Indian Journal of Agronomy **60** (3): 403–409 (September 2015)

Research Paper

Response of basmati rice (*Oryza sativa*) varieties to zinc fertilization

PRAKASH CHAND GHASAL[1], YASHBIR SINGH SHIVAY[2] AND VIJAY POONIYA[3]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012

Received : June 2015; Revised accepted : July 2015

ABSTRACT

A field experiment was conducted during rainy (July–November) seasons of 2013 and 2014 at New Delhi to evaluate the effects of varieties and zinc (Zn) fertilization on yield attributes, yields and economics of basmati/aromatic rice (*Oryza sativa* L.). Among the varieties, 'Pusa Rice Hybrid 10' had the highest yield attributes, viz. drymatter accumulation (DMA), panicle length and their weight, and grain weight (g)/panicle leading to the highest grain yield (5.67 t/ha), benefit: cost ratio (2.04). 'Pusa Rice Hybrid 10' led to a significant increase in grain yield which was 17.1, 21.2, 30.0, 39.3 and 88.4% higher than those of 'Pusa Sugandh 5', 'Pusa Basmati 1509', 'Pusa Basmati 1121', 'Pusa Basmati 1401' and 'Pusa Basmati 1460', respectively. 'Pusa Basmati 1509' rice showed the highest fertility percentage (87.6), 1,000-grain weight (27.7 g) and the lowest chaffy grains/panicle, followed by 'Pusa Basmati 1121' and 'Pusa Sugandh 5'. Among the Zn fertilization practices, 1.25 kg Zn (Zn-EDTA) + 0.5% foliar spray (FS) at maximum tillering (MT) and panicle initiation (PI) stages was found to be best for most of the yield attributes, grain (4.65 t/ha) and straw (7.87 t/ha) yields and gross returns (147.3×10^3 ₹/ha). A strong positive correlation (r^2=0.91–0.97) was also observed between yield attributes (effective tillers/hill, fertility percentage and grains/panicle) and yield of rice. From net returns and benefit: cost ratio viewpoint, application of 2.5 kg Zn/ha ($ZnSO_4.7H_2O$) + 0.5% FS at MT and PI proved better and gave the highest net returns. 'Pusa Rice Hybrid 10' or 'Pusa Sugandh 5' and 'Pusa Basmati 1509' in conjunction with 1.25 kg Zn/ha (Zn-EDTA) + 0.5% FS at MT and PI significantly improved yield attributes, leading to enhanced productivity of basmati/aromatic rice.

Key words : Productivity, Profitability, Rice varieties, Zn fertilization, Zn-EDTA, $ZnSO_4.7H_2O$

Rice is an important cereal crop in Asia and it provides ~35–80% of total calorie intake. Meanwhile, rice demand is increasing @ ~6% each year in western and African countries (IRRI, 1997; Carriger and Vallee, 2007; Pooniya *et al.,* 2012). Basmati rice is a geographical indicator of a special type of rice grown in South–Asia for its cooking quality parameters. Considering its uniqueness, good will among consumers and growers, and due to changing dietary needs, the demand for such rice is increasing every year in western countries, middle–East, and Asia. Concerted efforts were made at Indian Agricultural Research Institute (IARI), New Delhi, for development of rice varieties having both basmati traits and high yield potential. Therefore, replacement of low-yielding rice genotypes with promising, high-yield potential basmati cultivars can be a viable option for rice growers. In Indian sub-continent, traditional basmati rice varieties are low yielder ~1.5–2.0 t/ha (Shivay *et al.,* 2010). The IARI, New Delhi, has developed several basmati/aromatic rice varieties as well as hybrids which have higher yield potential ~4 to 5 t/ha and fetching premier prices in domestic as well as in international markets. As per an estimate, these cultivars covering maximum acreage under basmati rice grown in north–western Indian states, i.e. Haryana, Punjab, Western Uttar Pradesh, Uttarakhand and Delhi (Pooniya and Shivay, 2013). 'Pusa Basmati 1121', 'Pusa Sugandh 5', 'Pusa Basmati 1509' and 'Pusa Rice Hybrid 10' have high yield potential with excellent global acceptability. These varieties are famous among the farmers of Indo-Gangetic Plains (IGP) and are suitable for multiple cropping which lead to enhance production several-folds besides revolutionizing Indian basmati industry in trans- to upper IGP region.

Zinc (Zn) inadequacy is widespread globally (Cakmak, 2008) especially in high *p*H calcareous soils. In India, its deficiency is more prevalent in rice–wheat belt of northern India. The general recommendation for rice–wheat system

Based on part of Ph.D. thesis of the first author, submitted to ICAR-Indian Agricultural Research Institute, New Delhi 110 012 during 2015 (Unpublished)

[2]**Corresponding author Email:** ysshivay@hotmail.com
[1]Ph.D. Scholar; [2]Principal Scientist; [3]Scientist, Division of Agronomy, ICAR-IARI, New Delhi 110 012

in India is soil application of 10–25 kg Zn through $ZnSO_4.7H_2O$. Several Zn products are available in the market but these are beyond the reach of farmers, resulting in reduced crop productivity. Some sources of chelated Zn like Zn-EDTA etc. are also alternative, which supply substantial amount of Zn to the plants without interacting with soil components due to the fact that metal ion Zn^{2+} is surrounded by chelate ligands (Singh and Shivay, 2015). Foliar spray either through Zn sulphate or Zn-EDTA is an alternative strategy to fortify seed with Zn and also helps in improving human and animal nutrition and health (Stein, 2010; Prasad *et al.,* 2014). In foliar spray, the crop response to applied micronutrient is almost immediate, so that its deficiency can be corrected relatively rapidly (Pooniya and Shivay, 2013). Soils Zn application and foliar sprays are simple and effective solution to combat Zn deficiency in rice, which is inherently low in Zn content. Thus, ferti-fortification of rice through Zn fertilization is an economically viable strategy. As low soil Zn status is an important limiting factor responsible for poor rice yields, it is imperative to evaluate the response of Zn nutrition on basmati rice productivity vis-a-vis its economics. Since not much work has been done to assess the response of promising basmati rice varieties to Zn fertilization irrespective of sources and methods, an experiment was conducted to evaluate the effect of Zn fertilization sources, viz. Zn-EDTA and $ZnSO_4.7H_2O$, through soil and as well as foliar fertilization on productivity and economics of basmati rice varieties.

MATERIALS AND METHODS

A field experiment with basmati rice was conducted during the wet (*kharif*) season of 2013 and 2014 at Indian Agricultural Research Institute, New Delhi (28°38' N and 77°10' E, 228.6 m above mean sea-level). The climate of above unit is semi–arid with dry hot summers and cold winters with an average annual rainfall of 650 mm, 80% of which is received through south-west monsoons during July–September. Soils are alluvium-derived sandy clay loam (typic Ustochrept) with 50.2% sand, 23.2% silt and 26.6% clay. A uniformity trial on wheat was undertaken during the winter (*rabi*) season of 2012–13 to ensure uniform soil physico-chemical status in the entire field. The soil (0–30 cm layer) had *p*H 7.8 (1:2.5 soil: water ratio; Prasad *et al.*, 2006), Walkley–Black C (oxidizable-SOC) 0.51%, alkaline $KMnO_4$-oxidizable–N 252.8 kg/ha (Subbiah and Asija, 1956), 0.5 M $NaHCO_3$-extractable P 13.1 kg/ha (Olsen *et al.,* 1954), and 1 N NH_4OAc-extractable K 291.2 kg/ha (Hanway and Heidel, 1952). The diethylene triamine penta acetate (DTPA)-extractable Zn (Lindsay and Norvell, 1978) content of the soil was 0.63 mg/kg. The critical limits of DTPA-extractable Zn for rice grown in alluvial belt of northern India varies from 0.38 to 0.90 mg/kg.

The experiment was laid-out in a split-plot design and replicated thrice. Six basmati/aromatic rice varieties, viz. 'Pusa 1401', 'Pusa 1460', 'Pusa Rice Hybrid 10', 'Pusa Basmati 1509', 'Pusa Sugandh 5', and 'Pusa Basmati 1121' were assigned to main plots; and 5 Zn fertilization practices, viz. control, soil application of Zn @ 5 kg/ha through $ZnSO_4.7H_2O$, soil application of Zn @ 2.5 kg/ha through $ZnSO_4.7H_2O$ + 0.5% foliar spray of $ZnSO_4.7H_2O$ (ZnSHH) at maximum tillering (MT) and panicle-initiation (PI) stages, soil application of Zn @ 2.5 kg/ha through Zn-EDTA, soil application of Zn @ 1.25 kg/ha through Zn-EDTA + 0.5% foliar spray of Zn-EDTA at MT and PI stages, respectively were assigned to subplots. The foliar application were given 1.05 kg Zn/ha. Allocations of the treatments were done by the randomization following Fisher and Yates random number tables. Field was disc-ploughed twice, puddled thrice with a heavy puddler in standing water (5–7 cm) and then leveled. At final puddling, 26.2 kg P/ha through single superphosphate and 50 kg K/ha through muriate of potash were broadcast uniformly. Nitrogen @ 120 kg/ha as prilled urea was applied in all the treatments. Nitrogen was applied through urea (46% N) in 2 equal splits: half 7 days after transplanting and remaining at panicle-initiation stage. Soil application of Zn fertilizer sources were given as per the treatment details before transplanting of rice except in the control. Twenty five-day-old seedlings of rice were transplanted on hills at 20 cm × 15 cm in the first fortnight of July during both the years. The plot size was 4.0 m × 3.0 m for each treatment. The high yielding basmati rice varieties used for the experiments have been released from IARI, New Delhi and recommended for commercial cultivation by the farmers. Rice crop was grown as per the standard recommended package of practices and was harvested in the second fortnight of October in both the years of experimentation.

Plant height of rice was measured from the base of the plant at ground surface to the tip of the tallest leaf panicle using a standard meter scale. Tillers number was noted by counting from the sampling unit at harvesting stage. Five hills were selected at day 90 and at harvesting of the crop for recording of total dry-matter accumulation by basmati rice. These plants were air-dried and further dried in a hot-air oven at 60±2°C till constant weight was obtained. Dry weight was recorded and expressed in g/hill. Panicle-bearing tillers of the marked 5 hills were counted at harvesting. The length of the panicle was measured from a sample of 10 panicles drawn randomly from the marked 5 hills. Length was measured from neck to the tip of the panicle and average panicle length was computed. The selected 10 panicles, which were used for panicle length, also used to record the weight of the panicles and mean panicle weight was computed, and number of grains/panicle was counted. The selected panicles were cleaned and the filled and unfilled (chaffy) grains were separated. 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. The fertility percentage was calculated using following expression as:

$$= \frac{\text{Number of filled grains/panicle}}{\text{Total grains/panicle}} \times 100$$

After harvesting, threshing, cleaning and drying, the grain yield of rice was estimated at 14% moisture content. Likewise, straw yield was recorded by subtracting grain yield from the total biomass yield. Yield was expressed in t/ha. Gross and net returns were calculated based on the grain and straw yield and the prevailing market prices of basmati rice in respective seasons. Benefit: cost ratio was calculated by dividing the net returns from total cost of cultivation. The benefit: cost ratio was calculated by using following expression: Net returns (₹/ha) ÷ Cost of cultivation (₹/ha). The data obtained from this study for 2 years were analyzed statistically using the F–test, as per the procedure given by Gomez and Gomez (1984). CD values at P=0.05 were used to determine the significance of difference between treatment means.

RESULTS AND DISCUSSION

Growth and yield attributes

At maturity, 'Pusa Basmati 1121' had the tallest plants, being at par with 'Pusa Rice Hybrid 10', 'Pusa Sugandh 5' and 'Pusa Basmati 1401' remained significantly taller than 'Pusa Basmati 1509' and 'Pusa Basmati 1460' (Table 1). Application of 1.25 kg Zn/ha through Zn-EDTA + 0.5% foliar spray (FS) at MT and PI stages recorded the tallest rice plants closely followed by 2.5 kg Zn/ha (ZnSHH) + 0.5% FS at MT and PI stages. Split applications (soil + foliage) of zinc proved better than the basal application in terms of growth characteristics. Shivay *et al.* (2015a) reported more impact of chelated Zn than other fertilizer sources in respect of growth and Zn utilization in plants might be owing to greater transport of chelated Zn to plant roots. 'Pusa Basmati 1121' had the highest number of tillers and effective tillers/hill, being significantly higher than 'Pusa Basmati 1460' remained at par with rest of the varieties. Dry-matter accumulation (DMA), was the highest in 'Pusa Basmati 1401', being at par with 'Pusa Basmati 1460', 'Pusa Rice Hybrid 10' and 'Pusa Basmati 1121'. The higher DMA in turn resulted significantly more straw yield of 'Pusa Basmati 1401' than the others. The shortest panicle length was recorded in 'Pusa Basmati 1401', whereas the longest in 'Pusa Rice Hybrid 10' (Table 1). The longer panicles in 'Pusa Rice Hybrid 10' and 'Pusa Sugandh 5' led to produce significantly more

Table 1. Effect of varieties and zinc fertilization on growth and yield attributes of basmati rice (mean data of 2 years)

Treatment	Plant height at harvest (cm)	Tillers/hill at harvest (Nos.)	DMA at harvest (g/hill)	Effective tillers/hill (Nos.)	Panicle weight (g)	Panicle length (cm)	Grains weight/ panicle (g)	Filled grains/ panicle
Basmati rice varieties								
'Pusa Basmati 1401'	101.8	11.9	42.3	11.3	2.54	25.4	1.56	79.1
'Pusa Basmati 1460'	98.6	8.4	40.7	7.9	2.66	26.6	1.79	87.2
'Pusa Rice Hybrid 10'	103.4	11.8	40.6	11.2	2.70	28.1	2.53	107.2
'Pusa Basmati 1121'	108.1	12.8	39.8	11.9	2.36	26.4	1.44	57.4
'Pusa Basmati 1509'	94.7	12.0	38.8	11.1	2.17	26.2	1.91	72.9
'Pusa Sugandh 5'	102.2	12.1	39.6	11.4	2.78	26.8	2.38	94.6
SEm±	1.99	0.39	0.80	0.31	0.10	0.38	0.03	1.43
CD (P=0.05)	6.26	1.23	2.52	0.98	0.29	1.20	0.09	4.51
Zinc fertilization								
Control (no Zn)	99.9	11.1	38.3	10.4	2.31	26.3	1.75	73.6
5.0 kg Zn ($ZnSO_4.7H_2O$)	101.2	11.5	39.5	10.8	2.54	26.7	1.97	82.5
2.5 kg Zn ($ZnSO_4.7H_2O$) + 0.5% FS at MT and PI	102.2	11.7	41.2	11.0	2.60	26.6	2.02	86.5
2.5 kg Zn (Zn-EDTA)	101.4	11.5	40.6	10.8	2.58	26.5	1.91	84.6
1.25 kg Zn (Zn-EDTA) + 0.5% FS at MT and PI	102.7	11.7	41.9	11.0	2.66	26.9	2.06	88.2
SEm±	0.87	0.25	0.76	0.30	0.06	0.24	0.02	1.07
CD (P=0.05)	NS	NS	2.39	NS	0.18	NS	0.07	3.04

FS, Foliar spray; MT, maximum tillering; PI, panicle initiation; DMA, dry-matter accumulation panicle weight and grain weight/panicle than the other varieties. As expected from panicle length and grain weight (g)/panicle, 'Pusa Rice Hybrid 10' exhibited the highest number of filled grains/panicle and remained significantly superior to rest of the varieties. With regard to fertility percentage, 'Pusa Basmati 1460' and 'Pusa Basmati 1401' registered significantly the highest chaffy grains/panicle, which led to the lowest fertility percentage compared to 'Pusa Basmati 1509', 'Pusa Sugandh 5', 'Pusa Basmati 1121' and 'Pusa Rice Hybrid 10' (Table 2). 'Pusa Basmati 1509' and 'Pusa Basmati 1121' had significantly higher 1,000-grain weight than rest of the varieties.

Application of Zn significantly increased yield attributes, viz. tillers/hill, DMA, panicle weight and length, grain weight (g)/panicle and grains/panicle and the highest values were recorded with 1.25 kg Zn/ha through Zn-EDTA + 0.5% FS at MT and PI stages, which was very close to 2.5 kg Zn (ZnSHH) + 0.5% FS at MT and PI. Salton *et al*. (2005) and Pooniya and Shivay (2012) reported that Zn fertilization improved DMA of rice significantly. Chelated Zn source, i.e. Zn-EDTA proved superior to Zn sulphate in increasing DMA and total Zn content. In the case of tillers/hill and panicle length, the improvement owing to Zn treatments was non-significant (Table 1). Fageria (2001) observed increased tillering and consequently the number of panicles/unit area owing to adequate Zn supply in lowland rice. Chaffy grains/panicle and fertility percentage, were significantly highest in the control compared with Zn applied plots. Likewise, the lowest chaffy grains were obtained in with 1.25 kg Zn/ha through Zn-EDTA + 0.5% FS at MT and PI stages; therefore this treatment had the highest fertility percentage. Adequate soil application of Zn sulphate followed by its foliar application is the best approach to improve growth and yield attributes of rice (Shivay *et al.,* 2015b). Among Zn fertilization treatments, there was non-significant variation for 1,000-grain weight of rice (Table 2). Earlier reports indicated that Zn fertilization in rice has a stimulating effect on number of productive tillers, DMA and yield attributes. Application of chelated Zn-EDTA remained available to crops for longer time than other sources owing to less transformation of EDTA-chelated Zn into unavailable forms (Naik and Das, 2008). The interaction effect between the basmati rice varieties and Zn fertilization was significant for grain weight/panicle (Table 3). Application of 1.25 kg Zn (Zn-EDTA) + 0.5% FS at MT and PI in 'Pusa Sugandh 5' rice led to the highest grain weight/ panicle, which was similar to 2.5 kg Zn (ZnSHH) + 0.5% FS at MT and PI, both of which were significantly higher than that recorded under 2.5 kg Zn (Zn-EDTA), 5.0 kg Zn (ZnSHH) and control treatments.

Yields and harvest index

'Pusa Rice Hybrid 10' showed the highest grain yield

Table 2. Yield attributes, yields and economics of *basmati* rice as influenced by varieties and Zn fertilization (mean data of 2 years)

Treatment	Chaffy grains/ panicle	Fertility (%)	1,000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Cultivation cost (× 10^3 ₹/ha)	Gross returns (× 10^3 ₹/ha)	Net returns (× 10^3 ₹/ha)	Benefit: cost ratio
Basmati rice varieties										
'Pusa Basmati 1401'	46.6	62.9	21.6	4.07	9.36	30.6	58.01	134.5	76.5	1.33
'Pusa Basmati 1460'	60.6	58.9	21.3	3.01	8.06	27.4	58.01	101.8	43.8	0.76
'Pusa Rice Hybrid 10'	26.8	80.2	23.8	5.67	7.66	42.7	58.01	175.5	117.5	2.04
'Pusa Basmati 1121'	13.8	80.6	27.2	4.36	7.40	37.1	58.01	138.1	80.1	1.39
'Pusa Basmati 1509'	10.4	87.6	27.7	4.68	6.51	42.2	58.01	145.2	87.2	1.52
'Pusa Sugandh 5'	20.9	81.8	25.6	4.84	6.56	42.8	58.01	149.9	91.9	1.60
SEm±	1.16	0.84	0.17	0.17	0.35	1.29	–	4.93	4.93	0.09
CD (P=0.05)	3.66	2.65	0.53	0.55	1.08	4.04	–	15.54	15.54	0.27
Zinc fertilization										
Control (no Zn)	32.3	72.0	24.2	4.09	6.68	35.8	54.57	129.2	74.6	1.38
5.0 kg Zn ($ZnSO_4.7H_2O$)	30.8	74.4	24.5	4.37	7.77	37.1	55.37	139.5	84.2	1.53
2.5 kg Zn ($ZnSO_4.7H_2O$) + 0.5% FS at MT and PI	29.5	75.8	24.7	4.60	7.87	37.9	55.54	146.0	90.5	1.64
2.5 kg Zn (Zn-EDTA)	29.4	75.8	24.6	4.47	7.75	37.1	63.42	142.2	78.8	1.25
1.25 kg Zn (Zn-EDTA) + 0.5% FS at MT and PI	27.3	78.4	24.7	4.65	7.87	37.7	61.17	147.3	86.1	1.41
SEm±	1.10	0.74	0.20	0.09	0.20	0.79	–	2.40	2.40	0.04
CD (P=0.05)	3.14	2.11	NS	0.25	0.56	NS	–	6.83	6.83	0.12

FS, Foliar spray; MT, maximum tillering; PI, panicle initiation and was significantly superior to 'Pusa Basmati 1509', 'Pusa Sugandh 5', 'Pusa Basmati 1121', 'Pusa Basmati 1401' and 'Pusa Basmati 1460' while 'Pusa Basmati 1460' gave the lowest grain yield (Table 2). The lowest fertility percentage (58.9) led to the lowest grain yield of 'Pusa Basmati 1460'. 'Pusa Basmati 1401' gave the highest straw yield, being significantly more than all the other varieties except 'Pusa Basmati 1460'. Likewise, comparatively lower tillers/hill and 1,000-grain weights were the responsible characteristics for the lowest grain yield in 'Pusa Basmati 1460' rice too. On contrary, 'Pusa Rice Hybrid 10' registered the highest panicle length, grain weight/panicle and filled grains/panicle which led to produce significantly higher grain yield than rest of the varieties (Table 1). Likewise, 'Pusa Basmati 1509' showed the lowest straw yield. Yield variations were apparent among cultivars; finally, cultivar selection and Zn application will be effective strategies to improve rice grain yield and their quality. 'Pusa Sugandh 5' and 'Pusa Rice Hybrid 10' registered the highest harvest index, while the lowest 'Pusa Basmati 1460'. The higher harvest index in 'Pusa Sugandh 5' and 'Pusa Rice Hybrid 10' is directly correlated to efficient partitioning of photosynthates between harvesting and non-harvesting parts, besides, the economic produce has close association with plant growth and development. Consequently, the differences in photosynthates' partitioning besides varying sink and source relationships of different genotypes perhaps led to a significant variation in the harvest index (Pooniya and Shivay, 2011). A positive and strong correlation (r^2= 0.91 to 0.97) was observed between yield attributes such as effective tillers/hill, filled grains/panicle and fertility percentage, and grain yield of rice (Fig. 1) which ultimately resulted in higher grain yield in different rice varieties and Zn fertilization treatments.

Zinc, irrespective of its source, time and method of application, significantly improved grain and straw yields of rice over the control (no Zn). Among Zn fertilization practices, 1.25 kg Zn/ha through Zn-EDTA + 0.5% FS applied plots showed significantly the highest grain and straw yields, which remained significantly superior to the control. Zinc application through Zn-EDTA, the labile fractions, i.e. water soluble, exchangeable and other Zn complexes, increased in soil which ultimately improved Zn uptake and grain yield of rice (Alvarez *et al*., 2001). An application of Zn increased the DMA and positively improved yield attributes in basmati/aromatic rices, which ultimately resulted in higher yield (Shivay *et al.,* 2010; Pooniya and Shivay, 2012). Similarly, 2.5 kg Zn/ha (ZnSHH) + 0.5% FS and 2.5 kg Zn/ha (Zn-EDTA) were the next best treatments with respect to grain yield. On an average, rice grain and straw yields enhanced by 13.7 and

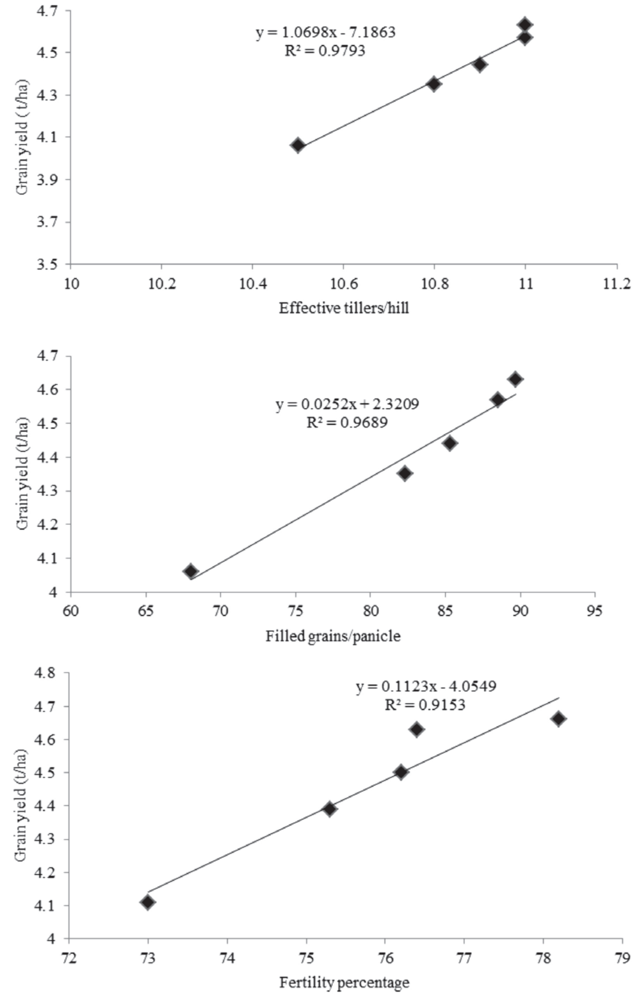

Fig. 1. Relationships between grain yield and yield attributes, viz. effective tillers/hill, filled grains/panicle and fertility percentage etc.

17.8% with 1.25 kg Zn/ha through Zn-EDTA + 0.5% FS over the control respectively. Harvest index in rice was not affected significantly due to Zn fertilization. Application of Zn through Zn-EDTA, *in-spite* of supplying the lowest amount of Zn resulted in the highest yields compared to $ZnSO_4$, or control plots.

Economics

The economics of rice were significantly influenced by the different Zn fertilization treatments (Table 2). The highest cost was involved in 2.5 kg Zn/ha (Zn-EDTA) treatment, followed by 1.25 kg Zn/ha through Zn-EDTA + 0.5% foliar spray at MT and PI stages. Among the Zn treatments, 2.5 kg Zn/ha (Zn-EDTA) was the costliest one with 63.4 × 10^3₹/ha and it was 16.2% higher than the control treatment. 'Pusa Rice Hybrid 10' gave the maximum net and gross returns as well as benefit: cost ratio, followed by 'Pusa Sugandh 5'. Although the maximum gross

Table 3. Interaction effect of basmati rice varieties and zinc fertilization on filled grains weight (g)/panicle (mean data of 2 years)

Treatment	Control	5.0 kg Zn ($ZnSO_4.7H_2O$)	2.5 kg Zn ($ZnSO_4.7H_2O$) + 0.5% FS at MT and PI	2.5 kg Zn (Zn-EDTA)	1.25 kg Zn (Zn-EDTA) + 0.5% FS at MT and PI
‘Pusa Basmati 1401’	1.23	1.67	1.51	1.74	1.68
‘Pusa Basmati 1460’	1.33	1.69	2.29	1.61	2.02
‘Pusa Rice Hybrid 10’	2.16	2.63	2.66	2.55	2.65
‘Pusa Basmati 1121’	1.25	1.52	1.28	1.68	1.46
‘Pusa Basmati 1509’	1.62	1.89	1.84	2.04	2.16
‘Pusa Sugandh 5’	1.92	2.07	2.77	2.59	2.78

SEm± for Zn fertilization at same level of varieties = 0.061
CD (P=0.05) for Zn fertilization at same level of varieties = 0.148
SEm± for varieties at same level of Zn fertilization = 0.053
CD (P=0.05) for varieties at same level of Zn fertilization = 0.155

FS, Foliar spray; MT, maximum tillering; PI, panicle initiation

returns was accrued with 1.25 kg Zn/ha through Zn-EDTA + 0.5% foliar spray, while net returns with 2.5 kg Zn/ha (ZnSHH) + 0.5% foliar spray which were 14 and 21% higher respectively, than the control (no-Zn). This might be owing to the higher cost of chelated Zn-EDTA than Zn sulphate hepta hydrate. A significant benefit : cost ratio was obtained with 2.5 kg Zn/ha (ZnSHH) + 0.5% foliar spray at MT and PI stages, which was at par with 5 kg Zn/ha (ZnSHH). Thus, 2.5 kg Zn/ha (ZnSHH) as soil application along with 2 foliar sprays resulted in higher net benefit: cost ratio and a better choice to realize maximum benefits to the farmers.

Our 2 year field experimentation clearly demonstrated the significant effects of Zn fertilization on basmati/aromatic rice for increasing crop productivity and profitability. Among the varieties, ‘Pusa Rice Hybrid 10’, ‘Pusa Sugandh 5’ and ‘Pusa Basmati 1509’ were found better for productivity and net returns. Application of 1.25 kg Zn/ha through Zn-EDTA + 0.5% foliar spray at MT and PI stages proved superior most in respect to most of yield attributes and yields; although from economic point of view, 2.5 kg Zn/ha (ZnSHH) + 0.5% foliar spray and 5 kg Zn/ha through ZnSHH are better choices to realize the highest net returns and benefit: cost ratio under Zn-stress conditions in the Indo–Gangetic plains of Northern India.

REFERENCES

Alvarez, J.M., Novillo, J., Obrador, A. and Lopez–Valdivia, L.M. 2001. Mobility and leachability of Zn in two soils treated with six organic Zn complexes. *Journal of Agriculture and Food Chemistry* **49**: 3,833–840.

Cakmak, I. 2008. Enrichment of cereal grains with zinc: Agronomic or genetic biofortification? *Plant and Soil* **302**: 1–17.

Carriger, S. and Vallee, D. 2007. More crop per drop. *Rice Today* **6**: 10–13.

Fageria, N.K. 2001. Screening method of lowland rice genotypes for zinc uptake efficiency. *Scientia Agricola* **58**: 623–26.

Gomez, K.A. and Gomez, A.A. 1984. *Statistical Procedures for Agricultural Research,* edn 2, An International Rice Research Institute Book. Wiley-Inter-Science Publication, John Wiley & Sons, New York.

Hanway, J.J. and Heidel, H. 1952. *Soil Analysis Methods as Used in Iowa State College Soil Testing Laboratory*. Bulletin 57, Iowa State College of Agriculture, Iowa, USA. pp 131.

IRRI, 1997. Rice Almanac, 2nd ed. International Rice Research Institute, Los Banos, Philippines, 181 p.

Lindsay, W.L. and Norvell, W.A. 1978. Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal* **42**: 421–28.

Naik, S.K. and Das, D.K. 2008. Relative performance of chelated zinc and zinc sulphate for lowland rice (*Oryza sativa* L.). *Nutrient Cycling in Agroecosystems* **81**: 219–27.

Olsen, R., Cole, C.V., Watanabe, F.S. and Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *Circular-939*, United States Department of Agriculture, Washington DC, USA.

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**): 29–35.

Pooniya, V. and Shivay, Y.S. 2012. Summer green-manuring crops and zinc fertilization on productivity and economics of basmati rice (*Oryza sativa* L.). *Archives of Agronomy and Soil Science* **58**(6): 593–616.

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 crops 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**(1): 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. *Learn-*

ing by Doing Exercises in Soil Fertility–A Practical Manual for Soil Fertility, pp. 68, Division of Agronomy, Indian Agricultural Research Institute, New Delhi, India.

Shivay, Y.S., Prasad, R. and Rahal, A. 2010. Genotypic variation for productivity, zinc utilization efficiencies, and kernal quality in aromatic rices under low available zinc conditions. *Journal of Plant Nutrition* **33**(12): 1,835–48.

Shivay, Y.S., Prasad, R., Kaur, R. and Pal, M. 2015a. 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* (Accepted for publication on 30 April, 2015. DOI: 10.1007/s40011-015-0544-7).

Shivay, Y.S., Prasad, R., Singh, R.K. and Pal, M. 2015b. Relative efficiency of zinc-coated urea and soil and foliar application of zinc sulphate on yield, nitrogen, phosphorus, potassium, zinc and iron biofortification in grains and uptake by basmati rice (*Oryza sativa* L.). *Journal of Agricultural Science* **7**(2): 161–73.

Singh, A. and Shivay, Y.S. 2015. Effect of summer green manuring crops and zinc fertilizer sources on productivity, Zn-uptake and economics of *Basmati* rice. *Journal of Plant Nutrition.* (Accepted author version posted online**:** 05 Feb 2015**.** DOI:10.1080/01904167.2015.1009108).

Slaton, N.A., Norman, R.J. and Wilson, (Jr.) E.C. 2005. Effect of zinc sources and application time on zinc uptake and grain yield of flood–irrigated rice. *Agronomy Journal* **92**: 272–78.

Stein, A.J. 2010. Global impacts of human mineral malnutrition. *Plant and Soil* **335**: 133–54.

Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Science* **25**(8): 259–60.