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Research Article

Rice cv. HUR105 response to zinc fertilizer combined with microbial consortia and cow dung grown in the eastern plain of Uttar Pradesh, India

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Abstract
The solubility and bioavailability of zinc in the soil determinethe efficiency of Zn fertilizers. A two-year (2018 and 2019) field experiment was performed to study the effectiveness of Zn sources combined with Zn solubilizing microorganisms, ZSM (*Acinetobacter calcoaceticus* + *Pantoea agglomerans*) and cow dung, in rice cv. HUR105 in alluvial soil at the Agriculture Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh. Among various treatments, the treatment (T8) 9.8 kg ZnO ha^{-1} with ZSM showed better grain and straw yields. However, 25.0 kg ZnSHH ha^{-1}+ ZSM (T6) was found to be statistically comparable to the treatment (T8). The addition of cow dung (CD) decreased the grain yield in T11 (9.8 kg ZnO ha^{-1} + ZSM + 200 kg CD ha^{-1}) and T12 (14.6 kg ZnO ha^{-1} + ZSM + 200 kg CD ha^{-1}), except the treatment (T10) 4.9 kg ZnO + ZSM + 200 kg CD ha^{-1}. Partial factor productivity of applied Zn varied from 347.2 to 1762.2 and 369.6 to 1855.6 kg grain kg^{-1} Zn, physiological Zn efficiency varied from 487.4 to 2075.3 and 775.5 and 2035.2 kg grain kg^{-1} Zn absorbed, agronomic use efficiency of Zn ranged from 20.1 to 189.6 and 28.7 to 180 kg grain kg^{-1} Zn, the recovery efficiency of Zn fertilizer varied from 3.58 to 11.9% and 3.57 to 11.8% among the treatments in both seasons, respectively. The maximum gross and net return were documented by T8- 9.8 kg ZnO ha^{-1} + ZSM, and 23.9% and 28.5% over the control due to higher grain yields.

Keywords: Efficiency indices, Rice economics, Solubilizing microorganisms, Zinc oxide, Zinc sulphate

INTRODUCTION

Commercially available zinc (Zn) fertilizers are manufactured and sold in several chemical compositions and physical properties, such as powder, granules and liquids. These fertilizers vary in water-soluble Zn (WsZn) and have a variety of total Zn contents. The level of WsZn in a particular fertilizer is a reliable indicator of its availability to crops. Generally, it is suggested that the minimum level of WsZn should be 40 to 50% in Zn fertilizers to support crop growth (Slaton *et al*., 2005). Several studies have investigated the crop response to Zn sulphate varying in Zn content and water-soluble level, but these fertilizers are more expensive and less concentrated (Shahane *et al*., 2019). Comparatively, ZnO is cheaper and condensed but low in water-soluble Zn. The movement of Zn is diffusion-limited in soil, so more water-soluble Zn fertilizer allows faster displacement of Zn nutrients away from an application point (Mcbeath and McLaughlin, 2014). Although critics believe that fertilizers with low levels of water-soluble Zn steadily release Zn throughout the growing season, high levels of water-soluble Zn once again convert to unavailable Zn pools by precipitation to carbonates, oxides, phosphates, etc. (Zhang *et al*., 2017). Thus, the low use efficiency of applied Zn fertilizers continues to be a challenge, particularly in the long term (Dinesh *et al.*, 2018). The use of soil microbes with multivariate quality could be one way to improve trace metal availability. To understand the nutrient mobilization of insoluble zinc (ZnO, $ZnCO_3$, or $ZnPO_4$) into the labile or available pool, several studies of coinoculation of microbes with Zn fertilizers have been conducted. However, the majority of the studies were conducted in pot experiments (Ramesh *et al.,* 2014, Gandhi and Muralidharan, 2016 and Dinesh *et al.*, 2018). The biogeochemical cycling of zinc is intimately linked to the action of bacteria and metabolic processes (Costerousse *et al.*, 2017). However, a key factor determining the success of these inoculation strategies includes the ability of the inoculated strains to colonize, survive, and mobilize trace elements under natural field conditions. Rice is the prime crop chiefly cultivated under moist and submerged conditions in the field and severely affected by a low Zn supply (Naik and Das, 2008). In the submerged state, the concentrations of iron (Fe^{2+}) and manganese (Mn^{2+}) increased, while the Zn^{2+} concentration decreased as it adsorbed on the hydroxide of iron and manganese (Singh and shivay, 2015). Alloway (2009) reported that the formation of insoluble Zn compounds such as smithsonite ($ZnCO_3$), sphalerite (ZnS), zincite (ZnO), franklinite ($ZnFe_2O_4$), and zinc hydroxide ($Zn(OH)_2$) under submerged conditions affects Zn availability. This problem is more common under rice cultivation, as a report suggested that one-third of cultivable global soil is suffering due to low bioavailable Zn (Dinesh *et al.*, 2018). Moreover, paddy soils also experience low organic matter (OM) contents because of high temperatures and moisture, which cause rapid decomposition of organic matter (OM) (Mohammad *et al.*, 2005). In rice fields, the addition of OM under flood conditions leads to anaerobic decomposition and influences the metal distribution and phytoavailability to crops, as it forms complexes and chalets of varying stabilities with OM (Zhou and Wong, 2001). However, this may be a legitimate argument that the mobility of metals increases as OM decomposition advances over time as a result of hydrolysis, oxidation and depolymerization (Martinez *et al.*, 2003). No scientific data have peered at the application of cow dung manure with microbial consortia and ZnO in rice crops to understand Zn availability. Therefore, the experiment reported here was designed under the following objectives: i) to find the rice response to soluble and insoluble Zn sources combined with microbial consortia and cow dung manure, ii) to evaluate the effect of microbial consortia and cow dung manure on Zn use efficiency, iii) to study the economics of the cost of cultivation of rice *Oryza sativa* L. cv. HUR105.

MATERIALS AND METHODS

The field experiment was conducted in kharif seasons for two consecutive years (2018 and 2019) at the research farm of the Institute of Agricultural Sciences, Banaras Hindu University (BHU), Uttar Pradesh, India, located at 25°18' north latitude and 83°03' east longitude. The experimental soil was sandy loam in texture. It had 176.4 kg ha^{-1} available nitrogen determined by the method of (Subbiah and Asija, 1956), 33 kg ha^{-1} available phosphorus extracted by the method of (Olsen *et al.*, 1954), 143.6 kg ha^{-1}available potassium determined by the method of (Hanway and Heidel, 1952) and 2.5 g kg^{-1} organic carbon determined by the method of (Walkley and Black, 1934). The soil was alkaline in nature (pH 7.3) and had 0.78 mg kg^{-1} DTPA Zn extracted by the method described by Lindsay and Norvell (1978). In North India, the critical level of DTPA-extractable Zn for rice soil ranges from 0.38 to 0.90 mg kg^{-1} soil (Takkar et al., 1997). The experiment was conducted in a randomized block design (RBD), with twelve treatments and three replications: T1: control (Zn_0), T2: 12.5 kg ZnSHH ha^{-1}, T3: 25.0 kg ZnSHH ha^{-1}, T4: microbial consortia (ZSM) (*Acinetobacter calcoaceticus* × *Pantoea agglomerans*), T5: 12.5 kg ZnSHH ha^{-1}+ ZSM, T6: 25.0 kg ZnSHH ha^{-1}+ ZSM, T7: 4.9 kg ZnO ha^{-1} + ZSM, T8: 9.8 kg ZnO ha^{-1} + ZSM, T9: 14.6 kg ZnO ha^{-1} + ZSM, T10: 4.9 kg ZnO ha^{-1} + ZSM + 200 kg cow dung ha^{-1}, T11: 9.8 kg ZnO ha^{-1} + ZSM + 200 kg cow dung ha^{-1} and T12: 14.6 kg ZnO ha^{-1} + ZSM + 200 kg cow dung ha^{-1}.

iThe experimental field was disk-plowed twice, puddled once with a puddler in standing water and levelled. The

Table 1. Properties of selected Zn fertilizer sources and zinc-solubilizing bacteria

Zn source	ZnO (zinc oxide)	$ZnSO_4.7H_2O$ (zinc sulpate heptahydrate)
Total Zn (%)	82	31
Water soluble % (w w^{-1})	< 0.3	99%
Microbes characteristics		
Bacterial spp.	*Acinetobacter calcoaceticus* (ZnJ10)	*Pantoea agglomerans* (ZnJ2A)
Solubilization efficiency (%) ZnO (2000µg/ml)	383	206.3
National Center for Biotechnology Information (NCBI) sequence accession no.	MT509803	MT509806
Relationship	Synergistic	synergistic

recommended dose of fertilizer (RDF) N: P_2O_5: K_2O: 120: 40: 60 kg ha^{-1} was applied uniformly in all treatments through urea, di-ammonium phosphate (DAP), and muriate potash. Half of the doses of N and full doses of P and K were applied at the basal stage, and the remaining half of the N was applied in two equal splits at the tillering and panicle initiation stages. All sources of Zn were applied as soil applications before transplanting (Table 1). For the application of ZSM, strains were inoculated in Bunt and Rovira broth and incubated in a rotary shaker (28±°C) for two days, followed by culture suspension dilution with distilled water to make up the bacterial population (~ × $10^8/10^9$ colony-forming units/ml). After that, sticking solution (water + 10% (w/v) jaggery + 10% (w/v) gum acacia) was prepared and mixed well with the microbial culture. During transplanting, seedlings were dipped in microbial consortia for half an hour before. The selected chemical properties of zinc fertilizers and microbial consortia are presented in Table 1.

The rice variety HUR-105 (Malviya Sugandha-105) was selected for study. Twenty-five-day-old seedlings were transplanted per hill at 20 cm x 15 cm in the second fortnight of July in both years of study. It is an aromatic, photoinsensitive variety with a strong aroma released from the Institute of Agricultural Sciences, Department of Genetics & Plant Breeding, BHU. At maturity, the rice was harvested plotwise, grains and straw of representative samples of a particular treatment were collected, and yields were expressed in qt ha^{-1}. The biological yield was obtained by the addition of grain and straw yields and was expressed in qt ha^{-1}. The harvest index (HI) of different cultivars was calculated as grain yield divided by biomass yield (grain yield + straw yield).

Estimation of efficiency of applied Zn

Different efficiencies of applied Zn were computed and expressed as proposed by Shahane et al. (2019).

iPartial factor productivity (PFP) = $(Y_{Zn})/Zn_a$ ……Eq. 1

where Y_{Zn} is the grain yield (kg ha^{-1}) in the Zn-applied plot and Zn_a is the zinc applied (kg ha^{-1}) in the plot.

Agronomic efficiency (AE) = $(Y_{Zn} - Yc) / Zna$ ……Eq. 2

iwhere Y_{Zn} is the grain yield (kg ha^{-1}) in the Zn-applied plot, Yc is the grain yield (kg ha^{-1}) in the control plot (no zinc) and Zn_a is zinc applied (kg ha^{-1}) in the plot.

Recovery efficiency (RE) = $[(U_{Zn} - Uc)/Zna] \times 100$ ……Eq.3

iwhere U_{Zn} is the total Zn uptake (kg ha^{-1}) in the zinc-applied plot, Uc is the total Zn uptake (kg ha^{-1}) in the control plot (no zinc), Zn_a is the zinc applied (kg ha^{-1}) in the plot.

Physiological efficiency (PE) = $(Y_{Zn} - Yc)/(U_{Zn} - Uc)$ ……Eq. 4

iwhere Y_{Zn} is the grain yield (kg ha^{-1}) in the Zn-applied plot, Yc is the grain yield (kg ha^{-1}) in the control plot (no zinc), U_{Zn} is the total Zn uptake (kg ha^{-1}) in the zinc-applied plot and Uc is the total Zn uptake (kg ha^{-1}) in the control plot (no zinc).

Zn harvest index (ZHI) = GU_{Zn} / TU_{Zn}……Eq. 5

where GU_{Zn} is Zn uptake (kg ha^{-1}) in grain and TU_{Zn} refers to total Zn uptake (kg ha^{-1}) in the grain and straw.

Economics of rice

The economics of rice was calculated based on the minimum support price (MSP) declared by the Government of India (GOI) during both cropping seasons. The gross and net returns were computed based on grain and straw yield. Net income was calculated by subtracting gross income and the total cost of cultivation, whereas the benefit-to-cost ratio (B:C) was computed by dividing the net return by the cost of cultivation.

Statistical analysis

Using the statistical software SPSS 16.0, the data from the experimental sets were analysed for ANOVA of randomized block design with twelve treatments and three replications. Tukey's honest significance test was used to compare pairs of means using least significant difference (LSD) values (P=0.05).

RESULTS

Yield attributing characters

The yield-forming attributes of rice, such as panicle length (cm), filled spikelet $panicle^{-1}$, fertility percentage (%) and 1000 grain weight, were significantly varied due to zinc fertilization, microbial inoculation and cow dung application (Table 2). In both years, rice crops respond more strongly to ZnO than ZnSHH. Panicle length (cm), filled spikelet $panicle^{-1}$ and 1000 grain weight were found superior in treatment (T8) received 9.8 kg ZnO ha^{-1} + ZSM, which was statistically comparable with treatment (T6) - 25 kg ZnSHH ha^{-1} + ZSM, and treatment (T9) - 14.6 kg ZnO ha^{-1} + ZSM. Alone application of treatment (T3) - 25.0 kg ZnSHH ha^{-1} produced significantly higher yield forming attributes than treatment (T2) - 12.5 kg ZnSHH ha^{-1} , which was, however, statistically comparable with treatment (T5) received 12.5 kg ZnSHH ha^{-1} + ZSM. It was observed that ZSM combined with Zn fertilizer improved the yield attributes compared with the individual application of Zn. All the treatments that received cow dung application along with ZnO and ZSM significantly reduced the yield forming attributes except no. of unfilled grains. The reduction was maximum with treatment (T9) 14.6 kg ZnO ha^{-1} + ZSM.

Yield and economics of rice

In both years, field experiments indicated a significant response up to 9.8 kg ZnO ha^{-1} , and these responses varied according to the Zn fertilizers and different combinations with ZSM and cow dung (Table 3). Among the Zn fertilizer sources, ZnO was found to be superior for grain and straw yield in both years. Among the two doses of ZnSHH, 25 kg ha^{-1} increased grain yield by 12.9 and 13.2%, while 12.5 kg ha^{-1} recorded 5.5 and 5.3% yield enhancement over the control in both years, respectively. Positive yield enhancement by applying ZnSHH and microbial inoculation was 19.1 and 18% and 9.9 and 11.6%, respectively. However, a maximum and significant yield was recorded with 9.8 kg ZnO ha^{-1} + ZSM, which increased by 19.3 and 20.2% compared with the control. Further addition of ZnO up to 14.6 kg ha^{-1} + ZSM (T9) reduced the yield but was statistically comparable to 9.8 kg ZnO ha^{-1} + ZSM (T8). These three treatments (T6- 25 kg ZnSHH ha^{-1} and T8- 9.8 and T9- 14.6 kg ZnO ha^{-1}) were found to be statistically superior and comparable to each other compared to the rest of the treatments. The beneficial action of microbial consortia was higher during the second year than in the first year, indicating that bacterial action was impeded as low rainfall and high temperature prevailed during the first cropping season. Cow dung application reduced the grain and straw yield in all the treatments T10 – 4.9 kg ZnO ha^{-1} + ZSM + 200 kg cow dung ha^{-1}, T11 – 9.8 kg ZnO ha^{-1} + ZSM + 200 kg cow dung ha^{-1} and T12 – 14.6 kg ZnO ha^{-1} + ZSM + 200 kg cow dung ha^{-1} , but the reduction was greater with the treatment (T12) that received 14.6 kg ZnO ha^{-1} + ZSM + 200 kg cow dung ha^{-1}. Nevertheless, compared to the control, the yield increased in the order of 8.3 & 12.7%, 14.6 & 17.1% and 6.9 & 7.7% during both years, respectively. The economics of rice were calculated for both years, and maximum gross returns (87.01 and 94.30 ×10^3₹ ha^{-1}), net return (55.14 and 63.38 ×10^3₹ ha^{-1}) and benefit:cost ratio (1.73 and 2.05) were documented by treatment (T8) - 9.8 kg ZnO ha^{-1} + ZSM , which was statistically comparable with T6 - 25 kg ZnSHH ha^{-1} + ZSM and T9 - 14.6 kg ZnO ha^{-1} + ZSM. Treatment T8 had 23.9% and 27.8% higher gross and net returns than the control due to higher grain yields (Table 3).

Zn nutrient use efficiency

Zinc use efficiency (ZnUE) provides an integrative index that quantifies total economic output relative to the utilization of all nutrient resources in the system. The data associated with different Zn use efficiencies (PPP, AE, PE, RE and ZnHI) are presented in Table 4. The recovery efficiency of Zn fertilizer varied between the two sources and increased significantly with the treatment (T10) 4.9 kg ZnO ha^{-1} + ZSM + 200 kg cow dung ha$^{-,1}$ followed by the T7 - 4.9 kg ZnO ha^{-1} + ZSM treatment. Among the ZnSHH doses, 25 kg ZnSHH ha^{-1} without ZSM increased the recovery efficiency. It was observed that as the fertilizer doses increased, the efficiency decreased. The physiological efficiency of zinc indicated no significant difference between the two doses of ZnSHH combined with ZSM, which showed that in both treatments, plants equally transformed Zn fertilizer into grain yield. However, among the ZnO sources, fertilizer combined with cow dung and ZSM showed a lower efficiency of plants to transform Zn into grain, as decomposition of organic matter into soil reduced the availability of Zn at an early stage of cropping. Agronomic Zn use efficiency varied between 20.1 to 189.6 and 28.7 to 180.0 (kg grain/kg fertilizer Zn) among the treatments in both years. A greater agronomic Zn use efficiency was recorded with the T6 - 25 kg ZnSHH ha^{-1} + ZSM treatment due to the greater PEZn in the ZnSHH treatments. The partial factor productivity(PPP) of Zn fertilizer increased with T3 - 12.5 kg ZnSHH ha^{-1} applied with ZSM (1762.2 & 1855.6 kg grain kg^{-1} Zn) and without ZSM application (1679.6 & 1733.3 kg grain kg^{-1} Zn applied). However, a significant PPP was recorded among the ZnO sources with 4.9 kg ZnO ha^{-1} + ZSM and was comparable to T10 - 4.9 kg ZnO ha^{-1} + ZSM + 200 kg cow dung ha^{-1}. The zinc harvest index (ZnHI) varied from 15.89 to 32% and 16.68 to 33.96%, and the differences between the treatments were significant. In general, the ZnHI decreased as the fertilizer doses increased. This ratio was greater for ZnSHH used without ZSM, while the application of cow dung with ZnO fertilizer reduced the ratio of 15.89 to 16.68% in the treatment (T11) of 9.8 kg ZnO ha^{-1} + ZSM+ 200 kg cow dung ha^{-1}.

DISCUSSION

In India, ZnSHH is a highly consumable source of water -soluble zinc fertilizer, which is recommended as 25 kg ZnSHH ha^{-1}. In addition, the product is costly and contains less Zn (31%). Nevertheless, ZnO is a comparatively avoided source of fertilizer and less experimented with under field conditions. The water solubility of ZnO is low and greatly influenced by the nature of the produce, method of application and recommended dose of fertilizer (Cardoso *et al*., 2021). The present investigation examines the effectiveness of two zinc sources with different water solubility levels combined with zinc solubilizing microorganisms (ZSM) and cow dung. The results of this study revealed that treatment (T8) 9.8 kg ZnO ha^{-1} + ZSM was superior among the treatments, while this dose was statistically comparable to T6 - 25 kg ZnSHH ha^{-1} + ZSM . The positive effect of ZnO over ZnSHH might be the result of the comparatively low chemical transformation of ZnO compared to the latter under anaerobic conditions. Zhang *et al*. (2017) reported that water-soluble Zn fertilizer tends to readily precipitate into insoluble compounds of smithsonite ($ZnCO_3$), sphalerite (ZnS), zincite (ZnO), and zinc hydroxide ($Zn(OH)_2$) and restrict the use efficiency to within 2-3%. This finding was in line with Zhang *et al*.

Table 2. Influence of zinc fertilizer sources, microbial consortia and cow dung application on yield parameters of rice (HUR-105)

Treatment	Panicle length (cm)		Filled spikelet panicle^{-1}		Unfilled spikelet panicle^{-1}		Fertility percentage (%)		1000 grain weight	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
T1: Control (No Zinc)	23.6^{e*}	24.1^{de}	96^{g}	101^{f}	32^{a}	31^{ab}	75^{f}	76.5^{d}	21.4^{de}	23.7^{bc}
T2: Zn 2.5 kg ha^{-1} ($ZnSO_4$)	24.1^{de}	24.9^{cde}	111^{f}	115^{e}	30^{b}	30^{b}	78.8^{ef}	79.3^{cd}	22.6^{cd}	24.8^{abc}
T3: Zn 5.0 kg ha^{-1} ($ZnSO_4$)	25.4^{cd}	26.3^{abc}	122^{bcd}	127^{cd}	26de	25^{cd}	82.4^{abcde}	83.6^{abc}	23.1^{bcd}	25^{abc}
T4: ZSM Seedling Treatment	23^{e}	23.1^{e}	93^{g}	98^{f}	23^{f}	25^{cd}	80.2^{cde}	79.7^{bcd}	20.6^{e}	23.3^{c}
T5: Zn 2.5 kg ha^{-1} (ZnSO4) + ZSM	25.5^{c}	26^{bc}	121^{cde}	128^{bcd}	28^{c}	26^{c}	81.2^{bcde}	83.1^{abc}	23.7^{abc}	25.2^{ab}
T6: Zn 5.0 kg ha^{-1} (ZnSO4) + ZSM	26.9^{ab}	27.1^{ab}	128^{abc}	131^{abc}	25^{e}	23^{d}	83.7^{abcd}	85.1^{a}	24.2^{abc}	25.8^{a}
T7: Zn 4.0 kg ha^{-1} (ZnO) + ZSM	25.4^{cd}	25.9^{bcd}	120^{cde}	125^{cd}	30^{b}	33^{a}	80de	79.1^{cd}	23.9^{abc}	24.4^{abc}
T8: Zn 8.0 kg ha^{-1} (ZnO) + ZSM	27.4^{a}	27.9^{a}	132^{a}	140^{a}	25^{e}	26^{c}	84.1^{abcd}	84.3^{abc}	24.7^{ab}	25.4^{ab}
T9: Zn 12.0 kg ha^{-1} (ZnO) + ZSM	27^{ab}	27.6^{ab}	130^{ab}	137^{ab}	28^{c}	25^{cd}	85^{ab}	86.7^{a}	24.9^{a}	25.5^{ab}
T10: Zn 4.0 kg ha^{-1} ZnO +200 kg CD ha^{-1}+ ZSM	25.2^{cd}	26^{bc}	119^{def}	121de	27^{cd}	30^{b}	81.5^{bcde}	82.9^{abc}	23.9^{abc}	25^{abc}
T11: Zn 8.0 kg ha^{-1} ZnO +200 kg CD ha^{-1} + ZSM	27.2^{a}	27.7^{ab}	122^{bcd}	128^{bcd}	22^{f}	23^{d}	84.7^{abc}	84.8^{ab}	24.1^{abc}	25.1^{abc}
T12: Zn 12.0 kg ha^{-1} ZnO +200 kg CD ha^{-1}+ ZSM	25.8^{bc}	26^{bc}	113^{ef}	129^{bcd}	22^{f}	25^{cd}	86.3^{a}	86.6^{a}	24.4^{ab}	25.8^{a}
SEM	0.256	0.367	1.557	1.938	0.251	0.44	0.904	1.046	0.334	0.367
LSD (0.05)	1.318	1.888	8.00	9.97	1.291	2.62	4.563	5.381	1.719	1.885

*Within a column, (mean = 3) followed by the same letters are not significantly different at the ($p \leq 0.05$) level of significance based on Tukey's HSD test.

Table 3. Influence of zinc fertilizer sources, microbial consortia and cow dung application on the economics of rice (HUR-105)

Treatment	Grain yield (q ha^{-1})		Straw yield (q ha^{-1})		Cost of cultivation (×10^3₹ ha^{-1})		Gross return (×10^3₹ ha^{-1})		Net return (×10^3₹ ha^{-1})		Benefit: cost ratio	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
T1: Control (No Zinc)	40.7^{fg*}	42.6^{de}	68.15^{cde}	70.28^{de}	30.47^{c}	29.52^{a}	70.23^{ef}	73.4^{g}	39.76^{fg}	45.72^{fg}	1.3^{ef}	1.55^{fg}
T2: Zn 2.5 kg ha^{-1} ($ZnSO_4$)	42^{efg}	44.3^{cde}	70.66^{bcde}	71.46^{cde}	31.72^{abc}	30.77^{a}	74.32^{de}	79.52^{f}	42.6^{ef}	48.75^{f}	1.34^{de}	1.58^{ef}
T3: Zn 5.0 kg ha^{-1} ($ZnSO_4$)	44.6^{cde}	47.8^{ab}	74.37^{abc}	75.96^{abcd}	32.97^{a}	32.02^{a}	80.63^{bc}	86.65^{bcde}	47.66^{cd}	54.63^{d}	1.45^{cd}	1.71^{de}
T4: ZSM Seedling Treatment	39.9^{g}	41.2^{e}	65.22^{e}	68.12^{e}	30.47^{c}	29.52^{a}	67.16^{f}	71.87^{g}	36.69^{g}	42.35^{g}	1.2^{f}	1.43^{g}
T5: Zn 2.5 kg ha^{-1} ($ZnSO_4$) + ZSM	43.1^{defg}	46.5^{bc}	73.16^{abcd}	74.96^{abcd}	31.72^{abc}	30.77^{a}	77.98^{cd}	85.12^{def}	46.26^{d}	54.36^{de}	1.46^{cd}	1.77^{cd}
T6: Zn 5.0 kg ha^{-1} ($ZnSO_4$) + ZSM	47.1^{abc}	50.8^{a}	78.16^{a}	79.53^{ab}	32.97^{a}	32.02^{a}	86.83^{ab}	91.75^{abc}	53.86^{a}	59.73^{abc}	1.63^{ab}	1.87^{bc}
T7: Zn 4.0 kg ha^{-1} (ZnO) + ZSM	44.3^{cdef}	46.9^{bc}	72.07^{abcd}	73.89^{bcde}	31.16^{bc}	30.21^{a}	78.41^{cd}	87.16^{bcde}	47.24^{cd}	56.95^{bcd}	1.52^{bc}	1.88^{bc}
T8: Zn 8.0 kg ha^{-1} (ZnO) + ZSM	49.2^{a}	51.0^{a}	77.84^{a}	79.08^{ab}	31.87^{abc}	30.92^{a}	87.01^{a}	94.3^{a}	55.14^{a}	63.38^{a}	1.73^{a}	2.05^{a}
T9: Zn 12.0 kg ha^{-1} (ZnO)+ ZSM	48.3^{ab}	50.6^{a}	76.11^{ab}	79.9^{a}	32.57^{ab}	31.62^{a}	85.54^{ab}	92.26^{ab}	52.98^{ab}	60.64^{ab}	1.63^{ab}	1.92^{ab}
T10: Zn 4.0 kg ha^{-1} ZnO +200 kg CD ha^{-1}+ ZSM	42.3^{efg}	45.8^{bcd}	70.49^{bcde}	72.73^{cde}	31.36^{abc}	30.41^{a}	76.6^{cd}	86.14^{cde}	45.24^{de}	55.73^{cd}	1.44^{cd}	1.83^{bcd}
T11: Zn 8.0 kg ha^{-1} ZnO +200 kg CD ha^{-1} + ZSM	46.4^{abcd}	48.9^{ab}	75.49^{ab}	76.67^{abc}	32.07^{abc}	31.12^{a}	82.2^{abc}	90.73^{abcd}	50.13^{bc}	59.61^{abc}	1.56^{bc}	1.92^{ab}
T12: Zn 12.0 kg ha^{-1} ZnO +200 kg CD ha^{-1}+ ZSM	44.7^{bcde}	46.3^{bc}	67.67^{de}	70.28^{de}	32.77^{ab}	31.82^{a}	73.74^{de}	81.55^{ef}	40.97^{f}	49.74^{ef}	1.25^{ef}	1.56^{fg}
SEM	0.52	0.68	1.21	1.16	0.32	0.51	1.21	1.17	0.67	0.92	0.02	0.03
LSD (0.05)	2.663	3.522	6.224	5.988	1.629	2.461	6.22	6.01	3.47	4.71	0.13	0.13

*Within a column, (mean = 3) followed by the same letters are not significantly different at the ($p \leq 0.05$) level of significance based on Tukey's HSD test.

Table 3. Influence of zinc fertilizer sources, microbial consortia and cow dung application on different Zn use efficiencies (HUR-105)

Treatment	Partial factor productivity (kg grain kg^{-1} Zn)		Agronomic efficiency (kg grain increased kg^{-1} Zn applied)		Physiological efficiency (kg grain kg^{-1} Zn uptake)		Recovery efficiency (%)		Zn harvest index (%)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
T1: Control (No Zinc)	-	-	-	-	-	-	-	-	27.67^{d}	28.18^{c}
T2: Zn 2.5 kg ha^{-1} ($ZnSO_4$)	1679.6^{b*}	1733.3^{a}	93.1^{e}	93.3^{g}	1069.4^{e}	1104.1^{f}	6.54^{f}	7.11^{e}	32^{a}	33.96^{a}
T3: Zn 5.0 kg ha^{-1} ($ZnSO_4$)	911.1^{e}	944.4^{c}	119.9^{cd}	124.4^{e}	1382.6^{c}	1254.8^{e}	8.45^{c}	9.55^{b}	28.85^{c}	30.04^{bc}
T4: ZSM Seedling Treatment	-	-	-	-	-	-	-	-	31.14^{b}	31.71^{b}
T5: Zn 2.5 kg ha^{-1} ($ZnSO_4$) + ZSM	1762.2^{a}	1855.6^{a}	176.9^{b}	175.6^{b}	2075.3^{a}	2031.2^{a}	8.02^{cd}	8.68^{c}	23.89^{f}	24.37^{d}
T6: Zn 5.0 kg ha^{-1} ($ZnSO_4$) + ZSM	981.1^{d}	1000^{c}	189.6^{a}	180^{a}	2051.0^{a}	2035.2^{a}	7.46^{e}	7.73^{d}	21.02^{h}	22.05^{ef}
T7: Zn 4.0 kg ha^{-1} (ZnO) + ZSM	1107.4^{c}	1187.5^{b}	111.8^{d}	137.5^{d}	1185.6^{d}	1526.1^{c}	9.04^{b}	9.3^{b}	21.61^{g}	22.56^{de}
T8: Zn 8.0 kg ha^{-1} (ZnO) + ZSM	614.5^{f}	642.4^{d}	125.4^{c}	129.9^{e}	1376.7^{c}	1466.4^{d}	7.58^{e}	7.38^{e}	16.49^{k}	17.48^{h}
T9: Zn 12.0 kg ha^{-1} (ZnO)+ ZSM	402.8^{h}	419^{ef}	77.7^{f}	77.3^{h}	1819.5^{b}	1717.8^{b}	3.58^{g}	3.57^{f}	19.66^{j}	19.91^{g}
T10: Zn 4.0 kg ha^{-1} ZnO +200 kg CD ha^{-1}+ ZSM	1081.9^{c}	1173.6^{b}	92.8^{e}	148.6^{c}	706^{g}	1049.7^{f}	11.9^{a}	11.85^{a}	20.4^{i}	20.19^{fg}
T11: Zn 8.0 kg ha^{-1} ZnO +200 kg CD ha^{-1} + ZSM	580.5^{g}	541.8^{de}	83.9^{f}	105.6^{f}	997.5^{f}	1210.6^{e}	7.4^{e}	7.5^{d}	15.89^{l}	16.68^{h}
T12: Zn 12.0 kg ha^{-1} ZnO +200 kg CD ha^{-1}+ ZSM	347.2^{i}	369.6^{f}	20.1^{g}	28.7^{i}	487.4^{h}	772.5^{g}	3.7^{g}	3.82^{f}	27.07^{e}	28.25^{c}
SEM	24.75	5.79	1.61	2.45	20.3	24.2	0.13	0.17	0.308	0.416
LSD (0.05)	29.35	125.51	8.17	12.294	102.9	122.9	0.48	0.68	1.58	2.14

*Within a column, (mean = 3) followed by the same letters are not significantly different at the ($p \le 0.05$) level of significance based on Tukey's HSD test.

(2017), who also reported that the extractability of zinc (Zn) decreases with time in soil, initially due to quick processes of outer- and inner-sphere surface complexations or surface precipitation followed by a slower process. However, many research studies supported the fact that ZnSHH was a more effective water-soluble source of Zn than ZnO at a lower dose; however, at the higher rate of application, these two sources proved to be equally effective. From comparative studies on Zn fertilizer effectiveness, a similar report documented by Mcbeath and McLaughlin (2014) reported that the plant zinc concentration was greater with ZnO than ZnSHH in durum wheat (*Triticum durum* L. cv. Yallaroi). In the present experiment, both sources were taken with a combination of Zn solubilizing microbes, which further quickened the solubilization process and increased root interception for translocation of zinc. Many experiments of bacterial zinc mobilization and positive effects on crops such as soybean cv. JS 95-60, durum wheat *Triticum turgidum durum*) cv. HI 8691, and rice cv. kranti were reported by Ramesh *et al*. (2014), Gontia- Mishra *et al*. (2016) and Khande *et al*. (2017). The greater growth of rice during the second year is a result of favorable weather parameters, which leads to better growth and adsorption of nutrients in comparison to the first year. The positive effect of rainfall and other weather parameters on rice growth and yield was reported by (Shahane *et al*.,2019) and (Shankar *et al*., 2013). The positive effect of zinc fertilization and microbial inoculation on filled spikelet panicle^{-1}, grain weight, panicle length and panicle^{-1} weight was previously reported by Shivay *et al*. (2015). The performance of different treatments in terms of yield of rice crop was in the order of (T8) 9.8 kg ZnO ha^{-1} + ZSM > (T9) 14.6 kg ZnO ha^{-1} + ZSM > (T6) 25 kg ZnSHH ha^{-1} + ZSM > (T11) 9.8 kg ZnO ha^{-1} + ZSM + 200 kg cow dung ha^{-1} > (T3) 25 kg ZnSHH ha^{-1} > (T10) 4.9 kg ZnO ha^{-1} +ZSM + 200 cow dung ha^{-1} = (T7) 4.9 kg ZnO ha^{-1} + ZSM > (T12) 14.6 kg ZnO ha^{-1} + ZSM + 200 kg cow dung ha^{-1} = (TT3) 12.5 kg ZnSHH ha^{-1} > (T1) control (nil Zn) > (T4) ZSM only observed in present study. Shivay and Prasad (2012) examined the comparative effect of Zn sulphate and ZnO-coated urea at different levels of conc. and found ZnO as a good coating material because it is easy to handle, precisely sticks to urea and is required in lesser quantities. Furthermore, the addition of cow dung with variable doses of ZnO+ ZSM was examined in the present study. This combination markedly lowered the yield-forming attributes, and grain yield reduction was highly prominent, with (T12) 14.6 kg ZnO ha^{-1} + ZSM + 200 kg cow dung ha^{-1} . The detrimental effect of cow dung on crop growth was due to early decomposition of organic matter, forming a number of complexes and chelates of varying solubility that reduced the soil solution concentration of Zn (Clemente et al., 2005). In addition, it may also have a negative impact on microbial culture, which reduces its efficiency under field conditions. As the fertilizer dose increased above 9.8 kg ZnO ha^{-1}, a reduction was observed in rice growth and yield parameters during the present study. This may be attributed to the fact that Zn utilization efficiency decreases as the fertilizer application increases per the law of diminishing return. Zinc use efficiency (ZnUE) provides an integrative index that quantifies total economic output relative to the utilization of all nutrient resources in the system. The recovery efficiency of Zn fertilizer (REZn) is the increase in plant Zn uptake per unit Zn fertilizer applied (kg plant Zn/kg fertilizer Zn). REZn varied from 3.57 to 11.9% among the treatments in the present investigation. The low recovery of zinc fertilizer is due to rapid adsorption on cation exchange sites and clay minerals, which further slows its desorption (Mandal *et al*., 2000). Physiological Zn efficiency (PEZn) is the increase in grain production per unit increase in plant Zn uptake from Zn fertilizer (kg grain kg^{-1} plant Zn). This efficiency varied from 487.4 to 2075.3 kg grain kg^{-1} Zn absorbed and 775.5 and 2035.2 kg grain kg^{-1} Zn absorbed in both seasons in the present experiment, respectively, against the value of 473.0 to 824.1 kg grain kg^{-1} plant Zn reported by Shivay et al. (2014).

Agronomic use efficiency of Zn (AEZn) expressed as the yield increase per unit Zn fertilizer applied (kg grain yield kg^{-1} fertilizer Zn). It varied from 20.1 to 189.6 kg grain kg^{-1} Zn for the first season and 28.7 to 180 kg grain kg^{-1} Zn in the second season, in contrast to the 212 to 311 kg grain kg^{-1} reported by Shivay and Prasad (2012). The economics ($\times 10^3$₹ ha^{-1}) of the present study of rice cultivation revealed that the net return was higher in 9.8 kg ZnO ha^{-1} + ZSM (T8) due to higher grain yield during both years. The report of Shahane et al. (2017), also in line with our findings, showed significant improvement in net returns due to the contribution of microbial biofilms with Zn fertilization in wheat variety HD 2967.

Conclusion

A two-year (2018-2019) field experiment showed that zinc solubilizing consortia with ZnO 9.8 kg Zn ha^{-1} (T8) boosted rice-HUR105 productivity and yield forming attributes like panicle length, filled grain panicle^{-1} and test weight which was statistically comparable with 25 kg ZnSHH ha^{-1} + ZSM (T6). Further application of 14.6 kg ZnO ha^{-1} apparently reduced the yield due to nutrient imbalance in soil. Cow dung applications after transplanting significantly reduced the grain yield due to anaerobic decomposition, and reductions reached a maximum with (T12) 14.6 kg ZnO ha^{-1} . The best economic return was attributed to the combined application of microbial consortia with 9.8 kg ZnO ha^{-1} +ZSM (T8).

Conflict of interest

The authors declare that they have no conflicts of interest.

REFERENCES

1. Alloway, B.J. (2009). Soil factors associated with zinc deficiency in crops and humans. *Environmental Geochemistry and Health*, 31, 537–548.
2. Cardoso, D., Narcy, A., Durosoy, S., Bordes, C. & Chevalier, Y. (2021). Dissolution kinetics of zinc oxide and its relationship with physicochemical characteristics. *Powder Technology*, 378, 746-759.
3. Clemente, R., Escolar, A. & Bernal, M. P. (2006). Heavy metals fractionation and organic matter mineralisation in contaminated calcareous soil amended with organic materials. *Bioresource Technology*, *97*(15), 1894–1901. https://doi.org/10.1016/j.bio rtech.2 005.08.018
4. Costerousse, B., Schönholzer-Mauclaire, L., Frossard, E. & Thonar, C. (2017). Identification of heterotrophic zinc mobilization processes among bacterial strains isolated from wheat rhizosphere (Triticum aestivum L.). *Applied and Environmental Microbiology*, 84(1), e01715-17. https://doi.org/10.1128/AEM.01715-17
5. Dinesh, R., Srinivasan, V., Hamza, S., Sarathambala, C., Gowda, S.J.A., Ganeshamurthy, A.N., Gupta, S.B., Aparn, N.V., Subila, K.P., Lijina, A. & Divya, V.C. (2018). Isolation and characterization of potential Zn solubilizing bacteria from soil and their effects on soil Zn release rates, soil available Zn and plant Zn content. *Geoderma*, 321,173–186.
6. Gandhi, A. & Muralidharan, G. (2016). Assessment of zinc solubilizing potentiality of Acinetobacter sp. isolated from rice rhizosphere. *European Journal of Soil Biology*, *76*, 1-8
7. Gontia-Mishra, I., Sapre, S., Sharma, A. & Tiwari, S. (2016). Amelioration of drought tolerance in wheat by the interaction of plant growth-promoting rhizobacteria. *Plant Biology,* 18, 992–1000. doi: 10.1111/plb.12505
8. Hanway J. J. & Heidel, H. (1952). Soil analyses methods as used in Iowa state college soil testing laboratory, *Iowa Agriculture*, *57*, 1–31.
9. Khande, R., Sushil, K. S., Ramesh, A. & Mahaveer, P. S. (2017). Zinc solubilizing *Bacillus* strains that modulate growth, yield and zinc biofortification of soybean and wheat. *Rhizosphere, 4*, 126–138. doi: 10.1016/j.rhisph.2017.09.002
10. Lindsay, W. L. & Norvell, W. A. (1978). Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of American Journal*, https://doi.org/10.2136/sssaj1978.03615995004200030009x
11. Mandal, B., Hazra, G.C. & Mandal, L.N. (2000). Soil management influences on zinc desorption for rice and maize nutrition. *Soil Science Society of America Journal, 64*,1699 –1705.
12. Martínez, C., Jacobson, A. & Mcbride, M. (2003). Aging and temperature effects on DOC and elemental release from a metal contaminated soil. *Environmental pollution* (Barking, Essex: 1987), 122, 135-43. 10.1016/S0269-7491(02)00276-2.
13. Mcbeath, T. & McLaughlin, M. (2014). Efficacy of zinc oxides as fertilizers. *Plant and Soil*, 374,10.1007/s11104-013-1919-2.
14. Mohammad, A., Hamad, R.J. Khan, E.A. & Mohammad, R. (2005). Comparative response of diverse rice varieties to green manuring (Sesbania aculeata). *Journal of Research (Science), 16*,39–43.
15. Naik, S. K., & Das, D.K. (2008). Relative performance of chelated zinc and zinc sulphate for lowland rice (Oryza sativa L.). *Nutrient Cycling in Agroecosystems*,81, 219–227.
16. Olsen, R., Cole, C.V., Watanabe, F. S. & Dean, L.A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circular 939. Washington, DC: United States Department of Agriculture.
17. Ramesh, A., Sharma, S.K., Sharma, M.P., Yadav, N. & Joshi, O.P. (2014). Inoculation of zinc solubilizing Bacillus aryabhattai strains for improved growth, mobilization and biofortification of zinc in soybean and wheat cultivated in vertisols of central India. *Applied Soil Ecology*, *73*, 87–96.
18. Shahane, A., Shivay, Y., Prasanna, R. & Kumar, D. (2019). Improving Water and Nutrient Use Efficiency in Rice by Changing Crop Establishment Methods, Application of Microbial Inoculations, and Zn Fertilization. *Global Challenges.* 3. 10.1002/gch2.201800005.
19. Shankar Maruthi, G. R., Sharma, L. K., Raddy, S. K., Pratibha, G., Shinde, R, Singh, S. R., Nema, A.K., Singh, R. P., Rath, B. S. & Mishra, A., et al. (2013). Efficient tillage and nutrient management practices for sustainable yield, profitability and energy use efficiency for rice–Based cropping system in different soils and agro-climatic conditions. *Experimental Agriculture, 49* (2),161–78. doi:10.1017/S0014479712001330.
20. Shivay, Y. S. & Prasad, R. (2012). Zinc-coated urea improves productivity and quality of Basmati rice (Oryza sativa L.) under zinc stress condition. *Journal of Plant Nutrition*, *35*, 928–51. doi:10.1080/01904167.2012.663444.
21. Shivay, Y. S., Prasad, R., Singh, R.K. & Pal, M. (2015). 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 Sciences*, *7* (2), 161–73.
22. Shivay, Y.S. (2014). Genetic variability for zinc use efficiency in chickpea as influenced by zinc fertilization. *International Journal of Bioresource and Stress Management*, *5*(1), 031-036
23. Singh, A. & Shivay, Y.S. (2015). Zinc application and green manuring enhances growth and yield in basmati rice (Oryza sativa L.). *Indian Journal of Plant Physiology*, *20*(3), 289–296.
24. Slaton, N. A., Norman, J. E. & Wilson, C. E. (2005). Effect of zinc sources and application time on zinc uptake and grain yield of flooded irrigated rice. *Agronomy Journal, 97*, 272–278.
25. Subbiah, B. V. & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science, 25*, 259–260.
26. Takkar, P.N., Singh, M. V., & Ganeshmurthy, A.N. (1997). In plant nutrient needs, supply, efficiency and policy issues, 2000- 2025. National Academy or Agricultural Sciences, New Delhi. P. 238-264.
27. Walkley, A. J. & Black, I. A. (1934). An examination of the

Degtjareff method for determination of soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science, 37*, 29–38.
28. Zhang, X., Jiang, B. & Ma, Y. (2017). Aging of zinc added to soils with a wide range of different properties: factors and modeling. *Environmental Toxicology Chemistry*, *36*, 2925–2933.
29. Zhou, L. & Wong, J. (2001) Effect of dissolved organic matter from sludge and sludge compost on soil copper sorption. *Journal of Environment Quality, 30*, 878-883.