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Improving hybrid cotton profitability and micronaire with stripcropping of soybean+pigeon pea with conservation furrows, Mn and B application

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Micronutrients and supplemental irrigations were evaulated in split plot design to improve hybrid cotton micronaire in last picking. Farmer's practices (FP) of sole hybrid cotton, soybean+pigeon pea (4:1) and cotton + pigeon pea (8:2) stripcroppings were compared alongwith soybean as intercrop in the existing cotton+pigeonpea stripcropping (8:2) for micronutrient requirement, rain water conservation and profitability. Soybean cultivation is best suited and most profitable in shallow soils of <0.45 m deep. Novel strip cropping of cotton + soybean + pigeon pea (4:4:2) alongwith opening of conservation furrow in pigeon pea with a profitability of 41 and 58% over sole cotton in shallow and medium deep soils. Micronutrients requirement was not arise with moderate cotton yield levels of sole and strip cropped cotton as INM application 5 t FYM ha^{-1} year^{-3}, compared to its absence in farmer's fields improved 15 to 35% seed cotton yield in Bt hybrid cotton under rainfed and two supplemental irrigations. Significant responses were observed for supplemental irrigations in low rainfall years alongwith Mn, B application in improving micronaire, seed cotton yield and profitability. Premium range of cotton micronaire was produced in last pick under rainfed and two supplemental irrigations in shallow and medium soils by Mn and B at 0.5 and 0.3% foliar spray 3 times after square initiation at fortnightly interval. Soil application of $MnSO_4$ at 25 kg ha^{-1} year^{-3} and Borax at 10 kg ha^{-1} year^{-3}, respectively in rainfed calcareous shallow and medium deep soils along with supplemental irrigations could improve micronaire.

Key words: Boron, conservation furrow, hybrid cotton, manganese, medium deep soils, micronaire, pigeon pea, profitability, strip cropping, soybean, shallow soils, supplemental irrigations.

INTRODUCTION

Boron and winter irrigations were suggested in coarse textured low water holding capacity soils for improving the lint yield, which produced variable fibre quality results across seasons lead to limited agronomical value (Bradow and Davidonis, 2000; Ahmed et al., 2012). Medium staple, long duration *Gossypium hirsutum* cotton hybrids were well adopted in rainfed *vertisols* 1972-2002 (Gruere and Sun, 2012). They had lower micronaire and strength with inefficient pink bollworm control in later pickings gave 25% lower profit realization by the farmers of central India (Sreenivasan and Venkata krishnan, 2007; Stone, 2007).

Winter flowering often caught in reduced atmospheric humidity, soil moisture and nutrients uptake under

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Abbreviations: **ICAR,** Indian Council of Agricultural Research; **LGP,** length of growing period; **VJAS,** Vidarbha Jan Andolan Samiti; **NGO,** Nagpur.

minimum temperatures 8°C during fibre elongation (Figure 2) results in lower micronaire and bundle strength in later pickings (Davidonis et al., 2004; Avgoulas et al., 2005; Wang et al., 2009; Yeates et al., 2010).

Supplemental irrigations or excess rains may further delay the maturity of cotton due to late production of bolls which reduces their micronaire and fibre strength (Brooker et al., 2006). Medium duration, long staple BT hybrid cotton introduction in 2002 to 2012 contributed by 19% yield improvement with 92% replacement of long duration medium staple *G. hirsutum* cotton hybrids and created shortages, which doubled their minimum support price (CAB, 2012; Gruere and Sun, 2012). Soils of central India were deficient in Zn, Fe and B which are required for the growth and development of cotton fibres and produced 5 to 16% higher lint yield (Dordas, 2006;Singh et al., 2008; Singh, 2012). Present research was conducted aiming at improving the profitability of cotton cultivation by improving micronaire in the later pickings through rain water conservation by stripcropping with soybean and pigeon pea (with conservation furrow) or winter irrigations with micronutrients as soil and foliar applications to shallow and medium deep soils.

MATERIALS AND METHODS

Study site

Experimental site was mild sloppy, medium deep *Vertisol*, Nagpur, India (21° 09'N 79° 09'E,). Nagpur has a tropical savanna climate (Köppen Aw) where cotton crop receives on an average 852 mm rainfall in 48 rainy days during June to October (Figure 1) in the past 115 years. Fluctuations in onset of monsoon rains with a seedling drought of 14 to 29 days was uncommon (Figure 1) and causing distress among Bt hybrid cotton farmers over repeated crop failures in central India (VJAS, 2011). Winter lasts from November to January, during which temperatures can drop below 10°C. Soil analysis found depth was <0.5 and 0.7 m, soil textural class clay loam, pH 8.1, organic carbon 0.4%, available N:P_2O_5:K_2O 280: 15:300 kg ha^{-1}, DTPA extractable Zn 0.57, Mn 2.54 ppm and B 0.114 ppm (Table 1 and Figure 3).

Field experiments were conducted to find out a management strategy for improving micronaire and bundle strength in later pickings of medium staple long duration intra *G. hirsutum* hybrid cotton NHH 44 as it covered largest area in India at the time of introduction of Bt hybrid cotton in 2002. Input response and efficiency in the soybean-hybrid cotton system a 4 years rotation were studied during 2002 to 2004 and stripcropping with soybean and pigeon pea during 2005 to 2007. Micronutrient builtup, input response and fibre qualities were assessed after six years in shallow and medium deep soils. Seven nutrition management treatments were evaluated as main plots *viz*., Control, $ZnSO_4$ 25 kg ha^{-1} $year^{-3}$, Borax 10 kg ha^{-1} $year^{-3}$, $MnSO_4$ 25 kg ha^{-1} $year^{-3}$, $ZnSO_4$, Mn SO_4, Borax 2/3 rd soil application and 1/3 rd foliar application, Foliar application of Zn, Mn and B at 0.5 and 0.3% with and without 2% Urea at flowering and early boll development stage in rainfed and two supplemental winter irrigations as sub plots were evaluated in split plot design.

Micronutrients were applied 10 days after basal application of complex phosphatic fertilizers to avoid interaction as side dressing. Need based plant protection measures and other in medium deep soils and only one year in shallow soils, followed recommended package of practices were followed time to time. These treatments were initially tested in sole cotton 2002 to 2004 by prevailing stripcropping mode to findout further response and profitability for agronomical value with wider implications. Sole cotton was spaced at 0.75 x 0.75 m during 2002 to 2004 in both shallow and medium deep soils as it was a farmer's practice.

Stripcropped cotton and soybean were planted at 0.45 x 0.45 m, 0.45 x 0.10 m, respectively in a paired planting at 0.90/1.35 m in alternate rows. Pigeon pea was stripcropped 0.90 x 0.15 with soybean and 0.45 x 0.45 m in cotton, after 8 rows, that is, same spacing to that of main crop as followed by the farmers. Soil and cotton plant samples were analyzed as per standard procedures. Available soil zinc and manganese were estimated by DTPA extraction method by GBC, AAS and Boron was estimated by hot water soluble method. Mean maturity days were estimated from multiple cotton pickings and fibre properties were analysed by HVI 900 Zellweger Uster in ICC mode.

RESULTS AND DISCUSSION

Biomass production and maturity

Micronutrients nutrients application could not significantly change in cotton maturity (Table 2) or biomass production of soybean and pod yield in both pure and strip cropped soybean (Table 3). Shallow soils significantly produced higher soybean biomass, pod yield g $plant^{-1}$ and grains pod^{-1} except pod weight g which was superior in medium deep soils in both pure and strip cropped soybean (Table 4). This was possible due to better aeration provided by sloppy, shallow soils under excess rains of July, August, 2006 (Figure 1). Therefore, the shallow soil resource should be better used for soybean crop of 100 days (LGP) for improving and stabilizing the profitability instead of growing 180 days duration hybrid cotton with a higher probability of crop failure in case of aberrant weather conditions (NBSS, LUP, 2013). Mn availability will be restricted in coarse texture calcareous soils with latent deficiency as observed in soil analysis (Table 1), therefore, soluble $MnSO_4$ 25 kg ha^{-1} $year^{-3}$ soil application significantly improved biomass production t ha^{-1} (BMP) and pod yield g $plant^{-1}$ in pure soybean (Singh, 2012). Significant improvements in BMP of soybean by Zn SO_4 25 kg ha^{-1} $year^{-3}$ soil application brought in medium deep soils and Zn, $MnSO_4$ 25 and Borax 10 kg $ha^{-1}year^{-3}$ micronutrients in shallow soils and foliar application of micronutrients along with 2% urea and also without urea on pod yield g $plant^{-1}$ at flowering stage needs further verification for wider agronomical recommendations. Biomass production of soybean + cotton + pigeon pea strip cropping was significantly reduced by two supplemental irrigations in shallow soils when excess rains received in the year 2006 with uncontrolled weed growth (Figure 1).

Yield advantage and profitability

Proportion of cotton and soybean planting in central India

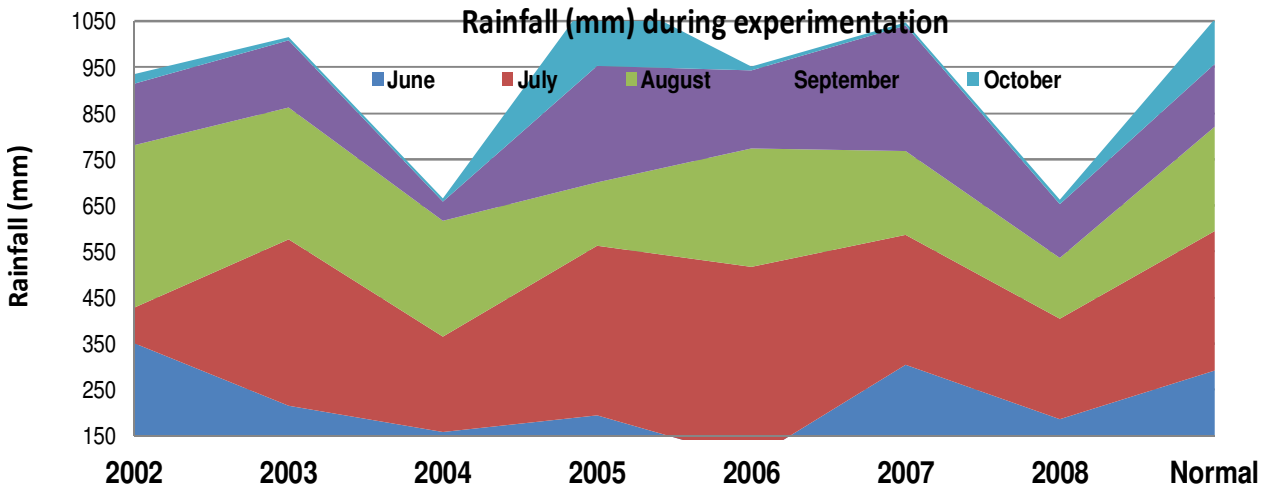

Figure 1. Monthly rainfall (mm) during experimentation.

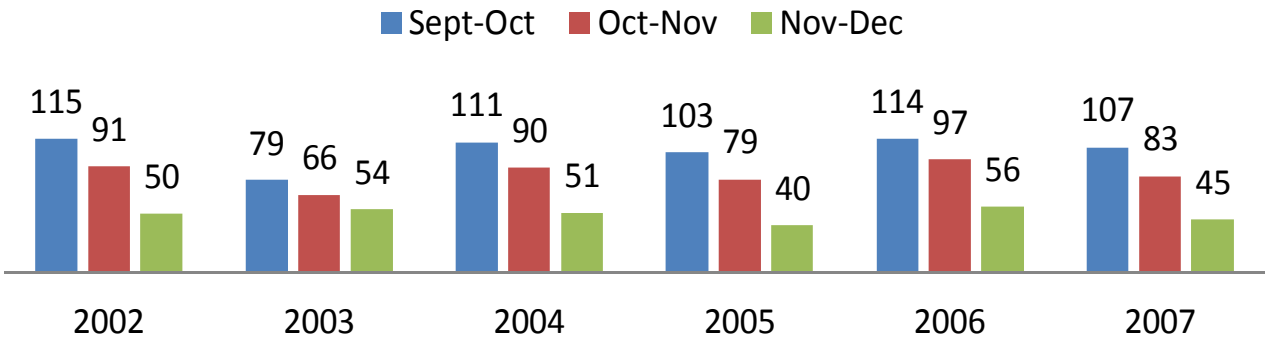

Figure 2. Mean temperature above base 15°C during boll development.

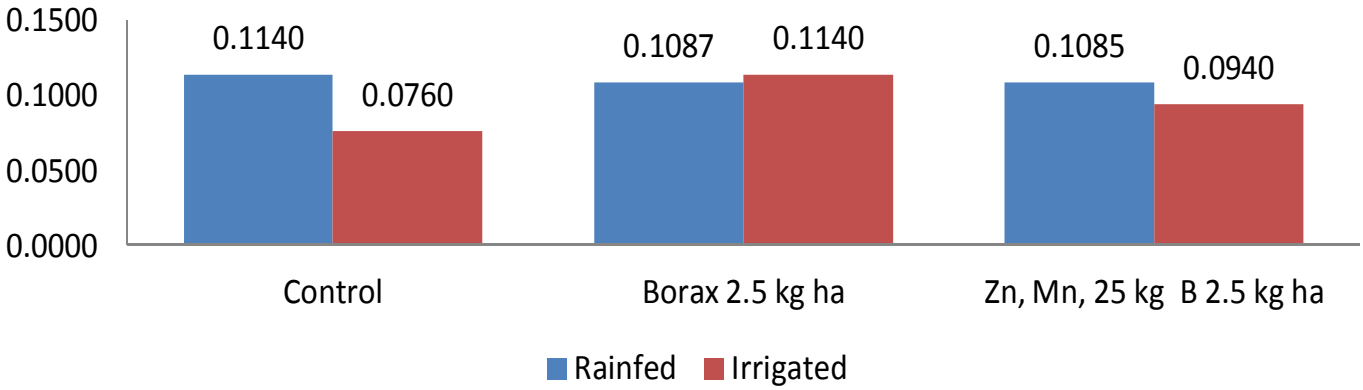

Figure 3. Boron content (ppm) after 6 years.

varies 40 to 60% of the farms area on year to year basis depends upon yield and price received in the previous monsoon season which depends on rainfall and pest incidence (Bhagawat, 2012). However, farmers feel there is double net returns/ Re investment on soybean due lower risks/ input costs unless severe semilooper or bollworms damage and weeds under excess rains may cause yield losses, respectively in cotton and soybean

Table 1. Zn, Mn status after 6 cycles of the cotton in medium deep soils.

Main plot treatment	Zn (ppm)						Mn (ppm)					
	20 cm			40 cm			20 cm			40 cm		
	I	R	Mean	I	R	Mean	I	R	Mean	I	R	Mean
Control	0.53	0.70	0.62	0.57	0.73	0.65	2.94	3.06	3.00	2.19	1.77	1.98
$ZnSO_4$ 25 kg ha^{-1} $year^{-3}$	0.71	1.12	0.92	1.76	1.89	1.83	2.79	3.61	3.20	2.85	2.25	2.55
$MnSO_4$ 25 kg ha^{-1} $year^{-3}$	0.49	0.75	0.62	0.62	2.03	1.32	3.37	2.14	2.75	2.60	5.59	4.1
Borax 10 kg ha^{-1} $year^{-3}$	0.47	0.58	0.53	0.51	0.63	0.57	1.23	4.82	3.03	2.22	1.93	2.08
Zn, $MnSO_4$ 25 Borax 10 kg ha^{-1} $year^{-3}$	0.62	0.91	0.76	1.17	0.38	0.78	2.86	2.20	2.53	2.34	2.33	2.33
Zn, Mn,B foliar spray at 0.5 and 0.3%	1.53	0.64	1.09	0.68	0.47	0.57	2.56	2.90	2.73	1.99	1.86	1.92
Zn, Mn,B foliar spray at 0.5 and 0.3% with 2% urea	0.68	0.61	0.65	0.84	0.57	0.71	4.10	3.04	3.57	2.39	2.59	2.49
Mean	0.72	0.76		0.88	0.96		2.84	3.11		2.37	2.62	
S.E.(m)±5%	0.27		0.15	0.96		0.36	0.96		0.36	0.8		0.26
CD 5 %	0.35		0.65	1.98		1.53	1.98		1.53	1.66		1.1

I = Two supplemental irrigations; R = Rainfed.

Table 2. Cotton crop maturity and biomass production t ha^{-1} in different soils.

Main plot treatment	Maturity days	Biomas production t ha^{-1}			Soybean pod yield g $plant^{-1}$			Pure soybean 2006	
		S	CSP	SPP	Pure	CSP	SPP	Grain g pod^{-1}	Pod wt g
Control	182	8.0	8.2	8.8	29.9	15.1	21.3	0.138	2.44
$ZnSO_4$ 25 kg ha^{-1} yr^{-3}	183	7.9	6.8	7.8	24.0	14.4	14.1	0.166	2.48
$MnSO_4$ 25 kg ha^{-1} yr^{-3}	183	10.1	8.3	10.2	26.8	20.5	22.3	0.149	2.27
Borax 10 kg ha^{-1} yr^{-3}	180	7.8	7.3	7.1	21.3	17.3	15.7	0.172	2.23
Zn, $MnSO_4$ 25 Borax 10 kg ha^{-1} yr^{-3}	186	9.2	9.4	8.0	19.5	15.3	12.7	0.133	2.23
Zn, Mn,B foliar spray @ 0.5 and 0.3%	180	11.1	9.6	8.5	32.9	17.3	17.1	0.145	2.30
Zn, Mn,B foliar spray @ 0.5 and 0.3% with 2% urea	184	10.6	9.7	10.6	29.3	25.1	20.8	0.153	1.93
S.E.(m) ± 5%	3	1.1	1.8	1.1	6.4	5.5	3.7	0.03	0.31
Medium	186	8.1	7.7	8.0	19.9	13.0	14.3	0.142	2.60
Shallow	179	10.3	9.2	9.4	32.6	22.8	21.1	0.160	1.94
S.E.(m) ± 5%	4		0.9	0.8				0.02	
CD ± 5%		1.4			5.6	5.9	4.4		0.37
Irrigation	183	8.8	8.5	8.4	25.6	18.1	17.3	0.151	2.27
Rainfed	182	9.7	8.4	9.0	26.9	17.6	18.1	0.151	2.26
S.E.(m) ± 5%	2	0.6	0.6	0.6	2.1	1.7	2.0	0.01	0.10
Micronutrients x soils	4	1.7	1.7	1.5	8.2	4.5	5.2	0.02	0.27
CD ± 5%	9	3.5	3.4	3.2	16.7	9.2	10.8	0.05	0.56

Table 2. Contd.

Sig	NS	S	NS	NS	S	NS	NS	NS	NS
Micronutrients x Irrigations	8	1.7	2.1	1.8	7.6	6.0	5.3	0.03	0.38
S.E.(m) ± 5%	18	3.4	4.3	3.8	15.8	12.1	11.2	0.07	0.50
Soils x Irrigations	5	0.9	0.9	0.8	4.0	3.2	2.8	0.02	0.20
CD ± 5%	10	1.9	1.8	1.7	8.4	6.8	6.0	0.04	0.43
Sig	NS	NS	S	NS	NS	NS	NS	NS	NS
Micronutrients x soils x Irrigations	12	2.4	2.9	2.5	10.7	8.5	7.5	0.05	0.39
S.E.(m) ±5%	25	5.1	6.0	5.3	23.5	18.1	15.9	0.10	0.79

Note: S = Soybean, CSP = cotton + soybean + pigeon pea stripcropping, SPP = soybean + pigeon pea stripcropping, Pure = sole soybean.

Table 3. Interaction of micronutrients x soils on soybean biomass and pod yield plant during 2006.

Main plot treatment	Biomass production t ha^{-1} pure soybean		Pod yield g $plant^{-1}$ pure soybean	
	Medium	Shallow	Medium	Shallow
Control	8	8	24.3	35.5
$ZnSO_4$ 25 kg ha^{-1} $year^{-3}$	10.3	5.5	29.3	18.7
$MnSO_4$ 25 kg ha^{-1} $year^{-3}$	7.7	12.5	13.0	40.5
Borax 10 kg ha^{-1} $year^{-3}$	6.7	9	17.2	25.3
Zn, Mn SO4 25 Borax 10 kg ha^{-1} $year^{-3}$	7.7	10.7	9.3	29.7
Zn, Mn, B foliar spray at 0.5 and 0.3%	8.2	14	22.0	43.8
Zn, Mn, B foliar spray at 0.5 and 0.3% with 2% urea	8.5	12.7	24.0	34.5
CD ± 5%	3.5		16.7	

Table 4. Interaction of supplemental irrigations x soils on soybean biomass t ha^{-1} cotton+ soybean strip cropping during 2006.

	Two supplemental irrigation	Rainfed
Medium	8.43	8.57
Shallow	6.95	9.91
CD ± 5%	2.9	

crops. Cotton + soybean + pigeon pea strip cropping in 4:4:2 ratio without change in planting and interculture implements (0.45 m apart) could give 41 and 54% more profit in shallow and medium deep soils by opening a conservation furrow at pigeon pea rows (Table 5). It is

Table 5. Sole and strip cropping of cotton and soybean yield and profitability in shallow soils.

Sole cropping	Mean	Stripcropping	Mean	Probability
Seed cotton yield kg ha^{-1}	1138	Cotton+soybean+pigeon pea intercropped cotton yield kg ha^{-1}	897	0.00002
Net profitability Rs/Re investment	0.93	Net profitability	1.32	0.00012
Soybean yield kg ha^{-1}	2186	Soybea+pigeonpea stripcropping soybean yield kg ha^{-1}	1499	1.2E-07
Net profitability Rs/Re investment	2.57	Net profitability	2.10	0.00013

Table 6. Sole and strip cropping of cotton and soybean yield and profitability in medium deep soils.

Sole cropping	Mean	Stripcropping	Mean	Probability
Seed cotton yield kg ha^{-1}	1186	Cotton+soybean+pigeon pea intercropped cotton yield kg ha^{-1}	1340	0.000635
Net profitability Rs/Re investment	1.33	Net profitability	2.91	2.06E-10
Soybean yield kg ha^{-1}	2186	Soybea+pigeonpea stripcropping soybean yield kg ha^{-1}	1714	2.93E-06
Net profitability Rs/Re investment	3.07	Net profitability	1.57	1.68E-07

concluded that soybean + pigeon pea stripcropping is not economical due to 18 and 28% yield losses in shallow and medium deep soils, respectively.However, farmers grow on trial and error basis soybean : pigeon pea (4:1) in strips to meet their food legume requirement for domestic consumption, which acts as insurance incase of crop and price failures (Tables 5 and 6). There is no agronomical response for supplemental irrigations on sole vs strip cropping systems due to conservation of runoff in conservation furrows opened after strips. Micronutrients application did not respond with regular application of 5 t ha^{-1}year^{-3} FYM and marginal yield levels of 1-1.5 t ha^{-1} when the soil content of Zn was in border line and B responded occassionally. However, verification of them in Bt hybrid cotton on farm trials for three years in Yeotmal district (M.S) found to improve 25 to 35% higher seed cotton yield when Zn, B along with two supplemental irrigations were applied (Raju and Thakare, 2012).

Pooled analysis of results found (Tables 7 and 13) $ZnSO_4$ 25 kg ha^{-1} year^{-3}, $MnSO_4$ 25 kg ha^{-1} year^{-3}, Borax 10 kg ha^{-1} year^{-3} alone or together 2/3 rd soil application and 1/3 rd foliar application 3 times after square initiation with without 2% urea did not significantly improved the seed cotton yield, gross and net profitability in sole cotton planted as checkrow planting (2002 to 2004) similar tofarmer's practice or strip cropping with soybean and pigeon pea systems (Tables 7 and 13) of *G. hirsutum* hybrid cotton NHH 44 grown in shallow (<0.45 m) and medium deep soils (0.45 to 0.90 m) along with recommended dose of fertilizers 90:45:45 kg ha^{-1}N, P_2O_5:K_2O and organic manures F.Y.M at 5 t ha^{-1} year^{-3} when soil available Zn(DTPA) was in border line, Mn in latent deficiency and B in deficient condition (Table 1 and Figure 3). This was due to sub-optimal seed cotton yields realized due to 4% lower plant stand than recommended plant population for sole cotton and 6.7% higher than recommended plant population was planted in stripcropping as followed by the farmers at border line of Zinc is not generating sufficient demand for micronutrients appication as its buildup was noticed in soil analysis (Table 1 and Figure 3).

However, significant improvement in yield for Zn, Mn, B soil application 2/3rd and 1/3 rd foliar application was observed only in 1/3 years, tha is, to the tune of 23% over control in 2002 to 2003 year with a normal onset of monsoon and slight deficit in July and excess in August month with more or less normal rainfall year. Present recommendation of integrated nutrient management package of chemical fertilizers 90:45:45 kg ha^{-1}N, P_2O_5:K_2O and organic manures F.Y.M at 5 t ha^{-1} year^{-3} met the nutrient demand of moderate yields 1.2 to 1.5 tonn ha^{-1} besides improving the soil available Zn status 0.57 to 0.62 ppm after 6 years (Table 2). However, direct chemical application of $ZnSO_4$ 25 kg ha^{-1} year^{-3} soil application benefitted only in years of better distribution or higher rainfall but built soil reserve was increased to 0.84 and 1.3 ppm at 20 and 40 cm depth compared to no change with foliar application (Table 1).

This was confirmed from the station and onfarm trials where regular annual application of farm yard manures in recommended level was practically impossible due to shortage of organic manures in Ralegaon Taluka of Yeotmal district (Maharashtra State), in Central India (Raju et al., 2011; Raju and Thakare, 2012). A regular application of F.Y.M at 5 t ha^{-1} year^{-3} along with recommended fertilizers does not create a demand on a border line soil status for micronutrients application to cotton and soybean, stripcropping with pigeon pea with a moderate seed cotton yield level of 1.1 to 1.5 tonn ha^{-1} in shallow and medium deep soils. Micronutrient response was not observed in less rainfall years compared to wet monsoon years significant response was noticed in shallow rooted Bt hybrid cotton due to higher nutrient uptake with higher growth and better yield driven demand for micronutrients

Table 7. Agronomic performance of NHH 44 hybrid cotton in shallow soils.

Main plot treatment	Farmer's practice yield kg ha^{-1}		Cotton + Soybean + Pigeon pea inter strip cropping system yield kg ha^{-1}					Soybean+ Pigeon pea system yield kg ha^{-1}		Farmer's practice yield kg ha^{-1}	
	Cotton	NR/Re	Cotton	Pigeon pea	Soybean	CEY	NR/Re	Soybean	NR/Re	Soybean	NR/Re
Control	1095	0.86	792	387	1160	2216	1.29	1555	1.92	2044	2.73
$ZnSO_4$ 25 kg ha^{-1} year^{-3}	1029	0.78	943	435	1162	2069	1.38	1653	2.22	2249	2.56
$MnSO_4$ 25 kg ha^{-1} year^{-3}	1111	0.82	924	398	1122	2213	1.17	1299	1.97	2162	2.74
Borax 10 kg ha^{-1} year^{-3}	1175	1.01	965	463	1245	2154	1.28	1491	2.18	2361	2.57
Zn, $MnSO_4$ 25 Borax 10 kg ha^{-1} year^{-3}	1116	0.94	911	436	1240	2167	1.53	1424	2.01	2274	2.40
Zn, Mn, B foliar spray at 0.5 and 0.3%	1191	0.98	890	405	1132	2289	1.40	1604	2.30	2143	2.71
Zn, Mn, B foliar spray at 0.5 and 0.3% with 2% urea	1250	1.15	852	416	1071	2251	1.17	1465	2.11	2072	2.28
S.E.M. ± 5%	140	0.27	120	82	248	130	0.30	260	0.38	182	0.17
Rainfed cotton	1105	0.93	891	413	1131	2211	1.39	1555	2.06	2150	2.55
Supplemental irrigations(2)	1172	0.94	903	427	1193	2177	1.24	1443	2.15	2223	2.59
S.E.M. ± 5%	47	0.07	91	46	180	70	0.20	205	0.25	101	0.19
2005		0.93	946	454	1164	2095	1.18	1498	2.00	2275	3.60
2006			900	422	1126	2247	1.43	1474	2.13	2166	1.50
2007	1138		844	385	1195	2240	1.34	1523	2.17	2119	
S.E.M.CD ± 5%			55	45	45	173	0.06	57	0.15	55	0.99
			S	NS	NS	NS	NS	NS	NS	S	S
Season x Irrigation			NS	NS	NS	NS			NS		NS
S.E.M. ± 5%			157	80	312	226	0.3	356	0.43	176	0.57
Season x Micronutrient			NS	NS	NS	NS	NS	304	NS	263	0.98
S.E.M. ± 5%			136	78	274	226	0.32	NS	0.39	NS	NS
Irrigations x Micronutrients	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S.E.M. ± 5%	188	0.28	208	119	477	184	0.49	465	0.28	263	1.28
S x I x M			NS	NS	NS	NS	NS	NS	NS	NS	NS
S.E.M. ± 5%			415	211	826	320	0.94	943	0.51	465	1.38

Zn, Mn and B application (Raju and Thakare, 2012).

Fibre quality

Shallow soils

Pooled analysis found $MnSO_4$ 25 kg ha^{-1} year^{-3}, Borax 10 kg ha^{-1} year^{-3} soil application or foliar spray at 0.5 and 0.3%, respectively 3 times after square initiation significantly improved the micronaire of the third pick cotton in 4 years trials of shallow soils by 3 to 4.6% (Table 8). However, in shallow soils 't' test indicated that micronaire 3rd picked cotton could be improved from discount range to premium quality with $MnSO_4$ 25 kg ha^{-1} year^{-3} and Borax 10 kg ha^{-1} year^{-3} soil application, respectively in rainfed and two supplemental irrigations (Table 11). Zn, Mn and B foliar spray at 0.5 and 0.3% twice from square initiation to flowering stage under supplemental irrigations also can produce similar effect (Tables 9 and 10). Similar to micronaire of 3rd pick cotton with two supplemental irrigations bundle strength g/tex of

Table 8. Fibre properties of NHH 44 hybrid cotton in shallow soils.

Treatment	Staple length mm		Uniformity ratio		Micronaire		Bundle strength g/tex	
Main plot treatment	**1st**	**3rd**	**1st**	**3rd**	**1st**	**3rd**	**1st**	**3rd**
Control	24.9	22.0	50.0	49.3	4.42	3.24	18.8	16.2
$ZnSO_4$ 25 kg ha^{-1} yr^{-3}	24.7	22.0	49.5	48.3	4.50	3.29	19.5	16.0
$MnSO_4$ 25 kg ha^{-1} yr^{-3}	25.0	21.9	50.6	49.6	4.43	3.35	19.4	16.0
Borax 10 kg ha^{-1} yr^{-3}	24.8	22.3	49.9	48.6	4.60	3.39	18.5	16.4
Zn, Mn SO_4 25 Borax 10 kg ha^{-1} yr^{-3}	24.4	21.8	49.6	49.1	4.44	3.34	19.3	16.0
Zn, Mn, B foliar spray at 0.5 and 0.3%	24.3	22.4	50.2	49.1	4.45	3.36	19.0	16.6
Zn, Mn, B foliar spray at 0.5 and 0.3% with 2% urea	24.5	22.2	50.4	49.3	4.41	3.24	19.1	16.7
S.E.M. ± 5%	0.5	0.4	0.4	0.7	0.10	0.17	0.4	0.4
CD ± 5%	0.9	0.9	0.8	1.6	0.21	0.34	0.8	0.8
	NS	NS	NS	NS	NS	S	NS	NS
Pure rainfed cotton	24.5	22.1	50.0	49.2	4.44	3.32	19.0	16.2
Two supplemental irrigations	24.9	22.1	50.0	48.9	4.49	3.31	19.2	16.3
S.E.M. ± 5%	0.3	0.3	0.3	0.3	0.04	0.30	0.3	0.1
CD ± 5%	0.9	0.6	0.6	0.6	0.08	0.11	0.6	0.3
	S	NS	NS	NS	NS	NS	NS	NS
2004	24.9	22.6	49.7	47.8	4.31	3.21	19.2	16.8
2005	24.4	21.8	50.1	49.5	4.68	3.47	19.1	16.2
2006	24.4	22.1	49.8	49.2	4.70	3.46	18.8	16.5
2007	25.0	21.8	50.4	49.5	4.17	3.13	19.1	15.7
SE ± 5%	3.5	0.2	0.4	0.3	0.08	0.07	0.3	0.2
CD ± 5%	0.4	0.5	0.7	0.6	0.16	0.13	0.5	0.4
	S	**S**	NS	S	S	S	NS	S
Micronutrients (M) x Irrigations (I)	0.5	0.7	0.9	0.9	0.21	0.17	0.7	0.6
CD ± 5%	1.0	1.3	1.7	1.8	0.42	0.34	1.4	1.2
M x S	0.5	0.7	0.9	0.9	0.20	0.18	2.6	0.6
CD ± 5%	1.0	1.5	1.9	1.9	0.39	0.36	0.7	1.1
Irrigations x Seasons	0.3	0.4	0.5	0.5	0.11	0.10	1.4	0.3
CD ± 5%	0.5	0.8	1.0	1.0	0.21	0.19	1.8	0.6
M x I x S	0.7	1.1	1.3	1.3	0.28	0.25	3.7	0.8
CD ± 5%	1.4	2.2	2.6	2.6	0.56	0.51		1.6

Medium deep soils

3rd pick cotton could be improved significantly with Zn, Mn and B foliar spray at 0.5 and 0.3% twice from square initiation to flowering stage in shallow soils (Table 12). Micronaire was abnormal in both pickings in 2004 and2007 due to drought in 2004 season (<49 mm) from September while it was six times higher in 2007(280 mm). Zn, Mn and B all of

Table 9. Micronaire of 3rd picked of cotton as influenced by different treatments during 2004 to 2006 in shallow soils.

Rainfed	Mean	Probability	Two supplemental irrigations	Mean	Probability
Control	3.37		Control	3.29	0.26
$ZnSO_4$ 25 kg ha^{-1} $year^{-3}$	3.40	0.37	$ZnSO_4$ 25 kg ha^{-1} $year^{-3}$	3.35	0.28
$MnSO_4$ 25 kg ha^{-1} $year^{-3}$	3.59	0.02*	$MnSO_4$ 25 kg ha^{-1} $year^{-3}$	3.28	0.47
Borax 10 kg ha^{-1} $year^{-3}$	3.50	0.17	Borax 10 kg ha^{-1} $year^{-3}$	3.60	0.01*
Zn, Mn SO_4 25 Borax 10 kg ha^{-1} $year^{-3}$	3.42	0.32	Zn, Mn SO_4 25 Borax 10 kg ha^{-1} $year^{-3}$	3.38	0.20
Zn, Mn, B foliar spray at 0.5 and 0.3%	3.42	0.32	Non chelated micronutrients spray	3.61	0.01*
Zn, Mn, B foliar spray at 0.5 and 0.3% with 2% urea	3.47	0.20	Chelated micronutrients spray	3.30	0.46
Mean	3.46		Mean	3.40	0.10

Table 10. Bundle strength g/tex of 3rd picked as influenced by different treatments during 2004 to 2006 in shallow soils.

Rainfed	Mean	Probability	Supplemental irrigations	Mean	Probability
Control	16.7		Control	17.2	0.17
$ZnSO_4$ 25 kg ha^{-1} $year^{-3}$	16.3	0.58	$ZnSO_4$ 25 kg ha^{-1} $year^{-3}$	17.1	0.44
$MnSO_4$ 25 kg ha^{-1} $year^{-3}$	16.9	0.33	$MnSO_4$ 25 kg ha^{-1} $year^{-3}$	16.9	0.35
Borax 10 kg ha^{-1} $year^{-3}$	16.7	0.42	Borax 10 kg ha^{-1} $year^{-3}$	16.7	0.19
Zn, Mn SO_4 25 Borax 10 kg ha^{-1} $year^{-3}$	17.0	0.28	Zn, Mn SO_4 25 Borax 10 kg ha^{-1} $year^{-3}$	16.6	0.21
Zn, Mn, B foliar spray at 0.5 and 0.3%	17.7	0.02	Non chelated micronutrients spray	16.4	0.14
Zn, Mn, B foliar spray at 0.5 and 0.3% with 2% urea	17.3	0.17	Chelated micronutrients spray	17.0	0.36
Mean	16.7		Mean	16.8	0.29

Table 11. Micronaire of 3rd picked cotton as influenced by different treatments during 2004 to 2007 in medium soils.

Rainfed	Mean	Probability	Supplemental irrigations	Mean	Probability
Control	3.23		Control	3.22	
$ZnSO_4$ 25 kg ha^{-1} $year^{-3}$	3.2	0.42	$ZnSO_4$ 25 kg ha^{-1} $year^{-3}$	3.10	0.14
$MnSO_4$ 25 kg ha^{-1} $year^{-3}$	3.13	0.11	$MnSO_4$ 25 kg ha^{-1} $year^{-3}$	3.25	0.42
Borax 10 kg ha^{-1} $year^{-3}$	3.23	0.33	Borax 10 kg ha^{-1} $year^{-3}$	3.26	0.38
Zn, Mn SO_4 25 Borax 10 kg ha^{-1} $year^{-3}$	3.31	0.47	Zn, Mn SO4 25 Borax 10 kg ha^{-1} $year^{-3}$	3.28	0.34
Zn, Mn, B foliar spray at 0.5 and 0.3%	3.22	0.29	Non chelated micronutrients spray	3.26	0.39
Zn, Mn, B foliar spray at 0.5 and 0.3% with 2% urea	3.22	0.30	Chelated micronutrients spray	3.20	0.42
Mean	3.22			3.23	0.44

them together soil application 66% and 33% foliar application or Zn, Mn and B foliar spray at 0.5 and 0.3%, respectively twice after square initiation brought significantly improved the micronaire of the 3rd pick cotton in medium deep soils from discount range to premium quality. Micronaire of 3rd pick cotton was significantly interacted with Irrigation and micronutrients besides strength with season (Tables 14 and 15). Soil application of micronutrient Mn SO_4 25 kg ha^{-1} $year^{-3}$, Borax 10 kg ha^{-1} $year^{-3}$ with two supplemental irrigations and Zn, Mn and B foliar spray at 0.5 and 0.3%, respectively under rainfed conditions significantly improved last pick cotton

Table 12. Bundle strength g/ tex of 3rd picking as influenced by different treatments during 2004 to 2007 in medium soils.

Rainfed	Mean	Probability	Supplemental irrigations	Mean	Probability
Control	15.9		Control	15.61	0.28
$ZnSO_4$ 25 kg ha^{-1} $year^{-3}$	15.62	0.27	$ZnSO_4$ 25 kg ha^{-1} $year^{-3}$	15.62	0.49
$MnSO_4$ 25 kg ha^{-1} $year^{-3}$	15.74	0.33	$MnSO_4$ 25 kg ha^{-1} $year^{-3}$	16.18	0.17
Borax 10 kg ha^{-1} $year^{-3}$	15.36	0.13	Borax 10 kg ha^{-1} $year^{-3}$	15.83	0.36
Zn, Mn SO_4 25 Borax 10 kg ha^{-1} $year^{-3}$	15.73	0.34	Zn, Mn SO_4 25 Borax 10 kg ha^{-1} $year^{-3}$	16.09	0.16
Zn, Mn, B foliar spray at 0.5 and 0.3%	15.96	0.44	Non chelated micronutrients spray	15.47	0.39
Zn, Mn, B foliar spray at 0.5 and 0.3% with 2% urea	16.16	0.29	Chelated micronutrients spray	16.12	0.22
Mean	15.78		Mean	15.91	0.23

Table 13. Agro economics of hybrid cotton inter/strip cropping in medium deep soils.

Main plot treatment	Cotton yield (kg ha^{-1})	NR/Re	CSPP inter crop yield (kg ha^{-1})			Net return Re investment Rs.		CEY (kg ha^{-1})		Soybean yield (kg ha^{-1})		
Micronutrient			**Cotton**	**Ppea**	**SPP**	**SPP**	**CSPP**			**SPP**	**Pure**	**Net Re/R**
Control	1256	1.41	1315	491	1776	1.55	2.83	2216		1618	2044	3.23
$ZnSO_4$ 25 kg ha^{-1} $year^{-3}$	1197	1.37	1205	465	1799	1.46	2.80	2069		1531	2249	3.18
$MnSO_4$ 25 kg ha^{-1} $year^{-3}$	1183	1.26	1339	412	1770	1.51	2.87	2213		1636	2162	3.26
Borax 10 kg ha^{-1} $year^{-3}$	1202	1.27	1364	430	1733	1.62	2.84	2154		1804	2361	3.08
Zn, Mn SO_4 25 Borax 10 kg ha^{-1} $year^{-3}$	1153	1.41	1303	387	1461	1.65	2.90	2167		1607	2274	3.11
Zn, Mn, B foliar spray at 0.5 and 0.3%	1143	1.34	1393	377	1696	1.64	3.01	2289		1654	2143	2.66
Zn, Mn, B foliar spray at 0.5 and 0.3% with 2% urea	1169	1.25	1461	318	1766	1.54	3.17	2251		1697	2072	3.00
S.E.M. ± 5%	19	0.19	151	S	213	0.20	0.32	130	186	182		0.47
CD ± %	NS	NS	NS	92	NS	NS	NS	NS	NS	NS		NS
Sub plot treatments: Irrigations (I)												
Rainfed cotton	1153	1.27	1354	403	1656	1.51	2.88	2177	1617	2223		3.25
Two supplemental irrigations	1220	1.39	1326	420	1773	1.63	2.95	2211	1682	2150		2.90
S.E.M. ± 5%	54	0.11	47	23	111	0.12	0.12	70	105	101		0.29
CD±5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		S
Sub –sub plot treatment: Seasons (S)												
2002/05	1395	1.56	1381	404	1649	1.30	2.58	2095	1615	2275		4.15
2003/06	1142	1.30	1282	430	1857	1.64	3.13	2247	1658	2166		1.72
2004/07	1022	1.14	1358	400	1637	1.77	3.03	2240	1675	2119		3.34
S.E.M. ± 5%	130	0.13	104	15	171	S	0.25	173	88	55		0.44

Table 13. Contd.

CD ± 5%	NS	NS	NS	NS	NS	0.21	NS	NS	NS	S	S
S x M	119	0.11	163	82	385	0.42	0.44	NS	366		NS
S.E.M. ± 5%	S	NS	S	S	S	S	S	226	S	176	0.25
S x I	NS	NS	231	NS	NS	NS	NS	NS	NS	263	NS
S.E.M. ± 5%	67	013	S	42	195	0.20	0.26	226	178	NS	0.29
I x M	NS	0.35	NS	NS	NS	NS	NS	NS	NS	NS	NS
S.E.M. ± 5%	91	S	125	63	294	0.30	0.34	184	272	263	0.59
S x I x M	316	0.35	432	217	1019	1.07	0.59	NS	NS	NS	NS
S.E.M. ± 5%	S	S	S	S	S	S	S	320	570	465	0.78

Table 14. Fibre properties of NHH 44 cotton in medium deep soils.

Fibre property	**2.5% staple length mm**		**Uniformity ratio**		**Micronaire**		**Strength g/tex**	
Picking	**1st**	**3rd**	**1st**	**3rd**	**1st**	**3rd**	**1st**	**3rd**
Main plots: Micronutrients								
Control	23	22	49.9	49.2	4.54	3.30	18.5	16.3
Zn 3 kg ha year	23.1	21.9	49.9	48.5	4.60	3.12	19.2	15.4
Mn 3 kg ha year	23.4	22.1	50.5	49.9	4.39	3.20	19.5	16.0
B 1 kg ha year	23.3	21.8	50.0	49.6	4.52	3.27	19.3	16.0
All	23.1	21.6	50.3	49.0	4.57	3.45	19.0	16.1
Zn, Mn, B foliar spray at 0.5 and 0.3%	22.9	21.8	50.3	49.1	4.46	3.35	19.9	16.3
Zn, Mn, B foliar spray at 0.5 and 0.3% with 2% urea	23	22.2	50.5	48.9	4.39	3.18	19.5	16.7
F test	NS	NS	NS	NS	S	S	NS	NS
SE/CD 5%	0.27	0.3	0.4	0.5	0.27	0.22	0.6	0.5
Sub plots irrigation								
Rainfed	23.1	21.9	50.2	49.4	4.4	3.3	19.3	16.1
Two supplemental Irrigations	23.2	21.9	50.2	49.0	4.5	3.4	19.4	16.1
F test	NS	NS	NS	NS	NS	NS	NS	NS
SE/CD 5%	0.16	0.14	0.3	0.2	0.04	0.04	0.3	0.1
Season								
2003	23.0	22.1	50.4	49	4.6	3.3	19.1	16.2
2004	23.2		50.6		4.5		19.3	
2005	23.2	22.1	49.9	49.6	4.4	3.4	19.1	16.3
2006	23.2	21.7	50.0	48.5	4.3	3.3	19.6	15.7

Table 14. Contd.

2007	23.0	21.0	50.1	49.6	4.4	3.3	19.3	16.1
F test	NS	NS	S	S	NS	NS	NS	NS
SE/CD 5%	0.16	0.16	0.51	0.7	0.8	0.1	0.5	0.3
Interaction								
S x I F test	S	S	NS	NS	NS	NS	NS	NS
SE/CD 5%	1.2	1.1	0.9	1.1	0.2	0.1	1.4	1.0
S x M F test	S	S	S	NS	S	S	NS	S
SE/CD 5%	1.2	1.1	0.94	1.0	0.3	0.3	1.4	2.0
I x M F test	NS	NS	NS	S	NS	S	NS	NS
SE/CD 5%	0.38	0.4	0.60	1.1	0.1	0.2	0.9	0.7
S x I x M F test	S	S	S	NS	S	S	S	S
SE/CD 5%	1.69	1.6	2.47	1.5	0.5	0.4	3.9	2.6

Table 15. Interaction of supplemental irrigations and micronutrients on micronaire of third pick cotton in medium soils.

Treatment	Supplemental irrigations	Rainfed
Control	3.37	3.25
Zn 3 kg ha year	3.26	3.39
Mn 3 kg ha year	3.40	3.24
B 1 kg ha year	3.45	3.23
All micronutrients	3.34	3.18
Zn, Mn and B foliar spray at 0.5 and 0.3%	3.27	3.42
Zn, Mn and B foliar spray at 0.5 and 0.3% with 2% urea	3.38	3.21
CD ± 5%		0.2

micronaire to premium range.

Supplemental irrigations

Yield and profitability: Two supplemental irrigations in the beginning of winter season in early October month from the harvested rainwater in farm ponds did not significantly improved the seed cotton yields or profitability in both shallow and medium soils in a six years experimentation period, it does not justify investments on farm ponds to create supplemental irrigations to deep rooted drought resistant either pure or strip cropped cotton/soybean (Tables 7 and 13). Rainfall distribution during July to October months of six years period followed more or less normal pattern (Figure 1). Therefore, there is no significant response or improved profitability of pure cotton 2002 to 2004 and rainwater conserved by stripcropping during 2005 to 2007 years (Singh et al., 2008).

Conclusion

Shallow soils were most profitable for sole soybean cultivation only in assured rainfall areas.

Strip cropping of cotton + soybean + pigeon pea d(4:4:2) is most profitable under rainfed conditions by 47 and 58% over sole cotton in shallow and medium deep soils, respectively. Micronaire of last picked cotton could be improved under rainfed conditions in coarse textured shallow soils with Mn SO_4 25 kg ha^{-1} $year^{-3}$ soil application or Zn, Mn and B at 0.5 and 0.3% foliar spray twice in medium deep soils. Two supplemental irrigations after cessation of monsoon can be benefitted with Borax 10 kg ha^{-1} $year^{-3}$ soil application in shallow soils or Zn, Mn and B at 0.5 and 0.3% foliar spray twice after square initiation in medium deep soils brought significant improvement in micronaire and kept the fibre discount to premium range.

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