Int.J.Curr.Microbiol.App.Sci (2020) *9*(8): 3053-3062

EXCELLENT PUBLISHERS

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 9 Number 8 (2020)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2020.908.345

Influence of Sulphur, Zinc and Organic Inorganic Assorted Customized Fertilizer on Yield and Quality of Cotton under Rainfed *Vertisols*

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A B S T R A C T

Keywords

Cotton, Customized fertilizer, Sulphur, Zinc, FYM

Article Info

Accepted:
24 July 2020
Available Online:
10 August 2020

Cotton, the major fibre crop of India grown mainly under the rainfed condition often faces multi-nutritional deficiencies. This experiment was conducted during the *Kharif* season of 2016-17 on to find out the best performing nutrient combination for rainfed cotton in which sulphur, zinc and FYM based nutrient management regime, as well as customized fertilizer, were evaluated. The result indicated that gradually adding sulphur and zinc along with compulsory nitrogen, phosphorus and potassic fertilizer improves yield and quality attributes, however, significantly higher yield attributes, yield and quality has been observed when farmyard manure at a rate of five tonnes per hectare has been used along with standard recommended dose of fertilizers.

Introduction

When it comes to the fibre crop; cotton takes the first position. It is also the most prominent cash crop of India (Mandal *et al.,* 2005). India ranks first in the world having an area of 105 lakh ha with the cotton production of 351 lakh bales and productivity of 568 kg lint per ha. Maharashtra is the leading cotton-growing state in India having 38.06 lakh ha area under cotton cultivation which is one-third of countries area under cotton cultivation with the production of 89 lakh bales. The productivity of cotton in Maharashtra is 398 kg lint per ha (Anonymous, 2016). An important cotton-growing zone in Maharashtra is Vidarbha. However; being a rainfed cotton growing zone; the area often faces problem due to erratic rainfall; imbalanced fertilizer use and low adoption of improved techniques while ultimately results deteriorating soil health thus limiting yield potential (Blaise *et al.*, 2005a).

In case of imbalanced fertilizer application; the end-result is often multiple nutrient deficiencies owing to the changing soil chemical properties. Sulphur is one such element which often found to be deficient in the soil. On average, 32.9 per cent sulphur deficiency has been noticed in Indian soils (Shukla *et al.,* 2016). Sulphur deficiency in Maharashtra recorded to the extent of 27.48 per cent while in the Vidarbha region, it is 25.76 per cent (Katkar *et al.,* 2017). Sulphur fertilization of crops needs to be an integral component of balanced nutrition for producing optimum yield and quality of crops. Crops like cotton, which have high protein and oil in seed, need more substantial quantities of sulphur. For typical yields, the crops with high sulphur requirements need 20 to 45 kg S ha^{-1} (Singh and Joshi, 2000).

Zinc is another essential micronutrient which is highly deficit in Indian soil. Survey of Indian soils revealed that about 39.9 per cent of 2.52 lakh soil samples analyzed were found deficient in available Zn distributed over 20 states (Shukla *et al.,* 2016). Zinc deficiency is widespread in all agro-ecological zones (AEZ). Zinc deficiency in Maharashtra has been reported to be 37.8 per cent, and in Vidarbha, 49 per cent (Katkar *et al.,* 2017). Without the regular supply of zinc to the plants; the ill effect becomes more prominent over time. Zinc directly influences yield and quality of crops because of functions such as its activity in biological membrane stability, enzyme activation ability and auxin synthesis (Marschner, 1997).

There are two general methods to correct the sulphur and zinc deficiency. The first method is to use customized fertilizers. Customized fertilizers are multi-nutrient carriers facilitating the application of the complete range of plant nutrients in the right proportion to suit the specific requirements of a crop during its stages of growth. Soil fertility status, climate, and cropping pattern in a region pave the way for the development of customized fertilizer formulations. It optimizes the nutrient use for quality produce, high farm productivity and profitability.

The other method is to the application of organic manure or supplementation of organic manure with inorganic chemical fertilizer. Earlier researches indicated that a more sustainable method of increasing yield potential in rainfed *vertisols* is the integrated use of both organic and inorganic sources of nutrients (Rajpoot *et al.,* 2009). Organic source of nutrition such as FYM has the potential to store moisture for a longer period as well as releasing nutrients in a steady manner (Patra *et al.,* 2000).

Considering all these factors, we had experimented to evaluate the performance of cotton based on yield and quality under these different nutrient delivery approaches.

Materials and Methods

Experimental site

This experiment was carried out during the *Kharif* (rainy) season of 2016-17 at Research Farm, All India Co-ordinated Research Project on Micro and Secondary Nutrients and Pollutant Elements in Soils and Plants, Department of Soil Science and Agricultural Chemistry, Dr.Panjabrao Deshmukh Krishi Vidyapeeth, Akola, India. The experimental plot is geographically located at the subtropical region between 22.42˚N latitude, 77.02˚ E longitude, and at an altitude of 307.42 m above mean sea level. The climatic condition is the sub-tropical type with hot summer, humid monsoon and mild winter. The mean weather data has been summed up on table 1. During the *Kharif* season of 2016-17, the total rainfall received (25th MW 2016 to 5th MW 2017) at Akola centre was 823.7 mm in 43 rainy days as against average rainfall of 711.1 mm in 38.4 rainy days (1971-2010).

The soil of the experiment site was deep black swell shrink, montmorillonitic mineralogy with clay texture and classified under *Vertisols* (Deshpande *et al*., 2014). The initial soil properties at the start of the experiment were slightly alkaline (8.15), non – saline (0.37 dS m^{-1}) (Jackson 1973), moderately calcareous (6.25 %) and moderately high in organic carbon (5.73 g kg^{-1}) (Keeney and Nelson, 1982).

The available nitrogen was low (188.15 kg ha^{-1}) (Subbaiah, 1956), medium in available phosphorus (16.74 kg ha^{-1}) (Olsen *et al.*, 1954) and high in available potassium (354.3 kg ha^{-1}) (Hanway and Heidel 1952) while marginal in available sulphur (10.37 mg ka^{-1}) (Chesnin and Yien, 1951). The experimental soil was deficient in DTPA – zinc (0.57 mg kg^{-1}) and sufficient in DTPA – Fe, Mn and Cu (Lindsay and Norvell, 1978). All physiochemical properties of the experimental site before the commencement of the experiment has been presented on table 2.

Experimental design and treatment compositions

The experiment was laid out in Randomized Complete Block Design (RCBD) with eleven treatments which were replicated thrice. The net plot size was 16.2 m^2. The treatments were: T_1: Absolute control (No NPK), T_2: Recommended dose of NPK, T_3: Recommended dose of NPKS, T_4: Recommended dose of NPKS Zn, T_5: Recommended dose of NPK + FYM, T_6: Recommended dose through NPS-1 (compensate N and K through conventional sources, T_7: Recommended dose through NPS-2 (compensate N and K through conventional sources), T_8: Recommended dose through NPS Zn (compensate N and K through conventional sources), T_9: Recommended dose of NPK + Sulphur equivalent to NPS-1 supplied in T_6, T_{10}: Recommended dose of NPK + Sulphur equivalent to NPS- 2 supplied in $T_7$and T_{11}: Recommended dose of NPK + Sulphur and Zn equivalent to NPS Zn supplied in T_8. The NPS-1 had nitrogen: phosphorus: sulphur at a ratio of 19:38:07 while the NPS-2 contained 12:46:07. In the case of NPS Zn, it had nitrogen: phosphorus: sulphur: zinc in a ratio of 12:45:05:01.

The half dose of nitrogen as basal, a full dose of phosphorus, potassium, sulphur and zinc was applied at the time of sowing while the remaining half of the nitrogen was applied thirty days after sowing by urea. Nitrogen, phosphorus and potassium were applied through urea, diammonium phosphate and muriate of potash.

The sulphur was applied through bentonite sulphur (90% S) while zinc sulphate heptahydrate (21% Zn) was used as zinc source. The compost was analysed in advance for chemical composition which revealed it had C: N ratio of 16.14:1, 0.61% N, 0.35% P, 0.42% K, 0.07 mg kg^{-1} S, 64.99 mg kg^{-1} Zn, 94.00 mg kg^{-1} Cu, 2109 mg kg^{-1} Fe and 439.4 mg kg^{-1} Mn.

Sowing and cultural operations

The experimental land was ploughed, harrowed, made free of grasses before the layout. Initial plot-wise surface soil samples were collected randomly from 0-20 cm depth. The collected samples were mixed thoroughly, and finally, plot-wise samples were retained for analysis.

The *Bt*. Cotton variety Ajeet 199 BG-II was sown using the dibbling method and two seeds were placed in each hole although one plant has been removed on a later stage to ensure even plant population. The spacing has been kept at 90 X 45 cm. The experimental site was kept weed-free by periodic hand weeding. Two sprays of Confidor 17.8 SL and Monocrotophous 3G on the crop leaves was undertaken to control the aphids, jassids and whitefly on cotton.

Recording of biometric observation and harvesting

Five plants were randomly selected from each plot and tagged for biometric observations. The pickings of seed cotton were done from each plot, four pickings were carried out, and total yield from each treatment in all the replications was recorded, and per hectare, seed cotton yield was determined.

The plant samples above-ground part were collected at second picking and kept in paper bags and air-dried in the shade. The samples were eventually kept in a hot air oven at 64˚ C till the constant weight has been achieved. After complete drying the; dry matter of stem, leaves and fruit parts were.

Oil content and fibre quality assessment

The Soxhlet apparatus has neem used to estimate the oil content in cottonseed. The standard procedures have been followed in case of fibre quality assessment. Digital fibrograph, stelometer, and micronaire instrument have been used to measure the span length, strength (tenacity) and fineness of the fibre.

Statistical analysis and interpretation of data

The observed, recorded, and data were analyzed in randomized complete block design using the R statistical program (deploying CRAN- Agricolae library) following the procedure of Gomez and Gomez (1984).

The significance of treatments was tested using the "F" test. The difference of treatment means was compared and alphabetically ranked using Duncan Multiple Range Test (DMRT) at 5% level of significance.

Results and Discussion

Effect of nutrient sources on yield attributes

Number of bolls per plant

Cotton yield and yield components are highly dependent on basic fertilizer levels and appropriate plant population (Ali *et al.*, 2007). Among yield components, Bolls plant^{-1}is one of the critical factors which directly influences the yield (Boquet *et al.*, 1994). The treatments of our experiment had a distinctive effect on bolls plant^{-1} (Table 3). The highest number of bolls plant^{-1} has been recorded with the application of RDN along with FYM (T_5) which had 52.69% more bolls than absolute control (T_1); however, it was found to be at par with T_4(NPKS Zn through conventional sources) and T_8 (RDN grade III + compensated N and K through conventional sources).

The treatment wise breakdown indicated that addition of NPK resulted in 30.63% increase in the number of bolls while further addition of S caused 8.01% and Zn caused 12.83% increment. The FYM in T_5 which seemingly supplied other micronutrients had 2.22% more Bolls plant^{-1} as compared to T_4 which had only N, P, K, S and Zn. Blaise *et al.*, (2005b) earlier reported that significantly higher bolls plant^{-1} has been observed in the case of collective application of fertilizer (NPK) and FYM, especially in the first year of application. In addition to supplying micronutrients; FYM also helps to store soil moisture which becomes crucial, especially in case of rainfed condition (Venugopalan and Pundarikakshudu, 1999; Gokhale *et al.*, 2011). Increment in number of bolls due to the sulphur application is may be due to sulphur being an essential constituent of enzymatic activity, responsible for nitrogen metabolism including nitrate and nitrite reductase (Swamy *et al.,* 2005). The increment due to zinc application are in agreement with those of Potarzycki and Grzebisz (2009) and Abid *et al.,* (2013) who argued that supplementation of zinc on soil results increased zinc content on plant leaf which enhances the higher assimilation of photosynthates from source to sink resulting in better yield. Another vital aspect of zinc application is that it improves the activity of tryptophan synthesis, which is responsible for the growth control compound indole-3- acetic acid; the compound which helps to retain a higher number of bolls per plant (Follett *et al.*, 1981 and Qingfang, 1996).

Table.1 Meteorological observations during study period (2016-2017)

Month	Temperature (˚C)		Relative humidity (%)		Total rainfall (mm)	Total evaporation (mm)
	Mean Maximum	Mean Minimum	Mean Maximum	Mean Minimum		
20- 30 June	35.4	26.1	72.66	44.33	139.7	28.1
1- 31 July	30.58	24.3	87.2	69.6	376.1	20.7
1-31 August	30.54	23.84	84.25	62.5	30.7	17.5
1- 30 September	31.34	23.4	88.4	61.8	123.2	18.2
1- 31 October	31.1	20.2	87.46	53.63	90.5	11.7
1-30 November	30.95	11.77	77.3	52.6	00	15.5
1-31 December	30.18	9.86	76.7	51.4	00	16.0
1-31 January	28.5	9.53	72.4	50.8	00	18.7
1-28 February	30.2	10.7	71.6	46.7	00	17.4

Table.2 Physiochemical properties of the soil prior to the experiment

Sr. No.	Particulars	Value
A	**Soil properties**	
1	pH (1:2.5)	8.15
2	EC (dS m^{-1})	0.37
3	Organic carbon (g kg^{-1})	5.73
4	Calcium carbonate ($CaCO_3$) (%)	6.25
B.	**Fertility analysis**	
1	Available N (kg ha^{-1})	188.15
2	Available P_2O_5 (kg ha^{-1})	16.74
3	Available K_2O (kg ha^{-1})	354.3
4	Available S (mg kg^{-1})	10.37
5	DTPA extractable Zn (mg kg^{-1})	0.57
6	DTPA extractable Mn (mg kg^{-1})	12.7
7	DTPA extractable Fe (mg kg^{-1})	4.93
8	DTPA extractable Cu (mg kg^{-1})	3.23
9.	Available extractable B (mg kg^{-1})	0.56

Table.3 Effect of different treatments on bolls plant^{-1}, boll weight (g), seed cotton yield (q ha^{-1}), cotton stalk yield (q ha^{-1}) and oil content (%)

Treatments	Bolls plant^{-1}	Boll weight (g)	Yield (q ha^{-1})		Oil%
			Seed Cotton	Cotton stalk	
T_1	17.50 ± 0.38f	3.02 ± 1.6f	10.44 ± 0.49e	23.52 ± 0.37g	18.93
T_2	23.83 ± 0.42e	3.29 ± 0.71de	16.07 ± 0.37d	35.38± 0.39f	19.38
T_3	25.82 ± 0.21de	3.59 ± 1.33bc	18.23± 0.42bc	37.57± 0.52de	19.52
T_4	29.36 ±0.44ab	3.72 ± 0.47a	19.88± 0.47ab	42.61± 0.49b	19.72
T_5	30.02± 0.32a	3.81 ± 0.45a	21.29± 0.79a	44.63± 0.61a	19.65
T_6	23.75 ± 0.28e	3.49 ± 0.52cd	17.58± 0.81cd	38.74± 0.67cd	18.99
T_7	25.43 ± 0.43de	3.31 ± 1.23 d	16.87± 0.69cd	37.97 ± 0.42cde	19.29
T8	28.75 ± 0.37ab	3.62 ± 0.65b	19.70± 0.86ab	41.91± 0.73b	19.41
T9	25.83 ± 0.39cd	3.42 ± 0.71cd	17.34± 0.67cd	37.56± 0.70de	19.11
T_{10}	26.63 ± 0.31cd	3.37 ± 0.67cd	16.60± 0.43cd	36.93 ± 0.59e	19.71
T_{11}	26.52 ± 0.43c	3.51 ± 0.44cd	17.98c± 0.77c	39.22 ± 0.66c	19.59

(NS: Not Significant. Treatments sharing at least one common alphabet does not differ significantly as per Duncan Multiple Range Test at 5% level of significance. Treatment effect is not significant in oil %)

Table.4 Effect of different treatments on fibre quality of cotton

Treatments	UHML (mm)	UI (%)	MIC (µg in^{-1})	Tenacity 3.2 mm (g tex^{-1})	EL (%)	GP (%)
T_1	29.87±0.8e	82.0±0.53	3.17±0.32	32.13±1.31c	6.27±0.21d	33.27±0.71b
T_2	30.77±1.13b	82.3±0.71	3.13±0.30	35.14±1.60a	6.60±0.34a	31.93±0.84f
T_3	30.43±1.11c	82.3±0.47	3.30±0.41	32.87±1.22bc	6.47±0.27abc	33.07±0.72c
T_4	30.20±0.98d	82.0±0.53	3.33±0.43	33.37±0.97abc	6.40±0.21bcd	33.17±0.59b
T_5	30.93±1.07a	82.3±0.21	2.97±0.41	35.27±1.15a	6.50±0.29ab	32.83±0.48d
T_6	30.13±1.2d	82.0±0.20	3.27±0.43	32.80±1.12bc	6.33±0.22cd	32.60±0.43e
T_7	30.07±1.27d	82.0±0.49	3.17±0.22	33.83±1.37abc	6.37±0.30bcd	32.87±0.41d
T8	30.47±1.21c	82.0±52	3.23±0.37	32.97±1.28bc	6.40±0.18bcd	31.97±0.62f
T9	30.47±0.97c	82.0±0.66	3.23±0.42	33.83±1.22abc	6.50±0.26ab	33.33±0.48b
T_{10}	30.80±1.21ab	82.3±0.65	2.97±0.34	34.67±1.13ab	6.43±0.19bc	32.83±0.52d
T_{11}	30.43±1.13c	82.0±0.53	2.98±0.21	34.50±1.25ab	6.37±0.27bcd	33.47±0.47a

(NS: Not Significant. Treatments sharing at least one common alphabet does not differ significantly as per Duncan Multiple Range Test at 5% level of significance. Treatment effect is not statistically significant in UI and MIC)

Table.5 Pearson correlation matrix among cotton yield, yield attributes and quality attributes

	Seed cotton yield	Stalk yield	No. bolls plant^{-1}	Boll weight	Oil content	UHML	Tenacity	EL
Seed cotton yield	1	0.988**	0.957**	0.959**	0.639*	0.514*	0.391#	0.400#
Stalk yield		1	0.957**	0.917**	0.627*	0.0.496#	0.435#	0.372#
No. bolls plant^{-1}			1	0.899**	0.768**	0.569*	0.470#	0.406#
Boll weight				1	0.634*	0.440#	0.253#	0.293#
Oil content					1	0.615*	0.570*	0.384#
UHML						1	0.819**	0.797**
Tenacity							1	0.688*
EL								1

- ** A strong (0.01) positive linear relationship
- * A moderate (0.05) positive linear relationship
- # A weak positive linear relationship

Boll weight (g)

The boll weight (g) was heaviest in T_5 and T_4, which were 23.13% and 20.77% higher than the control (T_1), respectively (Table 3). Among different graded fertilizers, T_8 recorded 18.07% heavier boll than the control. The treatment wise breakdown indicates that addition of NPK causes 8.56 % increase in boll weight over the control. Further addition of S with NPK causes 8.72% and increment in boll weight over NPK alone. Again, when Zn is added with NPKS, it caused 3.56 % additional increment. In the case of FYM, it recorded 2.39% heavier boll than NPKS Zn combination which might be due to the favourable soil condition, better water holding capacity and supply of additional micronutrient.

Seed cotton and cotton stalk yield

T_5 also recorded statistically higher seed cotton yield (q ha^{-1}) along with T_4 and T_8, which were 68.38%, 62.27% and 61.45% higher than the T_1(control) (Table 3). In case of cotton stalk yield (q ha^{-1}); T_5 (followed by T_4 and T_8) was absolutely superior over all other treatments and recorded 61.95% increment in yield over T_1. Among the graded fertilizer doses; grade III recorded higher seed cotton and stalk yield than grade I and grade II.

Higher boll weight, seed cotton yield and stalk yield with combined application of organic FYM, and inorganic chemical fertilizer might be due to an extended period of nutrient and moisture availability especially in later stages along with a copious supply of micronutrients and plant growth-promoting substances. These factors altogether have increased the photosynthetic activity and better root zone condition apprehending better yield (Das *et al*., 2006)

Oil content

Cottonseed oil content is a nutrient, especially sulphur dependent factor. The T_5 recorded highest oil Content (4.08% more than the control) although it does not reach the statistical significance level (Table 3).

Effect of nutrient sources on cotton fibre quality

The fibre quality of the cotton has been evaluated based on the parameters of Upper Half Mean Length -UHML (mm), uniformity index (UI%), fibre fineness based on micronaire- MIC (µg in^{-1}), Tenacity (g tex^{-1}), Elongation Percentage (%) and Ginning Percent (%) (Table 4).

The highest UHML (mm) length has been recorded with T_5 while T_{10} was statistically at par with it and recorded 3.49% and 3.06% longer UHML than the T_1. In the case of uniformity index and micronaire value; different treatments do not record any statistically significant result. Tenacity (g tex^{-1}) of the cotton fibre has been influenced due to different treatments and T_5, T_2, T_{10}, T_{11}, T_7, T_9, and T_4 recorded similar results; among these, highest value was recorded with T_5 (9.31% more than T_1). The moisture stress often adversely affects the fibre quality; addition of organic FYM helps the plant to evade the moisture stress by storing sufficient moisture at rootzone level (Davidonis *et al.*, 2004). The highest elongation percent was recorded with T_2, which was 5.13% higher than the control, although T_5, T_9, and T_3 were at par with T_2. Ginning percent was highest in T_{11} (0.6% over control) and lowest in T_6 (2.03% less than control). Our result indicates that the nutrient management has a consequent effect on fibre quality; however, sometimes, it is not prominent (Read *et al.*, 2006). The earlier researches suggest that the most prominent factors those directly influences the quality of fibre are pH, SOC and soil phosphorous (Johnson *et al.*, 2002) however we found that even micronutrients have a role to play with fibre quality.

Correlation study

A correlation study (Table 5) among different yield attributes, yield and quality attributes indicates that strongly positive and moderately positive linear relationship is present among different yield attributes and yield. However, at the same time, these yield attributing factors have moderate to weak positive relationship with quality attributes. The seed cotton yield and cotton stalk yield are totally positively related to each other. The balanced nutrition helps in significantly better photosynthate movement in the plant, which results in better dry matter accumulation and leaf expansion which in later stages results in better development in fruiting body. An increased number and weight of fruiting body resulted better seed cotton yield. Quality aspects of the fibre, on the other hand, are more of a genetic trait hence does not significantly correlate with quantitative yield attributes.

The result of our experiment concludes that highest yield, oil content and fibre quality of cotton has been observed when recommended dose of fertilizer (60:30:30 kg N, P_2O_5, K_2O) has been conjointly applied with farmyard manure (5-ton ha^{-1}). Addition of sulphur and zinc nutrient with NPK results better than the standalone NPK application but not necessarily better than the combined application of an organic and inorganic source of nutrients.

Acknowledgement

Authors are thankful to Dr.Panjabrao Deshmukh Krishi Vidyapeeth, Akola for providing financial and research facilities.

Declaration

Authors declares there is no conflict of interest exist. Further, declare that the manuscript has not been published in any journal/book or proceedings or in any other publication or offered for publication elsewhere in substantially the same or abbreviated form, either in print or electronically.

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How to cite this article:

Bhagchand Bairwa, R. N. Katkar, Vrushali Bhende, Shrutika Gawande and Subhradip Bhattacharjee. 2020. Influence of Sulphur, Zinc and Organic Inorganic Assorted Customized Fertilizer on Yield and Quality of Cotton under Rainfed *Vertisols*. *Int.J.Curr.Microbiol.App.Sci.* 9(08): 3053-3062. doi: https://doi.org/10.20546/ijcmas.2020.908.345