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Research Article

PRODUCTIVITY, SUSTAINABILITY AND ECONOMICS OF RICE-RICE CROPPING SYSTEM AS INFLUENCED BY ZN APPLICATION

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Abstract: Rice-Rice cropping system is one of the major cropping systems of Odisha occupying an area of 3.31 lakh ha with a productivity of 2.5 t/ha which is much below the national average (Odisha Statistics). Zinc deficiency is a common under rice cultivation. The soils of Odisha are deficient in Zn up to the extent of 28 %. Nutrient transformations under submerged condition are different from that of other aerobic systems. Zn utilization efficiency is 5-10 %.Losses of yield of 20% or more as a result of hidden zinc deficiency can have an economic impact on the farmer. To find out the optimum dose and frequency of Zn application a field experiment was conducted by taking 4 graded doses of Zn applied through 3 frequencies of once in six year ,alternate year up to 6 year ,every year upto six year to the first crop of a rice - rice cropping system grown in an Inceptisols of central farm, OUAT, Bhubaneswar, Odisha. After every 2 year of Zn application Zn fractionation study was conducted to find out the possible fate of Zn application on various Zn pools and on yield of rice - rice cropping system. Results after 5 cropping cycles revealed that Rice crop responded to Zn application with respect to increasing dose and frequency with a highest mean grain yield of 4.3 t/ha as well as cumulative yield of 21.3 t/ha in the treatment of every year Zn application @ 5 kg/ha with highest gross return of 1.33 per rupee investment . Among the pools affected by Zn application was organic and amorphous oxide bound forms .Residual fraction constituted the highest percent of total Zn among all fractions .Hence for rice growing lowland soils of Odisha application of Zn @ 2.5 kg/ha every year to the first crop of a rice-rice cropping system can produce a sustainable yield.

Keywords: *Productivity, Rice-Rice, Zn, Zn Pools*

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Introduction

Soil plays a major role in determining the sustainable productivity of an agro-ecosystem. The sustainable productivity of a soil mainly depends upon its ability to supply essential nutrients to the growing plants. The deficiency of micronutrients has become major constraint to productivity, stability and sustainability of soils [1]. It is well known that the optimum plant growth and crop yield depends not only on the total amount of nutrients present in the soil at a particular time but also on their availability which in turn is controlled by physico-chemical properties like: soil texture, organic carbon and calcium carbonate, cation exchange capacity, pH and electrical conductivity of soil. From 5000 soil samples collected from different districts of Odisha Zn deficiency was 36 % also its deficiency is found to increase over a period of 10 years due to intensive cropping (Annual Report AICRP) .Both deficiency and toxicity of Zn can hamper growth and yield of crop due to narrow range of critical limit. Thus, understanding the distribution of Zn among various fractions of soils will help to characterize the chemistry of Zn in soils and possibly its availability for plant uptake. Zinc availability to rice is strongly related to Zn fractions in the soil [2]. The soil Zn fractions are highly dependent on the physicochemical soil properties, such as pH, organic carbon (OC), clay content and cation exchange capacity (CEC). Paddy fields with different soil moisture regimes bring about numerous changes in the soil physicochemical and electrochemical properties, such as pH, Eh, electrical conductivity (EC), $CaCO_3$. The most important forms of Zn are water extractable (WE), organically bound (Org), amorphous sesquioxide (Amor), crystalline sesquioxide (Cry), manganese oxide (MN) and residual (Res), while the WE and Org are the phyto-available forms of Zn for crop growth. Of the micronutrients essential for plants also indispensible for human being, Zn and Fe are the most important nutrients and nearly half of the Indian soils are deficient in Zn [3].

The present study emphasizes on finding a suitable sustainable Zn dose as well as significant contributor of the Zn fraction to the Zn availability for a rice-rice cs grown under submerged soil.

Materials and Methods

To find out the optimum frequency and dose of Zn application and possible fate of applied Zn a field experiment was conducted at Central Farm of Odisha which continued for 5 years with rice-rice cropping system .Treatments were 4 doses of Zn(2.5,5.0,7.5 & 10.0 kg/ha) applied over 3 frequencies (F_1 once ,F_2 Alternate year ,F_3 Every year)with one no Zn control constituting 13 treatments replicated thrice in randomized block design. Rice Cv Lalat was the test crop. Starting from first year first crop of the sequence received the Zn fertilizer, *rabi* rice being grown on residual Zn treatments. All the crops received recommended doses of fertilizer. Zn fertilizer was applied as $ZnSO_4.7H_2O$ (21% Zn) with major nutrients as basal application. Before starting of the experiment initial soil samples were collected from surface soil upto a depth of 0-20 cm. The soil samples were air-dried, ground and passed through a 2-mm sieve. The physical and chemical properties of the initial soil samples were determined, such as texture, OC, pH [4], CEC, available Zn, Fe^{2+} and Mn^{2+}. DTPA extractable Zn content of soil was determined by using 0.005 M DTPA (pH 7.3) [5]. Fractionation study in initial as well as post harvest soils were carried as per the sequential fractionation procedure[6]. Residual fraction (RES) was estimated by subtracting the sum of all Zn fractions measured as described above from total Zn as per Rico et al. (2009) [7]. Total zinc was estimated by taking 0.5 g soil and digesting it in 12 mL Aqua regia as mentioned by Cheng and Ma (2001) [8]. After extraction, all aforementioned samples were centrifuged and Zn was determined using an Atomic Absorption Spectrophotometer (AAS) (Perkin Elmer 400) of Micronutrient Laboratory.

Table-2 *Direct and residual effect of Zn application on mean yield (t/ha)of rice-rice cropping system*

Frequency	Treatments	1st yr 2012-13	2nd yr 2013-14	3rd yr 2014-15	4th yr 2015-16	5th yr 216-17	Mean	Response (%)
F1 Once	Zn @ 2.5 kg/ha	3.76	3.03	3.50	3.51	3.47	3.5	11.42
	Zn @ 5 kg/ha	4.07	3.23	3.96	3.94	3.82	3.8	22.71
	Zn @ 7.5 kg/ha	4.63	3.58	4.06	4.05	4.48	4.2	34.19
	Zn @ 10 kg/ha	4.44	3.37	3.98	4.00	4.75	4.1	32.52
F2 Alternate Year	Zn @ 2.5 kg/ha	3.70	3.42	3.54	3.70	3.38	3.5	14.45
	Zn @ 5 kg/ha	4.20	3.70	4.32	3.96	3.64	4.0	27.87
	Zn @ 7.5 kg/ha	4.33	3.87	3.57	3.58	3.99	3.9	24.77
	Zn @ 10 kg/ha	3.81	3.98	4.48	3.98	3.78	4.0	29.23
F3 Every Year	Zn @ 2.5 kg/ha	4.02	4.57	4.27	4.22	3.76	4.2	34.45
	Zn @ 5 kg/ha	4.18	4.22	4.34	4.25	4.26	4.3	37.10
	Zn @ 7.5 kg/ha	4.25	3.67	4.25	3.59	4.23	4.0	28.97
	Zn @ 10 kg/ha	4.02	3.87	3.74	3.54	4.06	3.8	24.06
Control	Control (0)	3.21	2.63	3.17	3.40	3.05	3.1	
C.D.(0.05)		D=0.23 F =NS DF =NS	D=NS F=0.35 DxF	D NS F NS DxF 5.6	D NS F NS DxF NS	D = NS F= 0.27 DxF	D =0.15 F=0.12 DxF =0.26	

Table-4 *Economics of frequency and dose of Zn application in rice-rice cropping system*

Frequency	Treatments	Cumulative Zn applied (kg/ha)	Cumulative Yield(t/ha)	Mean Yield (t/ha)	SYI	Gross Return/rupee investment
F1 Once	Zn @ 2.5 kg/ha	2.5	33.9	3.45	0.52	1.09
	Zn @ 5 kg/ha	5.0	37.0	3.80	0.58	1.19
	Zn @ 7.5 kg/ha	7.5	39.6	4.16	0.64	1.28
	Zn @ 10 kg/ha	10.0	38.6	4.11	0.63	1.24
F2 Alternate Year	Zn @ 2.5 kg/ha	7.5	35.8	3.55	0.53	1.15
	Zn @ 5 kg/ha	15.0	39.6	3.96	0.60	1.27
	Zn @ 7.5 kg/ha	22.5	38.7	3.87	0.59	1.24
	Zn @ 10 kg/ha	30.0	40.1	4.01	0.61	1.28
F3 Every Year	Zn @ 2.5 kg/ha	12.5	41.4	4.17	0.64	1.33
	Zn @ 5 kg/ha	25.0	41.7	4.25	0.65	1.33
	Zn @ 7.5 kg/ha	37.5	38.9	4.00	0.61	1.24
	Zn @ 10 kg/ha	50.0	37.6	3.85	0.58	1.20
Control	Control (0)	0.0	15.46	3.00	0.46	0.98

Results

Since both Zn deficiency and toxicity can affect crop yield, controlled and sustainable application is highly essential. To find out the optimum dose and frequency of Zn application an experiment was conducted at central farm, Orissa University of Agriculture and Technology, Bhubaneswar, Odisha. Soils of the experimental site was acidic (pH 5.4) in reaction, low in OC and nutrient status. DTPA extractable Zn content was 0.48 mg/kg. Initial Zn content in different soil fractions was presented in [Table-1] .

Table-1 Zn Fractionation data (mg kg^{-1})

Zn fractions	mg/kg
Water soluble Zn	0.13
Exchangeable Zn	0.37
Water soluble Zn +Exchangeable Zn	0.50
Organically bound Zn	2.4
Oxide bound Zn	0.2
Crystalline Zn	0.33
Residual Zn	1.93
Carbonte bound Zn	-
Total Zn	5.36

Zinc fractionation study of initial soils is presented in [Table-1]

Zn fractionation Study after 2nd yr (after harvest of 4 crops) revealed that Initial Zn content of experimental site was 0.13 ppm as water soluble fraction , 0.37 ppm Exch. Zn .Highest content was organic bound form (2.40 ppm) among the 8 different forms residual form was highest followed by Amorphos –Fe form ,lowest form was in water soluble form .After 2 years of phasing of Zn application (harvest of 4 rice crops) slight increase in all forms were observed than the initial forms due to increase in soil solution. Different fractions increased with increase in Zn application dose as well as with frequency of application. Highest increase was observed in exchangeable Zn fraction due to Zn application indicating most of applied Zn remained in each sites to meet crop requirement. After 4 year with harvest of 8 crops, Zn fractionation study conducted the results of which along with percent contribution to total Zn is presented in [Fig-2]. The table revealed that water soluble Zn concentration ranged from 0.15-0.60 mg/kg. From 2nd year to 4th year water soluble fraction was found to decease in once applied treatments but increased in alternate and every year applied Zn treatments. But exchangeable fraction though followed same trend as WS fraction but decrease in this concentration after 4th year compared to 2nd year was observed. Increase in amorphous oxide and crystalline-oxide bound Zn from 2nd yr to 4th year was due to the fact that under reduced condition in soil there is an increase in the formation of hydrated oxides of Fe,Mn which are freshly formed compounds possessing larger surface area and hence have strong adsorption capacity.

Effect of dose and frequency of Zn on yield of rice-rice cropping system

Effect of frequency and dose of Zn application on mean grain yield of rice-rice CS over 5 year is presented in [Table-2].

Table-3 *Interaction effect of Zn dose and frequency on mean rice grain yield(10 crops)*

	F1 (Once)	F2 (Alt Year)	F3 (every year)	Mean
D1=Zn@2.5 kg/ha	3.5	3.5	4.2	3.7
D2=Zn@ 5.0 kg/ha	3.8	4.0	4.3	4.0
D3=Zn@ 7.5 kg/ha	4.2	3.9	4.0	4.0
D4=Zn@ 10.0 kg/ha	4.1	4.0	3.8	4.0
Mean	3.9	3.9	4.1	
SEM(±)				
C.D.(0.05)	D=0.15	F =0.12	DxF =0.26	

Mean rice grain yield as affected by Dose and frequency of Zn application is presented in [Table-3]. Significant effect of Dose, frequency and interaction was observed on rice grain yield. Mean rice grain yield at D_1(2.5 kg Zn/ha) was 3.7 t/ha which increased significantly at D_2(5 kg Zn/ha) to 4.0 t/ha .Similarly rice grain yield was found to increase with increase in frequency of Zn application highest being at F3(4.1 t/ha) significant increase over F1 or F2 .Interaction effect of Zn dose with frequency produced highest significant rice grain yield of 4.3 t/ha (D_2F_3). Yield increase was observed under residual Zn doses of 2.5-10 kg/ha but yield declined.

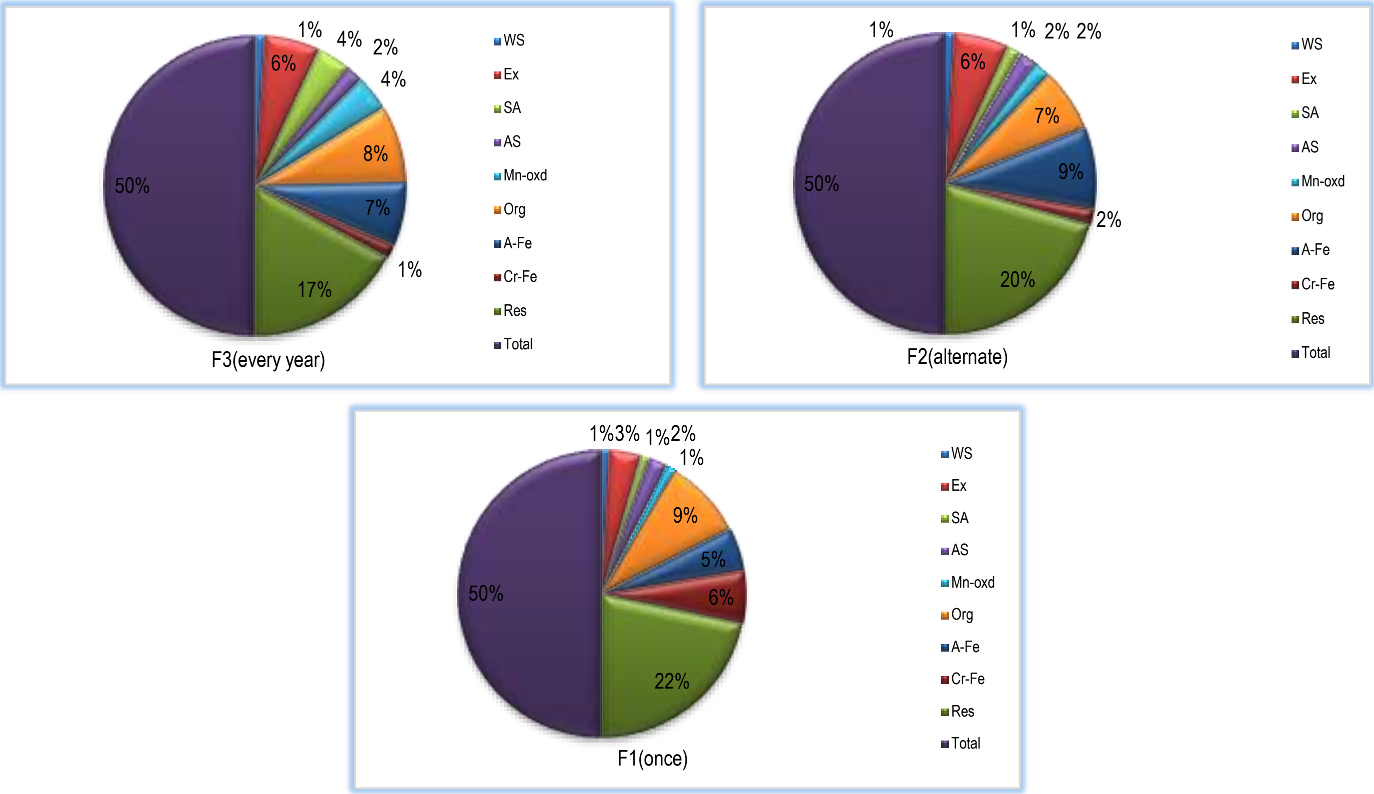

Fig-1 Zn distribution in Post harvest Soil after harvest of 8th crop of rice-rice CS

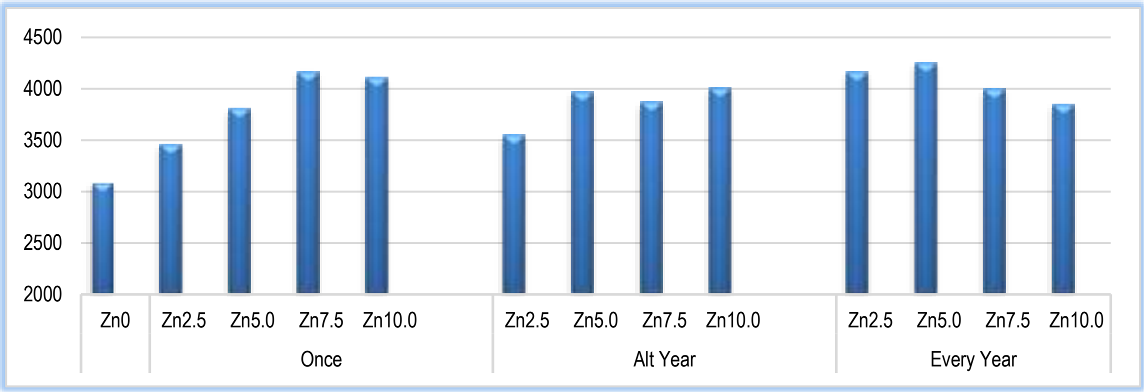

Fig-2 Graphical presentation of phasing of Zn on mean rice grain of rice-rice CS over 5 year

From the data presented in [Table-2] it was found that Rice crop responded to Zn application as seen from [Fig-1]. In control where no Zn was applied mean rice grain yield was 3000 kg/ha. Increase in rice grain yield was noticed due to Zn application. In the treatments of once applied Zn rice grain increased with increase in Zn dose from 2.5 to 7.5 kg/ha and magnitude of yield increase was 11-37 %. Similarly, in alternate year of Zn application highest rice grain was obtained in Zn @ 10.0 kg/ha. In case of every year Zn applications mean rice, grain yield was found to increase with increase in Zn dose upto 5 kg/ha after which yield declined. Since, micronutrients are costly inputs profit was calculated in terms of return per rupee investment. Every year Zn application @ 2.5-5.0 kg/ha produced highest gross return per rupee investment.

Table-5 *Post-harvest soil Zn status*

	pH (1:2.5)	DTPA-Zn (mg/kg)
Once (2.5-10 kg Zn/ha)	4.8-5.4	0.71-1.6
Alternate Year (2.5-10 kg Zn/ha)	5.0-5.4	1.72-2.53
Every Year (2.5-10 kg Zn/ha)	5.0-5.2	1.8-4.6
Control	5.0	0.40
Initial	5.4	0.48

After harvest of 6 cropping cycles of rice-rice system post-harvest soil samples were analysed and presented in [Table-3]. It was observed that initial pH was 5.5 and in post-harvest soil irrespective of $ZnSO_4$ application no change in pH was observed and pH remaining within 5.5 but pH slightly dropped in control treatment. Zinc build-up of was noticed in the treatment getting Zn application frequently.

Effect of Different Zn pools

Effect of dose and frequency of Zn application on various Zn pools were estimated and presented in [Fig-2] as percent of Total Zn.

Table-6 *Multiple regression equations*

Regression equation	R^2
Y=2.97+1.98(WS)-0.24(EX)-0.07(SA)-0.049(AS)-0.28(MnO)+0.30(org)+0.103(Amor)-0.095(Cry)	0.67
Y=3.22-0.308(AS)-0.363(MnO)+0.42(org)+0.041(Amor)-0.012(cry)	0.64
Y =2.79+5.20(WS)-0.21(Ex)-0.39(SA)	0.46
Y=3.21+0.22 (Org)	0.52
Y=3.58+0.14 (Ex)	0.16
Y=3.70 +0.15(cry)	0.10

Multiple regression analysis of the yield and different Zn fractions presented in [Table-6]. It was found that all the fractions combining contributed 67 % to the rice grain yield. Whereas organic fraction contributed 52 %, labile pools contributed 46 % and non-labile pools 64%.

Discussion

Zinc solubility is inversely proportional to the presence of organic compounds in soil [9]. More Zn in organic fraction due to high sorption of metals by Fulvic acids. Also, it was noticed that the treatments receiving Zn application every year most of the Zn getting converted to less labile pools as a result Zn toxicity was not noticed. Increase in amorphous oxide and crystalline-oxide bound Zn from 2nd yr to 4th year was due to the fact that under reduced condition in soil there is an increase in the formation of hydrated oxides of Fe, Mn which are freshly formed compounds possessing larger surface area and hence have strong adsorption capacity.

Conclusion

Under Zn deficient acidic sandy loam soils under rice-rice cropping system Zn application @ 2.5 -5.0 kg/ha every year produced highest cumulative yield ,mean yield as well as this dose and frequency is found to be economical giving highest gross return of rupees 1.33 per rupee investment . Also, it was found that 10 kg Zn if applied once can also sustain yield upto 5 year and give similar return.

Application of research: Zinc fractionation study revealed that most of the applied Zn in every year is converted to less labile pools like organic and amorphous Fe oxide bound forms which can be used as a quantity factor and organic fraction was found to significantly contribute to the yield.

Research Category: Cropping System

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Author Contributions: All authors equally contributed

Author statement: All authors read, reviewed, agreed and approved the final manuscript. Note-All authors agreed that- Written informed consent was obtained from all participants prior to publish / enrolment

Study area / Sample Collection: Central Farm of Odisha

Cultivar / Variety name: Rice

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.
Ethical Committee Approval Number: Nil

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