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Effect of boron fertilization on fate of soil boron pool under a rice-vegetable cropping system grown in an Inceptisols of Odisha

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Abstract
To get quality food grains micronutrient Boron plays an important role apart from many other functions. Since a narrow gap exists between the deficiency and toxicity and only a very small fraction of applied Boron is utilized by crops the possible fate of applied Boron is needed to be quantified. Hence a study was undertaken to find out a suitable and sustainable boron dose for a Rice-Vegetable cropping system as well as effect of Boron application on various Boron pools. For this 4 doses of Boron (0.5,1.0,1.5 & 2.0 kg/ha) applied through three different frequencies(Once, Alternate year, Every year) with one no Boron control constituting 13 treatments replicated thrice in Randomized Block Design was conducted in a Boron deficient Inceptisols of central farm, Bhubaneswar, Odisha. Rice (cv Lalat) was raised with the Boron treatments as direct crop followed by Okra (cv Utkal Gourab) during *rabi* on residual Boron. Both the crops received recommended dose of fertilizer. Rice responded to Boron application by producing highest grain yield of 38 q/ha at 0.5 kg B/ ha applied every year and Okra grown on residual Boron responded to higher dose of Boron application @ 1.0 kg applied every year. Boron fractionation study conducted on post-harvest soil found that with increase in Boron dose and its frequency different Boron pools also increased to various degrees. Out of five different fractions residual Boron constituted highest of total Boron (70-80%). Ready soluble boron and specifically adsorbed Boron constituted a very small fraction of total (1-2%). All the fractions contributed significantly to Rice as well Okra yield and uptake to an extent of 94%, 45% and 73% respectively. Fraction study after two year suggested that in unfertilized control plot depletion of Readily soluble pools were observed where as in Boron fertilized plots though labile pools like Readily soluble Boron and Specifically bound Boron fractions increased but most of soluble fractions converted to less labile and non-labile pools thereby maintaining the B concentration at optimum level to meet crop requirement.

Keywords: Rice-vegetable, dose, frequency, boron pools

1. Introduction
In India, on an average 33 percent soils are deficient in Boron [1]. In Boron deficient soils, the production of food grains, vegetables and fruits is drastically low. Since Boron leaching is a common process in sandyloam soil during kharif, growing of a shallow rooted crop like rice as direct crop followed by a deep rooted crop can utilize leached Boron efficiently from subsoil thereby benefitting both cereal and vegetable crop[2]. To assess the agricultural and environmental impacts of Boron, it is necessary to understand and quantify the different forms of Boron in soil as it could provide an insight into binding forms, dynamics, plant availability and possible environmental impacts of Boron and help in developing rational B fertilizer schedule for crops and cropping system. From reports on micronutrient study it was found that only a small fraction of applied Boron is utilized under rice-vegetable based cropping system. Knowledge of the existence of various Boron pools in soil is essential for future fertilizer schedule. Most of the fractionation study so far conducted is confined to laboratory incubation study or under greenhouse study. But very little work under field condition with graded doses of Boron application is available so for. To know whether small quantities of boron will be applied every year or bulk quantity once and skipping its application for few years the above experiment was designed by taking different graded doses of Boron which are applied over different frequencies to a Rice-Vegetable cropping system with the objective of effect of graded doses of Boron on yield, uptake of crops and B recovery, to determine the various Boron pools (fractions)in post-harvest soil and interrelationship among different Boron pools and their contribution to yield and uptake.

2. Materials and Methods

An experiment was started during 2012-13 under AICRP on micronutrients on Rice-Vegetable cropping system at E block of central research station, O.U.A.T, Bhubaneswar, which is situated at 20 ^{0} 15¨N latitude and 85^0 52 ¨ E longitude, elevation of 25.9 m above MSL (Mean sea level) and comes under East and South Eastern Coastal plain agro-climatic zone of Odisha and falls under the East Coastal Plains and Hills zone of the humid tropics of India.

The soils of experimental site was acidic in reaction with a pH value of 5.4. Electrical conductivity of surface soil was non saline and sandy loam in texture with clay content 10.6%. The bulk density was 1.68 Mg/M^3. The soil was low in organic carbon, low in Available N,P and K and medium in $CaCl_2$ extractable sulphur status. Hot water soluble boron content of the experimental site was 0.3 mg/kg. DTPA-Zinc content was medium whereas Copper content was low and Fe, Mn content were high. As per USDA classification the soil belongs to Vertic Ustochrept under order Inceptisols which cover 49% geographical area of Odisha.

The experiment was laid by taking 4 doses of Boron (0.5,1.0,1.5 & 2.0 kg/ha) applied through three different frequencies (F1-Once, F2-Alternate year, F3-Every year) with one no Boron control constituting 13 treatments replicated thrice in Randomized Block Design. Rice (cv Lalat) was raised with the Boron treatments as direct crop followed by Tomato as 1st residual vegetable crop and Okra (cv Utkal Gourab) as 2nd residual vegetable crop during respective *rabi* season on residual Boron treatments. All the crops received recommended dose of fertilizer. Crops were harvested at maturity. Grain, fruit and plant samples of all crops were collected, washed thoroughly with double distilled water and dried in oven at 65 ± 2 ^{0}C, processed and analysed for boron content in different parts.

Initial soil samples collected before initiation of crop as well as post harvest soils were subjected to sequential fractionation followed by method outlined by [3]. Boron in plant samples were analysed by dry ashing method of [4] and in soil by hot water soluble method followed by Azomethine H colourimetric method of [5]. Data were subjected to statistical analysis by following the method outlined by [6].

3. Results and Discussion

Rice grain and straw yield with different boron treatments is presented in tables 1 and 2.

Table 1: Effect of Dose & Frequency of Boron application on grain yield of Rice

Frequency / Dose	F1(Once)	F2 (Alternate Year)	F3 (Every Year)	Mean
	Rice grain Yield(q/ha)			
Control(0 B)	26.0			26.0
B@0.5 kg/ha	29.3	34.0	38.0	33.8
B@1.0 kg/ha	35.7	34.7	35.7	35.3
B@1.5 kg/ha	37.3	30.0	35.0	34.1
B@2.0 kg/ha	29.3	36.7	30.0	32.0
Mean	32.9	33.8	34.7	
	B	F	B×F	
C.D.(0.05)	NS	NS	6.9	

Table 2: Effect of Dose & Frequency of Boron application on straw yield of Rice

Frequency / Dose	F1(Once)	F2 (Alternate Year)	F3 (Every Year)	Mean
	Rice straw Yield(q/ha)			
Control(0 B)	29.8			29.8
B@0.5 kg/ha	33.3	34.0	35.7	34.3
B@1.0 kg/ha	36.7	37.7	41.7	38.7
B@1.5 kg/ha	43.3	44.7	35.0	41.0
B@2.0 kg/ha	34.0	35.0	34.0	34.3
Mean	36.8	37.9	36.6	
	B	F	B×F	
C.D.(0.05)	NS	NS	NS	

Mean rice grain yield due to different B doses varied from 32.0 to 35.3 q/ha. No significant difference in rice grain yield was observed due to various dose of B on mean rice grain yield. Similarly mean rice grain yield due to frequency varied from 32.9 to 34.7 q/ha, though rice grain increased with increase in frequency of B application. But the interaction effect of B doses and its frequency produced significant yield increase. Lowest yield of 29.3 q/ha was observed where B was applied once, with increase B doses significant increase in rice yield was observed upto 1.5 kg/ha applied once. Compared to yield produced at 1.0 kg/ha B applied once, 2.3 q /ha more yield produced by phasing of half dose over a period of two year or applied @0.5 kg/ha every year. Similarly by phasing application of 2.0 kg B/ha once @ 1.0 kg B /ha / year produced significant yield increase over same 2.0 kg/ha applied once.

Similar findings are also noticed by [7] where application of B@0.5,0.75,&1.0kg /ha enhanced the yield of paddy variety khusboo-95 by 9, 13 and 19% and Mahek by 7, 11 and 15% respectively. Similar findings were also reported by [8] in his long term experiment of Rice-Wheat system also observed 20%yield increased due to application of 1 kg B /ha.

Table 3: Effect of doses and frequency of Boron application on Okra Pod and Biomass Yield

Frequency	Treatments	Okra podyield (t/ha)	Okra biomass yield (t/ha)
F1 Once	B@0.5 kg/ha	6.9	1.6
	B@1.0 kg/ha	8.2	1.9
	B@1.5 kg/ha	9.1	2.1
	B@2.0 kg/ha	9.8	3.0
F2 Alternate Year	B@0.5 kg/ha	7.3	1.7
	B@1.0 kg/ha	9.8	1.8
	B@1.5 kg/ha	7.1	1.9
	B@2.0 kg/ha	9.8	2.1
F3 Every Year	B@0.5 kg/ha	6.9	2.6
	B@1.0 kg/ha	10.3	3.2
	B@1.5 kg/ha	7.8	2.8
	B@2.0 kg/ha	9.2	1.9
Control	No B	6.7	1.0
C.D (0.05)		0.76	0.89

Mean fresh pod yield of okra due to B doses ranged from 7.0 to 9.6 t/ha. With increase in B doses okra pod yield was observed to increase significantly except at 1.5 kg B/ha. Similarly mean pod yield of okra due to different frequency of B application was 8.5 to 8.6 t/ha and no significant difference was observed due to different frequency of B application. Combined effect of B doses and frequency produced okra yield in the range of 6.9 t/ha to 10.3 t/ha.

Highest okra pod yield of 10.3 t/ha was produced by application of B @ 1.0 kg/ha every year which was 0.5 t/ha more than the one time application of 2.0 kg/ha B to 1st crop.

Table 4: Effect of doses and frequency of Boron application on Boron pools in post harvest soil

Frequency	Treatment	Readily soluble B	Specifically Adsorbed B	Oxide bound B	Organically bound B	Residual B	Total B
	(mg/kg)						
F1 Once	B@0.5 kg/ha	0.58	0.31	4.92	4.36	41.68	51.84
	B@1.0 kg/ha	0.61	0.38	5.74	6.98	41.94	55.64
	B@1.5 kg/ha	0.72	0.49	5.94	7.05	42.97	57.17
	B@2.0 kg/ha	0.78	0.55	6.46	7.22	43.67	58.69
F2 Alternate Year	B@0.5 kg/ha	0.63	0.49	6.51	6.52	41.82	55.97
	B@1.0 kg/ha	0.69	0.55	6.53	6.77	42.63	57.16
	B@1.5 kg/ha	0.79	0.58	6.81	7.34	44.43	59.95
	B@2.0 kg/ha	0.82	0.61	7.34	8.35	45.04	62.15
F3 Every Year	B@0.5 kg/ha	0.74	0.44	5.93	7.96	42.99	58.05
	B@1.0 kg/ha	0.76	0.52	6.80	8.02	43.44	59.54
	B@1.5 kg/ha	0.86	0.60	7.39	8.22	43.52	60.59
	B@2.0 kg/ha	0.92	0.65	7.97	8.90	46.49	64.89
Control	No B	0.37	0.30	4.14	4.84	39.97	49.62
Range		0.37-0.92	0.30-0.65	4.14-7.97	4.36-8.90	39.97-46.49	
CD (0.05)		0.17	0.09	1.17	1.05	6.66	-
Initial Soil		0.43	0.32	3.75	3.90	34.89	43.29

Table 5: Percentage Contribution of different B fractions to the total soil B

Frequency	Treatment	Readily soluble B	Specifically Adsorbed B	Oxide bound B	Organically bound B	Residual B
F1 ONCE	B@0.5 kg/ha	1.12	0.57	9.49	8.42	80.40
	B@1.0 kg/ha	1.10	0.68	10.32	12.54	75.37
	B@1.5 kg/ha	1.26	0.86	10.39	12.33	75.16
	B@2.0 kg/ha	1.34	0.93	11.01	12.31	74.41
F2 ALTERNATE YEAR	B@0.5 kg/ha	1.12	0.88	11.63	11.65	74.72
	B@1.0 kg/ha	1.20	0.96	11.42	11.84	74.58
	B@1.5 kg/ha	1.32	0.96	11.37	12.24	74.11
	B@2.0 kg/ha	1.32	0.97	11.80	13.44	72.47
F3 EVERY YEAR	B@0.5 kg/ha	1.27	0.75	10.21	13.71	74.06
	B@1.0 kg/ha	1.27	0.87	11.42	13.47	72.97
	B@1.5 kg/ha	1.42	0.99	12.19	13.57	71.83
	B@2.0 kg/ha	1.41	0.94	12.29	13.72	71.64
CONTROL	No B	0.74	0.60	8.32	9.72	80.33
RANGE		0.74 to1.42	0.57 to 0.99	8.32 to12.29	8.12 to13.72	71.64 to 80.3

Different B fractions like readily soluble B, specifically adsorbed B, oxide bound B, organically bound B and residual B in post-harvest soil due to different doses of B and its frequency is presented in the Table no 5 and percent distribution of each fractions to the total B is represented in Table no.6

Readily soluble fraction includes both hot water soluble Boron and non-specifically adsorbed Boron. The readily soluble Boron content in the initial soil was 0.43 mg/kg and in the control after harvest of crops this fraction was found to be 0.37mg/kg lesser than the control. Readily Soluble Boron content due to various B doses and its frequency was found to be more than the initial as well as the control which ranged from 0.58 to 0.92 mg/kg and significant increase from the control was observed due to different treatments. The RSB contributed about 0.74% to 1.42% to the total boron. This findings are in accordance with findings of [9].

Specifically adsorbed Boron content in the initial soils was 0.32 mg/kg which was 1.0% of total B and in control plot this fraction reduced to 0.30 mg/kg. SA B content due to different B doses and frequency ranges from 0.30 to 0.65mg/kg. With increase in B doses, the Specifically Adsorbed Boron content was increased and increase was also observed with increase in frequency of B application compared to one time application and alternate year of application more SA B content in every year of application. The SA B content was less than the RS B and it contributed 0.57 to 0.99% of the total B content.

Oxide bound fractions includes tightly bound boron at the mineral surface as well as boron that has been replaced by Al^{+3} and Fe^{+3} through isomorphous substitution with the octahedral sheets of minerals. Oxide bound boron content in the initial soil was 3.75 mg/kg which was 8.6% of total boron and in control plot it was 4.14 mg/kg. Oxide bound B due to various B doses and its frequency of application was varied from 4.92 to 7.99 mg/kg which was 9.4 to 12.9% of total B. With increase in B doses the oxide bound B was also increased at all frequency but increase was more in every year application in compare to once and alternate year of application. Oxide B was 8 to 9 times greater than readily soluble B and 15 to 16 time higher than specifically adsorbed B in the soil.

Organic bound fraction mostly present as complexed with organic matter like humic substances. The native organically bound Boron of the experimental site was 3.9 mg/kg, which was about 9.0% of total Boron. Organically bound B of the control was found to increased 4.84 mg/kg. Organically bound Boron due to various direct or residual effect of graded doses of B ranged from 4.36 to 8.9 mg/kg which was 8.12 to 13.7% of total B. This fraction of B also found to increase with increase with B doses. This finding was in collaboration with [10, 11].

The residual Boron is associated with the structures of primary and secondary minerals. Native residual boron content of the experimental site was 34.89 mg/kg which formed 80% of total B. After harvest of four crops this fractions was found to increase in control to 39.97 mg/kg Residual B due to direct or residual effect of different graded level of B ranged from 39.97 to 46.4 mg/kg which was 71.64 to 80.4% % of total B. Boron fractionation study revealed that Boron dose and its frequency of application influenced various Boron pools to various extents, highest pool being the Residual Boron (71.64 to 80.4%) followed by Oxide bound, Organically bound pool. Lowest content of Boron was in labile pools i.e Readily Soluble Boron & Specifically Adsorbed Boron fraction (1-2%).As Boron concentration in soil solution increased due to its application through Boron fertilizers, sufficient Boron getting converted to various less labile and non-labile pools due to increase in rate of forward reaction thus maintaining boron concentration in the soil solution at optimum level to meet crop requirement preventing deficiency or toxicity. Various Boron pools affected by doses and frequency of B application was in order of Residual Boron >organically bound Boron>Oxide bound Boron >readily soluble Boron >specifically adsorbed Boron.

Table 6: Correlation coefficient (r) between B forms and soil properties, yield and uptake of Boron

Soil Properties	HWS B	RSB	SAB	OX B	ORG B	RES B
OC	0.301	0.301	0.372	0.473	0.189	0.269
pH	0.209	0.233	0.456	0.337	0.169	0.202
EC	-0.581*	-0.478	-0.705*	-0.551*	-0.616*	-0.207
Free Fe_2O_3	-0.369	-0.393	-0.469	-0.398	-0.573*	-0.327
Clay %	-0.162	-0.303	-0.210	-0.174	-0.128	-0.257
Rice Grain Yield	0.375	0.395	0.280	0.369	0.535	0.520
Okra Pod Yield	0.587	0.503	0.565	0.536	0.520	0.477
Total B Uptake	0.788*	0.79*	0.642	0.659	0.774	0.656*

To establish the relationship of different B fractions with soil properties correlation coefficients were calculated and presented in table 6. Positive and non significant correlation of pH and OC with soil B fractions were observed. Negative correlation was observed with free Iron oxide but nonsignificant with Boron pools. But all the boron fractions correlated to yield and Boron uptake positively and significantly. Significant correlation was observed for the HWS Boron and readily soluble Boron to total Boron uptake.

Table 7: Regression equations of different fractions of Boron with yield of Rice

Dependent variables	Regression equations	R^2
Rice grain yield		
1.	Y= -29.76-64.6(RS B)+28.3 (SA B)-5.3 (OX B)+5.29 (ORG B) +2.18 (RES B)-0.14 (T B)	0.94
2.	Y= -9.6 – 43.7 (RS B)+9.4(SA B)- 3.19(OX B) +4.29(ORG B) +1.38(RES B)	0.63
3	Y=19.25+0.97 (RS B)-30.6 (SA B)+1.44 (OX B)+2.7 (ORG B)	0.39
4.	Y=19.74+12.13 (RS B)-34.2(SA B)+3.4 (OX B)	0.23
5.	Y=25.27+20.41 (RS B)-13.2(SA B)	0.18
6.	Y=25.2 +11.02 (RS B)	0.15

3.1 Regression equations of different fractions of Boron with yield of Okra

The multiple regression equation developed by taking different fractions as independable variables and Rice, Okra pod yield as dependable variable presented in the table no 7 & and 8. From the R^2 values of multiple regression equations, all the fractions combiningly explained about 94% variability to the yield of rice grain which received the B application. But the individual fractions contributed less or nonsignificantly to the rice grain yield.

Likewise all the fractions explained only 45% variability to okra pod yield which was grown in residual Boron. But the individual fraction contributed very less variability and non-significant to okra pod yield.

Table 8: Regression equations of different fractions of boron with yield of Okra

Dependent variables	Regression equations	R^2
Okra pod yield		
i.	Y= -4.84-13.5(RS B)+19.8(SA B)-1.3 (OX B)+1.11 (ORG B)+0.75 (RES B)-0.36 (TB)	0.45
ii.	Y= 0.25-8.5(RS B)-14.7(SA B)-1.09(OX B) +0.53 (ORG B) +0.23(RES B)	0.39
iii.	Y=5.17-0.95 (RS B)+7.89 (SA B)-0.3 (OX B)+0.25 (ORG B)	0.33
iv.	Y=5.22+0.12 (RS B)+7.54(SA B)-0.1 (OX B)	0.32
v.	Y=5.05-0.14 (RS B)+6.88 (SA B)	0.31
vi.	Y=5.0 +4.72 (RS B)	0.25

4. Conclusion

Various Boron pools affected by doses and frequency of B application was in order of Residual Boron >organically bound Boron>Oxide bound Boron >readily soluble Boron >specifically adsorbed Boron. Since residual Boron is not available to plants and highest content of Boron is reserved in this pool can serve as a Boron store for a long term cropping system including vegetables where requirement of Boron is more. In post-harvest soil Readily Soluble Boron and Specifically Adsorbed Boron fraction was found to decline in control plots due to crop uptake without Boron supplementation. In Boron applied treatment plots as the Boron application increased, more of applied Boron was converted to less labile pools (organically bound Boron and Oxide bound Boron). Labile pool Boron concentration was maintained at optimum level not at toxic level to meet the crop requirement.

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