Original Research Article

Effect of zinc on growth, yield and zinc use efficiency of rice in rice–wheat cropping system

Abstract:

A four year rice-wheat cropping (2012-15) was developed on Nursery Jhilli area of Rajendra Agricultural University, Pusa, Bihar, where zinc applied in four different doses (2.5, 5.0, 7.5 and 10.0 kg ha^{-1}) and 3 modes of application under rice – wheat cropping system, to investigate the effect of different doses of Zn and modes of application on rice growth parameters, yield and Zn use efficiency. Results reveled that among the different growth and yield attributing characteristics of rice the highest of number of tillers m^{-2}, number of productive tillers m^{-2} and number of filled grain $panicle^{-1}$ were observed in 7.5 kg Zn ha^{-1} at alternate year applied plot. Root weight were highest in 7.5 kg Zn ha^{-1} every year applied plot. The grain and straw yield data clearly indicated that application of zinc significantly increased the both yields. The highest grain yield was found in 5 kg Zn ha^{-1} applied every year (40.20 q ha-^{1}) and 7.5 kg Zn ha^{-1} in initial year application was the lowest dose for optimum rice grain yield in the fourth year. Highest Agronomic Efficiency was found in 7.5 kg Zn ha^{-1} (101.33 kg grain/ kg Zn) and the order of apparent Zn recovery efficiency was in the order of, 2.5 kg Zn, alternate year (3.72%) > 2.5 kg Zn, initial year (3.70%) > 7.5 kg Zn, every year (3.61%) > 2.5 kg Zn, every year (3.58%). A suitable dose (5 kg Zn ha^{-1}) of Zn found more efficient in term of yield and recovery efficiency than high or low doses, this can be helpful to farming communities for better earning and reduce excessive application.

Keywords: Zinc application, Growth attributes, Agronomic Efficiency, Zinc recovery efficiency, Rice-wheat cropping system

Introduction:

Zinc an essential mineral for both plants and humans, it is involved in a number of physiological and biochemical processes in living organisms. However, it is deficient in most of the world's agricultural soils, resulting in significant yield losses [1]. Zinc deficiency in crop plants reduces not only grain yield but also the nutritional quality of the grain. The importance of micronutrients in crop production has increased in recent years because of intensive cultivation, use of highyielding cultivars, use of lime in acidic soils, increased use of high analysis fertilizers with low amounts of micronutrients and decreased use of organic manures. A global study by the FAO showed that about 30% of the cultivated soils of the world are Zn deficient [2]. Additionally, about 50% of the soils used worldwide for cereal production contain low levels of plant available Zn [3, 4]. The calcareous soil of Bihar occupying a sizable area are deficient in Zinc to the extent of 80-90 per cent of the tested soil samples [5] and symptoms of zinc deficiency are frequently observed on many crops [6].The normal concentration of this element is 25 to 150 mg kg^{-1} in plants. Deficiencies of Zn are usually associated with concentrations of less than 20 mg kg^{-1} and toxicities will occur when the Zn leaf concentration exceeds 400 mg L^{-1} [7]. Cultivars differ in their ability to take up Zn, which may be caused by differences in Zinc translocation and utilization, differential accumulation of nutrients that interact with Zn and differences in plant roots to exploit for soil Zn [8]. Field crops are known to take up only 0.3 to 3.5% of the annually applied fertilizer Zn. Consequently, fertilizer Zn accumulates in the soil. Because of its low mobility in the soil, positive effect of applied Zn on subsequent crops in the rotation may last over variable periods [9]. Fertilizer Zn recommendations for the cropping system as a whole are yet not available. The availability of fertilizer Zn to plants decreases rapidly after application to soil due to surface adsorption, cation exchange, chelation, and precipitation [10, 11]. Most of the fertilizer Zn applied to a calcareous soil at wheat sowing was bound to soil minerals at harvest. Only a small fraction of the fertilizer Zn was in the soil solution or bound to organic matter, carbonates, or Mn oxides [12]. Zn deficiency in Indian soils is very common and widely found in rice-wheat belts of northern India. In this region it is most common cropping system, serving more than 1/3rd population of the country. There is a need to understand the requirement of dose and frequency of Zn application in Zn deficiency prone upland calcareous soil under rice-wheat cropping system. A four year experiment was conducted on zinc applications in different doses and modes under rice – wheat cropping system to check its effect on growth parameters, yield and Zn use efficiency of rice.

Materials and methods:

The present investigation was undertaken in rice crop in a four year trial (2012-15) of rice-wheat cropping system having different combinations of three modes of Zn application (in the first year, alternate year and every year) with four doses. The site is located at Nursery Jhilli area of Rajendra Agricultural University, Pusa, Bihar, India. A total of 13(3 modes of application × 4 doses + Zn control) treatments with 3 replications were used. Randomized block design was used. Plot size maintained 4 × 2.5m. Puddled transplanted rice (var. Rajshree) was taken with the recommended dose of $N:P_2O_5:K_2O$ at 120:60:40 kg ha^{-1} in the form of urea, diammoium phosphate (DAP) and muriate of potash (MOP). Fifty per cent of N, full doses of P_2O_5 and K_2O were applied as basal and the rest fifty per cent of N was applied in two splits at 30 days interval. Zn was applied as $ZnSO_4$ after puddling in every year plot at four doses (2.5, 5.0, 7.5 and 10.0 kg ha^{-1}). Rice was taken in alternate wetting and drying condition and the soil moisture was kept at field capacity during the entire period. The irrigation was stopped 10 days before harvesting and the crop was harvested and grain yield was recorded at 14% moisture. The different growth and yield attributes of rice were recorded.

Agronomic efficiency was calculated using the following formula:

$$\text{Agronomic efficiency} = \frac{\text{Grain yield}_{\text{Zn fertilized}} - \text{Grain yield}_{\text{control}}}{\text{Zn}_{\text{applied}}} \times 100$$

Results:

Rice growth and yield attributes:

Among the rice growth and yield attributes, number of tillers m^{-2}, productive tillers m^{-2} and filled and unfilled grains $panicle^{-1}$, test weight and root weight were influenced significantly by Zn treatments (Table-1). Number of tillers per m^{-2} of rice varied from 312 in the control to 330 in 7.5 kg Zn ha^{-1}applied at alternate year7.5 kg ha^{-1}at alternate years was similar to 10.0 kg ha^{-1}in initial year and 5.0 to 10.0 kg ha^{-1} in alternate and every year Zn applications. It increased significantly over control at 5.0 and 7.5 kg ha^{-1} in every year and from 5.0 to 10.0 kg ha^{-1} in alternate and initial year applications. Number of productive tillers m^{-2} varied from 253 in control to 268 m^{-2} in 7.5 kg ha^{-1}Zn plots applied at alternate years. The highest value was similar to that of 5.0 kg ha^{-1}at every year and 5 and 10.0 kg ha^{-1}at alternate year applications. It increased significantly from 5.0 and 7.5 kg ha^{-1} in every year, 5.0 to 10.0 kg ha^{-1} in alternate year and from 5.0 to 10.0 kg ha^{-1} in initial year applications of Zn as compared to control. Number of filled grains per panicle varied from 72 in control to 89 in 7.5 kg Zn ha^{-1}at alternate year plot which was similar to 5.0 kg ha^{-1} at every and 10.0 kg ha^{-1}at alternate year applied plots. Unfilled grains per panicle were similar in all the treatments. Root weight was significantly higher in 2.5

to 10.0 kg Zn applied in alternate and every year as compared to control. It varied from 168.67 g m^{-2} in control to 219.33 g m^{-2} in 7.5 kg Zn ha^{-1} in every year applied plot. However, 5.0 to 10.0 kg ha^{-1} in alternate year and 2.5 to 10.0 kg Zn^{-1} in every year applications had similar root weights. Test weight varied from 19.09 g in control to 21.95 g in 7.5 kg Zn ha^{-1} every year applied plot. Most of the Zn treated and control plots had similar test weight. The highest value was found in 7.5 kg Zn ha^{-1} plot applied every year (21.95 g) which was similar to 10 kg ha^{-1} alternate year plot.

Grain and straw yields of rice:

Rice grain yields varied from 30.80 in the control to 40.20 q ha^{-1} in 5.0 kg Zn ha^{-1}at every year applied plot (Table-1). The highest yield was at par with the other three doses of every year applications, more than 5.0 kg ha^{-1} in alternate year applications and more than 7.5 kg dose in initial year application. Straw yield varied from 38.53 in the Zn control to 52.54 q ha^{-1} in 10.0 kg ha^{-1} alternate year applied plot. The highest yield of straw was at par with all the doses of every year and alternate year applications and with 10.0 kg ha^{-1} of initial year application. The response of Zn applications varied from 2.9 to 30.5 per cent to grain yield while 11.3 to 43.5 per cent to straw yield. Thus initial application of 7.5 kg ha^{-1} and 5.0 kg ha^{-1} at alternate years may be the optimum combinations of dose and mode of application of Zn for rice yield.

Zinc use efficiency:

Zinc use efficiency was calculated in term of Agronomic Efficiency and Apparent Recovery Efficiency. Agronomic efficiency varied from 18.17 kg grain per kg Zn in 10.0 kg ha^{-1} at every year to 101.33 kg grain per kg Zn in 7.5 kg ha^{-1} at initial year applications (Fig. 1). In the initial year application highest agronomic efficiency was found in 7.5 kg ha^{-1} while in alternate and every year applications highest efficiencies were found in 2.5 kg ha^{-1} treatments. Apparent Zn recovery efficiency varied 1.07% in 10.0 kg Zn ha^{-1} applied at every year to 3.72 % in 2.5 kg Zn ha^{-1} applied at alternate year (Fig. 2). The order of apparent Zn recovery efficiency was 2.5 kg Zn, alternate year (3.72%) > 2.5 kg Zn, initial year (3.70%) > 7.5 kg Zn, every year (3.61%) > 2.5 kg Zn, every year (3.58%).

Discussion:

Application of zinc sulphate at 20 kg ha^{-1} increased the productive tillers, panicle length and number of grains per panicle, 1000 grain weight and number of effective tillers per plant, fertile spikelet per panicle, panicle lengths and root weight [13, 14, 15]. Zinc and other micro nutrients play important role on yield contributing parameters of rice and grain yield increased significantly with the application of Zn alone or in various combinations with other micronutrients [16]. However, more increase in paddy yield and yield contributing growth parameters was noted in treatment comprising 10 mg kg^{-1} Zn along with 5 mg kg^{-1}Mn and a basal dose of N, P and K fertilizers. For Cauvery delta clay loam soils 25 kg $ZnSO_4$ha^{-1} was found optimum rate for rice cultivation [17]. Increase in rice grain and straw yield by the application of Zinc and the maximum yields were achieved at 5 and 20 mg Zn kg^{-1} of soil, respectively [18]. In another pot experiment with graded doses of Zn under continuous submergence [19], it was found that Zinc deficiency was corrected by application of suitable zinc fertilizer and the results also revealed that rice responded significantly to graded doses of zinc applied. The highest grain (37.53 g pot^{-1}) and straw yield (48.54 g pot^{-1}) was noticed at 5 mg Zn kg^{-1} which was about 100 % and 86% greater than control (no zinc) respectively. Zn fertilization significantly increased total dry weight and grain yield under alternate wetting and drying regimes [20], consistent with the previous studies that Zn application could significantly increase plant growth and grain yield in both low Zn status and high Zn status [21]. Application of 25.0 kg $ZnSO_4$ ha^{-1} in transplanted rice field or spraying standing crop with 0.5 per cent $ZnSO_4$ solution three weeks after transplanting or dipping seedling roots in 2 per cent ZnO suspension were equally effective in correcting zinc deficiency and also significantly affected the different characteristics [22]. Application of $ZnSO_4$ as basal @ 10 kg ha^{-1} during *kharif* season in alternate years with recommended dose of NPK gave rice grain yield at par with application in every year [23]. Zn use efficiency by upland rice genotypes was evaluated by [24] with ten upland rice genotypes grown on an Oxisol (Typic Hapludox).On average, 13% of the applied Zn was recovered by upland rice genotypes. Genotypes with high Zn recovery efficiency could be used in breeding of Zn efficient upland rice cultivars. Zinc concentration and uptake in shoot as well as Zn uptake in grain had significant quadratic increases as Zn concentration increased in the soil solution [18]. Zinc concentration as well as uptake was greater in the shoot as compared with concentration and uptake in the grain. Zinc-use efficiencies significantly decreased with increasing Zn rates in the soil except agro-physiological efficiency, which had significant quadratic increases with increasing Zn rates. On average, about 6% of the applied Zn was recovered by the lowland rice plants. The agronomic, physiological and agro-physiological apparent recovery and utilization efficiencies were highest at lower level of zinc application and decreased with Zn doses.

Conclusion:

It is found that most of the growth and yield attributing characteristics of rice were highest in 7.5 kg Zn ha^{-1}applied plot at alternate year applied plot, those were similar to 5.0 and 10.0 kg Zn ha^{-1} at alternate year and 7.5 kg Zn ha^{-1} at every year applied plot. The grain and straw yield data clearly indicated that application of zinc significantly increased the both yields. On the basis of above findings it is concluded that Zn applied at the rate of 7.5 kg ha^{-1}initially may be considered as optimum for the rice crop in the fourth year under rice-wheat crop rotation in increasing rice growth parameters and grain yield of rice in upland calcareous soil.

References:

1. Alloway BJ. Soil factors associated with zinc deficiency in crops and humans. Environ. Geochem. Health. 2009; 31: 537–548.
2. Sillanpaa M. Micronutrient Assessment at Country Level: An International Study. FAO Soils Bulletin No. 63, Rome. 1982.
3. Graham RD, Ascher JS, Hynes HC. Selecting zinc efficient genotypes for soils of low zinc status. Plant Soil. 1992; 146: 241-250.
4. Welch RM. Zinc concentrations and forms in plants for humans and animals. In Zinc in soils and plants. 1993; 183–195.
5. Sakal R, Singh AP, Singh BP, Sinha RB, Jha SN, Singh SP. Distribution of available micronutrient cations in calcareous soils as related to certain soil properties. Journal of the Indian Society of Soil Science. 1985; 33: 672-675.
6. Sakal R, Singh BP, Singh AP. Determination of critical limit of zinc in soil and plant for predicting response of rice to zinc application in calcareous soil. Plant and Soil. 1979; 66: 129-132.
7. Dobermann A, Fairhurst T. Rice: Nutrient disorders and nutrient management. International Rice Research Institute. 2000.
8. Tisdale SL, Nelson WL, Beaton JL. Soil fertility and fertilizers. New Jersey USA: Pearson Education. 1993.
9. Brennan RF. Residual value of zinc fertilizer for production of wheat. Australian Journal of Experimental Agriculture. 2001; 41: 541–547.

10. Lu AX, Zhang SZ, Shan SQ. Time effect on the fractionation of heavy metals in soils. Geoderma. 2005; 125: 225–234.

11. Jalali M, Khanlari ZV. Effect of aging process on the fractionation of heavy metals in some calcareous soils of Iran. Geoderma. 2008; 143: 26-40.

12. Wei XR, Hao MD, Zhang CX. Zinc fractions and availability in the soil of the Loess Plateau after long-term continuous application of Zinc fertilizer. Sci. Agric. Sin. 2005, 38:1386–1393.

13. Gill RS, Hardeep S. Effect of zinc sulphate on the grain yield performance of tall and dwarf varieties of rice. Indian Journal of Agronomy. 1978; 23: 375-376.

14. Uddin MJ, Bhuiya ZH, Hoque MS, Rahuman L. Effects of rates and methods of zinc application on rice. Madras Agricultural Journal. 1981; 68(4): 211-216.

15. Sriramachandrasekharan MV, Mathan KK. Influence of Zinc sources of the yield components, dry matter production and yield of rice (Var. IR-60). Madras Agricultural Journal. 1988; 75(5-6): 200-203.

16. Abid M, Ahmad N, Jahangir M, Ahmad, I. Effect of zinc, iron and manganese on growth and yield of rice (Oryza Sativa L.). Pakistan Journal of the Agricultural Science. 2001; 101:39(3).

17. Saravanan A, Ramanathan KM. Response of lowland rice to zinc fertilizer. International Rice Research Newsletter. 1986; 11(2): 31.

18. Fageria NK, Santos BD, Cobucci T. Zinc nutrition of lowland rice. Communications in Soil Science and Plant Analysis. 2015; 42(14): 1719-1727.

19. Muthukumararaja TM, Sriramachandrasekharan MV. Effect of zinc on yield, zinc nutrition and zinc use efficiency of lowland rice, Journal of Agricultural Technology. 2012; 8(2): 551-561.

20. Wang YY, Wei YY, Dong LX, Lu LL, Feng Y, Zhang J, Pan FS, Yang XE. Improved yield and Zn accumulation for rice grain by Zn fertilization and optimized water management. Journal of Zhejiang University-SCIENCE B (Biomedicine & Biotechnology) ISSN. 2014.1673-1581.

21. Wissuwa M, Ismail A, Graham R. Rice grain zinc concentrations as affected by genotype, native soil-zinc availability, and zinc fertilization.Plant Soil. 2008; 306(1-2): 37-48.

22. Kumar B, Singh SB, Singh VP. Effect of different methods of zinc application on yield attributes and yield of rice. Journal of Soils and Crops. 1998; 8(2): 112-115.

23. Katyal V, Gangwar B. Effect of frequency and levels of sulphur and zinc application on crop productivity of rice-rice system in east coast areas. Journal of the Indian Society of Coastal AgriculturalResearch. 2000; 18(1): 12-15.

24. Fageria NK, Baligar VC. Growth components and zinc recovery efficiency of upland rice genotypes. Communications in Soil Science and PlantAnalysis. 1997; 32(14): 171-189.

Table 1: Rice growth and yield as influenced by application of different doses and modes of Zn

Treatment	No. of tillers m^{-2}	No. of productive tillers m^{-2}	Root weight ($g\ m^{-2}$)	Length of Panicle (cm)	No. of filled grain $panicle^{-1}$	No. of Unfilled grain $panicle^{-1}$	Test weight (g)	Grain Yield ($q\ ha^{-1}$)	Straw yield ($q\ ha^{-1}$)
T_1: (2.5 kg Zn ha^{-1} at first year)	320	259	169.57	23.67	77	35	19.12	31.70	42.87
T_2: (5.0 kg Zn ha^{-1} at first year)	324	260	174.33	24.03	82	33	19.68	31.77	43.58
T_3: (7.5 kg Zn ha^{-1} at first year)	321	261	173.33	24.73	83	34	20.12	38.40	44.04
T_4: (10.0 Zn kg ha^{-1} at first year)	322	258	169.00	24.40	83	38	20.18	37.93	50.28
T_5: (2.5 kg Zn ha^{-1} at alternate year)	319	258	186.67	24.63	82	32	19.49	34.00	50.36
T_6: (5.0 kg Zn ha^{-1} at alternate year)	323	262	192.00	25.50	82	34	19.59	36.73	50.33
T_7: (7.5 kg Zn ha^{-1} at alternate year)	330	268	195.33	24.33	89	34	20.30	39.73	52.30
T_8: (10.0 kg Zn ha^{-1} at alternate year)	324	262	197.33	24.43	86	35	20.69	40.03	52.54
T_9: (2.5 kg Zn ha^{-1} at every year)	320	259	205.00	23.90	87	34	19.87	36.77	52.24
T_{10}: (5.0 kg Zn ha^{-1} at every year)	329	266	214.33	24.53	88	39	19.51	40.20	52.41
T_{11}: (7.5 kg Zn ha^{-1} at every year)	322	261	219.33	24.87	81	36	21.95	37.72	50.83
T_{12}: (10.0 kg Zn ha^{-1} at every year)	316	256	202.33	24.97	83	37	19.73	38.07	49.54
T_{13}: (Control)	312	253	168.67	23.30	72	33	19.09	30.80	38.53
SEm±	2.78	2.74	4.81	0.66	3.16	1.63	0.52	1.29	2.62
CD (5%)	8.11	7.99	14.04	NS	9.22	4.77	1.53	3.76	7.64

Fig. 1 Agronomic efficiency (kg grain/kg Zn) of the different Zn treatments in rice during fourth year under rice-wheat cropping system

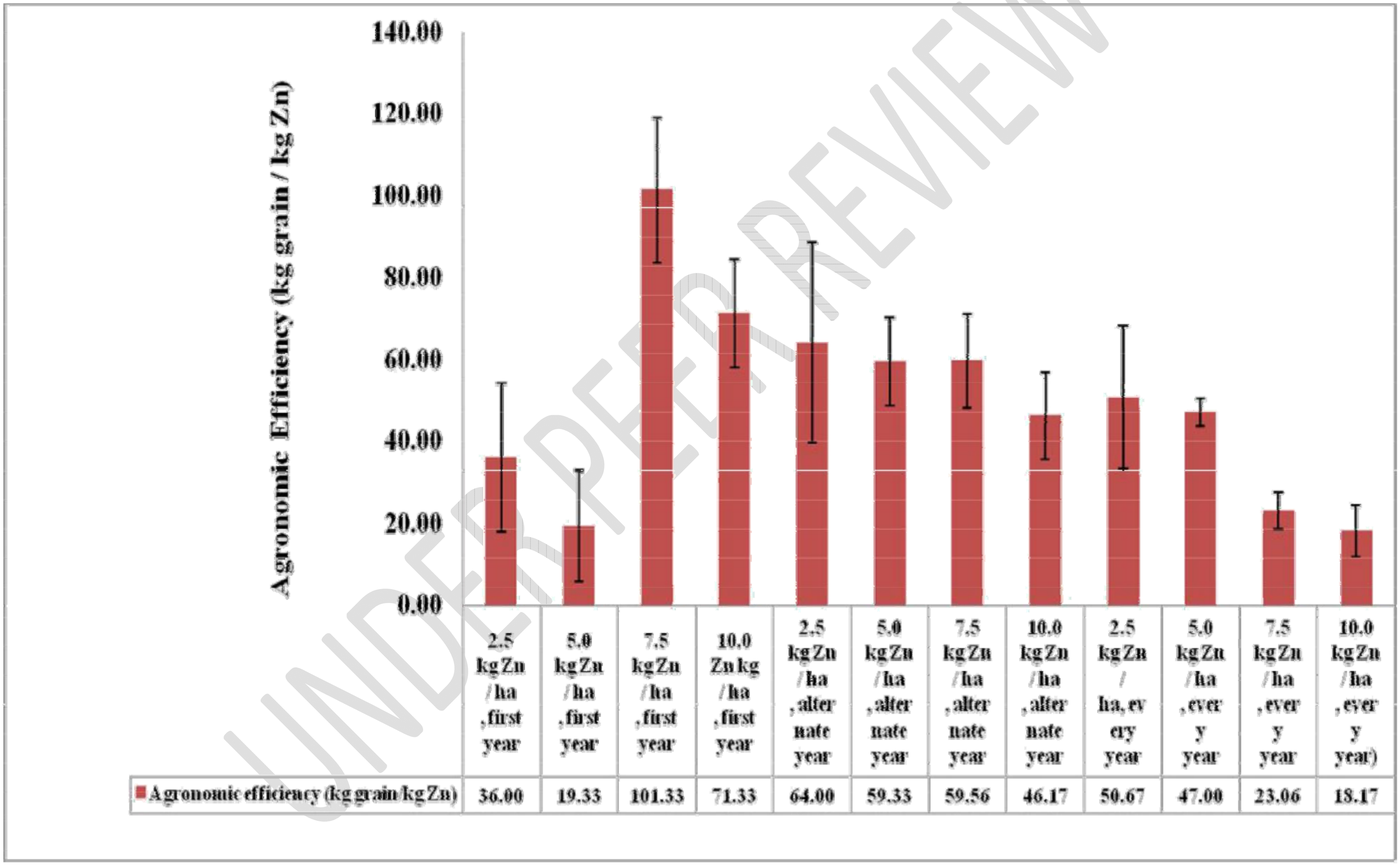

Fig. 2 Apparent Zn recovery efficiency (%) of the different Zn treatments in rice during fourth year under rice wheat cropping system