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Impact of nutrient scheduling for Bt hybrid cotton fertigation

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Abstract
Farm income, fertilizer, irrigation water use and labour use efficiencies, productivity, profitability and C:B were more than doubled with 100% of RDF i.e. 90:45:45:15 N: P_2O_5: K_2O: S kg ha^{-1} soil application, 30% of RDF as WSF i.e. 30:15:15:5 N: P_2O_5: K_2O: S kg ha^{-1}, bio-stimulants (NPK *consortia*, humic acid, *Sagarika*) and chelated micronutrients fertigation through venchuri in medium long duration commercial Bt hybrid cotton Boll guard II based pigeon pea + oranges / vegetable cropping systems in shallow, stony, medium and deep *Alfisols*, *Vertisols*, *Vertisols* with *calcite* substrata and *Vertic Inceptisols*. On an average investments were recovered within two years and saved inter planted orange groves during summer by adopting drip-fertigation in all the soils using limited water resources, unlimited soil and foliar application of fertilizer nutrients along with plant protection chemicals. Cost of lint production was brought down by 35% with labour saving pressure compensating inline drippers, WSF, phosphoric acid, urea, potash, chelated micronutrients and bio-stimulants. Constraints faced by the farmers were delayed on set of monsoon or excess rains, crop rotations, pink bollworm attack and electric power supply.

Keywords: Bio-stimulants, Chelated micronutrients, Fertigation, FUE, WSF, WUE

Introduction
Before the introduction of Bt hybrid cotton in this area the cropping pattern was hybrid cotton strip cropping with late maturing pigeon pea C*var* C-11 (8:2 ratio) in a replacement series (Raju and Deshmukh, 2012) [9]. Pigeon pea is a food legume, which, was buffering the losses from boll worms and also meet the yearlong protein requirement as green pods and remaining pods as dried lentils. Widely spaced check row planting of hybrid cotton at 0.90 x 0.90m under rainfed condition with 90:50:28 percentage of the recommended dose of fertilizers 90:45:45 (180) kg ha^{-1} N: P_2O_5: K_2O respectively i.e. 115 kg ha^{-1} (3:2:1 ratio) in *Alfisols*, *Vertisols* and *Vertisols* with *Calcite* sub strata produced 200, 300, 400 kg lint ha^1 alongwith pigeon pea legume grain yield of 150, 200 and 300 kg ha^{-1} respectively. Author introduced commercial Bt hybrid cotton in National Agriculture Technology Project "Institute Village Linking Programme" at *Telgaon*, *Thishti* in *Kalmeshwar*, Nagpur and in Chadrapur and Yeotmal districts (M.S.) India under Front line demonstration (FLD) programmes for three years (2003-2005) by ICAR Central Institute for Cotton Research, Nagpur. This was followed by large scale adoption of Bt hybrid cotton (Gutierrez, *et al.*, 2020) [3] in pre-dominantly rainfed central India. Severe and mild, wide spread of *El nino* effect in 1997 and 2003 respectively (Mc Phaden, 2004) [5] also leads to adoption of sprinkler and drip irrigation systems in 2004-2014 in rain shadow areas of *Kalmeshwar*, *Saoner*, *Katol* Tq of north Nagpur (Jain, 2023) [4]. *Vindhyan* range foot hills get 30% less rains compare to southern part of Nagpur due to obstruction by *Satpuda* hills on the SW monsoon direction. Undulating stony, shallow to medium deep *Vertic ustothrepts* soils with 15-20 cm *Calcite* layer below 30-60 cm soil depth in *Vertisols* of *Linga* series and mountainous *Alfisols* soils in north Nagpur humid tropics. Adoption of micro irrigation systems are expected to support pre monsoon Bt hybrid cotton for initial and early withdrawal of monsoon besides supporting hot dry summer season for orange plantations (Srinivas *et al.*, 2002) [16]. Although, farmer's had first adopted for perennial orange crop spread to annual vegetable crops including Bt hybrid cotton + pigeon pea strip cropping and vegetables in *Kanhan* river side sandy loam soils of *Saoner Tehsil* Nagpur District. Early adopters used button type of drippers, which had serious clogging and maintenance difficulties besides higher labor requirement. Therefore, majority of them still today used drip irrigation only for trickling irrigation water near the root zone in *Vidarbha* region of Maharashtra state in central India.

Pressure compensating (PC) inline drippers at standard spacing 1.2 x 0.4 m distance is now commonly followed for deficit irrigation in Bt hybrid cotton in central India. Irrigation scheduling is primarily based on experience gained by the farmers on an average evening half an hour or equal to 1.0 litre irrigation water delivery day^{-1} in alternate days in pre monsoon cotton at seedling stage for one month requires 200 mm and 2 hours or equal to 2 liters day^{-1} irrigation water delivery once in 4 days during post monsoon winter season requires another 200mm water i.e. during late flowering and early boll development stage which increased 50% seed cotton yield, besides saving 50% irrigation water and 25% fertilizers (Bhaskar, 2005 [1]; Brar and Singh, 2022 [2]). Pre monsoon cotton planted usually on 23rd May to 7th June with a yield advantage of 50% besides escaping weeds, insect pests, trapping the applied nutrients and more efficient fruiting compared to monsoon sown cotton. Unless weather is extremely hot in continuation, which will be postponed by a week in advance of pre monsoon showers besides also depend upon the well water availability for atleast $^{1}/_{2}$ hour day^{-1} in summer pumping by 3 HP submersible pump electric motor or 3 M^{3} or 3 m x 0.5 m depth well can sustain one acre pre monsoon Bt hybrid cotton.

Materials and Methods

List of drip irrigation farmers were procured from *Kalmeshowar*, Office of *Taluka* Agriculture Officer, and fourteen (14) farmers were selected in the *Telkamptee* and *Teeshti* (b) village *Panchayat* office with the help of Agriculture Assistant and a *whatsapp* group was also created for effective communication and co-ordination in executing the project objectives. Farmers were interviewed about their investment history of cotton production practices, profitability, scheduling, quantity, method of fertilization and irrigation practices based on willingness to accept and invest on the new interventions in Bt hybrid cotton on bio-stimulants, WSF, micronutrients based fertigation technology besides having different soil types and cropping systems. All the stake holders soil profiles one from each hectare field were dugout and composite samples were analyzed. The farm size of stake holders were minimum 2 to 7 hectares, therefore, second year (2018) onwords WSF were group purchased through IFFCO co-operatives and delivered at their doorstep. Fertilizer recommendation charts were provided to participating individual farmers to follow total RDF @ 120:60:60:20 N: P_2O_5: K_2O: S kg ha^{-1} including micro and secondary nutrients through soil and foliar application. Fertilizer recommendation charts were also displayed at IFFCO pesticide dealers, village level offices including village *panchayat* and Whatsapp groups for wider adaptation and popularization of fertigation. Water soluble fertilizer inputs 18:18:18, 17:44:0, 0:52:34, 0:0:50 N: P_2O_5: K_2O grades were advised to use @ one 30 kg bag at seedling stage (NPK), squaring to flowering (NP) and boll development stage (NK or K). The WSF quantity should not exceed 30% of RDF i.e. 30:15:15 N: P_2O_5: K_2O kg ha^{-1}. Commercial grade phosphoric acid and Urea were also used by *Calcareous* soil farmers in *Badegaon* (*Saoner*) and *Thishti*, who were not given the IFFCO project inputs. Few farmers also used Calcium Ammonium Nitrate (CAN) an acidifying fertilizer to clear the clogging of inline PC drippers. Soil application of 70% N, P, K, S fertilizers in 5 splits during July, August and September rainy season months. Bio-stimulants (*Sagarika*, humic acid) were also given as seed treatment, twice in a month as fertigation or foliar applications to stimulate the root and shoot growth. $MgSO_4$ was advised only to apply as soil or fertigation alone due to high raise in pH inorder to supply Mg and S both secondary essential nutrients to prevent leaf reddening in Bt hybrid cotton. Micronutrient IFFCO $ZnSO_4$ / chelated micronutrient to meet Zinc and *Solubor* as soil or venchury application @ 2.5 kg ha^{-1} for Zn and Boron requirement in the trial. Selected farmers soil profiles were excavated, photographed, identified and composite samples were collected in sterile plastic boxes for further laboratory analysis. Soils were analyzed for available major, secondary and micro nutrients. Application of basal, top dressing of complex, urea, potash, $ZnSO_4$, Boron fertilizers soil and foliar applications were scheduled. Scheduling recommendation of WSF were also made and provided to the adopted farmers. During the study period 2018-2022, it was advised to apply 90:45:45:15 kg ha^{-1} N: P_2O_5: K_2O:S or 70% RDF as basal soil application in atleast in two to three splits basal and three splits top dressing application during monsoon season, when fertigation is usually not given i.e. July to September months. It was advised to apply 10:5:5:5 kg ha^{-1} N: P_2O_5: K_2O:S as 30% RDF through fertigation in one month pre monsoon and 2 months post monsoon period in 6 and 12 splits respectively as weekly schedules alternated with fortnightly micro-nutrients. Application of N, P, K, S solid complex fertilizers costing Rs. 13, 550/- ha^{-1} in 5 splits during July, to September rainy season. Bio-stimulants NPK *consortia*, humic acid, *Sagarika* were also given as seed treatment, twice fertigation and foliar applications to stimulate the root and shoot growth of Bt hybrid cotton. Mg and $ZnSO_4$ @ 20 kg ha^{-1} yr^{-3} Borax 5 kg ha^{-1} yr^{-3} soil (2) or *venchury* (5) applications costing Rs. 3000/- ha^{-1} yr^{-3} were advised as per the availability, compatibility with WSF and input chemistry. Choice and amount on quantity of water soluble fertilizers (WSF) to be spent was left to the farmers as the soil type, actual requirement and crop response besides arrangement of finances is also the responsibility of farmers in adoption and continuation of the technology in future. Water soluble fertilizer inputs @ 70 kg ha^{-1} costing Rs. 15000/- ha^{-1} at seedling stage, squaring to flowering and boll development stage in the form of Urea and 0:52:34 were advocated to reduce cost of WSF and provided as per dealer price for the project on cost to cost basis for a period of three years. Although farmers demanded electronic solenoid sensors for scheduling of irrigations like in sugarcane costing Rs. 3000/- unit^{-1} which as was shown to them. Adoption of electrical conductivity resistance irrigation sensors Rs. 360/- unit^{-1} to cotton moisture range calibration was in progress could not be arranged to supply in the required number of fields to all the farmers with *Rf* frequency communication in the absence of signal tower and power supply for making automatic sensor based irrigation system, which could have saved time and water economy. Soil profile was excavated and layerwise nutrients analysis was done as per standard protocols (Raju and Deshmukh, 2012 [9], Raju et. al, 2023 [15]).

Results and Discussion

The on farm trial observations, results, opinions of the farmers were analyzed discussed under following heads.

Economic impact on *Alfisols*: Stony, *Alfisols* and *Vertic Inceptisols*, highly *Calcareous* soils with >30% $CaCO_3$,

where moisture is more critical than soil depth found economically viable for drip / fertigation with C: B ratio 3.0, 3.8, 4.0, IWUE 2.21, 1.75, 2.0 kg lint mm^{-1} irrigation water applied and a mean FUE 4.2, 3.04, 2.83 kg lint kg^{-1} $fertilizer^{-1}$ applied and cost of production ₹. 50, 56, 67 kg lint with net returns ₹ 1.52, 1.37, 0.74 *lakhs* ha^{-1} by investing ₹ 18, 22 and 26000 ha^{-1} on soil applied complex and *venchury* applied WSF fertilizers per season in *Alfisols*, *Vertisols* with *calcite* hard pan and highly *Calcareous* soils respectively in rain shadow area without mulching (Table 1). The cost of production in highly *Calcareous* soils is 20% higher than the present market cost needs more scientific approach inorder to reduce the cost of production N: P_2O_5: K_20: S 120:60:30: 20 kg ha^{-1} in 3:2:1 ratio, chelated Zn, Boron, humic acid, liquid phosphoric acid in fertigation and crop rotations with tolerant crops like wheat. These results on leaf reddening, cost and returns on Bt hybrid cotton in different soils were in agreement with those observed by Raju and Thakare, 2012 [7], Raju and Deshmukh, 2012 [6], Raju, 2023 [15] for different soils under rainfed, supplemental and drip irrigation methods with various levels of technology adoption in *Vidarbha* region of Maharashtra state, Central India.

Table 1: Economic viability of Bt hybrid cotton fertigation in different soils

	Highly *Calcareous* soils	**Clay loam with *caliche***	**Red stony soils**	**Mean**	**SD±5%**
Farm size ha^{-1}	6	15	20	13.7	
Number of farms	1	3	3	2.3	
Lint yield kg ha^{-1}	1200	1200	1282	1227	332
WUE kg lint mm irrigation water applied	2.0	1.75	2.21	2.00	
FUE kg lint kg fertilizers applied	2.83	3.04	4.20	3.29	1.8
Manures and fertilizers cost ₹ 000 ha^{-1}	25.5	22	18	17	7
Net returns ₹ 000 ha^{-1}	74	137	152	121	18
C: B ratio	4.0	3.8	3.0	4.0	
Cost of lint production ₹ kg^{-1} lint	66.5	56.3	50.4	58	5
Complex fertilizers Soil application @ kg ha^{-1}	281	234	141	218	84
Nitrogen kg ha^{-1}	120	94	36	83	23
P_20_5 kg ha^{-1}	86	67	69	74	41
K_2O kg ha^{-1}	75	73	36	61	44
Fertigation of WSF kg ha^{-1}	72	94	117	94	51
Nitrogen kg ha^{-1}	38	27	25	30	9
P_20_5 kg ha^{-1}	28	21	66	38	17
K_2O kg ha^{-1}	6	47	26	26	39
Fertigation of WSF percent	20.4	28.7	45.3	30.1	17.8

Shallow *Alfisols* had a neutral pH, low organic carbon%, P, K, S, Zn medium B, $CaCO_3$%, and high in Mn (Table 3) expected to perform well under own production and regular application of sufficient organic manures produced more than double national average cotton lint equivalent yields 1120 kg ha^{-1}, by Mr. Avinash Falke (Table 2) a success story of IFS with *peri* urban commercial dairying as one of the component in mountainous red soils despite of the limitation of wild animals and long distance transportation of water more than 2 km with 5m lift from the lake bed to arable field. Lint productivity of 1120 kg ha^{-1}, FUE 5.36 kg lint kg^{-1} fertilizer applied, IWUE 2.61 kg lint mm^{-1}, C:B ratio 3.0 was achieved with 78% soil application of RDF, *venchury* applied 45%WSF increase cost of production ₹. 30 to Rs. 50 kg^{-1} cotton lint over all extra 7.5% RDF was soil applied besides improving the lint and pigeon pea yields were also improved. The cost of production was within the competitive market price, doubled WUE and FUE besides tripling the lint productivity. Advices for this farming system is to go for liquid phosphoric acid 85% @ 70 L ha^{-1}, *neem* coated urea @ 260 kg ha^{-1}, *murate* of potash @ 30 kg ha^{-1} through *venchury* and *murate* of potash @ 70 kg ha^{-1}, 20 kg ha^{-1} $ZnSO_4$ soil application and increase quantity of soil applied N, P, K, S, Zn which were low as per soil test reporting to further reduce the cost of lint production.

Table 2: Fertigation of Bt hybrid cotton in shallow, stony, *Alfisols.*

Bt commercial hybrids	**NCS- 779**	**Rashi-659**		***Alfisols***	***Vertisols***	**Percentage of *Vertisols***
Name of the farmer	Mr.Deulkar	Mr.Bawane	Mr.Phalke			
Lint yield kg lint ha^{-1}	854	656	848	786	1197	66
Lint response due to fertigation over supplemental irrigation	1.35	0.64	1.12	0.96	1.99	48
Irrigation WUE kg lint mm^{-1} irrigation water applied	1.64	1.14	1.62	1.47	2.24	66
FUE kg lint kg^{-1} fertilizer applied	1.8	2.3	3.3	2.43	3.06	79
Manures & Fertilizers cost ₹ 000 ha^{-1}	26.12	25.4	14.6	22.08	24.36	91
Net returns ₹ 000 ha^{-1}	183	200	166	182	152	120
C:B Ratio	2.9	3.1	3.1	3.03	3.87	78
Cost of production ₹ lint kg^{-1}	63	60	59	60.5	69.7	87
Complex fertilizers soil application kg ha^{-1}	235	109	78	141	242	58
N kg ha^{-1}	45	51	13	36	98	37
P_20_5 kg ha^{-1}	115	58	33	69	70	99
K_2O kg ha^{-1}	75	0	33	36	73	49
Fertigation WSF kg ha^{-1}	138	93	120	117	90	130
N kg ha^{-1}	20	30	25	25	29	86

P_20_5 kg ha^{-1}	83	45	70	66	22	300
K_2O kg ha^{-1}	35	18	25	26	40	65
Fertigation WSF percent use	67.4	28.0	14.6	20.4	21.1	97

Table 3: Profile characters shallow stony *Alfisols*

Stony *Alfisols*	**OC**	**pH**	**P_2O_5**	**K_2O**	**Ca**	**S**	**Zn**	**Fe**	**Cu**	**Mn**	**B**
Soil depth m	%		mg kg	kg ha	%	ppm	ppm	ppm	ppm	ppm	ppm
0-0.20	0.41	7.6		212	20.7	0.16					0.93
0.20-0.30	0.24	7.6	0.86	123	14.1	0.12	0.2	0.2	1.23	81.2	
0.30-0.50	0.34	7.6	1.36	126	18.4	0.17	0.17	1.38	1.94	11.8	
>0.50	0.37	7.5	1.96	116	19.1	0.15	0.09	0.68	2.86	11.6	

Table 4: Profile characters medium deep *Alfisols*

Medium *Alfisol*	Bawane	pH	Ec	P_2O_5	K_2O	Ca CO_3	S	Zn	Fe	Cu	Mn	B
Soil depth m	OC%		mm hos	mg kg^{-1}	kg ha^{-1}	%	ppm	ppm	ppm	ppm	ppm	ppm
0.0-0.20	0.66	6.5	0.21	8.8	499	19.0	3.7	0.71	0.03	2.28	15.1	0.085
0.20-0.35	0.41	6.5	0.19	5.29	212	19.6	3.7	0.48	1.38	3.54	12.8	0.085
0.35-0.50	0.37	6.6		5.0	200	19.1	10.2	0.81	0.15	1.73	14.6	0.085
0.50-0.70	0.34	6.6		2.6	195	18.5	4.1	0.94	0.15	0.81	62.6	0.085
>0.70	0.31	7.5		4.3	265	19.3	3.9	0.53	0.23	1.55	4.5	0.085

Medium deep *Alfisols* of Mr. *Bawane* (Table 2, 3, 4) pH was found to be acidic to neutral, low in P, K, S, Fe, Zn and B medium in organic carbon, $CaCO_3$ and Cu. Soil application of complex commercial fertilizer use was very low 61% RDF and yields were also maintained with higher application of RDF 154% as WSF and higher WUE of 2.67 kg lint mm^{-1} irrigation water applied. Therefore, expenditure was also lower to keep lower cost of production @ Rs 56/- kg^{-1} cotton lint, FUE was tripled 8.54 lint kg fertilizer applied and maintained net returns fairly very high at Rs. 2, 39, 000/- ha^{-1}. Advices for this farm were to go for higher amount of complex commercial fertilizer 10:26:26 N: P_2O_5: K_2O @ 250 kg ha^{-1} or Zn and B coated single superphosphate specialty fertilizer to reduce expenditure on WSF besides soil application of deficit nutrients K, S, Zn and B @ 1.5 times RDF to improve and maintain the lint yields at 1367 kg lint ha^{-1} as they were already improved by three times in lower moisture and nutrient retentive *Alfisols*.

However, lowest FUE was observed in typic *Vertisols* without any crop rotation for last 8 years due to poor drainage and excess rains. Ideal FUE is 2.56 kg lint kg^{-1} fertilizer applied observed in *Alfisols* and increased FUE in *Calcisols* 4.22 kg lint kg^{-1} fertilizer applied is due to less soil application of complex fertilizer and more water soluble fertilizer (Phosphoric acid) consumption in fertigation. Top FUE in *Vertisols* with *Caliche* by fertigation 5.6 was due to following regular crop rotation and deep red soils 5.96 kg lint kg^{-1} fertilizer applied due to application of F.Y.M. 5 tonn ha^{-1} $year^3$ alongwith fertilizers. Inline PC dripper brought huge savings on labour cost of irrigation application due to zero clogging compared to previous button type of emitters. Significantly best lint yields, FUE, C:B ratio and WSF proportion were obtained with RDF 160% in *Vertisols* with *Caliche* medium deep *Alfisols*. Lint yields, FUE became 50% after 2020-2022 due to excess rains, needs adoption of BBF at 1.0% slope besides higher soil application of water soluble nutrients N, K, Zn, B preferably in 5 splits. Adoption of BBF with advance planting, inter and double cropping, summer crop rotations helps to overcome the losses due to excess rains in mono cropping of cotton cultivation (Raju, 2023) [15].

Impact assessment found fertigation with water soluble fertilizers, bio-stimulants and deficient micronutrients produced average additional 433 kg lint ha^{-1}. Fertigation reduced the fertilizer consumption by 81 kg ha^{-1} or 30% over consumed in two supplemental irrigations. Fertigation consumed **23**% water soluble fertilizers (WSF) out of the total fertilizers consumed and 25% micro and secondary (Mg, S) nutrients. Best lint yield of 1734 kg lint ha^{-1} 155% improvement was observed in *Vertisols* with *caliche* having 10% $CaCO_3$, which provided the best drainage for Bt hybrid cotton (Raju, 2023). Best FUE was observed in *Vertisols* with 10% $CaCO_3$ followed by *Alfisols* under supplemental irrigations primarily due to imbalance in N, P, K, S ratio and non application of deficit micronutrients Zinc and Boron.

Impact on *Vertisols*: Clay loam soils require good hydraulic conductivity >0.05m day^{-1} found viable under >0.30m high 1.2 m wide beds (BBF) preferably with >0.30m deep furrows with black polythene mulched cotton planting, when the rainfall is 600 to 800 mm (semi arid tropics or rain shadow areas) with irregular distribution. In the absence of crop rotations beyond three years seed cotton yield were decline by 30%. This was also noticed in Prakash Barmase's field for 6 years Bt hybrid cotton-wheat + oranges in very deep *Vertisols* had a neutral pH, low P, S, Zn, Fe medium $CaCO_3$% and high in K, Mn being mined here (Table 5). Farm was expected to perform well under labour constraints, no rotations were followed except by rotational wheat and domestic production of limited organic manures by milking animals for rural dairy produced additional 880 kg ha^{-1} cotton lint yields by application of pre monsoon and post monsoon fertigation 10-12 times. Additional lint productivity was 880 kg lint ha^{-1} with net returns of Rs. 1,35, 100/- ha^{-1}, cost of lint production by Rs. 79.8/-42% higher, FUE 2.43, IWUE by 1.8 lint kg mm^{-1} irrigation water applied by application of 57% more than recommended dose of fertilizers and 15%WSF with crop response of 1.2 kg lint kg fertilizer application. Advice as per soil test is to go for $ZnSO_4$ @20 kg ha^{-1} soil application, crop rotation with soybean-gram-wheat with adequate organic manuring and doubling of WSF quantity besides pre monsoon planting with BBF under 1% slope.

Table 5: Profile characters deep *Vertisols* of Bt hybrid cotton-wheat

Prakash Barmase	**OC**	**pH**	**Ec**	**P_2O_5**	**K_2O**	**Ca**	**S**	**Zn**	**Fe**	**Cu**	**Mn**	**B**
Soil depth m	%			mg kg^{-1}	kg ha^{-1}	%	ppm	ppm	ppm	ppm	ppm	ppm
0-0.30	0.75	7.6	0.42	3.60	665	18.6	8.6	0.63	0.29	0.57	0.88	1.2
0.30-0.60	0.16	7.6	0.28	6.39	340	18.4	11.2	0.17	0.14	5.35	38	0.9
0.60-0.90	0.21	7.6	0.40	0.44	370	10.8	5.8	0.04	0.23	2.19	15	
0.90-1.10	0.11	7.6	0.31	2.35	301	2.5	4.9	0.012	0.62	4.4	13	
>1.10	0.44	7.5	0.58	0.20	220	9	3.5	0.022	0.23	4.39	5	

Table 6: Profile characters of Mr. Satpute medium deep *Vertisols* with *Caliche*

Thisthi	**OC**	**pH**	**Ec**	**P_2O_5**	**K_2O**	**Ca**	**S**	**B**	**Zn**	**Fe**	**Cu**	**Mn**
Soil depth	%		Mm hos	mg kg^{-1}	kg ha^{-1}	%	ppm	ppm	ppm	ppm	ppm	ppm
0-0.20	0.37	7.6	0.30	6.07	160	3.5	4.9	0.9	0.34	0.09	3.14	10
0.20-0.30	0.11	8.0	0.29	5.69	116	4.5	3.6	0.8	0.02	0.00	2.98	25
0.30-0.50	0.29	7.6	0.35	6.93	99	4	3.1		0.075	0.18	4.4	11
0.50-0.70	0.11	7.7	0.27	5.45	51	3.4	3.2		0.38	0.00	4.18	50
>0.70	0.10	8.2	0.24	4.75	784	3.6	3.1		0.13	3.27	3.14	62

Table 7: Profile characters deep *Vertisols* with *Caliche*

Pravin Deshmukh	**OC**	**pH**	**Ec**	**P_2O_5**	**K_2O**	**Ca**	**S**	**Zn**	**Fe**	**Cu**	**Mn**	**B**
Soil depth	%		mm hos^{-1}	mg kg^{-1}	kg ha^{-1}		ppm	ppm	ppm	ppm	ppm	ppm
0-0.20	0.45	8.2	0.32	7.58	755	10	3.46	2.40	2.67	2.36	10.5	0.79
0.20-0.40	0.18	8.1	0.47	5.27	378	8.6	4.32	1.20	0.23	1.5	11.1	
0.40-0.60	0.34	8.5	0.33	1.57	424	9.4	3.14	1.35	1.06	1.09	43.4	
0.60-0.80	0.32	8.5	0.33	1.82	386	7.3	6.75	1.23	0.35	1.32	7.32	
0.80-1.00	0.31	7.6	0.42	0.24	472	8.7	4.73	1.50	0.26	1.5	8.15	
1.00-1.20	0.29	8.2	0.46	4.06	212	8.7	3.06	0.67	3.23	5.34	6.5	

***Vertisols* with *Caliche*:** In soybean-wheat-Bt hybrid cotton +oranges rotations was followed, where seed cotton yields were decline by lower application of fertilizer nutrients in soil tested for lower organic carbon%, available P, K, Zn and Iron is a typical example of low input agriculture in marginal medium *Vertic calcite* substrata at 0.40-0.60 m soil depth. This was also noticed in Mr Satpute's farm, at the village *Thishti bujurg* field for 3 years Bt hybrid cotton-wheat+ oranges *Vertisols* with *Caliche* had a neutral to alkaline pH, lower $CaCO_3$%. P, K, Zn, Fe medium in S, Cu, B and high in Mn (Table 6). The farm was expected to perform well under no labour constraints, regular crop rotations were followed except by rotational wheat and domestic production of limited organic manures by draft animals, produced additional 780 kg ha^{-1} cotton lint yield by application of pre monsoon and post monsoon fertigation 10-12 times. Additional lint productivity was 780 kg lint ha^{-1} with net returns of Rs. 1,79,700/- ha^{-1}, cost of production was Rs. 57.12/-which was comptetive in the market by lower application of fertilizers by little higher FUE 3.73 kg lint kg fertilizer applied, fertigation response was 1.10 kg lint, IWUE by 1.73 lint kg mm irrigation water applied. The results on *Vertisols* with *Calcareous* sub strata was in agreement with those observed by Raju *et al.*, 2023 [15] primarily by constraining the availability of P, Zn and Fe to crop production and root growth limitation at thick *calcite* band. These soils were better suitable for rotational pigeon pea and wheat although soybean may not perform well. The advices for this farm is to apply 150% RDP as phosphoric acid, K, Zn and Fe through soil or venchury and foliar application of Chelated Zn and Fe.

Table 8: Econometric efficiencies by fertigation in *Vertisols* with $CaCO_3$ layer at different depths

Bt commercial hybrids	***Moksha***	***Rashi-659***			**NCS-X**	**US 7067**	***Vertisols***	***Alfisols***
Name of the farmer	Deshmukh	Barmase	Satpute	Ranjit	Kuthe	Dafre	Mean	
Lint yield kg lint ha^{-1}	1740	1120	1080	1360	1200	680	1197	1.52
Lint response fertigation over supplemental irrigation	2.75	1.2	1.10	1.8	1.80	0.7	1.55	
Irrigation WUE kg lint mm^{-1} irrigation water applied	3.45	1.8	1.7	2.65	2.25	1.20	2.18	
FUE kg lint kg^{-1} fertilizer applied	4.50	2.43	3.73	3.44	2.83	1.39	3.06	1.26
Manures & Fertilizers cost ₹ 000 ha^{-1}	33.9	38.1	14.9	26.7	12.9	19.7	24.4	0.1
Net returns ₹ 000 ha^{-1}	146.4	135.1	179.7	159.3	89.0	203.4	152.1	0.1
C:B Ratio	4.6	3.8	3.7	4.2	4.0	2.9	4	1.27
Cost of production ₹ lint kg^{-1}	74.76	79.8	57.12	69.72	79.8	56.28	84	96.6
Complex fertilizers soil application kg ha^{-1}	281	323	186	268	281	111	242	1.72
N kg ha^{-1}	120	80	56	103	120	111	98	2.71
P_20_5 kg ha^{-1}	86	103	65	81	86	0	70	1.02
K_2O kg ha^{-1}	75	140	65	84	75	0	73	2.03
WSF Fertigation kg ha^{-1}	61	55	50	69	72	234	90	0.77
N kg ha^{-1}	28	18	14	27	38	50	29	1.17
P_20_5 kg ha^{-1}	28	0	36	24	28	15	22	0.33
K_2O kg ha^{-1}	6	38	0	22	6	169	40	1.54
Fertigation WSF percent use	18	15	21	20	20	68	27	31

In Bt hybrid cotton + pigeon pea+ oranges-turmeric-cucumber-rotations was followed seed cotton yield were decline by lower application of fertilizer nutrients. This was also noticed in Mr Pravin Deshmukh, at village *Telkamptee* field *Vertisols* with *Caliche* had a alkaline pH, low P, Fe medium in $CaCO_3$%, S, Cu, B and high in K, Zn and Mn (Table 7). The farm was expected to perform well under no labour constraints, rotations were followed except by rotational wheat and domestic production of limited organic manures by draft animals, produced 1740 kg ha^{-1} cotton lint yields, which is 3.5 times of national average by application of pre monsoon and post monsoon fertigation 10-12 times. Lint productivity was 1740 kg lint ha^{-1} with INR 2,93,000/-ha^{-1} cost of production Rs. 52/- kg^{-1} lint competitive by market standards i.e. reduced by 35% compared to rainfed cotton, by doubling FUE 5.66 kg lint kg fertilizer applied, by doubling WUE by 4.35 lint kg mm irrigation water applied. This was possible by soil application of 1.5 times RDF and with just WSF 30% RDF, thereby reduced cost of production. Cost of production can be further reduced with the soil application of FYM, sulphur containing complex and boron, zinc coated specialty single super phosphate fertilizer besides *venchury* application of phosphoric acid, WSF, urea, murate of potash, chelated Fe, Zn and water soluble Boron. These best performance was confirmed by Raju, 2023 [15] due to superior drainage.

Impact of crop rotations: In the absence of crop rotations beyond three years seed cotton yield will decline. This was also noticed in Prakash Barmase's field for 6 years Bt hybrid cotton-wheat + oranges and also after soybeans in *Adilabad*, *Telangana* state, groundnuts, maize and *Sorghum* in Gujarat and Andhra Pradesh states, cotton-wheat crop in north India. Cotton is considered as break crop for spread of labour demand, against buildup of soil born root rots, nematodes in vegetables, turmeric and banana crops. Pure pigeon pea is also takenup under minimal investments, besides summer gourds, cucumber, water and musk melons cultivation is preferred by the farmers and also found economically viable. *Telkamptee* farmers feel soil needs rest, so no intensive summer crops cultivation, besides their investments were already returned in two years time. They prefer, winter wheat or summer ploughing against heavy weed infestation instead of herbicides. Vegetable farmers in *Thishti in Calcareous* soils prefer Brinjal/ Cowpea/ Roselle/ *Dolichus purpureus* - wheat-Bt cotton with intensive pest management and phosphoric acid, urea and potash based fertigation with humic acid and chelated Zn, B. All vegetable farmers of *Badegaon*, *Saoner Calcareous* soils farmer prefer tomato,brinjal- Bt hybrid cotton-wheat. Weeds are serious problem in marginal, stony soils and appropriate post emergence herbicide are in greater demand despite of yellowing after their application. Monkeys, birds, stray and wild animal problems are also interfere in selection of summer oil seeds and horticulture and other rotational crops besides market demand.

Suitable Bt commercial hybrids: Medium duration rainfed high yielding Bt cotton hybrids produced *Maggot*-752*; Brent*-720*; Chaitanya*-680*; Ajit*-199 680*;Ajit*-155 544 *; Ankur*-3028 528*;Solar King Maker*, *Omega-520; Adilakshmi*-512 kg lint ha^{-1} with RDF 90:45:45 $N:P_2O_5:K_2O$ kg ha^{-1}. However, long duration Bt cotton hybrids preferred in summer fallow cotton with big boll size 6.0 g, 60-70 bolls $plant^{-1}$, erect centre stem with open branching, okra or non okra leaf, less sucking pests susceptible stay green, Boll guard II hybrids were preferred *Rashi*-659,*King Maker*, *Omega*, *Nuziveedu* 779, *X*, *Jabardast*, *US* 70-69, *Sigma*, *Raja*,*Vithal*, *Meghana* could produce 1120-1840 kg lint ha^{-1} produced with RDF 120:60:60 $N:P_2O_5:K_2O$ kg ha^{-1} respectively under two supplemental irrigations or six cycles each of drip/ fertigations in pre and post monsoon with extra 400 mm irrigation water, therefore, they are ruling the market.

Impact of winter irrigations: Two supplemental (winter) furrow irrigations with 100% RDF 257 kg ha^{-1} in a balanced ratio of 2:1:1 produced average additional lint yields of 267 kg lint ha^{-1} or 91% over rainfed condition by marginal increase of fertilizer nutrients (10 kg ha^{-1}). Winter irrigations during September-October fortnight after cessation of monsoon produced highest lint yield improvement in *Vertisols* 167% followed by *Alfisols* 133%.

Table 9: Bt hybrid cotton lint yield as influenced by methods of irrigations

Farmers soils	Lint yield improved kg ha^{-1}		Percent lint yield improved	
	Winter irrigations	Fertigation with WSF	Rainfed	Winter irrigations
Alfisols	140	320	41	67
Shallow *Alfisols*	240	320	100	67
Medium deep *Alfisols*	320	240	133	43
Vertisols	400	560	167	88
*Vertisol*s with *caliche* 10% $CaCO_3$	200	680	83	155
Calcisol 40% $CaCO_3$	240	480	60	75
Mean	257	433	91	80

Impact of Fertigation: Fertigation with water soluble fertilizers, bio-stimulants and deficient micronutrients in a wide row planting of with pressure compensating inline dripper (1.2m x 0.4m) produced average additional 433 kg lint ha^{-1} or 80% over conventional two winter supplemental irrigations. Average boll numbers produced per hill in rain fed cotton production system were 35 and supplemental irrigations 55 and fertigation achieved 80-90 bolls per plant with big boll weight of 5.5-7.5g lint boll. Fertigations reduced the fertilizer consumption by 81 kg ha^{-1} or 30% over consumed in two supplemental irrigations. Fertigation consumed 23% water soluble fertilizers (WSF) out of the total fertilizers consumed and 25% micro and secondary (Mg and S) nutrients. Best lint yield of 1734 kg ha^{-1} in 2019 was obtained (video documentation made by Sam TV telecasted available on youtube) i.e. 155% improvement in lint yield was observed in *Vertisols* with *caliche* having 10% $CaCO_3$ followed by *Vertisols* 88% and *Calcisols* 75%, the least 43% was very shallow stony soils due to heavy weed infestation and very low organic matter. The results were in agreement

with Raju, Raju *et al.* 2023 [15].

Impact on Fertilizer use efficiency: Best FUE was observed in *Vertisols* with proper drainage followed by *Alfisols* in rainfed and supplemental irrigations primarily due to imbalance in NPK ratio and non-application of deficit micronutrients. The lowest FUE was observed in typic *Vertisols* in both the irrigation systems was due to continuous Bt hybrid cotton-wheat without any crop rotation for last 8 years besides poor drainage. The ideal FUE is 3.52 kg lint kg^{-1} fertilizer applied observed in *Alfisols* and increased FUE in *Calcisols* 5.2 kg lint kg^{-1} fertilizer applied is due to less soil application of complex fertilizer and more water soluble fertilizer (Phosphoric acid) consumption in fertigation. The top FUE in *Vertisols* with *Caliche* by fertigation 6.56 kg lint kg^{-1} fertilizer applied was due to following regular crop rotation turmeric- Bt hybrid cotton BG II + pigeon pea strip cropping and deep red soils 6.91 kg lint kg^{-1} fertilizer applied due to application of domestically produced F.Y.M. 5 tonnes ha^{-1} $year^{-3}$ alongwith complex fertilizers and very limited WSF. The results were in agreement with Raju, Raju *et al.* 2023 [15].

Table 10: Fertigation in Bt hybrid cotton + pigeon pea strip cropping with *Alfisols*

	Deep red soil		Very shallow red soil
Bt hybrids OC	Conventional farm	Semi organic farm	Conventional
Lint yield kg ha^{-1}	915.8	1485.0	1074.0
Water use efficiency lint kg^{-1} ha mm^{-1} water applied	15.1	27.2	20.6
FUE kg lint kg fertilizer	6.2	9.0	3.0
Manures fertilizers cost Rs 000 ha^{-1}	18.7	52.0	56
Total cost of cultivation Rs 000 ha^{-1}	57.0	84.0	117
Net returns Rs 000 ha^{-1}	219.0	113.1	113
C:B ratio	3.0	3.2	3.9
Cost of production kg^{-1} seed cotton	33.9	30.8	49
Total fertilizers kg ha^{-1}	338.8	414.3	886
Soil application complex fertilizers kg ha^{-1}	78.8	201.3	655
Nitrogen kg ha^{-1}	130.0	94.4	159
$P_2 0_5$ kg ha^{-1}	130.0	86.3	334
K_2O kg ha^{-1}	5.0	82.5	163
Sulphur kg ha^{-1}	5.0	0.0	8
Zn SO_4 kg ha^{-1}	2.5	0.0	13
Boron kg ha^{-1}	0.0	0.0	5
Micronutrients mixtures kg ha^{-1}	0.12	0.12	2.5
Manures tonn ha^{-1}	0.2	4.1	
Fertigation NPK kg ha^{-1}	32.0	213	231
Nitrogen kg ha^{-1}	7.9	29.7	36
$P_2 0_5$ kg ha^{-1}	23.9	115.0	135
K_2O kg ha^{-1}	0.2	68.6	61
No of sprays for sucking pests	2.0	2.0	2
Noof sprays for Boll worms	2.0	2.0	2

Economic Impact: Inline PC dripper brought huge savings on labour cost of irrigation. Payback period was 2 years for these farmers. Significantly best lint yields, FUE, C:B ratio and WSF proportion were obtained with 160% RDF in *Vertisols* with *Caliche* medium deep *Alfisols*. Both provided best drainage besides nutrients compared to compared to typic *Vertisols*. Vegetable farmer with *Calcisols* had best resources and crop rotation but did not follow the typical technology (P, Zn, B) well due to inaccessible by stony road and telephone network. The lint yields obtained by the project validation were matching to China and Brazil even with the existing commercial BG II Bt hybrids available in Indian market. Therefore, ICAR, CICR, Nagpur and IFFCO New Delhi met the doubling of farmers income of prime minister of India. The results were in agreement with Raju, Raju *et al.* 2023 [15].

Table 11: Economics of *Vertic* integrades

	Vertisols		*Vertisols caliche*		*Calcareous soils*		*Alfisols*	
Boll guard II hybrids	**Mean**	**Farmer's practice**	**Mean**	**Farmer's practice**	**Mean**	**Farmer's practice**	**Mean**	**Farmer's practice**
Cotton Lint yield kg ha^{-1}	907	402	1070	346	815	170	1014	210
Farm size ha^{-1}	8	0	5.0	0	5.6	0	5.6	0
WUE lint kg mm irrigation water	0.91	1.005	1.02	0.865	0.78	0.425	0.97	0.525
FUE lint kg kg fertilizer nutrients	3.63	2.16	2.40	1.82	1.92	0.81	2.36	0.67
Manures & Fertilizers cost ₹ 000 ha^{-1}	11	9.6	16	7.7	26	15.8	46	25.8
Total cost of cultivation ₹ 000 ha^{-1}	50	25.9	88	17.0	92	27.1	113	28.5
Net returns ₹ 000 ha^{-1}	93	82.2	119	53.1	132	17.2	150	46.9
C: B ratio	6.47	8.29	2.31	0.45	1.75	0.15	1.81	0.46
Cost of production ₹ kg cotton lint	18.14	15.52	12.16	20.35	30	6.3	8.97	7.36
Rupee earned per Rupee investment	1.5	1.06	1.3	0.4	1.5	0.24	1.4	0.6
Soil application kg ha^{-1}	256	188	446	190	424	209	430	313
N	153	51	169	73	168	88	143	56
$P_2 0_5$	92	70	132	64	148	52	196	186

K_2O	98	46	145	92	108	79	121	92
S	18	0	33	14	0	0	3.1	3.9
Zn	1	13	15	5	0	0	5.2	6.4
B	25	0	3	0	0	0	2.1	2.6
Chelated micronutrients		0	14	12	0	0	0.8	1.2
Magnesium sulphate	0	0	23	15	0	0	0	0
Fertigation of WSF kg ha^{-1}	80	40	131	121	91.9	73.5	192.9	123.1
N	0	0	33	32	35.6	41.8	32.7	23.1
P_20_5	48	41	20	21	43.1	43.4	108.3	74.7
K_20	31	40	78	131	13.1	8.9	51.8	33.6
No of sprays for sucking pests	2	1	2	0	2.0	0.0	2	0
No of sprays for Boll worms	3	1	5	0	5	0	2	0

Table 12: Bt hybrid cotton lint yield, fertilizer application economics in fertigation

Bt hybrid	**NCS 779**	**Rashi-659**				**Rashi-659**	**Ankur 3028**		
Name of the farmer	**Deulkar**	**Bawane**	**Phalke**	**Ranjit**	**Mean**	**Drip_WSF**	**Rainfed**	**WSF**	**Stony WSF**
	VerticInceptisols	*Alfisols*		*Vertisols*			*Vertisols*		
Lint yield kg ha^{-1}	1344	1436	1176	1428	1319	1092	370	17	8
FUE kg lint kg fertilizer $^{-1}$	6.0	14.7	11.9	7.3	9.8	7.2	2.1	-0.4	-0.8
Manures & Fertilizers spent ₹ 000 Acre	8.7	8.45	4.86	6.55	7.34	8.7	2.84	-15.7	-9.1
Net returns ₹ 000 Acre	60.9	66.3	55.2	67.8	60.8	46.7	11.9	30.4	15.0
C:B Ratio	2.9	3.1	3.1	3.3	3.0	2.5	2.0	18.7	9.1
Cost/ ₹ kg lint	29	27	27	26	27	32	37	-24	-10
Soil application of fertilizers kg Acre $^{-1}$	94	44	31	45	56	107	72	-47.5	-10.9
N	18	20.5	5	44.5	15	30	36	-51.7	100.0
P_20_5	46	23	13		27	54	18	-49.4	-50.6
K_2O	30		13		22	23	18	-6.5	
Fertigation fertilizers kg Acre $^{-1}$	55	37	48	93	47	0	0		
N	8	12	10	20	10				
P_20_5	33	18	28	6	26				
K_2O	14	7	10	68	10				

Table 13: Bt hybrid cotton lint yield, fertilizer application economics in fertigation

Soil type	***Vertisol***	***Vertisol***	***Vertisol Caliche***	***Vertisol Caliche***	**Stony *Vertisol***	***Calsisol***				**WSF**	**CAL**	**Stony WSF**
Bt hybrid cotton	Rashi-659	Rashi-659	Moksha	Rashi-659	US 7067	NCS-X		Rashi-659	Ankur 3028			
	Barmase	Ranjit	Deshmukh	Satpute	Kishore Dafre	Kuthe	Mean	DripWSF	Rainfed			
Lint Yield Kg ha	1176	1428	1827	1134	714	1260	1222	1092	370	10	-44	15.8
FUE		10.3	12.2	7.5	5.0	13.3	9.1	10.2	5.1	11.1	1.4	-0.3
Manures & Fertilizers Cost		6550	11290	12700	4376	4950	8329	8700	2837	-4.3	72.9	-20.4
Net Returns Rs/Acre	60100	67800	82023	45025	29599	59900	55329	46650	11980	18.6	47.4	26.7
C:B	3.9	3.3	3.2	2.3	2.3	3.2	3.0	2.5	2.0	16.8	-1.3	11.0
Cost/Kg	18.5	22.4	22.4	31.7	31	22.4	25.1	27.7	31.7	14.0	1.1	-14.8
Soil Application		45	108	129	113	75	106	107	72	-0.9	31.3	-57.5
N		44.5	56	32	48	23	40	30	36	32.1		16.3
P_20_5			26	41	35	26	32	54	18	41.0	0.0	-59.0
K_2O			26	56	30	26	35	23	18	50.0	0.0	
Fertigation		93	42	22	29	20	28	0	0			
N		20	15	7	15	6	11					
P_20_5		6	12	0	11	15	9					
K_2O		68	15	15	2		11					

Future suggestions

1. Demand driven adoption of WSF, micro, chelated and nano fertilizers.
2. Communication signaling with solenoid sensor based irrigation water scheduling.
3. Application of 5tonne $ha^{-1}yr^{-3}$manures/crop residues, bio solids/press mud.
4. Diverse crop rotations and systematic cropping pattern brings more profits.
5. Combine canopy modifiers with pesticides, WSF and micronutrients.
6. Spend more on Mg, S, Zn and B containing speciality fertilizer for soil application.
7. Urea, phosphoric acid, WSF, and micronutrients for fertigation.
8. Management of drainage, aeration, weeds, insects and soil born pests and diseases.

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