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ORIGINAL ARTICLE

Interaction effect of phosphorus and sulphur application on their availability and tomato productivity in calcareous soil

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ABSTRACT
A field experiment was carried out in factorial randomised block design with three replication using tomato hybrid 'Arka Ananya' at Regional Horticultural Research and Extension Centre, University of Horticultural Sciences, Bagalkot, Karnataka, India. The factor-1 treatment comprised of five levels of phosphorous (P) application at the rate of 0, 50, 75, 100 and 125 per cent recommended dose of phosphorus (RDP) and factor-2 included various levels of sulphur (S) application at the rate of 0, 0.5, 1.5 and 2.5 per cent equivalent to total calcium carbonate content of soil. The result indicated that combined application P and S increased their availability in soil upto 40 days after transplanting (DAT) and decreased with advancement of crop growth. Their highest availability was seen in P_{125}+ $S_{2.5}$ while, lowest was recorded with P_0+ S_0 at all stages of crop growth. Similarly, P concentration in tomato leaf and fruit was found highest in P_{125}+ $S_{2.5}$. However, the S concentration was highest in P_{100}+ $S_{2.5}$ and further increasing the P rate 125 per cent RDP decreased S content indicating anionic antagonistic effect between these nutrients at higher concentration in plant system. In the present study application of P_{100}+ $S_{2.5}$ (100% RDP + 2.5% S) resulted in maximum tomato fruit yield (3.19 kg plant^{-1} and 42.30 t ha^{-1}) and quality viz., total soluble solids (4.17 ^{0}B), ascorbic acid (17.43 mg 100 g^{-1}) and β-carotene (3.61 mg 100 g^{-1}).
Keywords: *Ascorbic acid, β-carotene, fruit yield, total soluble solids*

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INTRODUCTION

Soils derived from limestone parent material contain free calcium carbonate thus they are grouped under calcareous soils. The occurrence of these kind of soils are common under arid and semi-arid climate where, carbonates formed during weathering process tends to accumulate in soil due to low rainfall that is unable to leach these minerals. Also, the use of carbonate and bicarbonate rich irrigation water leads to secondary accumulation of calcium carbonates in soil through precipitation process. These soils are relatively alkaline, consists of large amounts of calcium and magnesium carbonates and lesser amounts of transition metals carbonate, like Iron (Fe), Zinc (Zn) and Manganese (Mn) [42]. These soils though possess good physical properties, known to greatly influence productivity due to presence of carbonates, which influences soil pH and availability of plant nutrients. Phosphorus (P) is one of the major nutrient elements, which is deficient in calcareous soils. The fact is that, native or added P compounds to the soil react rapidly with various soil components and are quickly converted to slowly available forms. This creates major problem of maintenance and improvement of P fertility in soil. The reaction between orthophosphate ions and soil has been a subject of research, stating complex reactions generally ranging from adsorption to precipitation without clear delineation between the two mechanisms. The availability of P is low in calcareous soils due to high $CaCO_3$ and clay content [44]. Phosphorus can be adsorbed in large amounts on $CaCO_3$ rapidly and firmly from soil solution and may also leads to series of fixation reactions that gradually decrease P solubility and availability to plants through the precipitation of calcium phosphate compounds [28]. Phosphorus plays important chemical and biochemical role in plant metabolism. It is the main element involved in energy transfer for cellular metabolism and is a structural component of cell membranes, nucleic acids and other critical materials. To manage P fertility in calcareous soils, generally soluble P fertilizers are applied. But, their efficiency is generally very low, because applied P in the soil reacts with Ca, forming insoluble compounds such as di-calcium phosphate, octa-calcium phosphate, tri-calcium phosphates and ultimately hydroxy-apatites [45 & 28]. Sulfur is one of the most important secondary nutrient which plays a major role in synthesis of proteins and vitamins and is a co-factor for many enzymes [24]. Its application to calcareous soils is known to convert the unavailable form of nutrients to available form through bio-chemical reactions and desorption process (40). But, acidification of entire calcareous soil requires higher quantity of sulphur which is an impractical approach to adopt. Hence, there is a need to ascertain the quantity of sulphur required for effective transformation of unavailable nutrients into available form, which ultimately affects crop productivity and quality. Realising the importance of phosphorus and sulphur nutrition in plants and their dynamics in calcareous soil, the present study was undertaken using tomato (*Lycopersicum esculentum*) as the test crop. Tomato is universally treated as 'protective food' as it is a good source of mineral nutrients *viz.,* potassium, calcium and iron, rich in vitamins *viz.,* A, B and C and antioxidants *viz.,* lycopene, carotene, organic acids and phenols [18]. In recent years, the health benefits of its antioxidant content gained importance indicating reduced risk of colon, rectal, stomach and prostate cancer [26] with its consumption whilst, provides good remedy for the patients suffering from constipation. Soil nutrient status and plant nutrition are important to boost the production and productivity of tomato [36]. As tomato responds well to nutrient application [30] and semi-tolerant to soil salinity [32] supplementation of nutrients through fertilizers, amendments and organic manures plays a key role in improving its productivity and quality. High pH and calcium carbonate content in calcareous soil regulates the availability of nutrients. Hence, it is necessary that adequate amounts of nutrients should be made available in calcareous soil for higher productivity and quality of tomato. In this context, the present investigation is aimed in understanding the dynamics of interactive effect of sulphur and phosphorus application in calcareous soil on their availability, uptake and influence on tomato productivity.

MATERIAL AND METHODS

Field Experiment: A field experiment was conducted at Regional Horticultural Research and Extension Centre (RHREC), University of Horticultural Sciences, Bagalkot, situated in the Northern Dry Zone (Zone-3) of Karnataka. The experimental designed was factorial randomized block design 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} equivalent to 120, 100, 75, 50 and 0 per cent recommended dose of phosphorus (RDP) 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. The details of treatments imposed are as following

Factor-1: Phosphorus levels	Factor- 2: Sulphur levels
P_{125}- Application of P at 125% RDP*	$S_{2.5}$-Application of S equivalent to 2.5% (w/w) $CaCO_3$**
P_{100}- Application of P at 100% RDP	$S_{1.5}$- Application of S equivalent to 1.5% (w/w) $CaCO_3$
P_{75}- Application of P at 75% RDP	$S_{0.5}$- Application of S equivalent to 0.5% (w/w) $CaCO_3$
P_{50}- Application of P at 50% RDP	S_0- 0% S
P_0- 0% RDP	
Note: *RDP- Recommended Dose of Phosphorus *i.e.* 250 kg ha^{-1}	
** Acid soluble $CaCO_3$ in soil	

Tomato hybrid 'Arka Ananya' was used as test crop that were transplanted at spacing of 45 cm X 90 cm. 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 diammonium 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 diammonium 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.

$$\frac{1 \text{ meq } CaCO_3}{100 \text{ g soil}} = \frac{1 \text{ meq } S^{\circ}}{100 \text{ g soil}}$$

Soil analysis: Composite soil samples were collected from a depth of 0-15 cm from the experimental site before the start of the experiment for initial characterization. During the experiment, composite surface soil samples (0-15 cm) were drawn near root zone from each plot at 20, 40 and 60 days after planting and after the crop harvest. The collected soil samples were air dried, powdered with a wooden pestle and mortar, sieved (2 mm) and stored in air tight polythene bags for further analysis. The Available phosphorus from soil was extracted using Olsen's extractant. The blue colour was developed by ascorbic acid method and the intensity was read at 660 nm using spectrophotometer and calculated referring to P-standard curve [22]. Available sulphur was extracted from soil using 0.15% calcium chloride solution at 1:5 soil to extractant ratio. The concentration of sulphur was determined by turbidimetric method using spectrophotometer at 420 nm [5]. The initial properties of soil indicated it as medium calcareous with 6.5 per cent total calcium carbonate equivalent [9] and had clay loam texture. It had alkaline pH (8.67) with 1.02 dS m^{-1} EC and low organic carbon content (0.47%). 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 and available sulphur was 15.66 mg kg^{-1}.

Leaf and fruit analysis: Fifth tomato leaf (including the petiole) from the growing point was collected at 30, 60 and 90 days after planting. The samples were washed, air dried and then dried in hot air oven at 65 °C. Leaf samples were powdered by using stainless steel blade mixer and preserved in air tight plastic covers for further analysis. Similarly, three ripened fruits from different grades at second pickings were selected, washed and blended. Known weight of blended tomato fruits was digested using di-acid mixture and was diluted to known amount to determine its nutrient content Known weight of leaf samples was digested using di-acid mixture (HNO_3:$HClO_4$ in 9:4) to determine its nutrient content. Intensity of phosphorus in di-acid digested sample was estimated by phospho-vanado-molybdate complex method. Yellow colour was read using spectrophotometer at 430 nm and was estimated by referring to standard curve (35). Sulphur in the di-acid digested samples was determined by developing turbidity using $BaCl_2$ crystals. The intensity of turbidity developed was measured at 420 nm using spectrophotometer and estimated by referring to S- standard curve (35).

Tomato yield and quality: Tomato fruits were harvested in six pickings starting from 70 to 110 days after planting. Weight of marketable fruits harvested from net plot area at all pickings were recorded and added to get fruit yield per net plot further, fruit yield per hectare was estimated and expressed in tonnes per hectare. 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 (43) 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 [1]. The data were statistically analysed using Fisher's method of analysis of variance [41].

RESULTS AND DISCUSSION

P availability in soil: Phosphorus content in soil was significantly influenced by varied levels of P and S applications in calcareous soil at all stages of crop growth (Table 1). In general, it was observed that, increased rate of P application with or without S enhanced P availability in soil. But, at high rates of P application, increase in available P content was not proportional to its application rate and resulted in marginal accumulation. At 20 and 40 Days after transplanting (DAT), P_{100} recorded 48.03 and 42.32 P_2O_5 kg ha^{-1} which was marginally enhanced to 49.23 and 43.59 kg ha^{-1} with P_{125} respectively. This may be attributed to the conversion of available P to unavailable form. In calcareous soil, the presence of $CaCO_3$ reduces the availability of P through sorption process (47). In addition, high Ca content in these soils precipitates P to unavailable forms *viz.*, dicalcium phosphate, tricalcium phosphate and hydroxyl apatite thus, resulting in low available P_2O_5 contents in soil solution (31; 49; 2 and 4). Application of S without P marginally enhanced the P availability in soil. This may be due to low native P. Further, application of S along with P significantly enhanced P availability at all stages of crop growth except after crop harvest. Maximum P availability was at 40 DAT with P_{125} + $S_{2.5}$ (79.16 kg ha^{-1}) and the values were on par with P_{100} + $S_{2.5}$ (74.04 kg ha^{-1}). This may be attributed to the solubilization of $CaCO_3$ with application of S resulting in release of sorbed P. Further, sulphur reduces precipitation of P with Ca by formation of $CaSO_4$ (12 and 29). The decreased Ca contributes to high availability of P in soil solution. These results are in conformity with the works of Soaud *et al.* (40) who reported the enhancement of P solubility by S application. They stated that, SO_4^{2-} ions reacts with cations associated with phosphate and keeps P in soluble form by avoiding further precipitation of monocalcium phosphate to insoluble forms. Phosphorus content in soil increased upto 40 DAT in treatments receiving both P and S applications and later decreased. But, the treatments receiving only P without S showed decreasing trend with the advancement of crop growth. After harvest of the crop, highest P was observed with application of P_{100} + $S_{2.5}$ (46.63 kg ha^{-1}) and lowest P was recorded with P_0 + S_0 (16.35 kg ha^{-1}), which was lower than initial P content (33.45 kg ha^{-1}). These observations suggest that, application of P at lower rates leads to its deficiency in calcareous soil due to crop uptake and its transformation into unavailable form (39; 11 and 16).

Sulphur availability in soil: The availability of S in soils varied significantly with different levels of P and S application (Table 2). In general, sulphur content in soil increased progressively with increased rate of S application (37). Highest availability of S was recorded at 40 DAT and it decreased with the advancement of crop growth. This may be attributed to slow conversion of elemental sulphur to sulphuric acid, which is basically a microbial mediated process (46). The chemoautotrophs *viz., Thiobacillus sp.* oxidizes S to SO_4^{2-} resulting in its increased availability in calcareous soil (29; 8 and 46). However, increase in S content was not in proportion to S applications. The probable reasons could be precipitation of SO_4^{2-} with Ca as gypsum, crop uptake (38) and leaching losses (48). Further, with exhaustion of elemental S, the microbial oxidation decreases resulting in decreased S content in soil with the advancement of crop growth (46). Increased rate of P application without S significantly decreased S content in soil due to enhanced crop uptake. The treatments receiving only P application without S, significantly decreased available S content in soil recording 7.97 mg kg^{-1} with P_{125} + S_0 after crop harvest. Increased S uptake with high rates of P application results in S deficiency in soil, which is lesser than initial S content (15.6 mg kg^{-1}).

Phosphorus concentration in tomato leaf and fruits: Results of different levels of P and S application on total P content in tomato leaves and fruits indicated significant variation at all stages of crop growth (Table 3). Significantly higher P content in leaves was observed with application of P_{125} + $S_{2.5}$ recording 0.65 per cent in younger tomato leaves at 20 DAT which was decreased to 0.58 and 0.44 per cent with advancement of plant age to 40 and 90 days. Increased rate of S application enhanced P content with all rates of P. Enhanced availability of P in soil with application of increased rates of P and S (21; 12; 29; 8 and 40) might have resulted in higher accumulation of P in leaves (34). Very high P content showed negative impact on yield parameters and yield of tomato (53).

Application of P_{100} + $S_{2.5}$ was found optimum, which recorded 0.56, 0.47 and 0.39 per cent P in leaves at 20, 40 and 90 DAT respectively. Optimum level of P is required for proper root growth and for utilization of other nutrients. Phosphorus is one of the main components of nucleic acid known to help in production of blossoms, fruit setting and increase in the number of tomato fruits (10). However, its high concentration has adverse interactions with other elements such as Fe and Zn (3). Application of P_{100} + $S_{2.5}$ was found optimum for obtaining better quality of tomato fruits containing high amount of TSS, ascorbic acid and β-carotene which recorded 0.34 per cent P.

Sulphur concentration in tomato leaf and fruits: Results of sulphur content in tomato leaves and fruits varied significantly with different levels of P and S in calcareous soil (Table 4). In general, S content in tomato leaves increased with the advancement of crop age recording maximum S at 40 DAT and later decreased at 90 DAT. Tomato fruits contained less S compared to leaves. Among the different treatments, increased rate of P application enhanced S content both in leaves and fruits when applied without S. But, combined application of P and S increased S content upto $P_{100,}$ recording 0.76 to 0.92 and 0.64 per cent along with $S_{2.5}$ at 20, 40 and 90 DAT respectively. This may be attributed to increased availability of S with higher rates of its application to calcareous soil (40 and 8).

Further increasing P to P_{125} reduced S content both in leaves (0.69, 0.85 and 0.61 per cent along with $S_{2.5}$ at 20, 40 and 90 DAT respectively) and fruits (0.28% with $S_{2.5}$). The decrease in sulphur with very high rates of P application may be attributed to balancing of anionic concentration in plants. Enhanced accumulation of P and N with high rates of P application might have resulted in high concentration of orthophosphates and nitrates in plant tissues, which being anionic in nature reduced accumulation of SO_4^{2-} ions (25).

The results revealed that, application of $S_{2.5}$ along with P_{100} is best to obtain optimum S concentration in tomato leaves and fruits and further for better tomato growth, yield and quality. S is an essential nutrient required for synthesis of amino acids (Cysteine, Cystine and Methionine), chlorophyll and vitamins (6; 17; 33 and 14). Its optimum concentration is required to enhance the quality parameters *viz.*, lycopene, β-carotene, TSS and ascorbic acid of tomato fruits (52).

Interactive effect of phosphorus and sulfur application on yield and quality of tomato: The marketable tomato fruit yield was significantly influenced by different levels of P and S application. Highest fruit yield of 3.19 kg $plant^{-1}$ (42.30 t ha^{-1}) was recorded with application of P_{100} + $S_{2.5}$, followed by application of P_{100} + $S_{1.5}$ (2.93 kg $plant^{-1}$) (38.85 t ha^{-1}) and P_{125} + $S_{0.5}$ (2.84 kg $plant^{-1}$) (38.68 t ha^{-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. Optimum supply of nutrient is essential for higher productivity of tomato crop. Application of P enhanced the availability of phosphorus in calcareous soil and sulphur application helped in retaining nutrients in plant available form especially P and micronutrients (data not presented), besides keeping higher amount of S in soil solution. This resulted in an optimum uptake of nutrients by tomato as depicted by nutrient concentration in tomato leaves and fruits ultimately, resulting in better productivity of tomato fruits (19; 20; 7; 27; 13; 15 and 23).

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 (Fig. 1). 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 (3.83ºBx), 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 ^{0}B), 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 for obtaining quality tomato fruits. Winsor and Long (50) 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 (51) 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.

Table 1. Interaction effect of phosphorus and sulphur applications on available phosphorus (kg ha^{-1}) content in calcareous soil

Treatments	20 DAT					40 DAT				
	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean
P_{125}	60.73	54.27	52.21	49.23	**54.11**	79.16	68.70	63.25	43.59	**63.67**
P_{100}	57.05	53.86	48.86	48.03	**51.95**	74.04	66.17	59.79	42.32	**60.58**
P_{75}	52.85	47.14	44.52	40.64	**46.29**	61.15	57.34	50.31	36.65	**51.36**
P_{50}	44.42	39.16	34.73	32.47	**37.70**	52.03	46.25	40.13	30.35	**42.19**
P_0	27.93	25.34	27.51	27.36	**27.04**	29.23	25.83	24.06	21.65	**25.19**
Mean	**48.60**	**43.95**	**41.57**	**39.55**	**43.42**	**59.12**	**52.86**	**47.51**	**34.91**	**48.60**
	S. Em ±		CD @5%			S. Em ±		CD@5%		
P	0.80		2.29			1.01		2.88		
S	0.72		2.05			0.90		2.58		
P x S	1.61		4.59			2.00		5.77		
Treatments	**60 DAT**					**After harvest**				
	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean
P_{125}	68.14	62.13	55.43	36.03	**55.43**	46.13	43.28	42.49	32.16	**41.02**
P_{100}	69.18	56.59	48.32	35.14	**52.31**	46.63	42.48	40.81	30.83	**40.19**
P_{75}	53.26	46.81	41.28	32.29	**43.41**	39.23	37.36	35.04	24.31	**33.99**
P_{50}	43.18	39.24	32.19	24.15	**34.69**	31.75	30.46	29.66	22.29	**28.54**
P_0	28.46	24.13	22.01	17.23	**22.96**	22.21	20.81	17.25	16.35	**19.15**
Mean	**52.44**	**45.78**	**39.85**	**28.97**	**41.76**	**37.19**	**34.88**	**33.05**	**25.19**	**32.58**
	S. Em ±		CD @5%			S. Em ±		CD@5%		
P	0.75		2.15			0.64		1.84		
S	0.67		1.92			0.57		1.65		
P x S	1.50		4.30			NS		NS		

Table 2. Interaction effect of phosphorus and sulphur applications on available sulphur (mg kg^{-1}) content in calcareous soil

Treatments	20 DAT					40 DAT				
	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean
P_{125}	63.35	51.54	43.21	11.25	**42.34**	70.29	54.15	44.26	10.37	**44.77**
P_{100}	62.84	51.17	42.98	12.57	**42.39**	70.80	55.53	43.27	10.23	**44.96**
P_{75}	73.80	56.74	48.11	12.89	**47.89**	81.00	61.97	52.11	10.73	**51.45**
P_{50}	76.68	60.23	49.00	13.77	**49.92**	83.17	64.47	48.63	11.69	**51.99**
P_0	79.83	61.86	56.74	14.79	**53.30**	89.73	71.18	56.17	15.06	**58.03**
Mean	**71.30**	**56.31**	**48.01**	**13.05**	**47.17**	**79.00**	**61.46**	**48.89**	**11.62**	**50.24**
	S. Em ±		CD @5%			S. Em ±		CD@5%		
P	0.61		1.76			0.65		1.88		
S	0.55		1.57			0.58		1.68		
P x S	1.23		3.52			1.31		3.76		
Treatments	**60 DAT**					**After harvest**				
	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean
P_{125}	59.25	43.65	37.27	8.34	**37.13**	29.34	22.12	14.34	7.97	**18.44**
P_{100}	56.51	42.31	36.41	9.01	**36.06**	24.51	20.13	13.41	8.19	**16.56**
P_{75}	65.37	48.82	40.39	10.14	**41.18**	30.17	24.24	15.81	9.68	**19.98**
P_{50}	67.82	49.93	41.11	12.38	**42.81**	31.21	25.78	16.04	9.73	**20.69**
P_0	67.73	53.29	46.11	13.60	**45.18**	36.49	26.53	18.58	14.51	**24.03**
Mean	**63.34**	**47.60**	**40.26**	**10.69**	**40.47**	**30.34**	**23.76**	**15.64**	**10.02**	**19.94**
	S. Em ±		CD @5%			S. Em ±		CD@5%		
P	0.48		1.38			0.29		0.84		
S	0.43		1.23			0.26		0.75		
P x S	0.96		2.76			0.59		1.69		

Table 3. Interaction effect of phosphorus and sulphur applications on total phosphorus (%) content of tomato leaves and fruits in calcareous soil

Treatments	Tomato Leaves									
	20 DAT					40 DAT				
	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean
P_{125}	0.65	0.60	0.58	0.55	**0.60**	0.58	0.50	0.48	0.42	**0.50**
P_{100}	0.56	0.53	0.46	0.41	**0.49**	0.47	0.44	0.39	0.36	**0.42**
P_{75}	0.50	0.45	0.42	0.39	**0.44**	0.43	0.38	0.36	0.33	**0.38**
P_{50}	0.44	0.38	0.36	0.32	**0.38**	0.37	0.35	0.32	0.30	**0.34**
P_0	0.32	0.30	0.29	0.27	**0.30**	0.30	0.29	0.27	0.24	**0.28**
Mean	**0.49**	**0.45**	**0.42**	**0.39**	**0.44**	**0.43**	**0.39**	**0.36**	**0.33**	**0.38**
	S. Em ±		CD@5%			S. Em ±		CD@5%		
P	0.004		0.012			0.003		0.009		
S	0.004		0.011			0.002		0.008		
P x S	0.008		0.025			0.006		0.018		
Treatments	**90 DAT**									
	Tomato Leaves					**Tomato Fruits**				
	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean
P_{125}	0.44	0.39	0.37	0.34	**0.39**	0.39	0.36	0.34	0.31	**0.35**
P_{100}	0.39	0.38	0.36	0.33	**0.37**	0.34	0.33	0.32	0.29	**0.32**
P_{75}	0.35	0.36	0.32	0.28	**0.33**	0.32	0.30	0.28	0.25	**0.29**
P_{50}	0.30	0.29	0.27	0.24	**0.28**	0.31	0.28	0.22	0.22	**0.26**
P_0	0.28	0.26	0.25	0.22	**0.25**	0.22	0.21	0.19	0.18	**0.20**
Mean	**0.35**	**0.34**	**0.31**	**0.28**	**0.32**	**0.32**	**0.30**	**0.27**	**0.25**	**0.28**
	S. Em ±		CD@5%			S. Em ±		CD@5%		
P	0.002		0.006			0.003		0.008		
S	0.002		0.005			0.002		0.007		
P x S	0.004		0.012			0.006		0.017		

Table 4. Interaction effect of phosphorus and sulphur applications on total sulphur (%) content of tomato leaves and fruits in calcareous soil

Treatments	Tomato Leaves									
	20 DAT					40 DAT				
	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean
P_{125}	0.69	0.63	0.61	0.41	**0.59**	0.85	0.78	0.74	0.47	**0.71**
P_{100}	0.76	0.69	0.58	0.40	**0.61**	0.92	0.81	0.65	0.45	**0.73**
P_{75}	0.72	0.58	0.47	0.38	**0.54**	0.88	0.73	0.59	0.45	**0.66**
P_{50}	0.68	0.53	0.45	0.35	**0.50**	0.82	0.67	0.58	0.40	**0.62**
P_0	0.65	0.51	0.42	0.34	**0.48**	0.76	0.63	0.54	0.38	**0.58**
Mean	**0.70**	**0.59**	**0.50**	**0.37**	**0.54**	**0.84**	**0.72**	**0.62**	**0.43**	**0.65**
	S. Em ±		CD@5%			S. Em ±		CD@5%		
P	0.005		0.015			0.007		0.019		
S	0.005		0.013			0.006		0.017		
P x S	0.011		0.030			0.014		0.039		
Treatments	90 DAT									
	Tomato Leaves					Tomato Fruits				
	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean
P_{125}	0.61	0.55	0.48	0.27	**0.48**	0.28	0.23	0.21	0.15	**0.218**
P_{100}	0.64	0.57	0.50	0.26	**0.49**	0.33	0.25	0.19	0.14	**0.228**
P_{75}	0.63	0.49	0.43	0.24	**0.45**	0.30	0.23	0.18	0.14	**0.213**
P_{50}	0.59	0.43	0.38	0.23	**0.41**	0.29	0.22	0.17	0.13	**0.203**
P_0	0.50	0.36	0.34	0.22	**0.36**	0.25	0.20	0.15	0.12	**0.180**
Mean	**0.59**	**0.48**	**0.43**	**0.24**	**0.44**	**0.290**	**0.226**	**0.180**	**0.136**	**0.208**
	S. Em ±		CD@5%			S. Em ±		CD@5%		
P	0.004		0.011			0.002		0.006		
S	0.003		0.010			0.002		0.005		
P x S	0.008		0.022			0.004		0.013		

Table 5. Interaction effect of phosphorus and sulphur applications on marketable fruit yield of tomato in calcareous soil

Treatments	Yield per plant (kg)					Yield per hectare (tonnes)				
	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean	$S_{2.5}$	$S_{1.5}$	$S_{0.5}$	S_0	Mean
P_{125}	2.64	2.73	2.84	2.04	**2.56**	37.32	38.10	38.68	30.06	**36.04**
P_{100}	3.19	2.93	2.33	1.89	**2.59**	42.30	38.85	35.03	28.96	**36.29**
P_{75}	2.63	2.17	1.76	1.64	**2.05**	37.83	35.62	31.44	24.74	**32.41**
P_{50}	1.82	1.57	1.38	1.46	**1.56**	34.40	29.38	25.98	22.68	**28.11**
P_0	1.33	1.28	1.26	1.20	**1.27**	22.70	21.98	21.15	20.57	**21.60**
Mean	**2.32**	**2.14**	**1.91**	**1.65**	**2.00**	**34.91**	**32.79**	**30.46**	**25.40**	**30.89**
	S. Em ±		CD @5%			S. Em ±		CD@5%		
P	0.03		0.09			0.42		1.21		
S	0.03		0.08			0.38		1.08		
P x S	0.07		0.19			0.84		2.42		

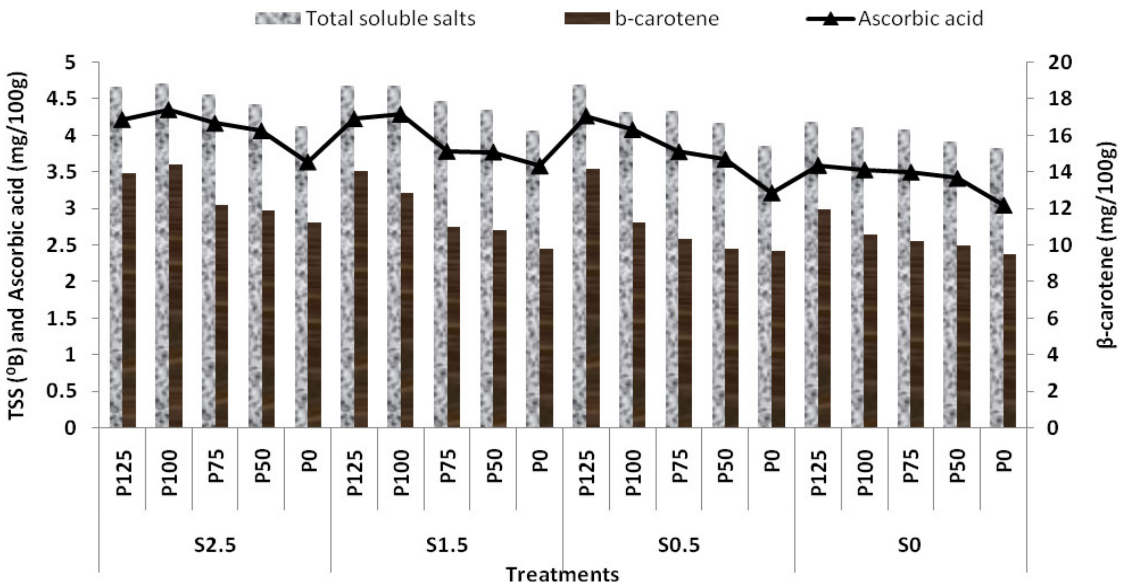

Fig. 1: Interaction effect of phosphorus and sulphur applications on quality parameters of tomato in calcareous soil

CONCLUSION

The present investigation revealed that combined application of P and S is more advantageous in enhancing their availability in soil and accumulation by tomato crop. Application of phosphorus or sulphur alone, even at higher rates is ineffective in obtaining higher yield and quality in calcareous soil. However, at high rate of P_{125} increasing rate of S application decreased tomato yield and quality. Thus, application of P_{100} + $S_{2.5}$ was found optimum for obtaining highest tomato yield and quality in calcareous soil.

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