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EFFECT OF PHOSPHORUS AND SULPHUR APPLICATIONS ON GROWTH, YIELD AND QUALITY OF TOMATO IN CALCAREOUS SOIL

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ABSTRACT
The present study was conducted to examine the effect of phosphorus and sulphur applications on growth, yield and quality of tomato in medium black calcareous clay loam soil. Phosphorus (P) was tested at rates of 312.5, 250, 187.5, 125 and 0 kg ha^{-1} in combination with sulphur (S) applied at rates of 2.5, 1.5, 0.5 and 0 percent equivalent to calcium carbonate content in calcareous soil. Increased rate of P and S applications enhanced the tomato growth recording maximum height (86.53 cm), internode length (7.54 cm), branches per plant (9.75) and flowers per cluster (7.49) in treatment receiving $P_{312.5} + S_{2.5}$. However, highest fruit setting rate (69.37%), number of fruits per cluster (4.94), fruits per plant (41.17), fruit weight (77.60 g) and fruit diameter (5.17cm) was obtained with application of $P_{250} + S_{2.5}$. Hence, application of 250 kg/ha Phosphorus along with 2.5 per cent S equivalent to $CaCO_3$ content in calcareous soil was found ideal for tomato, that resulted in maximum fruit yield (3.19 kg plant^{-1}) and better fruit quality *viz*., total soluble solids (4.71°Bx), ascorbic acid (17.43 mg 100g^{-1}) and â-carotene (3.61 mg 100 g^{-1}) content.

INTRODUCTION

Tomato is one of the popular and most consumed vegetables in the world and is treated as 'protective food' as it is a good source of mineral nutrients *viz.,* potassium, calcium and iron, vitamins *viz.,* A, B and C and antioxidants *viz.,* lycopene, carotene, organic acids and phenols (Giovanelli and Paradiso, 2002). Its quality and productivity depends on supple mentation of nutrients through soil fertilizers, amendments and organic manure as it has good response to nutrient application (Malash *et al.,* 2008) and semi-tolerant to soil salinity (Modaish *et al.,* 1989). Hence, integrated approach of fertilizer scheduling and organic manures application was found beneficial under arid condition (Singh *et al.*, 2013) that usually possess high calcium carbonate content in soil.

Amongst the essential nutrient elements, phosphorus is the most important major nutrient, because of its significant role in chemical and biochemical metabolism. It has critical role in energy transfer metabolism, as structural component of cell membranes and nucleic acids and for root growth and development (Tisdale *et al.*, 2007). Generally, soluble P fertilizers are applied to manage P fertility in calcareous soils. But, their efficiency is very low (Aulakh *et al.,* 2007), because of its rapid adsorption in large amounts on $CaCO_3$ and its precipitation with Ca as insoluble compounds *viz*., di-calcium phosphate, octa-calcium phosphate, tri-calcium phosphates and ultimately hydroxy-apatites. This will gradually decrease P solubility in soil and consequent availability to plants (Tunesi *et al.,* 1999; Leytem and Mikkelsen, 2005). Acidification of calcareous soil through application of soil amendments, containing sulphur compounds helps in release of fixed P through bio-chemical reactions and desorption processes (Soaud *et al*., 2011). Besides, sulphur has significant role as secondary essential nutrient in synthesis of proteins and vitamins and as co-factor for many enzymes (Kertesz and Mirleau, 2004). But, acidification of entire calcareous soil requires higher quantity of sulphur which is an impractical approach to adopt.

Hence, the present study is conducted with an objective to ascertain the quantity of sulphur required for effective transformation of applied and native phosphorus, there by its effect on growth, yield and quality of tomato in calcareous soil.

MATERIALS AND METHODS

Experimental site and weather data

A field experiment was conducted from July to December 2013 at Regional Horticultural Research and Extension Centre (RHREC), University of Horticultural Sciences, Bagalkot, situated in the Northern Dry Zone (Zone - 3) of Karnataka, India. The experimental site was located at 75°42' East longitude and 16°10' North latitude at an altitude of 542m above mean sea level. The initial chemical properties of experimental soil are shown in Table 1. The total rainfall of 230.1 mm was received during crop growth period. The mean relative humidity of morning and evening were 79 per cent and 56.5 per cent respectively and minimum and maximum air temperatures were 29.76°C and 18.05°C, during crop growth period.

Crop management

Tomato hybrid '*Arka Ananya*' released by Indian Institute of Horticultural Research (IIHR), Hesaraghatta, Bangalore, India were raised in a seedbed and 30 days old, uniform, healthy seedlings were transplanted at spacing of 45 cm X 90 cm. The intercultural operations *viz*., gap filling, weeding, staking, irrigation *etc*., were carried out as per standard management practice (Anon, 2013).

Experimental design and treatments

The experiment was conducted in a factorial randomized block design (Clarke and Kempson, 1997) with two factors and replicated three times. The treatments comprised of five different levels of P applied at the rate 312.5, 250, 187.5, 125 and 0 kg ha^{-1}as factor-1 and four different levels of sulphur applied at the rate of 2.5, 1.5, 0.5 and 0 per cent equivalent to calcium carbonate ($CaCO_3$) as factor-2.

Application of fertilizers

All treatments received uniform application of organic manure (38 t ha^{-1}) fifteen days before transplanting. Full dose of potassium (250 kg ha^{-1}) and phosphorus, as per treatment requirement, were applied using muriate of potash and di-ammonium phosphate at the time of transplanting. The nitrogen (250 kg ha^{-1}) was applied in two equal splits at the time of transplanting and 30 days after transplanting using di-ammonium phosphate and urea. Amount of sulphur required to neutralize $CaCO_3$ content as per the treatment requirement was calculated on weight/weight basis using the following relationship and supplied using sulphonite (90% S) at the time of transplanting (Prasad, 1970).

$$\frac{1\ \text{meq}\ CaCO_3}{100\ \text{g soil}} \quad \frac{1\text{meq}\ S^o}{100\ \text{g soil}}$$

Data Collection

The growth and yield parameters were recorded from five randomly selected plants from each plot by avoiding the border effect for higher precision. The parameters such as plant height, internodal length and number of branches per plant, flowers per cluster were determined at full bloom stage, fruits per cluster was recorded at breaker stage and per cent fruit setting rate was calculated using the ratio of the number of fruits to the number of flowers per cluster (Hazra *et al.,* 2011) as following,

$$\text{FSR\%} \quad \frac{\text{Number of fruitts}}{\text{Number of flowers}} \quad 100$$

Ripened fruits were harvested in four pickings starting from 70 to 100 days after planting, counted and weighed to record fruits per plant, fruit weight (g) and fruit yield (kg $plant^{-1}$). The broadest fruit diameter (horizontal axis) was measured using vernier callipers and expressed in centimetre.

Biochemical analysis

Fully ripened representative tomato fruits from second picking were blended using stainless steel mixer to determine quality parameters. Total soluble solids (TSS) was measured by hand refractometer and expressed in °Brix (0-32 degree brix). Ascorbic acid was determined using 2, 6- dichlorophenol indophenol dye method (Thimmaiah, 1999) and β-carotene content was estimated by calorimetric method using acetone, sodium sulphate and petroleum ether and colour intensity was measured using UV-Visible spectrophotometer at 452 nm (AOAC, 2004). The data were statistically analysed using Fisher's method of analysis of variance (Sunderaraj *et al*., 1972).

RESULTS AND DISCUSSION

Initial soil properties

The soil of the area under investigation was moderately

Table 1: Initial chemical properties of experimental soil

Soil chemical properties	Value
Soil pH (1:2.5)	8.67
Electrical conductivity (dS m^{-1}) (1:2.5)	1.02
Organic carbon (%)	0.47
CEC (cmol (p^+) kg^{-1})	34.80
Available N (kg ha^{-1})	298.30
Available P_2O_5 (kg ha^{-1})	33.45
Available K_2O (kg ha^{-1})	384.80
Exchangeable Ca (cmol (p^+) kg^{-1})	26.84
Exchangeable Mg (cmol (p^+) kg^{-1})	4.91
Available S (mg kg^{-1})	15.66
DTPA- Zn (mg kg^{-1})	0.89
DTPA- Fe (mg kg^{-1})	4.74
DTPA- Mn (mg kg^{-1})	3.84
DTPA- Cu (mg kg^{-1})	1.56
Acid soluble $CaCO_3$ (%)	6.50

Table 2: Growth parameters of tomato as influenced by different levels of phosphorus and sulphur application in calcareous soil

Treatments	Plant height (cm)	Internodal length (cm)	Number of branches $plant^{-1}$
$P_{312.5}+S_{2.5}$	86.53	7.54	9.75
$P_{312.5}+S_{1.5}$	85.99	7.39	9.63
$P_{312.5}+S_{0.5}$	85.2	7.25	8.22
$P_{312.5}+S_0$	79.08	6.98	7.68
$P_{250}+S_{2.5}$	86.07	7.49	9.53
$P_{250}+S_{1.5}$	83.67	7.38	8.36
$P_{250}+S_{0.5}$	81.03	7.24	7.78
$P_{250}+S_0$	78.47	6.97	7.38
$P_{187.5}+S_{2.5}$	83.42	7.28	9.5
$P_{187.5}+S_{1.5}$	82.01	7.18	8.26
$P_{187.5}+S_{0.5}$	78.12	7.1	7.48
$P_{187.5}+S_0$	77.44	6.74	7.25
$P_{125}+S_{2.5}$	79.59	7.25	8.67
$P_{125}+S_{1.5}$	80	7.14	8.11
$P_{125}+S_{0.5}$	77.2	7	6.96
$P_{125}+S_0$	75.33	6.7	6.68
$P_0+S_{2.5}$	77.68	6.53	7.31
$P_0+S_{1.5}$	77.6	6.48	7.15
$P_0+S_{0.5}$	73.67	6.44	6.8
P_0+S_0	64.78	6.14	6.44
S Em ±P	0.55	0.012	0.091
S	0.49	0.011	0.081
PXS	1.11	0.024	0.182
CD@5%P	1.58	0.035	0.26
S	1.41	0.031	0.232
PXS	3.17	0.070	0.52

Table 3: Effect of phosphorus and sulphur application on yield parameters and yield of tomato in calcareous

Treatments	Flowers cluster^{-1}	FSR%	Fruits cluster^{-1}	Fruits plant^{-1}	Fruit diameter	Fruit weight	Fruit yield (kg plant^{-1})
$P_{312.5}+S_{2.5}$	7.49	58.69	4.39	36.69	5.06	68.8	2.64
$P_{312.5}+S_{1.5}$	6.91	64.46	4.46	38.33	5.08	72.3	2.73
$P_{312.5}+S_{0.5}$	6.78	66.02	4.48	39.23	5.09	74.3	2.84
$P_{312.5}+S_{0}$	6.04	61.37	3.71	31.2	4.68	65.3	2.04
$P_{250}+S_{2.5}$	7.12	69.37	4.94	41.17	5.17	77.6	3.19
$P_{250}+S_{1.5}$	6.36	68.66	4.37	34.25	5.1	76.4	2.93
$P_{250}+S_{0.5}$	6.1	67.85	4.08	31.24	4.83	74.6	2.33
$P_{250}+S_{0}$	6.02	60.4	3.64	29.38	4.61	64.2	1.89
$P_{187.5}+S_{2.5}$	7.08	61.8	4.38	34.68	5.08	75.8	2.63
$P_{187.5}+S_{1.5}$	6.76	58.8	3.92	30.82	4.93	70.4	2.17
$P_{187.5}+S_{0.5}$	5.97	58.73	3.51	29.69	4.81	59.3	1.76
$P_{187.5}+S_{0}$	5.78	58.54	3.38	28.89	4.62	56.3	1.64
$P_{125}+S_{2.5}$	6.74	59.56	4.02	30.13	4.97	60.4	1.82
$P_{125}+S_{1.5}$	5.95	57.23	3.41	27.36	4.82	57.3	1.57
$P_{125}+S_{0.5}$	5.68	57.34	3.26	25.81	4.78	53.6	1.38
$P_{125}+S_{0}$	5.64	56.91	3.21	26.93	4.6	54.21	1.46
$P_{0}+S_{2.5}$	5.4	57.84	3.12	24.94	4.78	53.2	1.33
$P_{0}+S_{1.5}$	5.38	57.83	3.11	24.64	4.78	51.8	1.28
$P_{0}+S_{0.5}$	5.34	57.41	3.07	24.56	4.63	51.2	1.26
$P_{0}+S_{0}$	5.35	56.76	3.03	24.16	4.58	50.8	1.2
S. Em ±P	0.074	0.532	0.055	0.59	0.021	1.1	0.03
S	0.066	0.476	0.049	0.53	0.019	0.99	0.03
PXS	0.148	1.065	0.111	1.18	0.043	2.21	0.07
CD@5%P	0.212	1.522	0.159	1.69	0.062	3.16	0.09
S	0.19	1.362	0.142	1.51	0.056	2.82	0.08
PXS	0.425	3.045	0.318	3.38	0.125	6.31	0.19

calcareous in nature (Table 1) with 6.5% total calcium carbonate equivalent (Day, 1983). The accumulation of $CaCO_3$ in these soils might be due to semi-arid climatic conditions and drainage problems of the area (Dhir *et al.,* 1979). Based on soil test data, the soil sample was found to contain low in organic carbon (0.47%) due to poor vegetation and high rate of organic matter decomposition under hyper-thermic temperature regime which leads to high oxidising conditions (Kameriya, 1995). Soil possessed alkaline pH (8.67) with EC of 1.02 dS m^{-1}. Relative high pH of the soil is due to high base saturation of soils (Kumar *et al.,* 1997). The major nutrients N, P_2O_5 and K_2O (298.3, 33.45 and 384.8 kg ha^{-1} respectively) were medium in availability. The soil CEC was 34.8 c mol (p$^+$) kg^{-1}, of which exchangeable Ca and Mg occupied 26.84 and 4.91 c mol (p$^+$) kg^{-1} respectively. Available sulphur was 15.66 mg kg^{-1} and DTPA extractable iron, zinc, manganese and copper were 4.74, 0.89, 3.84 and 1.56 mg kg^{-1} respectively.

Effect of phosphorus and sulfur application on growth of tomato in calcareous soil

Application of different rates of P and S significantly influenced the growth parameters of tomato in calcareous soil (Table 2). Application of S at 2.5 per cent equivalent to $CaCO_3$ content along with P at 312.5 kg ha^{-1} recorded highest plant height (86.53 cm), internodal length (7.54 cm) and number of branches (9.75) which was on par with the treatment receiving P_{250} and $P_{187.5}$. Application of only P without S from 0 to 312.5 kg ha^{-1} enhanced plant height from 64.78 to 79.08 cm. Similarly, increasing S rate without P improved plant height to 77.68 cm with $S_{2.5}$ as compared to 73.67 cm with $S_{0.5}$. The results are in conformity with the works De-groot *et al.*, (2002) and Nawaz *et al*. (2012). They reported enhanced tomato height with application of P and S. Phosphorus helps in better root growth and to overcome transplantation shock. The application of S solubilize native $CaCO_3$ and to enhance P availability in calcareous soil, thus, getting the advantage of P application (Rongzhong *et al.,* 2011). Besides, S being an essential element helps in plant growth and development through synthesis of proteins and chlorophyll (Orman and Kaplan, 2011).

Internodal length is manifestation of plant nutrient uptake and hormonal impact. However, better nutrient availability and uptake is crucial for stem elongation (Yadav *et al*., 2004 and Colpan *et al.,* 2013). In the present study maximum intermodal length was recorded in $P_{312.5}$ + $S_{2.5}$ (86.53 cm). Number of branches with the application of $P_{312.5}$+ $S_{2.5}$ (9.75) was on par with $P_{312.5}$+ $S_{1.5}$ (9.63) and P_{250}+ $S_{2.5}$ (9.53) and P_{125} + $S_{2.5}$ (9.75). Optimum number of branches is essential for obtaining higher productivity. Too many branches may overshadow each other and may decrease cluster number and fruit setting rate, whilst, too less number will have negative impact on tomato yield (Haque *et al*., 2011).

Effect of phosphorus and sulfur application on yield and yield parameters of tomato in calcareous soil

Number of flowers per cluster was high with application of P_{325} + $S_{2.5}$ (7.49) but, its fruit setting rate was less (58.69%) resulting in decreased number of fruits per cluster (4.39) and fruits per plant (36.69) compared to P_{250} + $S_{2.5}$. Application of P_{250} + $S_{2.5}$ was found optimum for better flowers (7.12) and fruits per cluster (4.94), fruits per plant (41.17), fruit setting rate (69.37%) and fruit diameter (5.17 cm). This was followed by $P_{312.5}$ + $S_{0.5}$ and P_{250} + $S_{1.5}$ which recorded on par flowers per cluster (6.78 and 6.36 respectively), fruits per cluster (4.48

Table 4: Effect of different levels of phosphorus and sulphur application on Quality of tomato fruits in calcareous soil.

Treatments	TSS	Ascorbic acid	Beta carotene
$P_{312.5}+S_{2.5}$	4.67	16.89	3.48
$P_{312.5}+S_{1.5}$	4.69	16.93	3.51
$P_{312.5}+S_{0.5}$	4.7	17.08	3.54
$P_{312.5}+S_{0}$	4.19	14.39	2.99
$P_{250}+S_{2.5}$	4.71	17.43	3.61
$P_{250}+S_{1.5}$	4.69	17.18	3.21
$P_{250}+S_{0.5}$	4.33	16.34	2.81
$P_{250}+S_{0}$	4.11	14.15	2.65
$P_{187.5}+S_{2.5}$	4.57	16.68	3.05
$P_{187.5}+S_{1.5}$	4.48	15.16	2.75
$P_{187.5}+S_{0.5}$	4.34	15.13	2.58
$P_{187.5}+S_{0}$	4.09	14.02	2.55
$P_{125}+S_{2.5}$	4.43	16.28	2.98
$P_{125}+S_{1.5}$	4.35	15.12	2.71
$P_{125}+S_{0.5}$	4.17	14.73	2.45
$P_{125}+S_{0}$	3.92	13.68	2.5
$P_{0}+S_{2.5}$	4.13	14.58	2.81
$P_{0}+S_{1.5}$	4.07	14.36	2.45
$P_{0}+S_{0.5}$	3.86	12.89	2.42
$P_{0}+S_{0}$	3.83	12.21	2.38
S. Em ±P	0.064	0.157	0.047
S	0.057	0.141	0.042
PXS	0.128	0.314	0.094
CD@5%P	0.183	0.449	0.134
S	0.163	0.402	0.12
PXS	0.365	0.899	0.269

and 4.37 respectively), fruit setting rate (66.02 and 68.66 per cent respectively) and fruit diameter (5.09 and 5.10 cm respectively). The results are in conformity with Damse *et al*. (2014). Phosphorus is known to positively influence male functional parts *viz*., pollen production per flower, pollen grain size and pollen P concentration (Lau and Stephenson, 1994 and Jennifer *et al*., 2002) which enhances total flower production, fruit setting rate, fruit number and fruit weight in tomato.

Tomato fruit weight was highest with P_{250} + $S_{2.5}$ (77.60 g) which was significantly decreased at $P_{312.5}$+ $S_{0.5}$ (68.80 g). Similarly, highest fruit yield of 3.19 kg plant^{-1} was recorded with application of P_{250}+ $S_{2.5}$ followed by application of P_{250} + $S_{1.5}$ (2.93 kg plant^{-1}) and $P_{312.5}$ + $S_{0.5}$ (2.84 kg plant^{-1}). Increased rate of P application without S significantly enhanced fruit yield while increased S application without P marginally enhanced fruit yield. Lowest yield of 1.20 kg plant^{-1} (20.57 t ha^{-1}) was obtained with P_0 + S_0. Fruit yield is the manifestation of plant growth and yield parameters. Application of P_{250} + $S_{1.5}$ showed optimum plant growth, flowers and fruits per cluster, fruit setting rate, number of fruits per plant, fruit weight and diameter. This might have resulted in the production of maximum marketable fruits among all other treatments. Similar observations of enhanced tomato yield with the application of optimum P was reported by De-Groot *et al*. (2002), Adebooye *et al*. (2006) and Nawaz *et al*. (2012) and enhanced yield with S was reported by Khorsandi (1994).

Effect of phosphorus and sulfur application on quality of tomato in calcareous soil

Fruit quality parameters *viz*., TSS, ascorbic acid and β-carotene content in tomato varied significantly with different levels of P and S application in calcareous soil. Increasing rates of S application had positive impact on fruit quality parameters with P rates up to P_{250}. Application of P at 312.5 kg ha^{-1} decreased the quality of tomato fruits. Poor fruit quality was noticed with P_0 + S_0 recording lowest TSS (3.83°Bx), ascorbic acid (12.21 mg 100 g^{-1}) and β-carotene (2.38 mg 100 g-1). Application of P_{250} + $S_{2.5}$ recorded highest TSS (4.71°Bx), ascorbic acid (17.43 mg 100 g^{-1}) and β-carotene (3.61 mg 100 g^{-1}). The result signifies the role of optimum nutrient requirement (Pal *et al*., 2015) for obtaining quality tomato fruits. Winsor and Long (1968) reported, enhanced TSS, ascorbic acid and β-carotene content of tomato with combined application of P and S. But, a high rate of P is known to reduce these parameters. Further, Winsor (1966) stated that, high level of P increased proportion of unevenly ripened fruits and hollow fruits which declined the amounts of TSS, ascorbic acid and β-carotene content in tomato fruits.

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