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# Validation Cropping Systems and Input Management in Calcareous Vertisols

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

Inputs were tested and validated to supply optimum P and Zn content in index leaf of Bt hybrid cotton during squaring to flowering stage, such as seed treatment with NPK consortia to encourage soil biological activities in low organic carbon highly Calcareous Vertisols alongwith 75% RDF. Bentonite sulphur @20 kg ha-1 yr-1 soil application (SA) + RDF; Sagarika seed treatment @ 0.2% alongwith twice foliar sprays @ 0.002% at squaring and flowering + RDF; Nano ZnO 4% Seed treatment twice foliar sprays@0.004% + RDF produced significant agronomic response during 2019, exception was during 2020, the magnitude was 50% less due twice torrential (>60-100mm) and five times medium (25-50mm) rains during July and August months upset the reproductive physiology of cotton, shedded all the fruiting bodies, unable to maintain index leaf NPK, besides heavy pink bollworm attack. All these treatments were applied with 100% RDF @90:45:45 N:P2O5:K2O granular, two splits of basal spot application having 6.5% Sulphur containing, N: P2O5: K2O @ 22.5 kg ha-1 twice on 15, 30 DAS and twice as Urea at 45 and 60 DAS, Bentonite Sulphur @ 20 kg ha-1 +RDF or seed treatment and foliar applications of bio-stimulants Sagarika @ 0.02% and twice foliar applications of the same @ 0.002% and Nano ZnO @ 0.004% twice produced 67-86 ppm Zn in index leaf of the Bt hybrid cotton, similar to that of chelated Zn 0.5%.

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These inputs produced 161-287 kg lint ha-1 i. e. more than double 38 to 50% due to better nutrient uptake, biomass production, boll number with more than ₹. 15 to 30, 000/- ha-1 profitability and 1.5 to 2.2 C:B ratio, FUE 1.6 to 1.2 and lowest cost of production in both the years. Large scale OFTs in Kalmeshwar Tq, Nagpur district (M.S.) India in highly Calcareous soils, on suitable field and horticulture crops, irrigations and inputs management confirmed the beneficial effect of RDF 150% @120:60:60 N:P2O5:K2O three splits fertilizers mixture of SSP + Urea + 20:20:0:13 soil application and also Bentonite sulphur or with and without two winter irrigations in late September besides seed treatment with PGPRs or Sagarika 0.002% before sowing and twice foliar applications with the same or alongwith chelated micronutrients 0.5% + WSF 17:44:0 and 0:0:50 2.0% + Boron 0.3% alternately with ZnSO4 0.5% or nano ZnO 0.004% alongwith Urea 2% and Boron 0.3% or were help full in doubling the seed cotton yields besides reducing the pre mature leaf reddening by maintaining optimum index leaf nutrient content.

*Keywords: Bentonite sulphur; bio-stimulants; boron; calcareous; consortia; foliar sprays; granules; KMB; nano; PGPR; PSB; ZnO; ZnSB.*

## 1. INTRODUCTION

### 1.1 Soil Fertility and Fertilizer Management

*Calcareous* soils were formed in semi arid to humid tropics under different *litho* and *pedogenic* process covering 70% of the total geographical area of India [1-3]). *Calcareous* soils have high free calcium, permeable, sloppy and erodible with embedded limestone hard pan can restrict choice of crops, root growth,duration and often demands frequent light irrigations [4], 2012, [5,6,3]. *Calcareous* soils were low in organic carbon, N, Mg, S, Fe, Cu, Mn and Zn and B but medium in available P, rich in K (Table 4) expressing visible symptoms after the onset of reproductive stage under soil moisture deficit interacting with free lime, which interferes with the uptake and availability of nutrients [3], Raju, 2023). Major fraction of applied N has been lost through volatilization, P transformed into calcium P, however, available before cotton flowering cotton significantly responded in 17% of the low to medium P soils due to availability of band applied granular phosphorous upto 50 days as conformed by tracer studies Dorahy et al., 2007; [7]. *Calcareous* soils require a proper balanced application of multiple nutrient granular N, P, K, S, Zn, B coated, simple, mixed or complex fertilizers in four splits as spot application, has been recommended to reduce fixation and volatilization losses on clay, organic matter and $CaCO_3$ (Raju, 2023). Loss of urea as $NH4^+$ in runoff, $NO_3$ movement were traced with $P^{32}$, $P^{33}$ studies in *Vertisols* with light, medium and heavy rains as $NO_3$ moved 15, 60 and >100 cm away from the placement Soil PK nutrients balance were positive with response upto 60 kg $ha^{-1}$ (Raju, 2023). Three times $KNO_3$ foliar application during reproductive stage in cotton + pigeon pea strip cropping cropping systems on in *calcareous Vertisols* produced 15% higher lint yield. PGPRs solubilize P, K, Zn, fixes nitrogen, produce phyto-hormones like kinetin, $GA_3$, IAA,ACC-deaminase and siderophores, hydrogen cyanide, and ammonia, which enhances crop growth, yield, and fertility status of the soil [8]; Kumar et al., 2019; [9]. *Pseudomonas, Bacillus, Acinetobacter, Glucon acetobacter, Thiobacillus* and *Rhizobium* are some of the most powerful Zn solubilizing strains that can be efficient to boost soluble Zn in the soil which will benefit plant growth and yield. Bacterial strain-PS-4 solubilized 253 ppm of ZnO and produced a high quantity of lactic acid 169 g $ml^{-1}$ and acetic acid 471g $ml^{-1}$. Further, *in vitro* studies demonstrated higher production of auxin, gibberellic acid and siderophore by PS-4 [9] and proven field performance in cotton-wheat system at ICAR, CICR, Regional Station, Sirsa, Haryana, India by Raju and Uma [10]. *Consortia* of compatible Zn-SB,P-SB,K-SB/P-MB, *Pseudomonas, Trichoderma* and *Bacillus* strains as potential inoculants cum seedling protectants [11]. Highest rate of Zn release was by *Pseudomonas fluorescence* strain Ur-22 36 mg $L^{-1}$ which was associated with decrease in pH 6.8 to 4.2 [12]. Soil application of *Bacillus megatherium* broth showed significantly highest Zn solubilization followed by *Trichoderma viride* and *Pseudomonas striata* [13]. *Bacillus sp* inoculum produced significantly higher seed cotton yield 120 kg $ha^{-1}$ which was equal to 45 kg $ha^{-1}$ $P_2O_5$ fertilizer applied on clay loam soil with pH 8.3, and available P 10 mg $kg^{-1}$. Seed treatment with *Azotobactor*, PSB and KMB *Consortium* + 100 % RDF recorded higher *Sorghum* grain yield of 2137 kg $ha^{-1}$, net returns of Rs.55,422 $ha^{-1}$ with B: C ratio of 3.05 [14,8].

Benonite sulphur and seed treatment with P, S, Zn solubilizers and K mobilsers are also useful to make nutrients available to cotton [6], Raju et al., 2018. Crop-stimulants for better uptake, foliar correction of deficit nutrients in regular, chelated and nano forms are also being tested [6] and Raju, 2023 in station trials at ICAR, Central Institute for Cotton Research, Nagpur and onfarm trials in *calcareous Vertisols* with Bt hybrid cotton + pigeon pea strip cropping system in *Kalmeshwar*, north Nagpur.

## 1.2 Changing Rainfall Pattern

Delayed onset of monsoon by 25 days with dry sowing produced weak germinated seedlings under desiccating atmospheric conditions under 42% less rainfall in 37% less rainy days received towards the end of the June month in 2019 (Table 1). However, July, 2019 had a seedling drought in first three weeks followed by total last wet rainy week received 16% extra rains in 11% less rainy days (Table 2). July, 2020 month had received two heaviest (60-100 mm) rainy days on 14.7.20 and 23.7.20, remaining light to medium rains (25-50 mm), 89% rain in prolonged 13% extra rainy days over normal effective rainfall. Similarly, August, 2019 month had also received 22% extra rains in 67% more rainy days, where two heavy rainfall (60-100mm) events temporarily sub-merged cotton ridges, four medium rainfall (26-50mm) events filling cotton furrows and six light rainfall (<25mm) events and the same number were effective contributing to the soil moisture. August, 2020 month received 50% annual rainfall out of 60% effective rain events 30% were light, 13% were medium 3% or two events were heavy rains in the beginning and end of the month received 70% of the monthly or equal to that of normal monthly rainfall i.e. 200 mm or 83% extra rains in double number of rainy days being wettest month in both years interfering intercultural operations, weeding and top dressing of fertilizer applications over the normal. Similarly, September, 2019 was also wettest month received eight light and two medium rainfall events with 63% extra rains in very prolonged 2.25 times more number of rainy days, while in September, 2020 month received four light and three medium rainfall events with 10% extra rains in 88% more number of rainy days being wettest month in both years delaying the normal intercultural operations, weeding and top dressing of fertilizer applications. October, 2019 month had received two light rainfall events with 16% less rainfall 1.5 times more number of rainy days, while in October, 2020 month had received three light one medium rainfall events with 51% extra rains in 2.5 times more number of rainy days being wettest month in both years.

**Table 1. Rainfall mm and rainy days during 2019, 2020 seasons**

| | Rainfall mm | | | Rainy days (RD), Effective RD | | | | |
|---|---|---|---|---|---|---|---|---|
| Months | **2019** | **2020** | **Normal** | **2019** | **ERD** | **2020** | **ERD** | **Normal** |
| June | 132 | 126 | 208 | 7 | 5 | 8 | 6 | 11 |
| July | 398 | 305 | 481 | 13 | 6 | 17 | 16 | 20 |
| August | 343 | **515** | 314 | 20 | 13 | **24** | 17 | 12 |
| September | **299** | 201 | 228 | **22** | **18** | 15 | **8** | 12 |
| October | 48 | 86 | 27 | 3 | | 5 | 5 | 3 |
| Total | **1172** | **1147** | 1231 | **62** | **42** | **64** | **52** | 58 |

**Table 2. Soil analysis data of experimental site 2019 season**

| | | ***Calcareous* soils** | |
|---|---|---|---|
| **S.No.** | **Soil content** | **Content** | **Category** |
| 1 | pH | 7.66 | Normal |
| 2 | EC mS/m | 2.58 | Normal |
| 3 | Organic Carbon % | 0.39 | Low |
| 4 | Available Nitrogen kg $ha^{-1}$ | 180 | Low |
| 5 | Available $P_2O_5$ kg $ha^{-1}$ | 17 | Medium |
| 6 | Available $K_2O$ kg $ha^{-1}$ | 580 | High |
| 7 | Available Zinc ppm | 0.55 | Low |
| 8 | Available Sulphur ppm | 75 | Medium |
| 9 | Available Mg ppm | 0.22 | Low |
| 10 | Available B ppm | 0.25 | Low |
| 11 | Available $CaCO_3$% | 29.6 | High |

## 2. MATERIALS AND METHODS

A field experiment was conducted with Bt hybrid cotton *Rashi*-659 with ten nutrient management treatments with six checks already recommended for general cotton cultivation and 4 replications in RBD layout in highly *Calcareous* soils with root limiting 20cm thick calcium carbonate layer at 30 to 45 cm below the soil (Table 3,4). Experimental trial was for two years during 2019, 2020 monsoon season at ICAR, Central Institute for Cotton Research, Nagpur, Research Farm (21.15, 79.1). *Calcareous* soil depth and calcium carbonate content and seasons were diverse, therefore, they were not pooled together, but discussed their impact with reference bench mark independently. Nutrient management treatments were $T_1$. Control or Absence of external fertilizer application, estimates the seasonal changes in natural soil fertility and calculating the fertilizer application economics and use efficiency fertilizer application in the highly *Calcareous* soils. $T_2$. Seed treatment (S.Tr) with NPK *consortia* having *Azotobacter sp*. strain MTCC-3853 + *Rhizobium leguminoserum*- strain MTCC-99+ PSB: *Bacillus megatherium var. phosphaticum* strain MTCC-24121, MTCC 2412, *Bacillus licheniformis* strain -MTCC-2312, *Bacillus subtilis* strain MTCC-736 + KMB: K mobilising bacteria *Acido thiobacillus ferroxidans* strain: 5370; *Pseudomonas fluorescens migula*: strain 2659 alongwith 75% RDF only. $T_3$. 100% RDF through nitro phosphate *Suphala* 15:15:15 having 6.5% Sulphur complex fertilizer as basal dose followed by twice urea top dressing at 45 and 60 DAS, which was compared with the present general recommendation of balanced fertilization to hybrid cotton. $T_4$. 100% RDF + $ZnSO_4$ 20 kg $ha^{-1}$ $yr^{-3}$ + elemental sulphur (100%) 20 kg $ha^{-1}$ $yr^{-3}$ + Borax 5 kg $ha^{-1}$ $yr^{-3}$ as soil application (SA) at the time of sowing i.e.10 days before the basal dose of fertilizer application. $T_5$. RDF + S.Tr. Zn solublizer (ZnSB) *Acido thiobacillus ferroxidans* : strain 5370 *Pseudomonas fluorescens migula* : strain 2659. $T_6$. $ZnSO_4$ 20 kg $ha^{-1}$ $yr^{-3}$ as SA for deficit soils as soil application 10 days before after complex fertilizer application to avoid Zn fixation. $T_7$. RDF+ Borax 5 kg $ha^{-1}$ $yr^{-3}$ SA for deficit soils. $T_8$. RDF + Bentonite Sulphur (80% Sulphur and 15-20% Sodium) 20 kg $ha^{-1}$ $yr^{-3}$ as SA for medium to deficit soils. $T_9$. RDF + *Sagarika* seed treatment 0.02% of seed weight. $T_{10}$. RDF + *Sagarika* seed treatment and twice foliar sprays (FS) 0.002% at squaring and flowering stage. $T_{11}$. RDF + *Sagarika* granules 25 kg $ha^{-1}$ $yr^{-1}$ as SA. $T_{12}$. RDF + nano ZnO 4% twice foliar sprays (FS) 0.004 % at squaring and flowering stage. $T_{13}$. RDF 75% N: $P_2O_5$: $K_2O$ only. $T_{14}$. RDF 75% + Zn $SO_4$ 20 kg $ha^{-1}$ $yr^{-3}$ as SA for deficit soils + chelated commercial formulation of micronutrients foliar sprays (FS) 0.005% twice at squaring and flowering stage. $T_{14}$ RDF 75% +@RD of Zn B Fe SA + twice chelated micronutrients foliar sprays $T_{15}$. RDF 75% +Nano seed treatment twice FS of the same $T_{16}$. RDF 75% +Seed treatment with NPK *consortium* and Zn solubiliser. Soil of the experimental site was analyzed as per the standard protocol, before the start of the experiment. Field seedling growth observations on plant height, primary root length, shoot length, number of laterals, root and shoot biomass (Table 3) were recorded, analyzed and interpreted with weather conditions at one month from the date of sowing in both the years. Most recently matured index leaf top 4$^{th}$ leaf, samples were collected at 115, 122, 134, 170 during 2019 and 30, 60, 77, 115 DAS in 2020, twice washed in dilute HCl, followed by tap water and twice with distilled water. Leaf samples were shade dried, powdered and digested by wet acid digestion method [15]. Soil nitrogen (N) was analyzed by micro kjeldahl method and index leaf N was analyzed calorimetrically by modified Nessler's reagent method [16]. Soil organic carbon (SOC) was analyzed by Walkley and Black's (WBC) reverse titration method [17]. Soil Boron was estimated by HWE Azomethionine -H method [18]. Soil and plant potash was analyzed by flame photometer [19]. Soil and plant phosphorous by Olsen's method Ascorbic acid blue, Vanebdo molybdate yellow colour method respectively [20]. Mg, Zn, Fe, Cu,Mn DTPA extracted soil samples and wet acid digested plant samples were analyzed by AAS as per AOAC procedures [21]. *Calcareous* soil was found to be deficient in all parameters except medium in available P and rich in available K (Table 4).

## 3. RESULTS AND DISCUSSION

### 3.1 Impact on Seedling Growth

Plant height, primary root length, shoot length, number of laterals, root and shoot biomass were significantly influenced at 30 DAS in only July, 2019 by the seed treatment with NPK *consortia* alongwith 75% RDF and with *Sagarika* seed treatment alongwith 100% RDF, but not in 2020 due to 50% excess rains (Table 3). Bt hybrid cotton seedling performance at 30 DAS in July, 2019, was significantly influenced only when it

received 119 mm rain in 18 rainy days (RD) its performance was upset at the end of the month another 150 mm or 54% rain was received only in two continuous days on 31.6.19 and 1.7.19. Plant height and root length, were non significant due to shortage of soil moisture, compared to July, 2020, when cotton was planted after receiving 100 mm pre monsoon rains in 11 days before the sowing of Bt hybrid cotton. After sowing 102 mm rains were received in 17 rainy days followed by 177 mm i.e. 47% rain only in two rainy days (14 July and 23rd July). All bio-stimulants as seed treatment in highly *calcareous* soils were known to have the bio stimulating effect due to its Zn, cytokinin and other humic and fulvic acids content. *Calcareous* soils are known to be thirsty followed by hidden hunger, when crop reaches peak demand at early reproductive stage. These experiences were in agreement with those observed by Shingare et al. [3].

## 3.2 Yield and Yield Attributes

Inputs tested for highly *Calcareous* soils with significant agro economic performance were $T_5$ + *Consortia* of Zinc solubilising and K mobilising bacteria (ZnSB, KMB) as seed treatment (S.Tr) alongwith RDF 100% i.e. 90:45:45 N:$P_2O_5$:$K_2O$; $T_8$ RDF+ Bentonite sulphur @20 kg $ha^{-1}$ SA, T9: RDF+ *Sagarika* S.Tr, $T_{10}$ RDF+ *Sagarika* S.Tr alongwith twice foliar sprays (FS) at squaring and flowering,$T_{12}$ RDF + Nano ZnO S. Tr. twice FS during 2019 except $T_9$ during 2020, the magnitude was 50% less in 2020 (Table 5) due to torrential rains (Table 2) upset the reproductive physiology of cotton, shedded all the fruiting bodies, unable to maintain index leaf NPK, besides heavy pink bollworm attack during the year. These results were in agreement with those observed in *Calcareous* soils researches made by Raju, 2017, 2018, 2023 and Raju and Deshmukh [6] in normal years except too wet and dry years Bt hybrid cotton results could not be realized.

All these treatments were applied with two split applications of *Suphala* a 6.5% Sulphur containing, granular, 100% RDF @22.5 kg $ha^{-1}$ N: $P_2O_5$: $K_2O$ twice on 15, 30 DAS (RCF 15:15:15 Nitro phosphate) and twice as *Neem* coated Urea @ 22.5 kg N $ha^{-1}$ at 45 and 60 DAS i.e. squaring and flowering stage of Bt hybrid cotton depend upon rainfall events, when NPK demand was highest. RDF 100% along with Bentonite Sulphur 20 kg $ha^{-1}yr^{-1}$ ($T_8$) or Seed treatment and foliar applications of bio-stimulant *Sagarika* @ 0.02% and foliar applications of the same @ 0.002% ($T_{10}$) or nano ZnO @ 0.004% ($T_{12}$) twice at squaring and flowering stage produced 67-86 ppm Zn in index leaf of the Bt hybrid cotton (Table 4,5,7), similar to that of chelated Zn twice foliar applications. This produced 287 kg lint $ha^{-1}$ in 2019 and 125 to 161 kg $ha^{-1}$ during 2020 i.e. more than double to 38 to 50% due to better N, P, K, Zn nutrient uptake, biomass production, boll number in highly *Calcareous* soils with more than Rs. 16 to 30, 000/- $ha^{-1}$ in profitability and 1.59 to 2.15 C:B ratio, FUE 1.6 to 1.2 and lowest cost of production in both the years (Table 4,5). The results for Bentonite sulphur as soil amendment in highly *Calcareous* soils to solubilise and improve the supply of P and Zn were in agreement with those observed by Nayak and Patil, [22], Sisodiya et al. [23], Raju et al., 2018, 2023 in improving the agronomical performance of crops. The results for seed treatment with N fixing, P and Zn solubilising PGPRs were in agreement with those observed by Raju et al. [24] in *Vertisols*, by Raju et al., 2018 in highly *Calcareous* soils, by Uma and Raju, 2008 in red soils. The results for *Sagarika* seed treatment and foliar application of the same for cotton as cropgrowth stimulant by Raju et al., 2018, 2023. The results in highly *Calcareous* soils for foliar correction of nutrients deficiencies by spraying twice at squaring and flowering with nano ZnO 0.004% or $ZnSO_4$ 0.5% and Boron 0.3% alongwith WSF NPK to correct nutrient deficiencies were in agreement with those observed by Raju et al., 2018, 2023.

## 3.3 Index Leaf Nutrient Content

The year 2019 and 2020 both had 40% excess rains over the water requirement of cotton, same rainfall and rainy days, in 2020 each two monthly heavy rainfall events in July and August, 2020 (Table 1) followed by four medium rainfall events in both the years received major amount of rains during rainy season caused run off and leaching of all the applied water soluble nutrients N, P, K, and Zn. Fertilizer nitrogen (N) was applied in two splits as complex nitro phosphates and three splits of as *neem* coated prilled urea. Year 2019 had a seedling drought of 25 days, followed by two torrential and four medium rains also leads to N, P, K, Zn, B runoff and leaching losses as confirmed by Patra and Thomas [25] for leaching losses Raju, 2023 for these index leaf nutrients status in similar soils. Index leaf NPK could be maintained near optimum only in 2019 (Table 6), which was not even 50% of normal index leaf NP

due to runoff and leaching losses (Table 6), which was due to delayed fertilizer urea application followed by 24 and 15 rainy days in August and September, 2020 months respectively, resulted in 50% less bolls and lower lint yields (Table 4,5). Similar, to nitrogen, phosphorous was also could not be maintained after 45 DAS during 2020, which were far below, the threshold levels. This is a big challenge for cotton agronomist since 2020-2023, to apply and deliver NP fertilizer in index leaf during excess rains or delayed monsoon, which is changing the growth and reproductive physiology of cotton. The results in highly *Calcareous* soils for foliar correction of nutrients deficiencies by spraying twice at squaring and flowering with nano ZnO 0.004% or $ZnSO_4$ 0.5% and Boron 0.3% alongwith WSF NPK to correct nutrient deficiencies were in agreement with those observed by Raju et al., 2018, 2023, [26-28].

## 3.4 Validation in Farmer's Fields

Monitored the farmer's fields in *Budhla, Dhapewada, Ladai, Linga, Lohagad, Khairi, Nimboli, Mohgaon,Ramgiri,Sawangi, Sonegaon, Telgaon, Telkampti, Tishti, Uparwahi, Wathoda, Zilpi* MGMG adopted villages in *Kalmeshwar Tq* of north Nagpur by ICAR, CICR, Nagpur and confirmed the leaf reddening time as early to mid October caused by inadequacy of P and K nutrients availability, uptake and storage in index leaf to meet developing bolls heavy demand, which can be prevented a month in advance with soil and foliar applications of the deficit nutrients and soil moisture. NPK *Consortia* , PSB, ZnSB, KSB, *Sagarika* or humic acid seed treatment and *Sagarika* or humic acid or nanoZnO @ 4m $L^{-1}$ in water or Zn $SO_4$ 0.5% + B 0.3% or $MgSO_4$ @1% alone or WSF+$KNO_3$ or WSF 2%+ chelated micronutrients 0.5% foliar applications besides soil application of Bentonite Sulphur 20 kg $ha^{-1}$ or $ZnSO_4$ @ 20 kg $ha^{-1}$ or *Sagarika* granules 25 kg $ha^{-1}$ stimulated the crop vegetative growth improved the seed cotton yield by 1.5-2.0 and 3.0 q $ha^{-1}$ in rainfed and supplemental irrigations respectively in shallow *Calcareous* and medium deep soils at recommended fertilizer levels. They failed to respond in the absence of adequate fertilizer nutrients or irrigation water in year of drought 2018. Short duration pigeon pea *Virgin* for green pods gave double net income than to that of cotton i.e. Rs. 37,750/- $ha^{-1}$ under rainfed condition except being manual harvesting costs. All medium duration pigeon pea varieties in the market gave 5-10 q $ha^{-1}$ found superior to conventional long duration pigeon pea variety C-11 with 1.25 q $ha^{-1}$ and farmers have comfortably higher yields with improved varieties as a companion crop in the cotton + pigeon pea strip cropping system in highly *Calcareous* soils. *Lab Lab purpureus* gave an average net income of Rs. 64, 000/-$ha^{-1}$ under rainfed conditions with a range of Rs. 40, 000/- to 99, 000/- $ha^{-1}$. Technology adoption was in favour for Sulphur or K and Sulphur complex fertilizer mixtures, 2-3 split application of fertilizers basal dose with complex and super phosphate, urea, potash mixtures as 1-2 times top dressing, depend up on availability of capital, materials and soil moisture in a rain shadow area. Large scale introduced improved okra varieties *Pusa Sawani, Makhmali, Sada Bahar* and *Parbhani Kranti* in highly *Calcareous* soils were was at par with *Sorghum* by giving Rs.40,000/- $ha^{-1}$ net income. Green chillies, bottle, smooth, ridge and bitter gourds, ground nuts, cowpea, cluster beans under rainfed conditions were comparable to that of rainfed short duration Bt hybrid cotton + pigeon pea strip cropping system with BMPs and soil moisture conservation practices. Profitability of vegetables was always depends upon the early season market prices. Fertilizer nutrients @ 90:45:45 kg $ha^{-1}$ N: $P_2O_5$ and $K_2O$ improved 40% compared to 64% with @ 120:60:60 kg $ha^{-1}$ N: $P_2O_5$ and $K_2O$ seed cotton yield over control shows the inadequacy of fertilizer nutrients in shallow, stony, *Calcareous* and marginal soils. N fixers, P solubiliser and K mobilisers alone were ineffective in improving seed cotton yield without even 90:45:45 kg$ha^{-1}$. *Sagarika* seed treatment and WSF 17:44:0 + 0:0:50 @ 2% twice foliar spray at squaring and flowering stage had positive effect only when soils were adequately fertilized with atle@ RDF 90:45:45 kg $ha^{-1}$. Pooled onfarm trials with Bt hybrid cotton seeds were applied @ 0.2% *Sagarika*, humic acid or NPK *consortia*, PSB, Zn SB and complex fertilizer significantly produced highest seed cotton yield under *Calcareous* soils both rainfed and under supplemental irrigations 16.8 and 22.5 q $ha^{-1}$ (Table 13,14). respectively. Rashi-659 was best adopted which was followed by Ankur 651 and 3028 both under rainfed and two supplemental irrigations. Yield levels were varied 64% to 100 % of expected with two and three supplemental irrigations besides profitability depend with level of N, P, K, Mg, S, Zn, B fertilizers soil and foliar application of humic acid and chelated micronutrients @ 0.5%. Excess soil application complex $P_2O_5$ and $K_2O$ more than 185%RDF brought imbalance and deficiencies of Mg, Zn, B nutrients besides reducing 6% seed cotton cotton yield and Rs.

3800/- ha$^{-1}$ profitability. Rainfed farmers realized 64% of the seed cotton and 74% pigeon pea yield potential with 1:4.1 C: B ratio. Experiences farmers have realized 100% importance of supplemental irrigations, P, K, S, Zn multiple in season spot soil application of fertilizer mixtures (Table 12,13). We have shown them soil testing importance of interprettation, improving rhizosphere soil biology besides bentonite sulphur soil and foliar applications of chelated micronutrients 0.5% alongwith WSF 17:44:0 2.0% + Boron 0.3% alternately with Urea 2.0% + nano ZnO 0.004% or $ZnSO_4$ 0.5% + Boron 0.3%. Organic manures, silt and sugarcane press mud were locally not available, therefore could not be adopted. Leaf reddening was primarily caused by P K deficiencies at boll development stage. Mango, custard apple, *ber*, guava, orange, lime, lemon and drumstick crops were survived and performed well in *Calcareous* soils. *Dolichus purpureus / lab lab* is twice more profitable under no limitation of labour compared to Bt hybrid cotton + pigeon pea strip cropping system. Key yield limitations were total absence of rain water conservation measures, organic manures, K, Mg, S, Zn, Fe, B, WSF chelated micronutrients, soil and foliar applications besides 80% RDN, 125% RDP and application 20% RDK to Bt hybrid cotton in *Calcareous* soils. Soils were dried within 15-20 days immediately after the cessation of monsoon with forced boll drop therefore, needs atleast 1or 2 supplemental irrigations from easy access of ample shallow ground water resources doubled and tripled with fertigation(Table 13,14,15). . Management techniques like NPK consortia, P, K, Zn solubilisers, *Sagarika*, humic acid seed and foliar application had limited impact in the year of low rainfall rain shadow area but wider adoption across all the crops in the cropping systems. Split application of RDP 1.5 times,100% RDN and RDK fertilizers besides foliar application of WSF, chealated micronutrients in September month performed moderately in a drought year and excellent in excess rains or under supplemental irrigations. WSF foliar application corrected all the deficiency symptoms in a year of seedling and terminal droughts without improving yield. Positive aspects of farmers were three split application of mixture of fertilisers 125% RDP i.e. 58 kg ha$^{-1}$ besides irrigating and about understanding suitable crops and cropping systems. There is no significant agronomic response to input application against nutrient deficiency symptoms, leaf reddening was primarily due to nutrient deficiency's (PK) at the boll development stage [29-31].

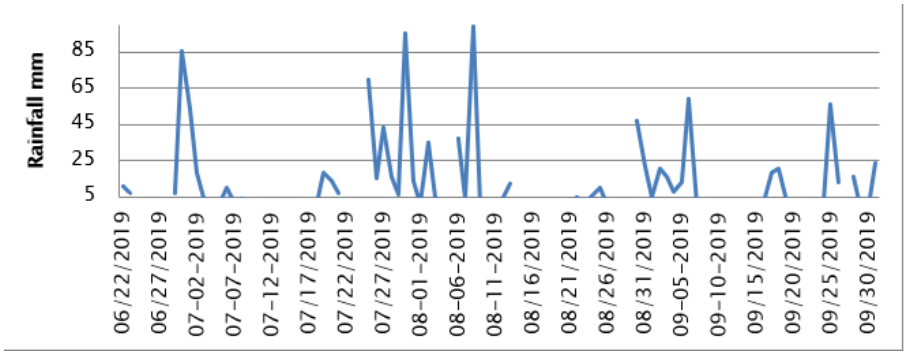


**Fig. 1. Rainfall mm day during 2019**

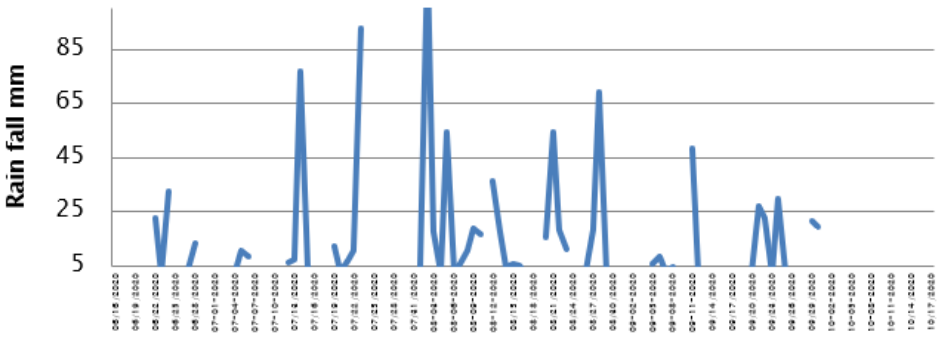


**Fig. 2. Daily Rainfall mm day during 2020**

**Table 3. Impact of Bio stimulants as seed treatment on Bt hybrid cotton seedling performance**

| | | Plant height cm | | Primary root length cm | | Lateral roots numbers | | Root biomass g plant | | Shoot biomass g plant | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Treatments** | **2019** | **2020** | **2019** | **2020** | **2019** | **2020** | **2019** | **2020** | **2019** | **2020** |
| T1 | Control | 13.1 | 22.2 | 26.3 | 11.8 | 11.0 | 4.8 | 1.56 | 1.2 | 18.0 | 4.8 |
| T2 | RDF 75%+ Seed Tr NPK *consortia* | 14.9 | 28.5 | **29.8** | 13.8 | 10.3 | 7.2 | 1.46 | 2.1 | **22.0** | 7.2 |
| T3 | RDF 90:45:45N:$P_2O_5$:$K_2O$ | **13.4** | 24.0 | 26.8 | 10.0 | 4.5 | 4.7 | 2.12 | 2.0 | **17.8** | 4.7 |
| T4 | RDF +SA Zn 20 S20 B5 kg $ha^{-1}yr^{-3}$ | 12.0 | 24.7 | 24.0 | 12.3 | 4.5 | 5.0 | 2.06 | 2.6 | 20.3 | 5.0 |
| T5 | RDF **+Zn solubiliser** as **Seed treatment.** | 13.0 | 25.3 | 26.0 | 11.8 | 7.5 | 7.7 | 2.35 | 1.9 | 17.6 | 7.7 |
| T6 | RDF +SA Zn 20 kg $ha^{-1}yr^{-3}$ | 11.8 | 25.9 | 22.5 | 13.5 | 11.0 | 7.8 | 1.69 | 2.1 | 21.5 | 7.8 |
| T7 | RDF +SA Borax 5 kg $ha^{-1}yr^{-3}$ | **12.3** | 23.8 | 24.5 | 12.5 | 9.0 | 8.2 | 1.60 | 1.7 | **17.5** | 8.2 |
| T8 | RDF +B Sulphur 20 kg $ha^{-1}yr^{-1}$ | **15.1** | 26.0 | 30.3 | 11.5 | 9.0 | 5.7 | 1.83 | 2.0 | **21.9** | 5.7 |
| **T9** | RDF ***+Sagarika* Seed treatment.** | **14.6** | 30.0 | 29.3 | **13.3** | 9.5 | **8.5** | **2.07** | **1.5** | **22.8** | **8.5** |
| **T10** | **9+*Sagarika* twice FS** | **16.5** | 24.0 | 34.5 | **10.8** | 9.3 | **6.0** | **1.55** | **1.9** | **21.8** | **6.0** |
| T11 | RDF +*Sagarika* Gr 25 kg $ha^{-1}$ | 13.1 | 27.0 | 26.3 | 11.3 | 13.0 | 6.5 | 1.41 | 2.2 | **23.4** | 6.5 |
| T12 | RDF +Zn nano fertilizers **twice** FS | **12.0** | 27.3 | 24.0 | 13.5 | 13.3 | 7.2 | 2.56 | 2.1 | **12.3** | 7.2 |
| T13 | RDF 75% N:$P_2O_5$:$K_2O$ SA | | 27.3 | 25.8 | 13.5 | 12.0 | 8.2 | 1.58 | 1.8 | | 8.2 |
| T14 | RDF75% + SA Zn20 B5 Fe 20 kg $ha^{-1}$ $yr^{-3}$ + chelated FS **twice** | | 25.5 | 25.0 | 12.0 | 10.5 | 6.5 | 1.73 | 1.9 | | 6.5 |
| **T15** | RDF 75% + Nano seed treatment **twice** FS | | 26.5 | | **13.3** | | **4.5** | **2.05** | **1.8** | | **4.5** |
| T16 | RDF 75% + Seed treatment with NPK *consortium* and Zn solubiliser . | | 25.5 | | 12.0 | | 6.0 | 1.18 | 6.0 | | 6.0 |
| | S.E at ± 5 % | S | 1.60 | S | 1.08 | S | 0.97 | 0.24 | 0.97 | S | 0.97 |
| | CD at± 5 % | 0.6 | NS | 9.48 | NS | 4.91 | NS | NS | NS | 1.6 | NS |

**Table 4. Input performance in *Calcareous* soils with Bt hybrid cotton 2019**

| | | Boll number | Yield | Bio mass | Lint Yield | C:B | Net returns | Cost Rs | FUE kg$^{-1}$ lint |
|---|---|---|---|---|---|---|---|---|---|
| | **Treatments** | **plant$^{-1}$** | **g plant$^{-1}$** | **Tonne ha$^{-1}$** | **kg ha$^{-1}$** | **ratio** | **Rs. 000 ha$^{-1}$** | **kg$^{-1}$ seed cotton** | **kg $^{-1}$ fertilizer** |
| 1 | Control | 27 | 48 | 4.97 | 254 | 1.1 | 2.5 | 73 | |
| 2 | Seed Tr (S Tr) with NPK *consortia* + RDF 75% | 31 | 67 | **6.68** | 324 | 1.6 | 18.9 | 50 | 0.52 |
| 3 | N:$P_2O_5$:$K_2O$ RDF 90:45:45 kg ha$^{-1}$ | 36 | 53 | 5.72 | 415 | 1.9 | 31.6 | 41 | 0.89 |
| 4 | RDF + Zn20 S20 Borax 5 kg ha$^{-1}$ Soil application (SA) | 36 | 57 | 6.37 | 454 | 1.9 | 35.2 | 41 | 1.11 |
| 5 | RDF + S. Tr with Zn Solublizer | 36 | 53 | 6.01 | 522 | 2.2 | 46.7 | 35 | 1.49 |
| 6 | RDF +Zn 20 kg ha$^{-1}$ SA | 38 | 61 | 4.77 | 363 | 1.7 | 23.3 | 47 | 0.61 |
| 7 | RDF + Borax 5 kg ha$^{-1}$ SA | 38 | **75** | 5.53 | 515 | 2.2 | 45.2 | 36 | 1.45 |
| 8 | RDF + Bentonite S 20 kg ha$^{-1}$ SA | 31 | 65 | 6.00 | 541 | 2.3 | 48.9 | 35 | 1.59 |
| 9 | RDF +*Sagarika* S Tr 0.2% | 34 | 73 | 6.57 | 514 | 2.2 | 45.5 | 36 | 1.44 |
| 10 | 9+*Sagarika* 2 foliar sprays (FS) | 35 | 63 | 5.27 | 539 | 2.2 | 48.4 | 35 | 1.58 |
| 11 | RDF +*Sagarika*granules SA 25 kgha$^{-1}$ | 35 | 52 | 5.76 | 418 | 1.8 | 31.0 | 42 | 0.91 |
| 12 | RDF + Nano Zn 0.04% 2 FS | 39 | 65 | 5.54 | 538 | 2.2 | 48.3 | 35 | 1.58 |
| 13 | RDF75% | 27 | 62 | 5.06 | 389 | 1.9 | 29.8 | 41 | 0.75 |
| 14 | RDF 75% + Zn 20 SA + Chelated FS | 34 | **72** | 6.04 | 449 | 2.0 | 35.7 | 40 | 1.08 |
| | S.E± C.D. at 5 % | 2.4 | 1.04 | **0.90** | 0.35 | | | | |
| | Sig | S | S | NS | S | | | | |
| | SED/ CD±5 % | 11 | 11 | 0.20 | 85 | | | | |

**Table 5. Input performance in *Calcareous* soils with Bt hybrid cotton 2020**

| | | Lint yield | FUE | Cost of production | Net returns | C:B | Index leaf Zn PPM | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Kg $ha^{-1}$ | Kg $kg^{-1}$ | $kg^{-1}$ | Rs $ha^{-1}$ | Ratio | 30 | 60 | 90 | 120 |
| T1 | Control | 268 | | 35 | 8586 | 1.92 | 35.5 | 35.2 | 88 | 89 |
| T2 | RDF 75%+ NPK solubiliser | 325 | 0.42 | 39 | 9116 | 1.72 | 30.8 | 41.5 | 104 | 56 |
| T3 | RDF NPK only | 321 | 0.29 | 42 | 7997 | 1.59 | 30.2 | 33.6 | 84 | 67 |
| T4 | RDF +Zn20 S20 B5 kg **$ha^{-1}$** soil | 293 | 0.14 | 49 | 5144 | 1.36 | 31.6 | 19.7 | 49 | 73 |
| T5 | RDF +Zn solubiliser | **446** | 0.99 | 33 | **15116** | 2.02 | 32.9 | 40.2 | 100 | 57 |
| T6 | RDF +Zn20 **$ha^{-1}$** soil app | 258 | -0.06 | 54 | 3269 | 1.23 | 30.6 | 18.3 | 46 | 66 |
| T7 | RDF +Borax **$ha^{-1}$** soil app | 372 | 0.58 | 39 | 10509 | 1.73 | 33.4 | 17.8 | 44 | 83 |
| T8 | RDF +Bentonite Sulphur20**$ha^{-1}$** | 256 | -0.06 | 52 | 3907 | 1.29 | 27.9 | 16.9 | 42 | 38 |
| T9 | RDF + *Sagarika* streatment | **486** | 1.21 | 31 | **17374** | **2.15** | 33.0 | 20.3 | 51 | 43 |
| T10 | RDF + *Sagarika* streatment+FS | **477** | 1.16 | 34 | **15871** | 1.99 | 35.1 | 19.1 | 48 | 84 |
| T11 | RDF +*Sagarika* granules | 410 | 0.79 | 38 | 12089 | 1.79 | 31.2 | 18.6 | 46 | 39 |
| T12 | RDF + nano Zn FS | 394 | 0.70 | 39 | 10991 | 1.71 | 30.3 | 17.3 | 43 | 39 |
| T13 | RDF75% | 317 | 0.36 | 40 | 8691 | 1.69 | 30.9 | 16.5 | 41 | 82 |
| T14 | RDF 75% +Zn B Fe SA + chelated foliar sprays | 346 | 0.58 | 43 | 8139 | 1.54 | 33.5 | 18.3 | 46 | 36 |
| **T15** | RDF 75% +**Nano seed treatment FS** | **447** | 0.99 | 33 | **15155** | **2.03** | 31.1 | 16.9 | 42 | 32 |
| T16 | RDF 75% + **seed treatment** NPK consortium and Zn solubiliser . | 331 | 0.35 | 45 | 7433 | 1.50 | 31.9 | 16.8 | 42 | 60 |
| | C.D. at 5 % | 125 | | | 82 | 0.82 | 2.4 | 2.3 | 6.7 | 30 |

**Table 6. Bt cotton index leaf Nitrogen content shallow *Vertisols* with *Calcalcareous* sub strata**

| | | 2019 | | | | 2020 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Treatments | Days after sowing | | | | | | | |
| | | **115** | **122** | **134** | **170** | **30** | **60** | **77** | **115** |
| 1 | Control | 3.1 | 5.3 | 3.0 | 3.2 | 4.45 | 2.25 | 2.66 | 1.32 |
| 2 | RDF 75%+ NPK solubiliser | 4.3 | 5.6 | 3.0 | 2.7 | 4.83 | 2.36 | 2.35 | 1.47 |
| 3 | RDF NPK only | 4.1 | 5.0 | 3.0 | 3.4 | 4.52 | 2.72 | 2.96 | 1.32 |
| 4 | RDF +Zn20 S20 B5 kg **ha$^{-1}$** soil | 3.9 | 4.2 | 3.8 | 3.3 | 3.04 | 2.66 | 2.65 | 1.31 |
| 5 | RDF +Zn solubiliser | 3.2 | 5.0 | 3.2 | 2.9 | 4.91 | 2.26 | 2.73 | 1.44 |
| 6 | RDF +Zn20 **ha$^{-1}$** soil app | 3.2 | 4.3 | 3.3 | 3.3 | 4.35 | 2.48 | 2.77 | 1.40 |
| 7 | RDF +Borax **ha$^{-1}$** soil app | 3.4 | 4.9 | 3.4 | 3.1 | 3.53 | 2.41 | 2.16 | 1.60 |
| 8 | RDF +Bentonite Sulphur20**ha$^{-1}$** | 3.1 | 5.4 | 2.9 | 2.8 | 4.47 | 2.09 | 2.63 | 1.33 |
| 9 | RDF + *Sagarika*streatment | 3.7 | 4.2 | 2.8 | 3.3 | 3.82 | 2.09 | 2.62 | 1.32 |
| 10 | RDF + *Sagarika*streatment+FS | 3.5 | 5.4 | 2.8 | 3.2 | 3.72 | 2.71 | 2.86 | 1.30 |
| 11 | RDF +*Sagarika* granules | 3.2 | 4.6 | 2.5 | 3.0 | 5.41 | 2.96 | 2.83 | 1.38 |
| 12 | RDF + nano Zn FS | 3.9 | 4.8 | 3.9 | 2.9 | 4.27 | 2.55 | 2.62 | 1.41 |
| 13 | RDF75% | 3.1 | 4.9 | 2.5 | 2.7 | 4.34 | 2.40 | 3.11 | 1.44 |
| 14 | RDF 75% +Zn B Fe SA + chelated foliar sprays | 3.7 | 4.4 | 3.9 | 3.3 | 3.81 | 2.79 | 2.67 | 1.47 |
| **T15** | RDF 75% +**Nano seed treatment FS** | | | | | 4.43 | 3.21 | 2.70 | 1.34 |
| T16 | RDF 75% + **seed treatment** NPK consortium and Zn solubiliser . | | | | | 4.05 | 2.80 | 2.67 | 1.33 |
| | Sig | NS | NS | NS | NS | NS | NS | 0.36 | NS |
| | C D+5% | 0.6 | 0.5 | 0.4 | 0.2 | 0.48 | 0.44 | | 0.10 |

**Table 7. Bt cotton index leaf Phosphorous content shallow *Vertisols* with *calcalcareous* sub strata**

| | | 2019 | | | | 2020 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Days after sowing | | | | | | | |
| | Treatments | 115 | 122 | 134 | 170 | 30 | 60 | 77 | 115 |
| 1 | Control | 0.51 | 0.33 | 0.29 | 0.50 | **0.12** | **0.21** | **0.43** | **0.58** |
| 2 | RDF 75%+ NPK solubiliser | 0.60 | 0.42 | 0.33 | 0.45 | **0.12** | **0.21** | **0.34** | **0.52** |
| **3** | RDF NPK only | **0.87** | **0.42** | **0.31** | **0.46** | **0.13** | **0.14** | **0.51** | **0.65** |
| 4 | RDF +Zn20 S20 B5 kg **ha$^{-1}$** soil | 0.55 | 0.44 | 0.26 | 0.47 | **0.11** | **0.20** | **0.43** | **0.65** |
| 5 | RDF +Zn solubiliser | 0.66 | 0.43 | 0.26 | 0.42 | **0.13** | **0.18** | **0.39** | **0.69** |
| 6 | RDF +Zn20 **ha$^{-1}$** soil app | 0.81 | 0.39 | 0.31 | 0.64 | **0.14** | **0.21** | **0.39** | **0.65** |
| 7 | RDF +Borax **ha$^{-1}$** soil app | 0.58 | 0.36 | 0.28 | 0.48 | **0.14** | **0.22** | **0.27** | **0.51** |
| 8 | RDF +Bentonite Sulphur20**ha$^{-1}$** | 0.52 | 0.37 | 0.30 | 0.45 | **0.15** | **0.17** | **0.36** | **0.55** |
| 9 | RDF + *Sagarika*streatment | 0.70 | 0.47 | 0.29 | 0.86 | **0.15** | **0.17** | **0.34** | **0.71** |
| 10 | RDF + *Sagarika*streatment+FS | 0.84 | 0.45 | 0.29 | 0.62 | **0.11** | **0.20** | **0.38** | **0.65** |
| 11 | RDF +*Sagarika* granules | 0.65 | 0.37 | 0.28 | 0.48 | **0.12** | **0.20** | **0.47** | **0.56** |
| 12 | RDF + nano Zn FS | 0.56 | 0.35 | 0.31 | 0.52 | **0.10** | **0.17** | **0.43** | **0.68** |
| 13 | RDF75% | 0.55 | 0.40 | 0.27 | 0.52 | **0.11** | **0.21** | **0.52** | **0.73** |
| 14 | RDF 75% +Zn B Fe SA + chelated foliar sprays | 0.65 | 0.40 | 0.28 | 0.45 | **0.11** | **0.21** | **0.39** | **0.62** |
| **T15** | RDF 75% +**Nano seed treatment FS** | | | | | **0.10** | **0.20** | **0.52** | **0.81** |
| T16 | RDF 75% + **seed treatment** NPK consortium and Zn solubiliser . | | | | | **0.12** | **0.23** | **0.38** | **0.65** |
| | CD+5% | 1.6 | 0.5 | 0.7 | 0.7 | **26.5** | 21.24 | **1.61** | **2.2** |
| | Sig | | | | | **2.6** | **2.07** | | |

**Table 8. Bt cotton index leaf Potash content in shallow *Vertisols* with *Calcalcareous* sub strata**

| | | 2019 | | | | 2020 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Days after sowing | | | | | | | |
| | Treatments | **115** | **122** | **134** | **170** | **30** | **60** | **77** | **115** |
| 1 | Control | 1.2 | **0.4** | **0.4** | **0.5** | **2.6** | **2.07** | **1.61** | **2.2** |
| 2 | RDF 75%+ NPK solubiliser | 1.6 | **0.6** | **0.5** | **1.1** | **3.0** | **2.20** | **1.72** | **2.6** |
| 3 | RDF NPK only | 1.6 | **0.5** | **0.7** | **0.7** | **1.7** | **2.32** | **1.61** | **2.1** |
| 4 | RDF +Zn20 S20 B5 kg **ha$^{-1}$** soil | 1.5 | **0.5** | **0.6** | **0.7** | **2.2** | **2.11** | **1.44** | **1.2** |
| 5 | RDF +Zn solubiliser | 1.5 | **0.7** | **0.6** | **0.6** | **2.4** | **1.87** | **1.42** | **2.5** |
| 6 | RDF +Zn20 **ha$^{-1}$** soil app | 1.5 | **0.6** | **0.6** | **0.6** | **3.2** | **2.08** | **1.49** | **1.1** |
| 7 | RDF +Borax **ha$^{-1}$** soil app | 1.5 | **0.5** | **0.6** | **0.8** | **1.5** | **2.12** | **1.58** | **1.1** |
| 8 | RDF +Bentonite Sulphur20**ha$^{-1}$** | 1.5 | **0.6** | **0.6** | **0.8** | **3.3** | **1.80** | **1.68** | **1.1** |
| 9 | RDF + *Sagarika*streatment | 1.6 | **0.6** | **0.6** | **0.7** | **3.3** | **1.80** | **1.58** | **1.3** |
| 10 | RDF + *Sagarika*streatment+FS | 1.6 | **0.7** | **0.7** | **0.6** | **2.3** | **2.27** | **1.55** | **1.2** |
| 11 | RDF +*Sagarika* granules | 1.4 | **0.5** | **0.5** | **0.7** | **2.4** | **1.99** | **1.53** | **1.2** |
| 12 | RDF + nano Zn FS | 1.5 | **0.6** | **0.6** | **0.7** | **3.2** | **1.78** | **1.68** | **1.1** |
| 13 | RDF75% | 1.2 | **0.4** | **0.5** | **0.7** | **1.6** | **1.54** | **1.53** | **0.1** |
| 14 | RDF 75% +Zn B Fe SA + chelated foliar sprays | 1.5 | **0.6** | **0.6** | **0.8** | **2.1** | **2.13** | **1.58** | |
| T15 | RDF 75% +Nano seed treatment FS | 0.07 | 0.04 | 0.04 | 0.07 | 1.8 | 2.35 | 1.58 | |
| T16 | RDF 75% + seed treatment NPK consortium and Zn solubiliser . | 0.19 | 0.12 | 0.12 | 0.20 | 2.3 | 2.52 | 1.59 | |
| | Sig | 1.6 | 0.6 | 0.5 | 1.1 | 1.08 | NS | 1.72 | 0.4 |
| | CD±5% | 1.2 | 0.4 | 0.4 | 0.5 | 0.37 | 0.25 | 1.61 | |

**Table 9. Bt cotton index leaf Zinc content in shallow *Vertisols*with *calcalcareous* sub strata**

| | | 2019 | | | | 2020 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Days after sowing Zn ppm | | | | | | | | |
| | Treatments | **115** | **122** | **134** | **170** | **30** | **60** | **77** | **115** | **135** |
| 1 | Control | 48 | 37 | 28 | 37 | 35.5 | 35.2 | | 35.5 | 35.2 |
| 2 | RDF 75%+ NPK solubiliser | 61 | 87 | 48 | 53 | 30.8 | 41.5 | | 30.8 | 41.5 |
| 3 | RDF NPK only | 50 | 63 | 47 | 44 | 30.2 | 33.6 | | 30.2 | 33.6 |
| 4 | RDF +Zn20 S20 B5 kg **ha$^{-1}$** soil | 65 | 84 | 38 | 45 | 31.6 | 19.7 | | 31.6 | 19.7 |
| 5 | RDF +Zn solubiliser | 67 | 90 | 50 | 45 | 32.9 | 40.2 | | 32.9 | 40.2 |
| 6 | RDF +Zn20 **ha$^{-1}$** soil app | 65 | 88 | 41 | 45 | 30.6 | 18.3 | | 30.6 | 18.3 |
| 7 | RDF +Borax **ha$^{-1}$** soil app | 54 | 58 | 48 | 56 | 33.4 | 17.8 | | 33.4 | 17.8 |
| 8 | RDF +Bentonite Sulphur20**ha$^{-1}$** | 54 | 63 | 40 | 55 | 27.9 | 16.9 | | 27.9 | 16.9 |
| 9 | RDF + *Sagarika* seed treatment | 64 | 66 | 51 | 53 | 33.0 | 20.3 | | 33.0 | 20.3 |
| 10 | RDF + *Sagarika* seed treatment+FS | 65 | 64 | 51 | 56 | 35.1 | 19.1 | | 35.1 | 19.1 |
| 11 | RDF +*Sagarika* granules | 67 | 55 | 40 | 53 | 31.2 | 18.6 | | 31.2 | 18.6 |
| 12 | RDF + nano Zn FS | 67 | 83 | 66 | 53 | 30.3 | 17.3 | | 30.3 | 17.3 |
| 13 | RDF75% | 49 | 37 | 37 | 51 | 30.9 | 16.5 | | 30.9 | 16.5 |
| 14 | RDF 75% +Zn B Fe SA + chelated foliar sprays | 86 | 85 | 66 | 54 | 33.5 | 18.3 | | 33.5 | 18.3 |
| 15 | RDF 75% +**Nano seed treatment FS** | 11 | 14 | 16 | 9 | 31.1 | 16.9 | | 31.1 | 16.9 |
| 16 | RDF 75% + **seed treatment** NPK consortium and Zn solubiliser . | 12 | 14 | 25 | 13 | 31.9 | 16.8 | | 31.9 | 16.8 |
| CD±5% | C D±5% | 4 | 5 | 6 | 3 | 2.4 | 2.3 | | NS | 6.7 |

**Table 10. Bt cotton index leaf Iron content in shallow *Vertisols* with *Calcareous* sub strata**

| | | 2019 | | | | 2020 | | |
|---|---|---|---|---|---|---|---|---|
| | | Days after sowing Fe ppm | | | | | | |
| | Treatments | **115** | **122** | **134** | **170** | **30** | **60** | **77** |
| 1 | Control | 208 | 198 | 155 | 237 | 71.7 | 88 | 89 |
| 2 | RDF 75%+ NPK solubiliser | 201 | 196 | 139 | 554 | 76.7 | 104 | 56 |
| 3 | RDF NPK only | 193 | 211 | 141 | 454 | 76.5 | 84 | 67 |
| 4 | RDF +Zn20 S20 B5 kg **ha$^{-1}$** soil | 188 | 135 | 165 | 558 | 66.0 | 49 | 73 |
| 5 | RDF +Zn solubiliser | 267 | 281 | 153 | 557 | 73.0 | 100.4 | 57 |
| 6 | RDF +Zn20 **ha$^{-1}$** soil app | 205 | 167 | 188 | 587 | 87.9 | 46 | 66 |
| 7 | RDF +Borax **ha$^{-1}$** soil app | 253 | 161 | 144 | 640 | 86.9 | 44 | 83 |
| 8 | RDF +Bentonite Sulphur20**ha$^{-1}$** | 169 | 204 | 148 | 445 | 85.2 | 42 | 38 |
| 9 | RDF + *Sagarika*streatment | 241 | 204 | 159 | 421 | 80.9 | 51 | 43 |
| 10 | RDF + *Sagarika*streatment+FS | 254 | 139 | 144 | 513 | 78.7 | 48 | 84 |
| 11 | RDF +*Sagarika* granules | 179 | 170 | 140 | 521 | 81.7 | 46 | 39 |
| 12 | RDF + nano Zn FS | 199 | 180 | 181 | 562 | 85.4 | 43 | 39 |
| 13 | RDF75% | 188 | 176 | 189 | 545 | 79.2 | 41 | 82 |
| 14 | RDF 75% +Zn B Fe SA + chelated foliar sprays | 193 | 188 | 203 | 442 | 93.8 | 46 | 36 |
| 15 | RDF 75% +**Nano seed treatment FS** | 16 | 24 | 22 | 33 | 69.7 | 42 | 32 |
| 16 | RDF 75% + **seed treatment** NPK consortium and Zn solubiliser . | 46 | 68 | NS | 96 | 81.5 | 42 | 60 |
| | Sig | 16 | 25 | 27 | 14 | 14 | 16.8 | 10.42 |

**Table 11. Bt cotton PCA deficiency symptoms in *Vertisols* with *Calcareous* sub strata**

| Calcareous soil | Growth | N | P | K | Zn | B | BN |
|---|---|---|---|---|---|---|---|
| Growth | 1.000 | -0.082 | -0.350 | -0.360 | -0.226 | -0.346 | 0.275 |
| N | -0.082 | 1.000 | 0.320 | 0.183 | 0.019 | -0.081 | 0.189 |
| P | -0.350 | 0.320 | 1.000 | **0.729** | **0.630** | 0.404 | 0.100 |
| K | -0.360 | 0.183 | **0.729** | 1.000 | **0.559** | 0.375 | 0.151 |
| Zn | -0.226 | 0.019 | 0.630 | 0.559 | 1.000 | 0.458 | -0.069 |
| B | -0.346 | -0.081 | 0.404 | 0.375 | 0.458 | 1.000 | -0.225 |
| Bolls | 0.275 | 0.189 | 0.100 | 0.151 | -0.069 | -0.225 | 1.000 |

**Table 12. Bt cotton PCA deficiency symptoms in *Vertisols* with *Calcareous* sub strata**

| ***Vertisols* with *Calcareous* sub strata** | **Eigen Value** |
|---|---|
| Cotton growth | 2.861 *** |
| Boll number plant | 0.233 NS |
| Deficiency symptoms severity | Index value |
| Nitrogen | 1.457 *** |
| Phosphorous | 0.946 *** |
| Potassium | 0.633 ** |
| Zinc | 0.531 ** |
| Boron | 0.339 NS |

**Table 13. Rainfed Bt hybrid cottons for calcareous soils**

| Bt hybrid | Seed cotton yield | Pigeon pea yield | Net returns | C B | Boll | Reddening time | Fertilizer nutrients applied Kg ha$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RCH- | Q ha$^{-1}$ | Q ha$^{-1}$ | US $ ha$^{-1}$ | ratio | No | DAS | N | $P_2O_5$ | $K_2O$ | Total | Sulphur | Zinc sulphate | Humic sprays | chelate sprays |
| 659 | 18.8 | 5.3 | 1463 | 4.3 | 80 | 160 | **73** | 60 | **95** | 228 | 18 | 25 | 2 | 2 |
| 659 | 15.8 | 2.5 | 1135 | 4.1 | 65 | 160 | 108 | 43 | **18** | 168 | **43** | 25 | 1 | 1 |
| Ankur 6 51 | 17.0 | 5.0 | 1350 | 4.6 | 65 | 150 | **45** | 45 | **25** | 115 | 18 | **Compost** | | |
| 3028 | 15.8 | 2.0 | 1055 | 3.5 | 65 | 120 | **85** | **88** | **85** | 255 | **0** | Deficiency | | |
| **Mean** | **16.8** | **3.7** | **1250.6** | **4.1** | **68.8** | **147.5** | **77.5** | **58.8** | **55.6** | **191.3** | **19.4** | **25.0** | | |
| **PC of RD** | **84** | **74** | **125** | **165** | **115** | **148** | **73** | **60** | **95** | **228** | **18** | **125** | | |

**Table 14. Supplemental irrigations for Bt hybrid cottons in *Calcareous* soils**

| Bt Hybrids | Irrigations Numbers | Seed cotton yield | Pigeon pea | Net returns | C B | Boll | Fertilizer nutrient s applied kg ha$^{-1}$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Q ha$^{-1}$ | Q ha$^{-1}$ | US $ ha$^{-1}$ | ratio | No | N | $P_2O_5$ | $K_2O$ | Total |
| RCH 659 | **3** | **22.0** | **5.0** | **16853** | **4.7** | **70** | **55** | **30** | **28** | **112.5** |
| RCH 659 | **3** | **23.5** | **5.8** | **1540** | **4.1** | **60** | **80** | **43** | **12.5** | **135** |
| RCH 659 | **3** | **22.0** | **7.5** | **1458** | **3.5** | **55** | **120** | **115** | **62.5** | **298** |
| Ankur 3028 | **3** | **21.6** | **5.8** | **5328** | **4.2** | **66** | **82** | **62** | **49.4** | **193** |
| CD+5% | **0.6** | **1.1** | **1.2** | **4** | **1.2** | **1.1** | **0.7** | **1.0** | **0.8** | **0.8** |
| Mean | **2.0** | **22.5** | **6.1** | **6616.7** | **4.1** | **61.7** | **85.0** | **62.5** | **34.2** | **181.7** |
| PC of RD | **100** | **113** | **122** | **662** | **164** | **103** | **85** | **52** | **57** | **303** |

- *Medium deep Black soils F=Farm yard manure @1 trolley/Acre*

**Table 15. Fertigation with water soluble fertilizers in different soils 2018-2019**

| | Farm Size | Lint yield | Net returns | C: B | NPK | FUE | Fertilizer cost | WSF |
|---|---|---|---|---|---|---|---|---|
| | ha | Kg $ha^{-1}$ | Rs. 000 $ha^{-1}$ | Ratio | Kg $ha^{-1}$ | | Percent | Percent |
| ***Vertisols*** | 6 | 1291 | 108 | 2.6 | 451 | 4.1 | 24 | **13** |
| ***Vertisols* with *caliche*** | 8 | 1625 | 183 | 3.6 | 386 | 8.6 | 20 | **32** |
| **Red stony soils.** | 10 | 1479 | 141 | 2.6 | 504 | 5.8 | 35 | **35** |
| **Highly *Calcareous*** | 6 | 1272 | 81 | 3.0 | 283 | 5.5 | 16 | **56** |
| **Mean** | 7.5 | 1269 | 128 | 3.0 | 406 | 6.0 | 24 | **34** |
| **SD±5%** | | 244 | 53 | 0.56 | 76 | 2.67 | 9 | **27** |

## 4. SUMMARY AND CONCLUSION

The conclusion is package performance in highly *Calcareous* soils was split application of 150% RDF granular, split, spot application of two basal and three top dressing of fertilizer nutrients three days after the heavy rain during the crop growth (15-60 days) are required alongwith Bentonite sulphur 20 kg $ha^{-1}$ $yr^{-1}$ or Sulphur containing complex fertilizer. Seed treatment with PGPRs or bio-stimulant to a dry sown cotton is a must. Foliar application of bio-stimulant *Sagarika* @ 0.002% or nano ZnO @ 0.004% or Zinc sulphate 0.5% twice at squaring and flowering stage produced 87-67 ppm Zn in index leaf, similar to chelated Zn twice foliar applications produced 170-287 kg lint $ha^{-1}$ i.e. more than double due to better N, P, K, Zn nutrient uptake, biomass production, boll number in highly *Calcareous* soils with more than Rs. 16-30, 000/- $ha^{-1}$ profitability which was doubled and tripled under supplemental irrigation and fertigation. Higher rain fall like 2020 dry bed planting of cotton followed by using a sticker spraying 3 times (45-75 days) with WSF along with insecticides, fungicides, Urea 2% + Zinc sulphate 0.5% or WSF 17:44:0 + 0:0:50 2.0% alongwith chelated micronutrients 0.5% or nano ZnO 0.004% and Boron 0.3% are also required to augment the soil supply. PCA confirmed the P, K, Zn significance against growth, leaf reddening, boll number and seed cotton yields.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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