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Validation of Bio-stimulant Seed Treatment, Soil and Foliar Application of Nano DAP, Urea, K, Zn, Cu, B Formulations in a Flood Affected Bt Hybrid Cotton

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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Original Research Article

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ABSTRACT

Bt hybrid cotton faced 30-60% excess rains in 70% years since its release and four times water logging in 2021, in a deep and shallow *Vertisols* with *Calcareous* sub-strata forced to confirm all the agronomical advices to it. Water logging reduced the biomass, boll number and cotton lint yields to more than 50 percent except the fibre quality. Prevailing runoff and leaching losses of soil applied fertilizer nutrients were accumulated at downstream, which increased the soil test values. Water logging caused reduction of index leaf N, P, K, Zn and B nutrient status below the threshold levels. Soil application of Zn and B once in three years alone or seed treatment formulation with N, P, K Bio-inoculant *consortia* along with nano ZnO 0.0004% + CuO 0.0001% as seed treatment at the time of sowing with or without foliar application of NPK WSF 2%, Zn 0.5%, B 0.3% or 0.04% nano formulations of DAP alternated with Urea alongwith ZnO and K with common insecticides and fungicidal sprays significantly improved index leaf nutrient status, biomass, boll number and seed

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cotton yields in both the soils. Validation of these results in station trials during 2022-24 found the need for atleast two foliar application of nano nutrients each DAP + ZnO + K followed by nano Urea+ ZnO + K 0.004% alternately at the mid and end September and October months. This increased N, P, K, Zn, B content in index leaves and seeds with additional cotton lint yield 209 kg ha^{-1} worth 174 US \$ ha^{-1} net profit by soil application $ZnSO_4$ 20 and Borox 5 kg ha^{-1} yr^{-3} in *Vertisols* and three times foliar application at squaring, flowering and boll formation stage with nano ZnO 0.004%+ B 0.3% or $ZnSO_4$ 0.36% +Boron 0.2% in *Vertisols* with *calcareous* sub-strata.

Keywords: Boron; floods; foliar application; leaching losses; nano fertilizers; nano NPK; runoff; water logging; water soluble fertilizers; nano zinc oxide.

1. INTRODUCTION

1.1 Changing Rainfall Pattern

Since the introduction of Bt hybrid cotton in the last 20 years best productivity and profitability in Central India was achieved only in 20% years of semi dry years compared to 10% extreme dry and excess rains in 70% years with 164 to 234% more than that of the minimum required rainfall (650mm) lead to 50% yield losses despite of adoption of BMPs except planting at 1% slope on broad beds and furrows. Depressions formed fortnightly in Bay of Bengal during July to September months (Tables 1, 2,3,4 Figs. 1, 2) as expected to gave 40 to 60% extra rains in 34-62% more rainy days. However, often they also stalled and disturbed the progress of regular south west monsoon from Arabian ocean during June to September months adversely affecting the rainfall dependent activities in interior areas of Indian cotton producing states [1].

1.2 Crop Growth, Yield, Quality and Profitability

Excess rains beyond 60 mm leads to water logging, shortage of oxygen supply and leaching of soluble nutrients from the root zone [2]. Repeated situation once in September and October months reduced plant growth and total shedding of first two flushes of fruiting parts besides rotting of young un opened bolls [3,4] However, there was also improved productivity in *Vertic Inceptisols* and *Calcisols* due to better soil moisture storage and enhanced water and nutrient supplies ensured by the excess rains. However, the increase in yields in these soils did not compensated the loss of yield from *Vertisols*, which was visible in the lint productivity decline of 100 kg ha^{-1} [5]. Therefore, the highest price realized in *Jalgaon* market was two and half to three times what used to be paid per quintal by traders *via* ginners to cotton farmers in India [6,7].This price realization contradicts with the area, production and productivity data of trade and agriculture department [6].Traders claim that textile manufacturing will become non viable once it exceeds Rs. 50/- kg^{-1} seed cotton, which they used to pay to the cotton farmers anything excess will be passed on to the customers, which was reflected in 10% increase in the whole sale prices in the cotton yarn, textiles and apparels market [6,8] with an excellent opportunities for 19 billion US \$ export markets. However, the big challenge is in the shortage of raw materials and sky racketing of input costs, labour wages, power and transportation incurring a losses to the tune of 25 to 50 kg^{-1} yarn [6].

1.3 Rain Water Management

High intensity of rainfall events exceeding 60 mm per day rain, on steep slope may breaks ridges very easily with high speed runoff, carrying mud and stones lead to severe soil erosion and submergence of low lying cotton fields and silting of runoff harvesting ponds to the tune of >10 tonnes ha^{-1} yr^{-1} [9,1] Although the best agro-techniques adjudged for wet monsoon areas were planting of cotton on broad bed and furrows (BBF) or advance planted cotton with opening of ridges and furrows or BBF before 2nd intercultural operations. However, this was never adopted by the cotton farmers even upto the last 4 wet monsoon years (Tables 1, 2, 3, 4 Figs. 1, 2). Weak starting of south west monsoon also adversely affected the cotton germination and seedling growth by delayed starter fertilizer application. Sub-sequent heavy down pour in July and August months also did not permitted intercultural operations [10,11].

1.4 Nutrient Supply System

Cotton lint yield response to added Zn, B was considerably higher magnitude on low available Zn and B soil status. Boron deficiencies are also very common in marginal soils or high pH calcareous soils when the available soil boron is less than 0.50 ug^{-1} g of soil [12]. Zn and B deficiencies were found in more than 50% of the area of the cotton growing states in India [13]. Critical levels of available Zn 0.90 mg kg^{-1} in soil and concentration of Zn in cotton 4th leaf 58 mg kg^{-1} at 30 days and 25 mg kg^{-1} at maturity were found to be adequate [14] for cotton crop [15,16] Zinc and boron applications were recommended for both *Vertisols* and *calcareous* soils (chelated) as soil and foliar applications alongwith other agro-chemicals inorder to correct anticipating Zn and B deficiencies [17,1] Zn and B both are highly soluble and subjected to leaching, runoff and fixation on clay or organic matter. HWS extraction of Azomethine-H method was the most sensitive in determining extractable B content of soils and plant tissues comparable to other methods [18] [1]. Soil application of zinc and boron once in three years along with N:P_2O_5:$K_2$0 90:45:45 to 120:60:60 kg ha^{-1} needs reconfirmation as the rainfall was more than 1.5 times found to be beneficial in *Vertisol* and associated series in improving the productivity of rainfed Bt hybrid cotton [19,20,21].

Now, there is an urgent need to test the existing and new nutrients and formulations / technologies to suit under challenging wet climatic conditions to produce cotton with profitabilty. Therefore, this experiment was planned on soils having different drainage, water and nutrient holding capacities to test wide range of nutrients and their formulations to meet these unforeseen challenge of excess rains.

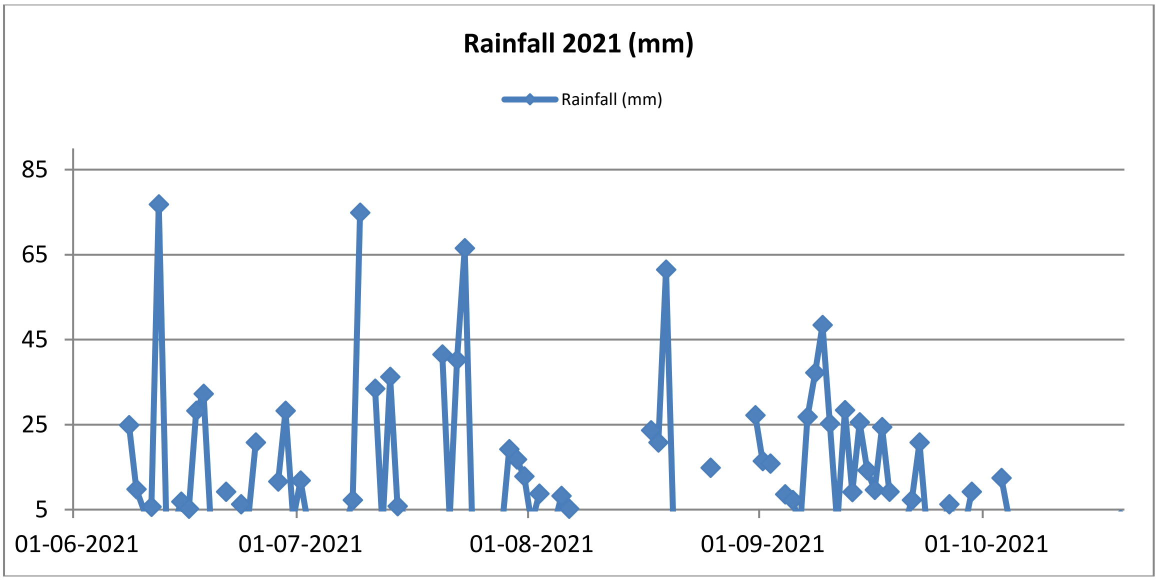

Fig. 1. Monthwise rainfall amount and distribution during 2021

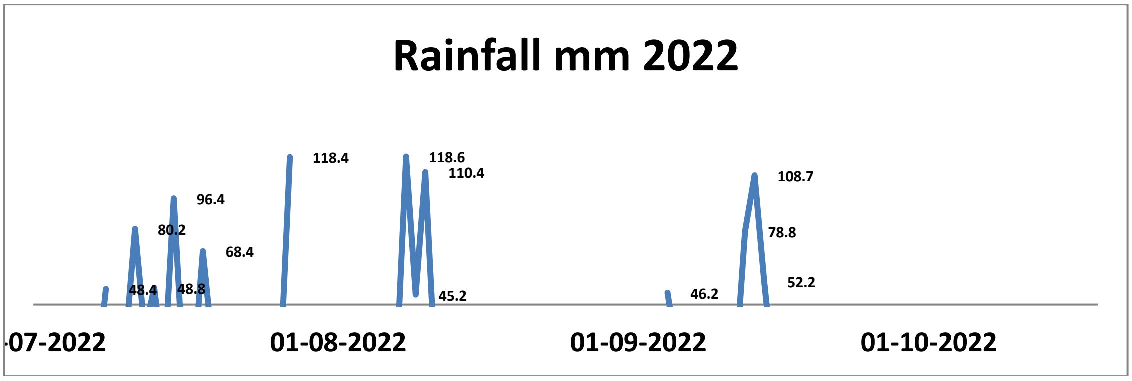

Fig. 2. Monthwise rainfall amount and distribution during 2022

Table 1. Statistical analysis of rainfall in humid tropics after the release of Bt hybrid cotton

	Rainfall mm						Number of Rainy days					
	June	**July**	**August**	**September**	**October**	**Total Ra**	**June**	**July**	**August**	**September**	**October**	**Total**
Mean	193	322	259	188	31	993	8.95	13.7	11.4	9.3	2.1	45
Standard Error	23	31	22	21	8	105	0.841	1.0	0.9	0.8	0.4	4
Median	162	331	257	184	15	948	9.5	15.0	11.0	9.0	1.0	46
Mode			181	113	0	294	11	15.0	11.0	9.0	1.0	47
Standard Deviation	104	147	103	94	35	483	3.76	4.8	4.3	3.8	1.8	18
Kurtosis	-0.13	0.51	0.72	0.12	0.02	1.24	-0.69	-0.41	0.76	1.04	-1.18	-0.48
Skewness	0.69	0.47	0.41	0.58	1.15	3.30	0.15	-0.41	0.39	0.64	0.45	1.22
Range	394	621	455	368	114	1952	14	19.0	19.0	16.0	5.0	73
Minimum	32	74.0	60	41	0	207	3	3.0	3.0	3.0	0.0	12
Maximum	426	695	515	409	114	2159	17	22.0	22.0	19.0	5.0	85

Table 2. Two decades of rainfall pattern and Bt hybrid cotton lint yield.

Rainfall mm	**Nagpur**	**600**	**650**	**780**	**812**	**940**	**975**	**1000**	**1170**	**1220**	**1300**
Probability	**district**				**25%**		**50%**		**75%**		**100%**
Year	Lint	Rainfall	RD	Rainfall	RD	Rainfall	RD	Rainfall	RD	Rainfall	RD
Percent	yield	15	15	30	30	10	10	25	25	25	25
Mean	Ha^{-1}	649	41.6	808	38	951	37.5	1052	45.4	1393	59
Percent		99.9	94.7	124	86	146	85	162	103	214	134
2002	164.9			916	40						
2003	263.5	648	37								
2004	236.3							1015	53		
2005	229.5	648	37								
2006	210.8							1039	***50***		
2007	287.3					961	43				
2008	243.1							1051	40		
2009	238.0	651	51								
2010	265.2							1017	50		
2011	236.3			788	51						
2012	336.6			801	42						
2013	377.1									1468	*53*
2014	229.5			802	26						
2015	217.6							1138	*34*		
2016	685.1			775	*35*						
2017	406.3			768	*34*						

Rainfall mm	Nagpur	600	650	780	812	940	975	1000	1170	1220	1300
Probability	**district**				**25%**		**50%**		**75%**		**100%**
2018	387.6					942	32				
2019	453.9									1226	51
2020										1342	67
2021										1228	64
2022										1703	60

Table 3. Rainfall mm and number of rainy days 2016-2022

	2016		2017		2018		2019		2020		2021		2022		Mean	
	Rain	**Days**	**Rain**	**Days**	**Rain**	**Days**	**Rain**	**Days**	**Rain**	**Days**	**Rain**	**Days**	**Rain**	**Days**	**Rainfall**	**Days**
June	126	6	132	7	217	11	131	5	234	13	283	17	123	7	208	11
July	455	17	246	18	480	11	308	16	318	17	383	16	695	22	481	20
August	60	3	276	8	171	8	317	12	515	22	181	9	362	11	314	12
September	92	9	99	10	74	3	299	13	201	12	356	19	246	8	228	12
October	42	3	15	1		0		4	86	5	22	3			27	3
SED+5%	171	6	107	6	174	5	89	5	160	6	147	7	246	7	182	6
Total	775	38	768	44	942	33	1055	50	1354	69	1225	64	1426	48	1257	58

Table 4. Rainfall (mm), distribution and number of rainy days during 2021

Months	2021	Total rain	>5mm	>25 mm	60 mm
June	Rainfall	283	76.8	106.2	76.8
June	Rainy days	20	7	5	1
July	Rainfall	371	150	293	141.3
July	Rainy days	19	9	4	2
August	Rainfall	150	120.6	59.2	61.4
August	Rainy days	14	5	3	1
September	Rainfall	329.4	76.4	216.3	0
September	Rainy days	22	5	7	0

2. MATERIALS AND METHODS

Two field experiments were sown on 23.6.2021 in very deep typical *Vertisols* and medium deep *Vertisols* with calcareous sub strata at 45 cm depth soils at ICAR-Central Institute for Cotton Research Farm, Nagpur (N 21.2, E 79.1) Maharashtra state, India. Soil application of soluble Zn can be easily precipitated in shallow *Vertisols* with calcareous sub strata soils, renders unavailable to crop due to high pH and more than 20% $CaCO_3$. Therefore, only foliar applications of micronutrients three times at squaring, flowering and boll formation stages were tested, confirmed and validated in high rainfall humid tropics of Nagpur. Micronutrient $ZnSO_4$ 0.5% alongwith potassium nitrate (13:0:45) 2.0 % and B 0.25%, chelated 0.5% and nano Zinc 0.04% with mono potassium phosphate (0:52:34), were applied on a baseline status of available Zn content was low 0.63 ug g^{-1} B 0.5 ug g^{-1} soil. Treatments under testing were T_1: Control. T_2: Three times foliar application of Zinc sulphate 0.5% at 45, 66, 87 days (squaring, flowering and boll development stages); T_3: Three times foliar application of chelated Zinc sulphate 0.5%; T_4: Three times foliar application of nano Zinc oxide 0.04%; T_5: Three times foliar application of Boron 0.3%; T_6: Three times foliar application of nano Zinc oxide 0.04% + Boron 0.3%; T_7: Seed pelletization of nano ZnO 0.004% + nano CuO 0.001% with N, P, K bio-inoculants *consortia* and three times foliar application nano ZnO; T_8: Seed pelletization of nano ZnO 0.0004% + nano CuO 0.0001% with Zn solubilizer and three times foliar application of nano ZnO 0.004%; T_9: Higher dose Zn 0.54% B 0.33% three foliar sprays T_{10}. Medium dose Zn 0.36% B 0.2% three foliar sprays T_{11}. Lower dose Zn 0.18% B 0.1% three foliar sprays T_{12}.Nano DAP 0.004% three foliar sprays.

Soil and foliar application of Zn and B alongwith nano formulations of Zn, DAP were validated in *Vertisols* with base line available Zn was 0.50 ug g^{-1} B 0.2 ug g^{-1} soil. Treatment details were T_1: Control. T_2: Three times foliar application of Zinc sulphate 0.5% at 45, 66, 87 days; T_3: Three times foliar application of chelated Zinc sulphate 0.5%; T_4: Three times foliar application of nano Zinc oxide 0.04%; T_5: Three times foliar application of Boron 0.3%; T_6: Three times foliar application of nano ZnO 0.04% + Boron 0.3%; T_7: Soil application of $ZnSO_4$ 20 kg ha^{-1} 30 days ; T_8: Soil application of Borax 5 kg ha^{-1} in borate form 30 DAS.; T_9: Soil application of 20 $kgha^{-1}$ $ZnSO_4$ and 5 $kgha^{-1}$ Borax in borate form 30 days; T_{10}: Soil and three times foliar application of $ZnSO_4$ form B in borate form; T_{11}: Soil and foliar application of chelated Zn B in borate and solubor form; T_{12}: Seed pelletization of nano Zn 0.004% + nano Cu 0.001% with Zn solubilizer and three times foliar application of nano ZnO ; T_{13}: Seed pelletization of nano ZnO 0.004% + nano CuO 0.001% with N, P, K *consortia* and three times foliar application nano ZnO 0.004% T_{14}: Lower dose of 3.24 g L^{-1} $ZnSO_4$ and 0.32 g L^{-1} Boron three times foliar application; T_{15}: Medium dose of 4.86 g L^{-1} $ZnSO_4$ and 0.65g L^{-1} Boron three times foliar application; T_{16}: High dose of 6.48 g L^{-1} $ZnSO_4$ and 0.97 g L^{-1} Boron three times foliar application was applied to Bt hybrid cotton to supplement the initial soil status of available Zinc. RCH-659 Boll guard II hybrid cotton was planted at 90 x 90 cm spacing on 23.6.2022 followed by the farmers with recommended dose of fertilizer (90:45:45 kg ha^{-1} N: P_2O_5: K_2O) in basal dose of complex fertilizer and twice urea top dressing. Post emergence herbicides *Pyrithiobac* sodium alongwith graminicides were applied followed by twice hoeing followed by hand weeding to remove resistant weeds. Although need based plant protection measures were ensured but they were less effective in epizootic conditions of bollworm complex. Plot wise soil samples were analyzed for available Zinc status by Atomic Absorption Spectrophotometer with D.T.P.A. extractant. Bt hybrid cotton index leaf samples were collected before and after the spray to monitor the macro and micronutrients level with standard analytical procedures and data were subjected to ANOVAs and interpreted with prevailing soil and weather conditions. Nano materials for experimentation were supplied by Ms. IFFCO, New Delhi, of commercial grade.

3. RESULTS AND DISCUSSION

3.1 Flooded *Vertisols*

A rainfall of more than 60 mm on every 1st week of June, July, August and September, 2021 months in *Vertisols* caused severe runoff followed by 4 times flooding of cotton fields and rain water harvesting ponds (Table 1, 2, 3, 4 Fig.1). The relationship between rainfall or rainy days with Nagpur district lint yields in 17 years was negative with R^2 value 0.10 not dependable due to the abscense of any adoption of rain water management practices. These results were in agreement with those observed by Raju *et al*., 2011 about probability of excess rains and their consequences on decreasing the lint yield of Bt hybrid cotton in long term rain water harvesting validation studies in humid tropics. Four times sub-merged cotton fields (Table 4) caused leaching of soil applied N, P, K, Zn, B fertilizers from the flooded cotton fields, which had depleted index leaf NPK 92 and 115 DAS to bare minimum (ICAC, 2015).Top dressing soil fertilizer application in this saturated soils was also mere impossible except foliar application of NPK alongwith fungicides against the spread of wilts [4].Water soluble fertilizer mono potassium phosphate i.e. 0:52:34 N:P_2O_5:K_2O alongwith micronutrients foliar application which does'nt have nitrogen, helped to maintain significantly higher levels of index leaf P content at all concentrations and forms, of Zn and B both as soil and foliar applications during 92 and 115 DAS recovered by 115 and 136 DAS (Table 6). These results were in agreement with Raju and Thakare,2012, [20] ICAC, 2015. [22] Soil application of zinc sulphate, chelated Zn and seed pelletization with N, P, K *consortia* or Zn solubilisers alongwith nano ZnO 0.004% and CuO 0.001% followed by three times foliar application of nano ZnO 0.004% alongwith water soluble fertilizer potassium nitrate i.e. 13:0:45 N: P_2O_5: K_2O could maintain significantly higher cotton index leaf K during 92 and 115 DAS (Table 6). These results were in agreement with those observed by Basavanneppa *et al.*, 2015 [23] in Bt hybrid cotton. Significantly higher K was maintained in the seeds formed by all the soil and three times foliar application of low, medium, higher concentration of Zn and B due to combined foliar application of water soluble fertilizer potassium nitrate i.e. 13:0:45 N: P_2O_5: K_2O alongwith micronutrients, insecticides and fungicides (Table 7). Flooding of Bt hybrid cotton depleted cotton root, shoot and index leaf nutrient content at 92 DAS reduced cotton index leaf N, P, K in 92, 115 and 136 DAS, which adversely affected phosphorous content of seeds formed during this time. This necessitated to supply of the N: P_2O_5: K_2O through water soluble fertilizers as foliar application having compatibility with non chelated Zinc 13:0:45 and 0:52:34 with nano and chelated Zinc alongwith insecticides and fungicides to maintain optimum nutrient content in the index leaf (GSFC, 2022,[24] IFFCO, 2022; [25] Table 6).

Table 5. Impact of floods on Vertisols and associated series soil analysis

S.No.	Soil content	*Vertisols* with *calcareous* substrata		Typic *Vertisols*	
		Before floods	After floods	Before floods	After floods
1	pH	7.66	7.8	7.68	7.7
2	EC	2.58	2.61	2.41	2.50
3	Organic Carbon %	0.39	0.7	0.10	0.22
4	Available P_2O_5 kg ha^{-1}	17	22.3	19	22
5	Available K_2O kg ha^{-1}	580	610	847	928
6	Available Zinc ppm	0.63	2.5	0.54	2.4
7	Available Fe ppm	3.5	5.1	3.5	5.0
	Available Mg ppm	0.22	0.26	0.24	0.26
8	Available S ppm	0.49	0.52	0.79	0.90
9	Available B ppm	0.5	1.0	0.2	1.3
10	Available $CaCO_3$%	29.6	18.3	22.3	29

Table 6. Nutrient content of flooded Bt hybrid cotton in *Vertisols*

	Seed nutrients			Index leaf NPK before and after flooding										
	N	P	K	Nitrogen%				Phosphorous%			Potash%			
Vertisols	**%**	**%**	**%**	**18/8.**	**18/9**	**8/10**	**29/10**	**18/9**	**8/10**	**29/10**	**N18/8**	**N18/9**	**N8/10**	**N29/10**
Control	3.79	0.36	0.96	4.28	2.24	2.75	3.60	0.41	0.47	0.41	1.69	0.43	0.71	1.18
Zn 3 foliar sprays	4.75	0.37	0.91	4.26	3.04	2.88	3.03	0.36	0.62	0.55	1.56	0.47	0.65	1.21
Chel Zn 3 foliar sprays	3.84	0.41	0.95	4.40	2.55	2.54	3.60	0.47	0.58	0.46	1.55	0.42	0.67	1.40
Nano ZnO 3 foliar sprays	3.91	0.29	1.03	4.13	2.62	2.60	3.86	0.43	0.57	0.48	1.56	0.39	0.68	1.22
Boron 3 foliar sprays	4.28	0.30	1.03	4.10	3.33	2.27	3.36	0.46	0.46	0.48	1.46	0.45	0.49	1.14
Boron+Nano ZnO 3 foliar sprays	4.73	0.38	1.09	4.32	2.18	2.89	3.38	0.45	0.43	0.59	1.48	0.32	0.66	1.27
Soil application of Zn	4.77	0.35	1.37	4.57	2.15	4.23	4.02	0.41	0.69	0.61	1.63	0.35	1.00	1.31
Soil application of B	4.97	0.42	1.37	4.12	2.03	3.63	3.78	0.45	0.72	0.59	1.50	0.34	0.89	1.37
Soil application of Zn B	4.66	0.35	1.37	3.28	2.49	3.07	3.51	0.46	0.61	0.59	1.33	0.37	0.87	1.09
Soil application of Zn B foliar sprays	4.11	0.43	1.38	4.41	2.40	2.61	4.11	0.45	0.62	0.64	1.60	0.34	0.90	1.22
Soil application of chel Zn B	4.25	0.33	1.38	4.23	2.07	3.14	3.68	0.42	0.61	0.51	1.45	0.36	0.96	1.16
Seed Tr ZnSol nano Zn Cu + Nano ZnO foliar sprays	4.26	0.44	0.68	4.44	2.62	3.41	3.38	0.37	0.51	0.44	1.61	0.71	0.74	1.43
Seed Tr NPK *consortia* nano ZnO+ CuO + 3 foliar sprays ZnO	4.12	0.44	0.72	4.80	2.25	2.66	3.22	0.37	0.47	0.40	1.71	0.62	0.69	1.20
Low Zn 0.3% B 0.1% foliar sprays	4.94	0.36	1.44	4.25	2.36	2.25	3.69	0.50	0.58	0.58	2.18	0.36	0.89	1.26
Medium Zn 0.4% B 0.2% foliar sprays	4.65	0.35	1.38	4.34	2.18	3.33	3.52	0.46	0.65	0.58	1.30	0.34	0.91	1.26
High Zn 0.5% B 0.3% foliar sprays	4.61	0.39	2.16	4.41	1.84	2.70	3.81	0.45	0.53	0.50	1.56	0.27	0.84	1.26
SE+5%	0.21	0.03	0.15	0.38	0.16	0.27	0.20	0.02	0.04	0.04	0.15	0.05	0.07	0.05
CD +5%	NS	NS	0.43	NS	NS	NS	NS	NS	0.10	0.10	NS	0.14	NS	0.15

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Table 7. Yield attributes and economics of the micronutrient advices in *Vertisols*

Vertisols	**Biomass tonne ha^{-1}**	**Boll No's $plant^{-1}$**	**Lint yield ha^{-1}**	**Net returns ₹ 000**	**C B Ratio**	**Index leaf zinc ppm**		
						31/8	18/9	29/10
Control	3.4	27.3	199	18	1.69	126	136	94
Zn 3 foliar sprays	3.0	34.0	231	31	2.05	110	134	93
Chel Zn 3 foliar sprays	3.5	34.3	259	27	2.08	117	150	92
Nano ZnO 3 foliar sprays	4.0	28.7	191	13	1.52	98	144	95
Boron 3 foliar sprays	4.4	43.3	266	24	2.06	104	146	82
Boron+Nano ZnO 3 foliar sprays	4.2	31.3	219	13	1.63	109	143	90
Soil application of Zn	3.3	42.0	264	39	2.36	133	150	84
Soil application of B	3.3	42.0	277	32	2.27	115	158	83

Vertisols	**Biomass tonne ha^{-1}**	**Boll No's plant^{-1}**	**Lint yield ha^{-1}**	**Net returns ₹ 000**	**C B Ratio**	**Index leaf zinc ppm**		
						31/8	18/9	29/10
Soil application of Zn and B	3.9	43.0	390	54	3.16	130	146	85
Soil application of Zn B foliar sprays	4.0	44.3	255	28	2.07	125	153	87
Soil application of chel ZnB	3.4	33.7	339	21	2.28	145	134	85
Seed Tr Zn solubilisers nano ZnO +CuO three foliar sprays Nano ZnO	3.7	38.0	272	28	2.15	176	147	96
Seed Tr NPK *consortia* nano ZnO+ CuO+ 3 foliar sprays ZnO	3.9	15.7	299	37	2.42	111	137	87
Low Zn 0.3 B 0.1 foliar sprays	4.4	13.7	269	31	2.20	153	128	86
Medium Zn 0.4 B 0.2 foliar sprays	3.9	45.3	276	26	2.13	155	141	83
High Zn 0.5 B 0.3 foliar sprays	4.5	28.0	269	31	2.19	154	149	86
SE±5%	0.2	5.1	32	5.0	0.19	15	8	5
CD ±5%	0.6	15	NS	14.1	0.55	42		

In flooded *Vertisols* maintenance of index leaf N, P, K nutrients concentration at reproductive stage through water soluble fertilizers is crucial with compatible Zinc forms alone or together in conjunction with compatible pesticides application. Boron or chelated Zn or nano ZnO combined with combination of Mono ammonium (12:61:0 $N:P_2O_5:K_2O$) and or potassium phosphate (0:52:34 $N:P_2O_5:K_2O$) alone or together 2% and alternated fortnightly with alone potassium nitrate 2% (13:0:45 $N:P_2O_5:K_2O$) or Urea 2% combined with Zinc sulphate 0.5% and Boron 0.3% sprays may be helpful to Bt hybrid cotton during reproductive stage for flood affected Bt hybrid cotton. These results were in agreement with Basavanneppa *et al* [23] IFFCO and GSFC [25] in maintaining N, P, K, Zn, B status of Bt hybrid cotton with compatible insecticides and fungicides. The confirmatory lab, field and OFTs found very encouraging results in the similar situation in 2022-23 season with three times heavy floods, significant reduction of leaf reddening and square drop were also observed besides meeting the target [26-28].

As the soil available Zn content was low 0.54 ug g^{-1} B 0.2 ug g^{-1} soil, despite of prevailing flooded condition with higher leaching, runoff, weed growth, epizootic conditions of sucking pests and boll worms significant improvement in biomass production (Table 7) by all the existing recommendations for *Vertisols* and associated series. This validation of micronutrient Zn is in agreement with the field studies made by Lindsay and Noerwell,[15] Sarkar *et al*., 2012. Soil application of alone or both Zn 4.0 kg ha^{-1} yr^{-3} + B 2.0 kg ha^{-1} yr^{-3} and new interventions like chelated Zn 0.4 kg ha^{-1} yr^{-3} + B 2.0 kg ha^{-1} yr^{-3} and seed pelletization of N, P, K solubilisers *consortia* and nano ZnO 0.0004% + CuO 0.0001% along with three foliar sprays of nano ZnO 0.004% at the time of squaring, flowering and boll development stages. In *Vertisols,* therefore, flood resilient micronutrient technology is either soil application or seed pelletization with NPK solubilisers *consortia* alongwith nano ZnO + CuO or combination of compatible water soluble fertilizers together with three foliar applications of nano ZnO 0.004%.However, the fiber quality was unaffected by the Zn and B soil or foliar applications except micronaire, which was low from the last flush of squares formed to bolls in the month of October, 2021 (Table 11).

Table 8. Nutrient content of flood affected Bt hybrid cotton in Calcareous soils

Calcareous soils	Index leaf NPK Squaring &Boll formation					
	N%	**N%**	**P%**	**P%**	**K%**	**K%**
Treatments	**31-8**	**8-10**	**31-8**	**8-10**	**31-8**	**8-10**
1.Control	4.53	2.79	0.56	0.22	1.84	0.87
2.Zn three foliar sprays	4.82	2.43	0.53	0.19	1.91	0.76
3.Chel Zn three foliar sprays	4.54	2.19	0.48	0.21	1.89	0.74
4.Nano ZnO 0.04% three foliar sprays	4.38	2.41	0.61	0.22	1.87	0.75
5.Boron 0.3% three foliar sprays	4.58	2.62	0.47	0.23	2.09	0.75
6.Nano ZnO B three foliar sprays	4.56	2.60	0.51	0.21	1.86	0.78
7.Seed Tr NPK Con Nano ZnO+CuO ZnO three foliar sprays	4.69	2.95	0.55	0.22	2.05	0.69
8.Seed Tr Zn solubiliser NanoZnO+ CuO ZnO three foliar sprays	4.53	3.09	0.52	0.22	1.90	0.76
9.High Zn 0.54 B 0.33 three foliar sprays	5.04	2.63	0.61	0.21	1.84	0.83
10.Medium Zn 0.36 B 0.2 three foliar sprays	4.53	3.02	0.51	0.40	0.83	0.70
11. Low Zn 0.18 B 0.1 three foliar sprays	4.87	2.59	0.59	0.23	0.73	0.83
12.Nano DAP three foliar sprays	4.78	2.89	0.54		0.66	0.95
SE+	0.17	0.27	0.05	0.01	0.13	0.05
CD 5%	0.37	NS	NS	NS	NS	0.13

Table 9. Index leaf Zn yield, biomass and economics of the micronutrient advices in calcareous soils

	BM	Boll	Lint	NR	C B	Index leaf Zn ppm		
Calcareous	**Ton**	**Plant**	**Yield**	**₹ 000**	**Ratio**	**31-08**	**18-09**	**29-10**
Control	4.00	18	350	47	2.0	126	94	149
Zn three foliar sprays	3.89	60	583	79	2.8	110	93	152
Chel Zn three foliar sprays	4.11	40	513	75	2.5	117	92	179
Nano ZnO 0.04% three foliar sprays	3.61	46	513	66	2.5	98	95	141
Boron 0.3% three foliar sprays	3.81	39	497	65	2.5	104	82	132
Nano ZnO B three foliar sprays	4.24	37	643	89	2.9	109	90	140
Seed Tr NPK *Con* Nano ZnO+CuO ZnO three foliar sprays	3.91	47	558	89	2.6	133	84	133
Seed Tr Zn solubiliser NanoZnO+ CuO ZnO three foliar sprays	3.65	44	527	68	2.6	115	83	153
High Zn 0.54 B 0.33 three foliar sprays	3.77	26	488	62	2.5	130	85	144
Medium Zn 0.36 B 0.2 three foliar sprays	4.20	42	535	70	2.7	125	87	162
Low Zn 0.18 B 0.1 three foliar sprays	3.88	36	411	49	2.2	145	85	124
Nano DAP three foliar sprays	3.93	16	371	51	2.0	176	96	157
SE±5%	0.2	9	56	9	0.2	15	5	13
CD± 5%	NS	NS	159	26	0.49	42	NS	NS

Table 10. Fibre properties of flood affected Bt hybrid cotton by micronutrient advices

	Calcareous soils					*Vertisols.*					
Tr	**UHML mm**	**UI%**	**MICug/ inch**	**Bundle Strength g tex**	**El%**	**Tr**	**UHML mm**	**UI%**	**MIC ug/ inch**	**Bundle Strengthg tex**	**El%**
0	27.2	83.0	3.47	26.1	4.9	0	26.5	81.3	2.6	25.6	4.73
T1	27.2	83.8	3.52	26.4	4.5	T 1	26.4	82.3	2.8	25.0	4.80
T2	27.4	82.7	3.37	26.3	5.0	T 2	27.4	82.3	2.7	26.4	4.90
T3	26.8	83.2	3.63	25.8	5.0	T 3	27.0	82.3	2.9	25.7	4.70
T4	27.5	83.7	3.33	26.5	4.7	T 4	26.8	82.0	2.7	25.8	4.77
T5	27.7	83.5	3.52	26.0	4.8	T 5	26.7	81.3	2.5	26.0	4.80
T6	27.1	83.0	3.23	25.4	4.8	T 6	27.5	83.0	2.8	26.3	4.85
T7	27.5	82.7	3.50	25.9	4.8	T 7	27.3	82.3	2.8	25.8	4.78
T8	27.4	83.0	3.47	26.0	5.0	T 8	27.0	82.0	2.8	26.3	4.80
T9	27.9	83.3	3.48	26.3	4.8	T 9	26.6	81.8	2.6	25.8	4.88
T10	27.3	83.2	3.48	26.2	5.0	T 10	26.8	81.8	2.8	25.5	5.05
T11	27.9	83.5	3.10	26.5	4.7	T 11	27.2	81.0	2.6	25.4	4.88
						T 12	26.6	80.8	2.6	25.4	4.88
						T 13	26.5	81.8	2.6	25.5	4.78
						T 14	27.0	82.0	2.8	26.3	4.86
						T15	27.0	82.2	2.8	26.0	4.96
SE±5%	0.3	6.1	0.11	0.3	0.2	SE±5%	0.32	0.44	0.11	0.5	0.15
Sig	NS	NS	NS	NS	NS	Sig	NS	NS	NS	NS	NS

Table 11. Validation of Bio-stimulants as seed treatment and foliar application of nano Urea, DAP, Zn, K on yield, FUE, B:C ratio 2023

	Validation of interventions in high rainfall condition					
Treatments	**Yield kg ha^{-1}**	**B:C Ratio**	**FUE kg Kg fert**	**Yield g plant^{-1}**	**Boll No plant^{-1}**	**Bpll Wt.g**
RDF 10:26:26	776	2.87	4.25	67	13	4.2
RDF 20:20:0:13 + Seed Tr NPK Zn sol *consortia* +3 foliar sprays of nano Urea+K and ZnO+K	830	2.40	3.05	52	14	4.1
RDF 20:20:0:13 + Seed Tr NPK Zn sol *consortia*+ 3 foliar sprays of nano DAP+ ZnO + K	893	2.54	3.12	72	10	4.8
SE±5%	157		1.09	13	3	0.4
CD±5%	453		NS	39	7	1.1

Table 12. Validation of Bio-stimulants as seed treatment and foliar application of nano Urea, DAP, Zn, K on index leaf NPK content 2023

	Index Leaf pooled content		Index leaf P% 10 days after foliar correction					
ZTreatments	**N%**	**K%**	**6th Sept**	**27 th Sept**	**20- th Oct**	**2nd Nov**	**2. nd Dec**	**Pooled**
RDF 10:26:26	3.94	1.32	0.22	0.17	0.06	0.30	0.19	0.19
RDF 20:20:0:13 + Seed Tr NPK Zn solublizer *consortia* +3 foliar sprays of nano Urea+K and ZnO+K	4.07	1.31	0.26	0.19	0.09	0.29	0.16	0.20
RDF 20:20:0:13 + Seed Tr NPK Zn sol *consortia*+ 3 foliar sprays of nano DAP+ ZnO + K	4.06	1.34	0.21	0.19	0.07	0.30	0.18	0.19
SE±5%	0.24	0.03	0.02	0.02	0.01	0.02	0.17	0.01
CD±5%	NS	0.08	NS	NS	NS	19	NS	NS

Table 13. Validation of Bio-stimulants as seed treatment and foliar application of nano Urea, DAP, Zn, K on seed nutrient and index leaf Zn content 2023

	Seed nutrient content				Index leaf Zn content					
Treatments	**N%**	**P%**	**K %**	**Znppm**	**6th Sept**	**27th Sept**	**20th -Oct**	**2nd Nov**	**2nd Dec**	**Poo l**
RDF 10:26:26	3.2	0.54	1.0	63	73	95	85	121	103	93
RDF 20:20:0:13 + Seed Tr NPK Zn sol *consortia* +3 foliar sprays of nano Urea +K and ZnO + K	3.1	0.53	0.88	69	81	120	90	146	96	109
RDF 20:20:0:13 + Seed Tr NPK Zn sol *consortia*+ 3 foliar sprays of nano DAP+ ZnO + K	3.2	0.54	0.90	79	74	110	88	115	101	97
SE±5%	NS	0.02	0.06	15	NS	20	NS	NS	20	NS

3.2 Flooded *Vertisols* with Calcareous Substrata Soils

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Bt hybrid cotton was submerged in the month of September, 2021 (Fig. 1) for nearly two weeks. Although the calcareous sub soils produced lint yields 1.5 times of their normal capacity, which was more than double of *Vertisols* was due to self aeration and enriched by the nutrients brought by the flood water (Table 5). This was possible due to higher porosity and relative better drainage by sub soil calcareous strata. N, P, K content of index leaves in September, 2021 flooding was reduced to more than 50% compared to before flooding nullifying the impact of all soil applications of N, P and K fertilizers due to leaching losses**.** Three times foliar application of nano D.A.P., produced highest K and Zn content in index leaf before flooding despite of lower yield was due to very high weed intensity in some of these plots. Although, the biomass produced was non significantly differed highest was produced in three foliar applications of nano Zn + B, medium concentration of Zn and B followed by chelated Zn confirms the significance of Zn foliar application needs in calcareous soils. Significantly highest number of bolls were also produced in three foliar applications of Zn while the yield per hectare was produced in three foliar applications of nano Zn + B. However, statistically similar seed cotton yields were produced in three foliar applications of lower concentration level of Zn 0.36% + B 0.18% and nano D.A.P 0.004%. Economical returns with better C:B ratio were observed with three foliar applications nano ZnO, Zn and chelated Zn at squaring, flowering and boll development stages with or without seed pelletization with bio-inoculants and nano ZnO + CuO. Flooding did not influence fibre properties in both the soils except late formed immature bolls reduced micronaire. These results were in agreement with sample test done by ICAR-CIRCOT, GTC, Nagpur during this season in the entire cotton area [29-30].

4. CONCLUSION

These soils were better aerated compared to typic *Vertisols* by embedded calcareous substrata at 45 cm depth. Their inundation 4 times brought more nutrients enrichment by the flood water (Table 5). The seed treatment with Bio inoculant *consortia* NPK with Nano ZnO 0.004% + Nano CuO 0.001% had better deep roots higher biomass and better tolerance to flood water when they were supplemented with nano forms of DAP + Zn + B + K sources even at sub optimal level. These soils were more thirsty followed by hunger when they were met better productive with deficient N, P, K, Mg, S, Zn, B were met from timely foliar corrections than typic *Vertisols* under poor aeration with excessive weed growth where soil application was better performed as runoff resilient technology (Tables 11, 12, 13). All the old and new recommendation of micronutrients improves the productivity and profitability of cotton with a limitation of compatability, time and price tag. The lowest cost is Urea 2% +Zinc Sulphate 0.36% + Boron 0.18% or KNO_3 and cheleted Zn, Fe, with WSF Sulphates and phosphates are as effective as nano forms in alleviation of N, P, K, S, Mg, Zn, B deficiencies.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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