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ND Parlawar
Associate Dean, College of Agriculture, Nagpur, Zonal Agricultural Research Station (Dr. Panjabrao Deshmukh Krishi Vidhyapeeth), Waghapur Road, Yavatmal, Maharashtra, India

MD Giri
Assistant Professor (Agronomy), Buldana, Zonal Agricultural Research Station (Dr. Panjabrao Deshmukh Krishi Vidhyapeeth), Waghapur Road, Yavatmal, Maharashtra, India

RS Raut
Junior Research Assistant, ZARS, Waghapur Road, Yavatmal, Zonal Agricultural Research Station (Dr. Panjabrao Deshmukh Krishi Vidhyapeeth), Waghapur Road, Yavatmal, Maharashtra, India

RN Katkar
Professor, Department of Soil Science and Agril. Chemistry, Dr. PDKV, Akola

Correspondence
MD Giri
Assistant Professor (Agronomy), Buldana, Zonal Agricultural Research Station (Dr. Panjabrao Deshmukh Krishi Vidhyapeeth), Waghapur Road, Yavatmal, Maharashtra, India

Response of *Bt* Cotton (*Gossypium hirsutum* L.) to Sulphur application under rainfed conditions

ND Parlawar, MD Giri, RS Raut and RN Katkar

Abstract
A field experiment was carried out at Yavatmal (Maharashtra) India in consecutive years of 2013 to 2015 to study the response of Response of bt cotton (*Gossypium hirsutum* l.) to sulphur application under rainfed conditions. Eight treatments comprising sulphur application (application of 15, 30, 45kg sulphur through gypsum, 15, 30, 45 kg sulphur through bentonite sulphur and control) were tested. Results indicated that application of 45kg sulphur through gypsum registered significantly higher plant height, bolls/ plant, boll mass, seed index, oil content and yield of seed cotton, uptake of nutrients and registered the higher sulphur use efficiency. Similarly the same treatment recorded higher gross and net monetary returns and benefit: cost ratio.

Keywords: Bt cotton, oil content, seed cotton yield, sulphur

Introduction
India accounts for 32 per cent of the global cotton area and contributes to 21 per cent of the global cotton, currently ranking second after China. Maharashtra is one of the most important cotton growing state of India, ranks first in acreage with 3.87 million ha and producing 7.12 million bales with average productivity of 342 kg lint ha^{-1}, which is low as compared to national average of 503 kg ha^{-1} (AICCIP, 2016).
Soil available S is generally low in the Cotton growing regions due to the hot and humid climate and high likelihood of sulfate leaching. High soil pH, light textured soils; low level of organic matter besides development of plough pan further aggravates the availability of sulphur to growing crops (Hue *et al*., 1984) [4]. In general, oil crops require about the same amount of S as, or more than, phosphorus for high yield and product quality. In intensive crop rotations including oil crops, S uptake can be very high, especially when the crop residue is removed from the field along with the product. This leads to considerable S depletion in soil if the corresponding amount of S is not applied through fertilizer. Sulphur shortage often impedes protein synthesis leading to accumulation of soluble nitrogen compounds. These compounds cause leaf crinkling and other morphological abnormalities (Tiwari *et al*., 1997) [14]. An insufficient S supply can affect yield and quality of the crops, caused by the S requirement for protein and enzyme synthesis as well it is a constituent of the amino acids, methionine and cysteine. Total sulphur requirement of cotton may approach the level of phosphorus. Cotton absorbed 12-15 kg ha-^{1} of sulphur (Makdum *et al*., 2001) [8]. Cotton yield was significantly increased due to added sulphur 11 kg ha^{-1} (Messick, 1992). Fertilizers, which have so far contained sulphur as a combining ingredient, are being replaced with high analysis fertilizer that is low in sulphur.
Increased use of S-free fertilizers, greater S removal from soil by crops with higher yields, less S deposition to soil from the atmosphere, and decreased use of S-containing pesticides have contributed to more S deficiencies in crops during recent years (Yin, et. al., 2012) [15]. S is increasingly being recognized as the fourth major plant nutrient after nitrogen, phosphorus and potassium. The importance of S in agriculture is being increasingly emphasized and its role in crop production is well recognized (Scherer, 2009; Jamal *et al*., 2010) [12, 6].
Little is known about the effects of sulphur on cotton growth, yield and quality, and therefore the present investigation was planned with the object to determine the effects of sulphur application cotton growth, yield and quality of cotton.

Materials and methods
Experimental Site
The experiment was conducted at the Zonal Agricultural Research Station (Dr. PDKV), Waghapur road, Yavatmal (20023' N, 7808' E and 445 m MSL), Maharashtra, India for successive 3 years (2013 to 2015).

The soil type during all the seasons was Clayey. Textural properties and chemical characteristics of the soil are given in Table 1. Yavatmal is situated $20^0$23'N $78^0$8'E and its mean height above sea level is 496 m. It receives most of the rainfall from South-West monsoon, commencing from middle of June. The mean annual precipitation approximates to about 1070 mm receives in 50 to 55 rainy days from the middle of June to September, receives from South-West monsoon.

For studying the response of bt cotton (*Gossypium hirsutum* L.) to sulphur application under rainfed conditions, randomized block design was used. The details of the treatments and symbols used are given in Table 2. In all, there were eight treatments of sulphur application replicated three times. The experimental field was laid out in 24 unit plots, each plot measuring 34.02 m^2 (6.3m x 5.4m). There were seven rows of cotton crop in each plot and twelve plants in each row. One row of crop from both sides of length and also both sides of breadth were left as guard rows. The net plot consisted of five rows with ten plants per row (4.50m x 4.50m). The plan of randomization of the treatments adopted for the first year was also followed in subsequent years.

Seeds and planting

Two seeds of cotton hybrid NCS- 207 BG-II were planted @ 2.5 kg ha^{-1} with the spacing of 90cm between rows and 45cm between plants on 04^{th}, 3^{rd} and 4^{th} July in 2013, 2014 and 2015, respectively. Thinning operation was carried out at 15 days after planting and one healthy seedlings $hill^{-1}$ was maintained after thinning operation.

Agronomic operations

A fertilizer dose of 60 kg N, 30 kg P_2O_5 and 30 kg K_2O ha^{-1} through urea, di ammonium phosphate (no sulphur) and muriate of potash was applied as recommended dose of fertilizer as per the treatments. Sulphur was applied at the time of planting. The details of sulphur application are given in the Table 2 and 3.

Three manual weedings were done to keep the crop free of weeds. Timely recommended plant-protection measures for rainfed cotton were followed to save the crop from pests and diseases. Different yield components, viz. plant height, Sympodial branches, bolls/plant, seed-cotton yield/plant and boll weight (g), were recorded periodically. The seed-cotton weight of different pickings from net plot area was recorded treatment-wise and total seed-cotton yield/ha was calculated.

Plant nutrient uptake and S-use efficiency

The plant samples after recording observations were dried in oven at 65° C. The samples were made composite and after the grinding into fine powder, used for analysis of nitrogen, phosphorus, potassium and sulphur content using micro Kjeldahls' method, vanadomolybdate yellow colour method, flame photometric method (Jackson, 1973) [5] and Tubidimetrically. Sulphur-use efficiencies were computed as follows with the formulae given by Choudhary and Behera (2013) [2]. Agronomic S-use efficiency (kg yield increase/kg S applied): [(Yt – Y0)/ Sa]

where Yt: Yield in test treatment (kg/ha); Y0: Yield in control plot; Sa: Units of sulphur applied in the test treatment (kg/ha).

Cotton seed oil content

The cotton seed oil content (%) was determined by Nuclear magnetic resonance (NMR) method.

Statistical analysis

The data on various parameters recorded from experimental plot were statistically analysed as suggested by Panse and Sukhatme (1995) [10] by using the randomized block design. Whenever results were found significant the critical difference (C.D.) values at 5 % level of probability were worked out.

Results and discussion

Effects of sulphur (S) nutrition on cotton growth and yield parameters

Application of sulphur significantly influenced the cotton plant height (Table 4). The maximum cotton plant height was observed with the treatment application of 45 kg S through gypsum (107.30 cm) and it was at par with 15 and 30 kg S/ ha through gypsum and 15, 30, and 45 kg S/ ha through bentonite sulphur.

sympodial (boll bearing) branches $plant^{-1}$ is the important growth parameter that influences directly or indirectly the seed cotton yield. These branches are the important indicator of sink. Significant variation in number of sympodial branches $plant^{-1}$ and their further role to produce reproductive parts have played a prominent role in the yield and yield components of Bt. cotton in present investigation (Table.4). Treatment application of 45 kg S through gypsum (T4) recorded more number of sympodial branches $plant^{-1}$ (15.27) and it was at par with 15, 30, and 45 kg S/ ha through bentonite sulphur. Cotton being an indeterminate crop with long duration, supply of sulphur might have helped in inducing more sympodial branches $plant^{-1}$.

The harvested bolls/ plant significantly higher with the application of 45 kg S through gypsum (24.13) and it was at par with 15 and 30 kg S/ ha through gypsum and 15, 30, and 45 kg S/ ha through bentonite sulphur (Table 4). The same treatment recorded higher seed cotton/ plant.

The boll mass (g) and seed index (g) were recorded significantly higher with the application of 45 kg S through gypsum (4.55g and 7.66g respectively) and it was at par with all other treatments except no sulphur ((Table 4).

Increase in number of bolls per plant might be due to enhancement of S containing amino acids, which are an essential component of protein and also prevent shedding of bolls. It can exploit full genetic potential of a crop, when it is grown under favorable conditions and well balanced supply of nutrients to the crop. The marked increase in plant height due to sulphur application could be due to the more soluble sulphur into the soil solution resulting in better absorption of sulphur nutrient. This would have increased the metabolic processes and maintained the process of photosynthesis in the plants and promoted the meristematic activities causing increased branching and biomass production due to proper partitioning of photosynthates from sources to sink. Further, S has an impact on photosynthesis as well as synthesis of nucleic acids, proteins, amino acids and other essential compounds, which are major constituents affecting boll weight and consequently cottonseed yield. The results are in agreement with the findings made by Legha and Giri, 1999 [7] and Gormus (2014) [3].

The increase in boll mass and seed index by application of sulphur could be attributed to the favorable effect of sulphur on carbohydrate metabolism and accelerated mobility of photosynthates from source to sink. Similar findings were made by Gormus (2014) [3].

Effects of sulphur (S) nutrition on seed cotton yield (kg ha^{-1}), oil content (%) and agronomic S-use-efficiency (kg kg^{-1})

Application of 45 kg S through gypsum recorded significantly higher seed cotton yield (Table 5) and it was at par with all other treatments except no sulphur (T8). The best treatment (T4) recorded 23 per cent more seed cotton yield than that of no sulphur treatment (T8). The stalk yield (2615 kg ha^{-1}) and oil content (20.70%) was significantly higher with the application of 45 kg S ha^{-1} through gypsum and it was at par with application of 45 kg S ha^{-1} through bentonite sulphur.

Increase in the growth and yield parameters, which are an index of higher photosynthetic capacity of plant, with the treatment T4 improved the bolls/plant by enabling the plant to trap more solar radiation energy and the supply of sulphur on S deficit soil resulted in higher plant height, sympodial branches hence formation of more bolls and thus resulted in higher seed-cotton yield. Increase in oil content by sulphur application might be attributed to involvement of sulphur in the biosynthesis of oil. Sulphur is involved in the formation of glucosides and glucosinolates and sulphydril-linkage and activation of enzymes, which aid in biochemical reaction within the plant. The higher oil yield by sulphur application was obviously because of higher seed yield and oil content. The increase in yield with sulphur supply is similar to the observations made by Singh and Kairon (2001) [13], Makhdum *et al*. (2001) [8] and Gormus (2014) [3].

Effects of sulphur (S) nutrition on economics of cotton

The highest gross and net monetary returns (Table 6) were received with the application of 45 kg S ha^{-1} through gypsum (Rs. 73937/- and Rs. 37193/-) and it was at par with all other treatments except no sulphur (T8). B: C ration of 2.01 was recorded with the application of 45 kg S ha^{-1} through gypsum. Increased yield owing to application of sulphur significantly increased the gross and net monetary returns.

Effects of sulphur (S) nutrition on cotton nutrient uptake (kg ha^{-1}) and quality parameters

Application of 45 kg S/ ha through gypsum recorded significantly higher uptake of N, P, K and S (Table 7) and it was at par with application of 45 kg S ha^{-1} through bentonite sulphur. Nutrient uptake by cotton is directly related to dry-matter accumulation, supply of sulphur to the plant during the growth period resulted in higher dry-matter production, which reflected into higher uptake of nutrients. These results are in accordance with the findings of Parmar *et al*. (2010) [11]. Quality parameters of the cotton (Table 8) were not affected by the application of sulphur in the present investigation.

Table 1: Textural and chemical properties of soil samples of experimental site

Particulars	Values	Method adopted
Textural properties		
Coarse sand (%)	7.43	International Pipette method
Fine sand (%)	9.90	
Silt (%)	41.50	
Clay (%)	41.17	
Textural Class	Clay loam	
Chemical properties		
Organic matter (g kg^{-1})	3.5	Wet oxidation method
pH (1:2.5)	8.10	Conductometer
EC at 25 ^{0}C (dSm^{-1})	0.30	Potentiometric
Available Nitrogen (kg/ha)	247.74	Alkaline permanganate method
Available Phosphorus (kg/ha)	20.24	0.5M NaH_2CO_3 (pH 8.5)
Available Potassium (kg/ha)	324.80	Neutral N NH_4OAC
Available Sulphur (mg kg^{-1})	8.34	Tubidimetrically

Table 2: Experimental treatment details and symbols used

Sr. No.	Treatment details	Symbols used
1	Recommended dose of fertilizers (60:30:30 kg N:P:K ha^{-1}) through urea, single super phosphate and murate of potash (22.5 kg S ha^{-1} due to application of single super phosphate)	T_1
2	Recommended dose of fertilizers (60:30:30 kg N:P:K ha^{-1}) + 15 kg S ha^{-1} through Gypsum	T_2
3	Recommended dose of fertilizers (60:30:30 kg N:P:K ha^{-1}) + 30 kg S ha^{-1} through Gypsum	T_3
4	Recommended dose of fertilizers (60:30:30 kg N:P:K ha^{-1}) + 45 kg S ha^{-1} through Gypsum	T_4
5	Recommended dose of fertilizers (60:30:30 kg N:P:K ha^{-1}) + 15 kg S ha^{-1} through bentonite sulphur	T_5
6	Recommended dose of fertilizers (60:30:30 kg N:P:K ha^{-1}) + 30 kg S ha^{-1} through bentonite sulphur	T_6
7	Recommended dose of fertilizers (60:30:30 kg N:P:K ha^{-1}) + 45 kg S ha^{-1} through bentonite sulphur	T_7
8	Recommended dose of fertilizers (60:30:30 kg N:P:K ha^{-1}) (0 kg Sulphur)	T_8

Recommended dose of fertilizers (60:30:30 kg N: P:K ha^{-1}) through urea, di-ammonium phosphate (DAP) and murate of potash in treatments T_2 to T_8

Table 3: Quantity of S applied in various treatments

Symbol used	Quantity of Gypsum (12.01% S) added (kg ha^{-1})	Quantity of Single super phosphate (12% S) added (kg ha^{-1})	Quantity of Bentonite S (90% S) added (kg ha^{-1})	Quantity of S added (kg ha^{-1})
T_1	0	187.5	0	22.5
T_2	124.9	0	0	15.0
T_3	249.8	0	0	30.0
T_4	374.7	0	0	45.0
T_5	0	0	16.7	15.0
T_6	0	0	33.3	30.0
T_7	0	0	50.0	45.0
T_8	0	0	0	0.0

Table 4: Growth and yield parameters of cotton (mean data of 3 years)

Treatments	Plant height (cm)	Sympodial branches plant^{-1}	Bolls harvested plant^{-1}	Seed cotton yield plant^{-1} (g)	Boll mass (g)	Seed index (g)
T_1	98.3 b	12.1 c	19.1 b	69.3 b	4.46 a	7.24 c
T_2	99.4 a	12.6 b	19.6 a	73.8 a	4.45 a	7.17 c
T_3	101.5 a	13.3 b	20.4 a	72.8 a	4.50 a	7.24 c
T_4	107.3 a	15.3 b	24.1 a	90.7 a	4.55 a	7.66 a
T_5	99.6 a	14.0 a	19.6 a	71.6 a	4.47 a	7.12 c
T_6	104.4 a	13.7 b	20.4 a	72.2 a	4.52 a	7.24 c
T_7	106.7 a	15.0 a	22.7 a	89.5 a	4.53 a	7.47 b
T_8	94.6 a	11.8 c	18.4 b	59.3 c	4.26 b	7.11 c
LSD 0.05	8.7	1.4	4.6	20.53	0.15	0.13
Means followed by the same letter do not differ significantly at the 0.05 probability level						

Table 5: Yield parameters of cotton (mean data of 3 years)

Treatments	Seed cotton yield (kg ha^{-1})	Agronomic S use efficiency (kg kg^{-1})	Seed oil content (%)	Cotton stalk yield (kg ha^{-1})
T_1	1320 a	3.4	20.5 b	2186 c
T_2	1333 a	5.9	20.4 b	2135 c
T_3	1390 a	4.9	20.4 b	2346 b
T_4	1526 a	6.3	20.7 a	2589 a
T_5	1374 a	8.7	20.4 b	2414 b
T_6	1367 a	4.1	20.5 b	2433 a
T_7	1411 a	3.7	20.6 a	2565 a
T_8	1244 b	-	20.3 c	1939 d
LSD 0.05	235	-	0.13	173
Means followed by the same letter do not differ significantly at the 0.05 probability level				

Table 6: Economics of cotton production in various treatments (mean data of 3 years)

Symbol used	Cost of production (x10^3 Rs. ha^{-1})	Gross income (x10^3 Rs. ha^{-1})	Net income (x10^3 Rs. ha^{-1})	B:C ratio
T_1	32.9	63.9 a	31.0	1.94
T_2	33.7	64.5 a	30.7	1.91
T_3	35.1	67.3 a	32.2	1.92
T_4	36.7	73.9 a	37.1	2.01
T_5	33.5	66.6 a	33.0	1.99
T_6	33.9	66.2 a	32.3	1.95
T_7	34.7	68.4 a	33.7	1.97
T_8	28.9	60.1 b	31.2	1.85
LSD 0.05	-	11.3	NS	-
Means followed by the same letter do not differ significantly at the 0.05 probability level				

Table 7: Uptake of nutrients by cotton (mean data of 3 years)

Treatments	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})	S uptake (kg ha^{-1})
T_1	48.19 b	14.11 b	51.19 b	11.71 c
T_2	47.07 b	14.32 b	51.24 b	11.66 c
T_3	52.04 b	15.36 b	55.27 b	12.87 b
T_4	59.44 a	17.80 a	62.37 a	15.18 a
T_5	53.35 a	15.61 b	55.89 b	12.86 b
T_6	51.77 b	15.54 b	56.46 b	13.21 b
T_7	55.51 a	16.76 a	59.96 a	14.74 a
T_8	44.02 c	12.82 c	47.05 c	9.69 d
LSD 0.05	6.25	1.81	5.53	1.21
Means followed by the same letter do not differ significantly at the 0.05 probability level				

Table 8: Cotton lint quality parameters (mean data of 3 years)

Treatments	Ginning out turn (%)	Fibre length (mm)	Fibre uniformity (%)	Fibre Micronaire value (μ/in)	Fibre strength (g/tex)
T_1	33.7	30.6	82.7	4.1	30.3
T_2	33.7	29.9	82.7	4.0	29.3
T_3	33.8	30.4	83.0	4.2	28.5
T_4	33.8	30.6	83.0	3.9	30.9
T_5	33.6	30.2	82.7	3.9	30.7
T_6	33.8	30.5	82.7	3.8	30.2
T_7	33.8	30.3	82.7	3.7	30.2
T_8	33.5	30.4	82.3	3.4	32.3
LSD 0.05	NS	NS	NS	NS	NS
*NS= Non significant a t the 0.05 probability level					

Conclusion

The results observed in the present field research experiment are encouraging and hence sulphur must be included in fertilizer recommendation for higher yield and oil content of cotton on sulphur deficit soils.

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