Original Research Article https://doi.org/10.20546/ijcmas.2018.708.177

Effect of Different Sources and Levels of Sulphur on Growth and Yield of Maize (*Zea mays* L.)

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A B S T R A C T

A field experiment was conducted during *Kharif*, 2017 at College Farm, College of Agriculture, Rajendranagar, Hyderabad to compute the optimum dose and source of sulphur in maize and to evaluate the impact of sulphur on growth, yield attributes and yield of maize. The experiment was carried out with three different sources of sulphur (Gypsum, Ammonium Sulphate and Bentonite Sulphur) and three levels (S @ 40 kg ha^{-1}, S @ 60 kg ha^{-1} and S @80 kg ha^{-1}) and one source as urea, DAP and MOP and another source as urea, SSP and MOP comprising of eleven treatment combinations which were laid out in randomized block design and replicated thrice. In all the treatments nitrogen was applied in two split doses 50% as basal and 50% as top dressing at 45 DAS and entire dose of phosphorous, potassium and sulphur were applied as basal. Treatment T_1 was application of recommended dose of fertilizer *i.e*., N-P$_2$O$_5$-K$_2$O-S @ 200-60-50-60 kg ha^{-1} without sulphur. Treatment T_2 was application of recommended dose of fertilizer through Urea, SSP and MOP. T_3 was T_1 + application of sulphur @ 40 kg ha^{-1} through gypsum; T_4 was T_1+ application of sulphur @ 60 kg ha^{-1} through gypsum; T_5 was T_1 + application of sulphur @ 80 kg ha^{-1} through gypsum. T_6 was T_1 + application of sulphur @ 40 kg ha^{-1} through ammonium sulphate. T_7 was T_1 + application of sulphur @ 60 kg ha^{-1} through ammonium sulphate. T_8 was T_1 + application of sulphur @ 80 kg ha^{-1} through ammonium sulphate. T_9 was T_1+ application of sulphur @ 40 kg ha^{-1} through bentonite sulphur. T_{10} was T_1+ application of sulphur @ 60 kg ha^{-1} through bentonite sulphur. T_{10} was T_1 + application of sulphur @ 80 kg ha^{-1} through bentonite sulphur. Highest grain (5596 kg ha^{-1}) and stover yield (6995 kg ha^{-1}) was recorded by treatment T_{10} (S@60 kg ha^{-1} through bentonite sulphur) followed by treatment T_2 (5581 and 6976 kg ha^{-1}) S@40 kg ha^{-1} through urea, SSP and DAP. Highest gross returns were recorded by T_{10} (Rs. 80139 ha^{-1}) followed by T_2 (Rs. 78623 ha^{-1}) though highest B: C ratio was recorded by T_2 because of higher cost of bentonite sulphur fertilizer.

Introduction

Maize is one of the important cereal crops in the world's agricultural economy both as food for humans and feed for animals, because of its higher yield potential compared to other cereals it is called as "Queen of Cereals". Maize is a miracle crop as there is no cereal crop on earth which has so immense potentiality and nutrient extensive feature.

India is ranks 6th in World's maize production. In India, maize is cultivated in an area of 8.85 lakh ha with a total production of 22.84 lakh tons and productivity of 2580kg ha^{-1} (Department of Economics and Statistics, 2017). Maize has been considered as highly nutrient responsive crop with wide adaptability and compatibility under diverse soil and climatic conditions. It has a variety of uses and has become popular due to its nutritive value and wide spread acceptability by humans. In India, maize (*Zea mays* L.) is the third most important cereal after rice and wheat that provides food, feed, fodder and serves as a source of raw material for developing hundreds of industrial products *viz.,* starch, protein, oil, alcoholic beverages, food sweeteners, pharma, cosmetics, bio-fuel etc. Maize contains 4.5% oil which is ideal cooking medium for various recipes. About 66% of total maize production is used as feed, 25% as food and industrial products while the rest is used as seed *etc.* (Binod kumar *et al.,* 2016). Due to higher yield potential, short growing period, high value food, forage and feed for livestock, poultry and a cheaper source of raw material for agro based industry, it is increasingly gaining importance in cropping systems. Among many reasons for low productivity, mismanagement of plant nutrition and agronomic practices are considered to be the major ones. Hence, for getting higher maize production of better quality, there is a need to improve these two major components of production technology.

Sulphur is one of the 16 elements essential for crop production (Marshner, 1995). Sulphur is considered as the fourth major nutrient element for crops (Platou and Jones, 1982). It is typically considered a secondary macronutrient (along with calcium and magnesium), but is essential for maximum crop yield and quality. Sulphur is often ranked immediately behind nitrogen, phosphorus and potassium in terms of importance to crop productivity (Krishnamoorthy, 1989 and Patil 1998). Sulphur is a component of the amino acids cysteine, cystine and methionine (Gangadhara *et al.,* 1990 and Kumar and Yadav, 2007) making it essential for protein synthesis in plants. Plants also contain a large variety of other organic sulphur compounds such as glutathione. Sulphur is also a constituent of vitamins (thiamine and biotin), glycosides and co-enzyme A (Tisdale *et al.,* 1985).

In recent years sulphur deficiency has become an increasing problem in agriculture. Saalbach (1973) reported maize yield loss to an extent of 10 to 30% and Pal and Singh (1992) upto 35% due to Sulphur deficiency. In general, cereals have high yield potential and low sulphur requirement. The sulphur requirement of cereals to produce one ton of cereals is low but uptake per unit area becomes almost equal to that of oilseeds mainly due to higher productivity of cereals (Sutar *et al.,* 2017). Sulphur is an essential nutrient for all organisms due to its function in a large variety of processes (Gangadhara *et al.,* 1990).

In the early 1990's, sulphur deficiencies in Indian soils were estimated to occur in about 130 districts. More recently, soil fertility surveys by the ICAR system (analysis of 60,000 soil samples 2009) have shown sulphur deficiencies to be a wide spread problem. A soil is considered deficient in S if it tests less than 10 mg S/kg soil extractable with 0.15% $CaCl_2$. Sulphur status of Indian soils is going down with each passing year. Close to 70% of soil samples analyzed by the ICAR system and TSI-FAI-IFA (The Sulphur Institute) project and other programs have been found to be either deficient or marginal in plant available sulphur. Soil analysis and crop response data generated by the TSI-FAI-IFA project (1997-2006) re-enforced the findings of the ICAR system. Based on reported results, out of over 49,000 soil samples

analyzed across 18 states, 46% of samples were deficient in sulphur and another 30% were medium in available sulphur which could be considered as potentially sulphur deficient. These data prove that sulphur deficiencies are a critical problem in 40-45% of districts translating into 57-64 million ha of net sown area.

Materials and Methods

A field experiment was carried out during *kharif* 2017 at College Farm, College of Agriculture, Rajendranagar, Hyderabad which is geographically situated at 17° 19' N latitude and 78° 23' E longitude and an altitude of 542.3 m above mean sea level. It is in the Southern Telangana agro-climatic zone of Telangana. According to Troll's climatic classification, it falls under semi-arid tropics (SAT). The experimental site was sandy loam in texture with pH (608), EC ($0.28dSm^{-1}$), and OC (Low).The soil was low in available nitrogen (120 kg ha^{-1}) and available sulphur (21.2kg ha^{-1}) and high in available phosphorus (74 kg ha^{-1}) and available potassium (308 kg ha^{-1}). Bulk density, porosity and moisture holding capacity were also determined by Keen's cup method (initial and final). The experiment was carried out with three different sources of sulphur (Gypsum, Ammonium Sulphate and Bentonite Sulphur) and three levels (S @ 40 kg ha^{-1}, S @ 60 kg ha^{-1} and S @80 kg ha^{-1}) and one source as urea, DAP and MOP and another source as urea, SSP and MOP comprising of eleven treatment combinations which were laid out in randomized block design and replicated thrice.

In all the treatments nitrogen was applied in two split doses 50% as basal and 50% as top dressing 45 DAS and entire dose of phosphorous, potassium and sulphur were applied as basal. Treatment T_1 was application of recommended dose of fertilizer *i.e.*, N-P_2O_5-K_2O-S @ 200-60-50-60 kg ha^{-1} without

sulphur. Treatment T_2 was application of recommended dose of fertilizer through Urea, SSP and MOP. T_3 was T_1 + application of sulphur @ 40 kg ha^{-1} through gypsum; T_4 was T_1+ application of sulphur @ 60 kg ha^{-1} through gypsum; T_5 was T_1 + application of sulphur @ 80 kg ha^{-1} through gypsum. T_6 was T_1 + application of sulphur @ 40 kg ha^{-1} through ammonium sulphate. T_7 was T_1 + application of sulphur @ 60 kg ha^{-1} through ammonium sulphate. T_8 was T_1 + application of sulphur @ 80 kg ha^{-1} through ammonium sulphate. T_9 was T_1+ application of sulphur @ 40 kg ha^{-1} through bentonite sulphur. T_{10} was T_1+ application of sulphur @ 60 kg ha^{-1} through bentonite sulphur. T_{10} was T_1 + application of sulphur @ 80 kg ha^{-1} through bentonite sulphur. Initial (30 DAS) and final (harvest) plant population was recorded. Plant samples were collected from gross plot to record dry matter production, plant height and LAI. To determine grain yield cobs from net plot were collected, sundried till 12% moisture attained and weighed. To determine stover yield stalk were harvested to ground level and sundried.

Results and Discussion

Initial and final plant population was taken at 30 DAS and harvest and was found non-significant when analysed statistically among the treatments. Plant height was non-significant at 30 DAS but at 60 DAS, 90 DAS and harvest T_2 and T_{10} recorded highest values which were on par followed by T_4 and T_7. Lowest plant height was recorded by T_1 (Table 1). Different sources and levels of sulphur were non-significant with respect to crop phenology. Different sources and levels of sulphur showed significant influence on LAI (Table 2) and TDM (Table 3) at 30 DAS, 60 DAS, 90 DAS and harvest, T_2 and T_{10} recorded highest LAI and TDM values which were on par followed by T_4 and T_7. Least LAI and TDM was achieved by T_1.

Table.1 Plant height of maize (cms) at different stages as influenced by different sources and levels of Sulphur

	Treatments	30 DAS	60 DAS	90 DAS	Harvest
T_1	Application of recommended dose of NPK through Urea, DAP and MOP	50.4	128.4	144.7	144.7
T_2	Application of recommended dose of NPK through Urea, SSP and MOP (sulphur supplied through SSP is 41.25 kg ha $^{-1)}$	51.3	134.1	150.6	150.4
T_3	T_1 + Application of Sulphur @ 40 kg ha^{-1} through gypsum	50.8	132.6	149.0	149.0
T_4	T_1 + Application of Sulphur @ 60 kg ha^{-1} through gypsum	50.6	133.9	150.3	150.3
T_5	T_1 + Application of Sulphur @ 80 kg ha^{-1} through gypsum	51.0	133.6	149.9	149.9
T_6	T_1 +Application of Sulphur @ 40 kg ha^{-1} through Ammonium Sulphate	50.7	132.4	148.9	148.9
T_7	T_1 +Application of Sulphur @ 60 kg ha^{-1} through Ammonium Sulphate	50.5	133.9	150.3	150.3
T_8	T_1 +Application of Sulphur @ 80 kg ha^{-1} through Ammonium Sulphate	50.7	133.5	150.1	150.1
T_9	T_1 +Application of Sulphur @ 40 kg ha^{-1} through Bentonite Sulphur	50.4	131.7	148.0	148.0
T_{10}	T_1 + Application of Sulphur @ 60 kg ha^{-1} through Bentonite Sulphur	51.7	134.6	151.0	151.0
T_{11}	T_1 + Application of Sulphur @ 80 kg ha^{-1} through Bentonite Sulphur	50.9	133.8	150.3	150.3
	S. E(m)±	0.64	0.55	0.55	0.55
	CD (5%)	NS	1.15	2.17	2.17

	Treatments	30 DAS	60 DAS	90 DAS	Harvest
Table.2 LAI of maize at different stages as influenced by different sources and levels of Sulphur					
T_1	Application of recommended dose of NPK through Urea, DAP and MOP	0.32	5.8	4.6	3.6
T_2	Application of recommended dose of NPK through Urea, SSP and MOP (sulphur supplied through SSP is 41.25 kg ha^{-1})	0.40	6.4	5.2	4.2
T_3	T_1 + Application of Sulphur @ 40 kg ha^{-1} through gypsum	0.38	6.0	4.8	3.9
T_4	T_1 + Application of Sulphur @ 60 kg ha^{-1} through gypsum	0.40	6.3	5.1	4.2
T_5	T_1 + Application of Sulphur @ 80 kg ha^{-1} through gypsum	0.40	6.3	5.1	4.1
T_6	T_1 +Application of Sulphur @ 40 kg ha^{-1} through Ammonium Sulphate	0.38	6.0	4.7	3.9
T_7	T_1 +Application of Sulphur @ 60 kg ha^{-1} through Ammonium Sulphate	0.40	6.3	5.1	4.2
T_8	T_1 +Application of Sulphur @ 80 kg ha^{-1} through Ammonium Sulphate	0.40	6.3	5.1	4.1
T_9	T_1 +Application of Sulphur @ 40 kg ha^{-1} through Bentonite Sulphur	0.38	6.0	4.8	3.9
T_{10}	T_1 + Application of Sulphur @ 60 kg ha^{-1} through Bentonite Sulphur	0.41	6.5	5.2	4.2
T_{11}	T_1 + Application of Sulphur @ 80 kg ha^{-1} through Bentonite Sulphur	0.39	6.3	5.0	4.1
	S. E(m)$\pm$	0.01	0.03	0.02	0.06
	CD (5%)	0.02	0.45	0.36	0.13

	Table.3 Dry matter production (g plant^{-1})of maize at different stages as influenced by different sources and levels of sulphur				
	Treatments	**30 DAS**	**60 DAS**	**90 DAS**	**Harvest**
T$_1$	Application of recommended dose of NPK through Urea, DAP & MOP	10.2	80.0	126.2	138.2
T$_2$	Application of recommended dose of NPK through Urea, SSP & MOP (sulphur supplied through SSP is 41.25 kg ha$^{-1)}$	13.3	89.3	129.3	141.3
T$_3$	T$_1$ + Application of Sulphur @ 40 kg ha^{-1} through gypsum	10.3	85.0	126.3	138.3
T$_4$	T$_1$ + Application of Sulphur @ 60 kg ha^{-1} through gypsum	12.3	87.3	128.3	140.3
T$_5$	T$_1$ + Application of Sulphur @ 80 kg ha^{-1} through gypsum	12.3	81.3	128.3	140.3
T$_6$	T$_1$ +Application of Sulphur @ 40 kg ha^{-1} through Ammonium Sulphate	10.3	87.7	126.3	138.3
T$_7$	T$_1$ +Application of Sulphur @ 60 kg ha^{-1} through Ammonium Sulphate	12.7	88.7	128.7	140.7
T$_8$	T$_1$ +Application of Sulphur @ 80 kg ha^{-1} through Ammonium Sulphate	12.3	86.7	128.3	140.3
T$_9$	T$_1$ +Application of Sulphur @ 40 kg ha^{-1} through Bentonite Sulphur	10.7	82.7	126.7	138.7
T$_{10}$	T$_1$ + Application of Sulphur @ 60 kg ha^{-1} through Bentonite Sulphur	13.3	89.3	129.3	141.3
T$_{11}$	T$_1$ + Application of Sulphur @ 80 kg ha^{-1} through Bentonite Sulphur	11.6	88.3	127.6	139.6
	S. Em. +/-	0.48	1.04	1.02	1.02
	CD (5%)	1.00	2.17	1.17	1.17

Table.4 Yield attributes of maize as influenced by different sources and levels of Sulphur		No of cobs plant-1	No. of rows cob^{-1}	No. of grains row^{-1}	No of grains cob^{-1}
	Treatments				
T_1	Application of recommended dose of NPK through Urea, DAP and MOP	1.0	12.0	20.7	244.0
T_2	Application of recommended dose of NPK through Urea, SSP and MOP (sulphur supplied through SSP is 41.25 kg ha $^{-1)}$	1.0	13.3	23.7	306.0
T_3	T_1 + Application of Sulphur @ 40 kg ha^{-1} through gypsum	1.0	13.3	22.3	277.3
T_4	T_1 + Application of Sulphur @ 60 kg ha^{-1} through gypsum	1.0	13.3	22.7	302.7
T_5	T_1 + Application of Sulphur @ 80 kg ha^{-1} through gypsum	1.0	12.7	21.3	284
T_6	T_1 +Application of Sulphur @ 40 kg ha^{-1} through Ammonium Sulphate	1.0	13.3	22.3	281.3
T_7	T_1 +Application of Sulphur @ 60 kg ha^{-1} through Ammonium Sulphate	1.0	13.3	22.8	302.7
T_8	T_1 +Application of Sulphur @ 80 kg ha^{-1} through Ammonium Sulphate	1.0	12.7	22.6	286.7
T_9	T_1 +Application of Sulphur @ 40 kg ha^{-1} through Bentonite Sulphur	1.0	13.3	22.3	282.0
T_{10}	T_1 + Application of Sulphur @ 60 kg ha^{-1} through Bentonite Sulphur	1.0	13.3	24.0	320.0
T_{11}	T_1 + Application of Sulphur @ 80 kg ha^{-1} through Bentonite Sulphur	1.0	12.7	22.8	294.0
	S. E(m)$\pm$	0.0	0.7	0.7	18.1
	CD (5%)	NS	NS	1.4	37.9

Table.5 Test weight (g), grain yield (kg ha^{-1}) and stover yield (kg ha^{-1}) of maize as influenced by different sources and levels of Sulphur

Treatments		Test weight (g)	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})
T$_1$	Application of recommended dose of NPK through Urea, DAP & MOP	27.1	5477	6792
T$_2$	Application of recommended dose of NPK through Urea, SSP & MOP	31.3	5581	6976
T$_3$	T$_1$ + Application of Sulphur @ 40 kg ha^{-1} through gypsum	28.7	5527	6908
T$_4$	T$_1$ + Application of Sulphur @ 60 kg ha^{-1} through gypsum	31.1	5561	6933
T$_5$	T$_1$ + Application of Sulphur @ 80 kg ha^{-1} through gypsum	29.3	5550	6930
T$_6$	T$_1$ +Application of Sulphur @ 40 kg ha^{-1} through Ammonium Sulphate	29.0	5519	6898
T$_7$	T$_1$ +Application of Sulphur @ 60 kg ha^{-1} through Ammonium Sulphate	31.1	5561	6950
T$_8$	T$_1$ +Application of Sulphur @ 80 kg ha^{-1} through Ammonium Sulphate	30.7	5552	6945
T$_9$	T$_1$ +Application of Sulphur @ 40 kg ha^{-1} through Bentonite Sulphur	29.3	5518	6898
T$_{10}$	T$_1$ + Application of Sulphur @ 60 kg ha^{-1} through Bentonite Sulphur	31.5	5596	6995
T$_{11}$	T$_1$ + Application of Sulphur @ 80 kg ha^{-1} through Bentonite Sulphur	29.3	5561	6993
	S. E(m)$\pm$	1.1	23.8	29.71
	CD (5%)	2.2	49.8	62.09

Table.6 Sulphur uptake (kg ha$^{-1)}$of maize in stover and seed as influenced by different sources and levels of Sulphur

	Treatments	Sulphur		Sulphur uptake in stover and seed
		Stover	seed	
T$_1$	Application of recommended dose of NPK through Urea, DAP and MOP	12.15	5.67	17.82
T$_2$	Application of recommended dose of NPK through Urea, SSP and MOP (sulphur supplied through SSP is 41.25 kg ha $^{-1)}$	12.88	10.24	23.12
T$_3$	T$_1$ + Application of Sulphur @ 40 kg ha^{-1} through gypsum	13.21	10.03	23.24
T$_4$	T$_1$ + Application of Sulphur @ 60 kg ha^{-1} through gypsum	16.34	14.25	30.59
T$_5$	T$_1$ + Application of Sulphur @ 80 kg ha^{-1} through gypsum	15.90	13.26	29.16
T$_6$	T$_1$ +Application of Sulphur @ 40 kg ha^{-1} through Ammonium Sulphate	13.44	10.26	23.70
T$_7$	T$_1$ +Application of Sulphur @ 60 kg ha^{-1} through Ammonium Sulphate	16.42	14.38	30.80
T$_8$	T$_1$ +Application of Sulphur @ 80 kg ha^{-1} through Ammonium Sulphate	15.86	13.31	29.17
T$_9$	T$_1$ +Application of Sulphur @ 40 kg ha^{-1} through Bentonite Sulphur	13.54	10.37	23.91
T$_{10}$	T$_1$ + Application of Sulphur @ 60 kg ha^{-1} through Bentonite Sulphur	16.46	14.83	31.29
T$_{11}$	T$_1$ + Application of Sulphur @ 80 kg ha^{-1} through Bentonite Sulphur	15.96	13.69	29.65
	S. E(m)±	0.29	0.14	0.33
	CD (5%)	0.61	0.29	0.69

Table.7 Effect of different sources and levels of sulphur on economics

	Treatments	Cost of Cultivation (Rs. ha^{-1})	Gross returns(Rs. ha^{-1})	Net returns(Rs.ha^{-1})	B:C ratio
T$_1$	Application of recommended dose of NPK through Urea, DAP and MOP	22936.00	77176.65	50109.30	2.59
T$_2$	Application of recommended dose of NPK through Urea, SSP and MOP (sulphur supplied through SSP is 41.25 kg ha$^{-1)}$	22869.57	78623.80	52154.23	3.04
T$_3$	T$_1$ + Application of Sulphur @ 40 kg ha^{-1} through gypsum	23636.72	77499.80	50354.86	2.93
T$_4$	T$_1$ + Application of Sulphur @ 60 kg ha^{-1} through gypsum	23698.88	77537.27	49983.59	2.92
T$_5$	T$_1$ + Application of Sulphur @ 80 kg ha^{-1} through gypsum	24118.88	77452.97	48962.73	2.87
T$_6$	T$_1$ +Application of Sulphur @ 40 kg ha^{-1} through Ammonium Sulphate	24677.98	77518.53	50239.65	2.82
T$_7$	T$_1$ +Application of Sulphur @ 60 kg ha^{-1} through Ammonium Sulphate	25588.46	77527.90	49829.02	2.75
T$_8$	T$_1$ +Application of Sulphur @ 80 kg ha^{-1} through Ammonium Sulphate	26522.80	77649.66	49530.79	2.64
T$_9$	T$_1$ +Application of Sulphur @ 40 kg ha^{-1} through Bentonite Sulphur	25452.00	79729.07	51171.83	2.75
T$_{10}$	T$_1$ + Application of Sulphur @ 60 kg ha^{-1} through Bentonite Sulphur	26178.00	80139.34	50236.60	2.71
T$_{11}$	T$_1$ + Application of Sulphur @ 80 kg ha^{-1} through Bentonite Sulphur	27348.00	79897.66	48707.94	2.57
	S. E(m)±		275.00	274.00	0.01
	CD (5%)		818.00	813.98	0.02

Yield attributes *i.e.,* number of cobs plant[-1] and number of rows cob[-1] were non-significant when analysed statistically but number of grains row[-1] and number of grains cob[-1] were significant among different treatments, T_2 and T_{10} recorded highest values which were on par followed by T_4 and T_7. Lowest data was recorded by T_1 (Table 4).

Highest grain (5596 kg ha^{-1}) and stover yield (6995 kg ha^{-1}) was recorded by treatment T_{10} (S@60 kg ha^{-1} through bentonite sulphur) followed by treatment T_2 (5581 and 6976 kg ha^{-1}) S@40 kg ha^{-1} through urea, SSP and DAP. Treatments T_7 and T_4 were statistically on par with each other. Similarly treatments T_3, T_6 and T_9 were statistically on par with each other followed by T_5, T_9 and T_{11} which were in turn on par (Table 5). Lowest grain (5477kg ha^{-1}) and stover yield (6847 kg ha^{-1}) was recorded by T_1 which was non sulphur treatment.

Initial and final soil physico chemical properties like bulk density, porosity, maximum water holding capacity, soil texture, pH, Ec, OC were found non-significant when analysed statistically. Initial and final nutrient status of soil was also non-significant.

Highest sulphur uptake in stover and seed was noted by T_{10} and lowest by T_1 (Table 6).

Highest gross returns were recorded by T_{10} (Rs. 80139 ha^{-1}) followed by T_2 (Rs. 78623 ha^{-1}) though highest B: C ratio was recorded by T_2 because of higher cost of bentonite sulphur fertilizer (Table 7).

Highest growth and yield parameters were recorded by treatment T_{11} followed by treatment T_2, but highest B: C ratio was recorded by treatment T_2. Variation in soil physico chemical properties was non-significant among different treatments but

sulphur uptake studies indicate that uptake was highest at 60 kg ha^{-1} and 80kg ha^{-1} which were statistically on par.

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