3.67	4.57	44.5	59.2	45.0	3.19
$ZnSO_4.7H_2O$ (21% Zn)	4.47	5.14	46.5	71.0	56.9	4.03
$ZnSO_4.H_2O$ (33% Zn)	4.30	4.98	46.2	68.3	54.2	3.84
ZnO (82% Zn)	3.92	4.72	45.3	62.8	48.6	3.44
$ZnSO_4.7H_2O$+ZnO (50% + 50%)	4.10	4.85	45.8	65.5	51.3	3.64
EDTA-chelated Zn (12% Zn)	4.78	5.38	47.0	75.6	61.5	4.35
SEm±	0.023	0.023	0.07	0.35	0.35	0.025
CD (P=0.05)	0.066	0.065	0.19	1.00	1.00	0.070

ment of durum wheat plants with residual Zn resulting into higher biomass production. Pooniya and Shivay (2011) also reported the similar findings. These observations clearly indicated that Zn applied through EDTA-chelated Zn remained available to crops for a longer period of time than other Zn sources due to lesser transformation of applied Zn through EDTA-chelated Zn into unavailable forms (Srivastava *et al.*, 2008).

Zn concentration and uptake by durum wheat

Significantly higher Zn concentration in grain and straw of durum wheat and its uptake was recorded with *Sesbania* incorporation and EDTA-chelated Zn (Table 3). The Zn concentration and its uptake by grain and straw as well as total uptake were significantly higher with residual effect of *Sesbania* compared with sunhemp, cowpea and summer fallow treatments.

Zn fertilizer applications to rice appreciably increased Zn concentrations in grain and straw of succeeding wheat compared to control, but the rates of increase varied from source to source (Table 3). Significantly higher Zn concentrations in grain and straw and uptake were observed with the residual effect of EDTA-chelated Zn over all other Zn sources. Zn concentration in grain and straw were 36.1% and 27.7% higher with residual effect of EDTA-chelated Zn compared to control. The application of $ZnSO_4.7H_2O$ was second best treatment with respect to Zn concentration in grain and straw and its uptake after EDTA-chelated Zn, but was statistically inferior to it. The lowest values were recorded with control (no Zn application to preceding *Basmati* rice crop). These results are in agreement with the findings of Shivay *et al.* (2008) and Pooniya and Shivay (2011). A significantly high correlation (0.994 and 0.996) was recorded between grain yield and Zn uptake by grain (Table 4 and Fig.1). Zn exerts an effect on carbohydrate metabolism through its effects on photosynthesis, sugar transformations and seed development. Increased Zn content and its uptake in grains help in production of bolder grains, thus increasing the grain yield (Alloway, 2008). High grain Zn concentration is consid-

Table 3. Residual effect of summer green manuring crops and Zn fertilizer sources on Zn concentration of durum wheat grain, straw and their uptake by succeeding durum wheat under *Basmati* rice-durum wheat cropping system (Pooled data of two years)

Treatment	Zn concentration in grain (mg/kg grain)	Zn concentration in straw (mg/kg straw)	Zn uptake by durum wheat grain (g/ha)	Zn uptake by durum wheat straw (g/ha)	Total Zn uptake [durum wheat grain + straw] (g/ha)
Summer-green manuring crops					
Sesbania aculeata (Dhaincha)	43.0	126.6	195.2	655.7	850.8
Crotalaria juncea (Sunhemp)	41.0	122.9	178.1	621.7	799.8
Vigna unguiculata (Cowpea)	38.4	115.5	158.7	565.5	724.2
Summer fallow	35.5	110.6	139.8	520.8	660.6
SEm±	0.48	0.74	2.23	5.37	7.40
CD (P=0.05)	1.67	2.56	7.71	18.54	25.55
Zn sources					
Control	33.3	104.5	122.8	478.4	601.3
$ZnSO_4.7H_2O$ (21% Zn)	41.5	124.7	186.3	642.3	828.6
$ZnSO_4.H_2O$ (33% Zn)	40.2	121.6	173.4	606.8	780.1
ZnO (82% Zn)	37.2	111.8	146.5	529.1	675.6
$ZnSO_4.7H_2O$+ZnO (50% + 50%)	39.2	117.3	161.5	569.4	731.0
EDTA-chelated Zn (12% Zn)	45.3	133.5	217.1	719.5	936.6
SEm±	0.21	0.80	1.37	5.92	6.83
CD (P=0.05)	0.61	2.30	3.93	16.92	19.52

Table 4. Correlation coefficients of yield attributes, grain Zn uptake and yield of durum wheat (Pooled data of two years)

	Yield	Number of tillers	Spike weight	Number of grains/spike	Grains weight/spike	Zn uptake by grain
Yield	1.00 (**)	0.99 (**)	0.97 (**)	0.98 (**)	0.99 (**)	0.99 (**)
Number of tillers		1.00 (**)	0.97 (**)	0.99 (**)	0.99 (**)	0.99 (**)
Spike weight			1.00 (**)	0.97 (**)	0.99 (**)	0.99 (**)
Number of grains/spike				1.00 (**)	0.98 (**)	0.98 (**)
Grains weight/spike					1.00 (**)	0.99 (**)
Zn uptake by grain						1.00 (**)

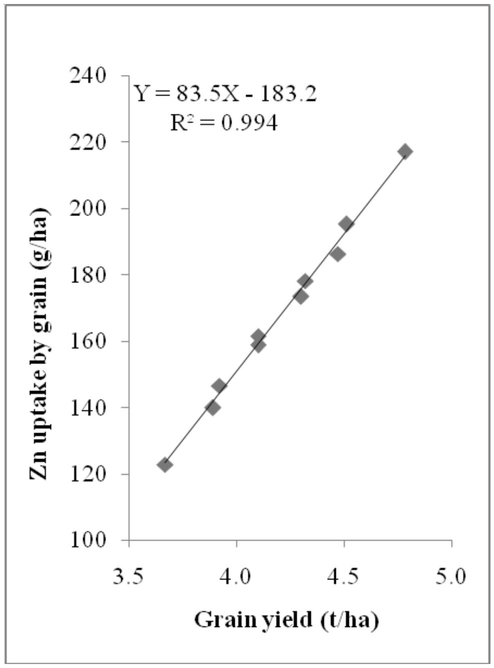

Fig. 1. Correlation and regression of durum wheat grain yield with Zn uptake by wheat grain (Pooled data of two years).

ered a desirable quality factor which could increase the nutritional value of the grain for humans (Prasad, 2006). Besides, high Zn content in seed is also a desirable trait for conferring seedling vigour when re-sown on Zn-deficient or low-Zn soil (Graham *et al.*, 1992).

Economics

As the durum wheat was grown on residual fertility and so there was no treatment was applied to it, therefore the cost of cultivation remained same across the treatment combinations. Among the summer green manuring crops, residual effect of *Sesbania* incorporation gave highest gross and net returns, *viz.* ₹71,597and ₹57,451/ha, respectively, followed by sunhemp, cowpea and summer fallow (Table 2). The higher values of net B: C ratio (4.07) was obtained by the same treatment. Among the Zn fertilization treatments, application of EDTA-chelated Zn gave significantly higher gross returns (₹75,612/ha) and net returns (₹61,467/ha) compared to other Zn sources. Its residual effects also resulted in significantly higher net B:C ratio of 4.35. However, the EDTA-chelated Zn was much costlier Zn source compared with other sources, but its cost was involved in preceding *Basmati* rice cultivation only, because no fertilizer treatment was applied for durum wheat cultivation.

Based on this study it can be concluded that the residual effect of *Sesbania* green manure incorporation and EDTA-chelated Zn improved the growth, yield attributes, productivity and zinc uptake of succeeding durum wheat compared to residual effect of other summer green manuring crops and Zn sources. Adequate Zn fertilization along with incorporation of summer green manure crops can thus lead to higher crop productivity of rice-wheat cropping system.

REFERENCES

Alloway, B.J. 2008. *Zinc in Soils and Crop Nutrition*. International Zinc Association Publication. International Zinc Association, Brussels, Belgium.

Alvarez, J.M., Almendros, P. and Gonzalez, D. 2009. Residual effects of natural Zn chelates on navy bean response, Zn leaching and soil Zn status. *Plant and Soil* **317**:277–91.

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: *Proceedings of the National Symposium on Conservation Agriculture and Environment*, October 26-28, Banaras Hindu University, Varanasi, India, pp 193–94.

Brennan, R.F. and Bolland, D.A. 2006. Residual values of soil-applied zinc fertilizer for early vegetative growth of six crop species. *Australian Journal of Experimental Agriculture* **46**: 1341–47.

Gomez, K.A. and Gomez, A.A. 1984. *Statistical Procedures for Agricultural Research*. Second Edition. John Wiley & Sons, New York, USA.

Graham, R.D., Ascher, J.S. and Hynes, S.C. 1992. Selecting zinc efficient genotypes for soils of low zinc status. *Plant and Soil* **146**:241–50.

IFA. 2007. Help eliminate the fifth leading disease risk factor in developing countries. In: *Fertilizer and Agriculture*, January 2007. Sukalac, K.E. (ed.), International Fertilizer Agency, Paris, France. 6 p.

Karak, T., Singh, U.K., Das, S., Das, D.K. and Kuzyakov, Y. 2005. Comparative efficacy of $ZnSO_4$ and Zn-EDTA application for fertilization of rice (*Oryza sativa* L.). *Archives of Agronomy and Soil Science* **51**(3):253–64.

Kumar, B. and Sharma, R.P.R. 2000. Effect of preceding crops and nitrogen rates on growth and yield attributes of wheat. *Indian Journal of Agricultural Research* **34**(1): 34–38.

Mortvedt, J.J. 1979. Crop response to zinc sources applied alone or with suspensions. *Fertilizer Solutions* **23**:64–79.

Nayyar, V.K. and Chhibba, I.M., 2000. Effect of green manuring on micronutrient availability in rice–wheat cropping system of northwest India. In: *Long-term Soil Fertility Experiments in Rice–Wheat Cropping Systems*. Rice–Wheat Consortium Paper Series 6. I.P., Abrol and K.F. Brown (Eds.), New Delhi, India, pp. 68–72.

Pooniya, V. and Shivay, Y.S. 2011. Effect of green manuring and zinc fertilization on productivity and nutrient uptake in *Basmati* rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy* **56**(1):28–34.

Prasad, R. 2005. Rice–wheat cropping systems. *Advances in Agronomy* **86**:255-339.

Prasad, R. 2006. Zinc in soils and in plants, human and animal nutrition. *Indian Journal of Fertilizers* **2**(9): 103–19.

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, Indian Agricultural Research Institute, New Delhi, India, 68 p.

Schardt, D. 2006. The zincing feeling–zinc in human nutrition, *Special Report Nutrition Action Health-letter*, http://www.findarticles.com.

Sharma, S.N. and Prasad, R. 1999. Effect of *Sesbania* green–manuring and mungbean residue incorporation on productivity and nitrogen uptake of a rice–wheat cropping system. *Bioresource Technology* **87**:171–75.

Sharma, S.N., Prasad, R. and Singh, S. 1995. The role of mungbean residues and *Sesbania aculeata* green manure in nitrogen economy of rice–wheat cropping system. *Plant and Soil* **172**: 123–29.

Shivay, Y.S., Kumar, D. and Prasad, R. 2008. Effect of zinc-enriched urea on productivity, zinc uptake and efficiency of an aromatic rice–wheat cropping system. *Nutrient Cycling in Agroecosystems* **81**(3):229–43.

Srivastava, P.C., Singh, A.P., Surendra, K., Ramachandran, V., Shrivastava, M. and D'souza, S.F. 2008. Desorption and transformation of zinc in a mollisol and its uptake by plants in a rice–wheat rotation fertilized with either zinc enriched biosludge from molasses or with inorganic zinc. *Biology and Fertility of Soils* **44**:1035–41.

Takkar, P.N., Singh, M.V. and Ganeshmurthy, A.N. 1997. A critical review of plant nutrient supply needs, efficiency and policy issues for Indian agriculture for the year 2000: Micronutrients and Trace elements. In: *Plant Nutrient, Supply Efficiency and Policy Issues: 2000-2025*, eds. J.S. Kanwar and J.C. Katyal, National Academy of Agricultural Sciences, New Delhi, India. pp 238–64.

Singh, Yadvinder, Khind, C.S. and Singh, Bijay. 1991. Efficient management of leguminous green manures in wetland rice. *Advances in Agronomy* **45**:135–89.