Effect of Zinc on Growth, Yield and Zinc Use Efficiency of Rice in Rice–Wheat Cropping System

Pankaj Kumar Keshari¹, Ranjan Laik¹, Abhinandan Singh²* and Sudip Sarkar¹

¹Department of Soil Science, Dr. Rejendra Prasad Central Agricultural University, Pusa, Bihar -848125, India.
²Department of Agronomy, Dr. Rejendra Prasad Central Agricultural University, Pusa, Bihar -848125, India.

Authors’ contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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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 revealed 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 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.

*Corresponding author: E-mail: agabhi92@gmail.com;
1. 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 [2]. The importance of micronutrients in crop production has increased in recent years because of intensive cultivation, use of high-yielding cultivars, use of lime in acidic soils, increased use of high-analysis fertilisers with low amounts of micronutrients and decreased use of organic manures [3]. A global study by the FAO showed that about 30% of the cultivated soils of the world are Zn deficient [4]. Additionally, about 50% of the soils used worldwide for cereal production contain low levels of plant available Zn [5,6]. 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 [7] and symptoms of zinc deficiency are frequently observed on many crops [8]. 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 [9]. Cultivars differ in their ability to take up Zn, which may be caused by differences in Zinc translocation and utilisation, differential accumulation of nutrients that interact with Zn and differences in plant roots to exploit for soil Zn [10]. Field crops are known to take up only 0.3 to 3.5% of the annually applied fertiliser Zn. Consequently, fertiliser Zn accumulates in the soil. Because of its low mobility in the soil, a positive effect of applied Zn on subsequent crops in the rotation may last over variable periods [11]. Fertiliser Zn recommendations for the cropping system as a whole are yet not available. The availability of fertiliser Zn to plants decreases rapidly after application to soil due to surface adsorption, cation exchange, chelation, and precipitation [12,13]. Most of the fertiliser Zn applied to a calcareous soil at wheat sowing was bound to soil minerals at harvest. Only a small fraction of the fertiliser Zn was in the soil solution or bound to organic matter, carbonates, or Mn oxides [14]. 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 [15]. 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.

2. 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 Jhili 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:P₂O₅:K₂O at 120:60:40 kg ha⁻¹ in the form of urea, diammonium phosphate (DAP) and muriate of potash (MOP). Fifty per cent of N, full doses of P₂O₅ and K₂O 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 ZnSO₄ 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.

Keywords: Zinc application; growth attributes; agronomic efficiency; zinc recovery efficiency; rice-wheat cropping system.
Agronomic efficiency was calculated using the following formula:

\[
\text{Agronomic efficiency} = \frac{(\text{Grain yield}_{\text{Zn fertilised}} - \text{Grain yield}_{\text{control} / \text{Zn applied}}) \times 100}{1}
\]

3. RESULTS

3.1 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 year 7.5 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 the 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 ha\(^{-1}\) 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.

3.2 Grain and Straw Yields of Rice

Rice grain yields varied from 30.80 in the control to 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 the 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.

3.3 Zinc Use Efficiency

Zinc use efficiency was calculated in term of Agronomic Efficiency and Apparent Recovery Efficiency. Agronomic efficiency varied from 18.17 kg per kg Zn in 10.0 kg ha\(^{-1}\) at every year to 101.33 kg 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%).

4. 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 [16,17,18]. 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 [19]. 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 fertilisers. For Cauvery delta clay loam soils 25 kg ZnSO\(_4\)ha\(^{-1}\) was found optimum rate for rice cultivation [20]. 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
Table 1. Rice growth and yield as influenced by application of different doses and modes of Zn

<table>
<thead>
<tr>
<th>Treatment</th>
<th>No. of tillers m⁻²</th>
<th>No. of productive tillers m⁻²</th>
<th>Root weight (g m⁻²)</th>
<th>Length of Panicle (cm)</th>
<th>No. of filled grain panicle</th>
<th>No. of Unfilled grain panicle</th>
<th>Test weight (g)</th>
<th>Grain Yield (q ha⁻¹)</th>
<th>Straw yield (q ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1: (2.5 kg Zn ha⁻¹ at first year)</td>
<td>320</td>
<td>259</td>
<td>169.57</td>
<td>23.67</td>
<td>77</td>
<td>35</td>
<td>19.12</td>
<td>31.70</td>
<td>42.87</td>
</tr>
<tr>
<td>T2: (5.0 kg Zn ha⁻¹ at first year)</td>
<td>324</td>
<td>260</td>
<td>174.33</td>
<td>24.03</td>
<td>82</td>
<td>33</td>
<td>19.68</td>
<td>31.77</td>
<td>43.58</td>
</tr>
<tr>
<td>T3: (7.5 kg Zn ha⁻¹ at first year)</td>
<td>321</td>
<td>261</td>
<td>173.33</td>
<td>24.73</td>
<td>83</td>
<td>34</td>
<td>20.12</td>
<td>38.40</td>
<td>44.04</td>
</tr>
<tr>
<td>T4: (10.0 kg Zn ha⁻¹ at first year)</td>
<td>322</td>
<td>258</td>
<td>169.00</td>
<td>24.40</td>
<td>83</td>
<td>38</td>
<td>20.18</td>
<td>37.93</td>
<td>50.28</td>
</tr>
<tr>
<td>T5: (2.5 kg Zn ha⁻¹ at alternate year)</td>
<td>319</td>
<td>258</td>
<td>186.67</td>
<td>24.63</td>
<td>82</td>
<td>32</td>
<td>19.49</td>
<td>34.00</td>
<td>50.36</td>
</tr>
<tr>
<td>T6: (5.0 kg Zn ha⁻¹ at alternate year)</td>
<td>323</td>
<td>262</td>
<td>192.00</td>
<td>25.50</td>
<td>82</td>
<td>34</td>
<td>19.59</td>
<td>36.73</td>
<td>50.33</td>
</tr>
<tr>
<td>T7: (7.5 kg Zn ha⁻¹ at alternate year)</td>
<td>330</td>
<td>268</td>
<td>195.33</td>
<td>24.33</td>
<td>89</td>
<td>34</td>
<td>20.30</td>
<td>39.73</td>
<td>52.30</td>
</tr>
<tr>
<td>T8: (10.0 kg Zn ha⁻¹ at alternate year)</td>
<td>324</td>
<td>262</td>
<td>197.33</td>
<td>24.43</td>
<td>86</td>
<td>35</td>
<td>20.69</td>
<td>40.03</td>
<td>52.54</td>
</tr>
<tr>
<td>T9: (2.5 kg Zn ha⁻¹ at every year)</td>
<td>320</td>
<td>259</td>
<td>205.00</td>
<td>23.90</td>
<td>87</td>
<td>34</td>
<td>19.87</td>
<td>36.77</td>
<td>52.24</td>
</tr>
<tr>
<td>T10: (5.0 kg Zn ha⁻¹ at every year)</td>
<td>329</td>
<td>266</td>
<td>214.33</td>
<td>24.53</td>
<td>88</td>
<td>39</td>
<td>19.51</td>
<td>40.20</td>
<td>52.41</td>
</tr>
<tr>
<td>T11: (7.5 kg Zn ha⁻¹ at every year)</td>
<td>322</td>
<td>261</td>
<td>219.33</td>
<td>24.87</td>
<td>81</td>
<td>36</td>
<td>21.95</td>
<td>37.72</td>
<td>50.83</td>
</tr>
<tr>
<td>T12: (10.0 kg Zn ha⁻¹ at every year)</td>
<td>316</td>
<td>256</td>
<td>202.33</td>
<td>24.97</td>
<td>83</td>
<td>37</td>
<td>19.73</td>
<td>38.07</td>
<td>49.54</td>
</tr>
<tr>
<td>T13: (Control)</td>
<td>312</td>
<td>253</td>
<td>168.67</td>
<td>23.30</td>
<td>72</td>
<td>33</td>
<td>19.09</td>
<td>30.80</td>
<td>38.53</td>
</tr>
<tr>
<td>SEM±</td>
<td>2.78</td>
<td>2.74</td>
<td>4.81</td>
<td>0.66</td>
<td>3.16</td>
<td>1.63</td>
<td>0.52</td>
<td>1.29</td>
<td>2.62</td>
</tr>
<tr>
<td>CD (5%)</td>
<td>8.11</td>
<td>7.99</td>
<td>14.04</td>
<td>NS</td>
<td>9.22</td>
<td>4.77</td>
<td>1.53</td>
<td>3.76</td>
<td>7.64</td>
</tr>
</tbody>
</table>
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
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.

5. 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.

REFERENCES


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